

# NeuroMod tXES System User Manual

Santa Fe Neurosciences  
714 East Monument Avenue  
Suite 115  
Dayton, Ohio 45402  
(937) 531-6676  
[neuromod@sfneuro.com](mailto:neuromod@sfneuro.com)



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## Table of Contents

1. Introduction_____	2
2. NeuroMod tXES System Packing List_____	4
3. NeuroMod tXES System Options_____	4
4. NeuroMod tXES Hardware_____	8
1. NeuroMod tXES Stimulator_____	8
2. NeuroMod tXES Head Box_____	13
3. NeuroMod tXES Electrode Assemblies_____	14
5. NeuroMod tXES Software_____	16
1. NeuroMod tXES Controller GUI_____	16
1. Impedance Monitoring_____	21
2. Hardware Setup (Advanced Settings)_____	22
2. NeuroMod tXES Electrode Use_____	27
3. NeuroMod tXES Electrode Maintenance_____	28
4. NeuroMod tXES Waveform Creation_____	29
1. tACS_____	29
2. tDCS_____	30
3. tRNS_____	31
4. tXES_____	32
5. NeuroMod Waveform Plotting_____	32
6. Appendix 1: Weisend et al., 2017	



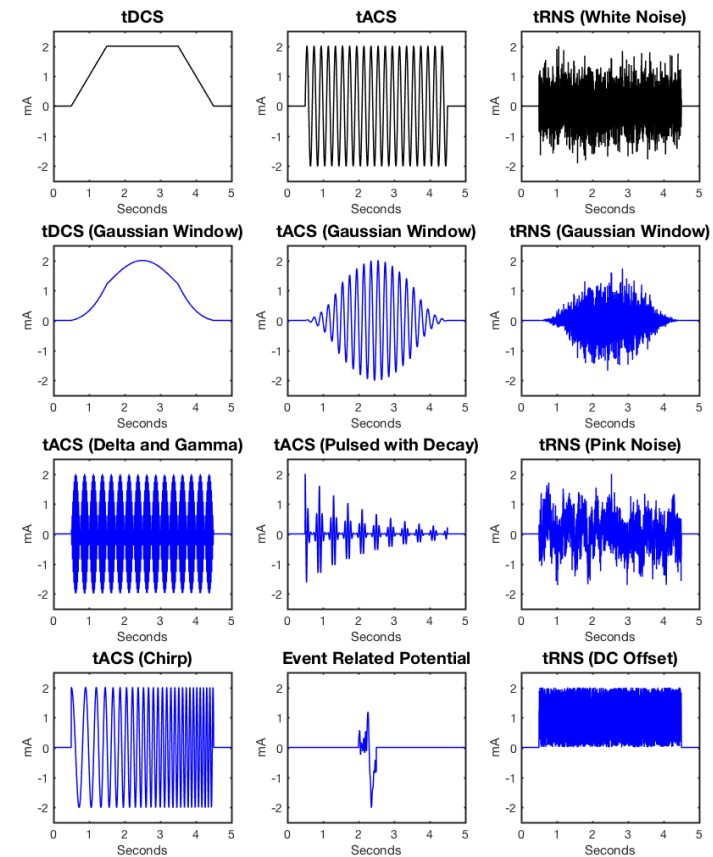


## Introduction

Congratulations on your purchase of the NeuroMod tXES System for transcranial electrical stimulation (tES) system. The NeuroMod tXES System is the most advanced neuromodulation device on the market. Please read this manual carefully and completely to ensure the safe and effective use of the NeuroMod tXES System.

**The NeuroMod tXES System is for research use only. Medical use in any diagnosis or treatment for disease is strictly forbidden.**

The NeuroMod tXES System is capable of all common types of tES including transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS), and transcranial random noise stimulation (tRNS). In addition, the NeuroMod System is uniquely capable of tXES - wherein the user has the ability to define the stimulation paradigm. Examples of common and tXES waveforms are shown in Figure 1. tXES allows the user to combine any of the elements of tDCS, tACS, and tRNS to create unique waveforms. Further, the waveforms can contain windowing functions, pulses, combinations of frequencies, and anything else the user can define. The NeuroMod tXES system can even replay EEG activity back to the subjects



**Figure 1: The top row shows standard tES waveforms in black. The lower boxes show tXES waveforms in blue. Any waveform can be reproduced on up to 16 fully independent channels with the NeuroMod tXES System. This is only a small sample of the capabilities of the NeuroMod tXES System.**



from which it was recorded.

tXES waveforms can be created in any program that allows the user to write text files with comma separated values. Matlab scripts are included with the NeuroMod tXES System to create the tDCS, tACS, and tRNS waveforms like those shown in Figure 1. The Matlab scripts allow the user to vary the amplitude, duration, and frequency of the tDCS, tACS, and tRNS waveforms within limits and where applicable. Software to reproduce the tXES waveforms is also available.

The NeuroMod tXES system can be used like any other table top tES device where the waveform is specified by the user and started with the push of a button on the front. However, the stimulator can also be externally triggered for inclusion in real-time, closed-loop systems. The stimulator comes with 2, 4, 8, and 16 fully independent, programmable channels, each of which, can deliver up to 2 mA of stimulation.

If you need assistance in addition to this manual, hardware and software support are available from the experts at Brain Vision or Santa Fe Neurosciences at the addresses below. We look forward to working with you.

Brain Vision: [support@brainvision.com](mailto:support@brainvision.com)

Santa Fe Neurosciences: [neuromod@sfneuro.com](mailto:neuromod@sfneuro.com)



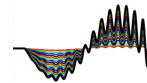


## NeuroMod tXES System Packing List

The NeuroMod tXES System basic kit comes with the hardware and software noted below and are depicted in Figure 2.

- **Hardware**
  - 1 NeuroMod tXES Stimulator
  - 1 NeuroMod tXES Head Box
  - 2-16 NeuroMod tXES Electrode Assemblies<sup>1</sup>
  - 1 Forty Conductor Ribbon Cable
  - 2 Keys
  - 1 Internet Protocol Address Identifier
  - 1 Consumables Package for 10 Subjects
- **Software**
  - NeuroMod Controller Software
  - Standard Waveform Library
    - tDCS
    - tACS
    - tRNS
    - Impedance Check
  - tES Waveform Design Matlab Functions
- **Documentation**
  - 1 Internet Protocol Address Identifier
  - 1 Password Identifier
  - 1 System Manual

<sup>1</sup> The NeuroMod tXES System can be purchased with 2, 4, 8, or 16 fully independent channels. The number of electrode assemblies will correspond to the number of channels in your device. Channel upgrades are available.



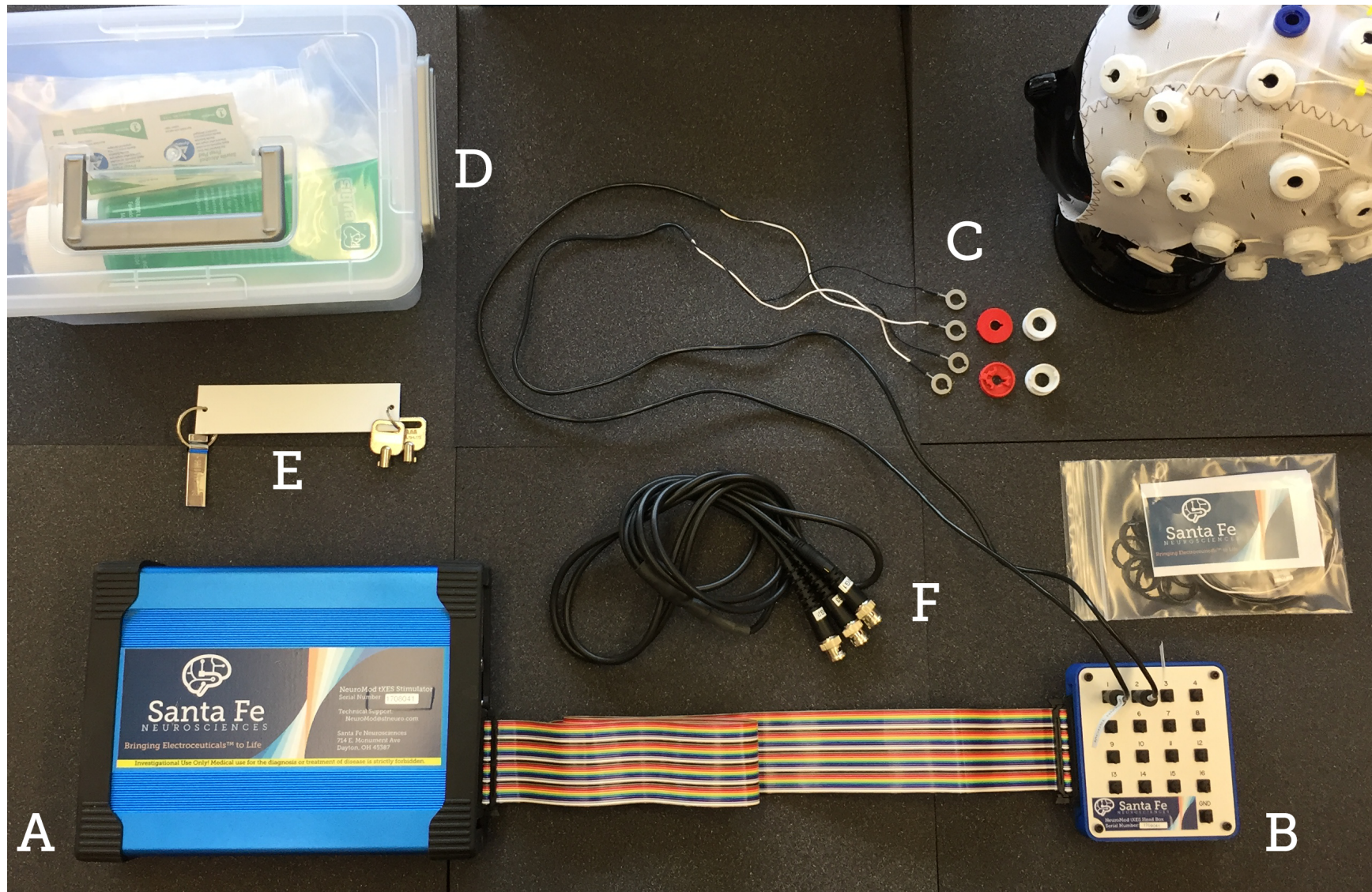
## NeuroMod tXES System Options

There are optional hardware, software, and services that can be purchased to enhance or support the NeuroMod tXES System. A partial list is included below. Please contact Brain Vision or Rio Grande Neuroscience for information on availability and pricing. If you have ordered an optional item, it will be noted in the list below.

- **Hardware**
  - **Optical Isolator for Ethernet Cable** - this is necessary to isolate the participant from power line voltage if the NeuroMod Controller Software is being used from a computer that is plugged into the wall socket or an uninterruptible power supply (UPS) during stimulation.
  - **Trigger Cables** - these cables are used to externally trigger the NeuroMod tXES Stimulator. Trigger cables can be configured with 1-3 BNC connectors. The NeuroMod tXES Stimulator can be triggered with any transistor-transistor logic (TTL) pulse from an external device that is more than 2.5 V in amplitude. These cables are used to place the NeuroMod tXES Stimulator in a closed-loop system.
  - **Polarity Trackers** - these should be used with







**Figure 2: The contents of the NeuroMod tXES Kit. A: The NeuroMod tXES Stimulator. B: The NeuroMod tXES Head Box. C: NeuroMod tXES Electrodes. D: Consumables Kit. E: Software, Keys, Password, and IP indicator. F: Trigger Cables (Optional)**



waveforms that are not charge balanced, i.e. do not have a zero mean across the duration of stimulation. tDCS and other stimulation paradigms that include DC offset are examples of waveforms that are not charge balanced. The lifetime of the NeuroMod tXES Electrodes can be significantly prolonged by reversing the polarity with each use. Polarity Trackers allow the user to track the polarity across multiple uses.

- **EEG Caps** - these can be used to hold NeuroMod tXES Electrodes in place on the scalp. The caps come in configurations from 2-256 perforations that approximate the 10-20, 10-10, or 10-5 International Systems for EEG electrode placement. NeuroMod tXES electrodes are placed into the perforations to hold them in place similar to EEG electrodes. These caps are especially useful when EEG is being recorded during tES. Custom cap configurations are also available.
- **Stacking Cables** - these are used to coordinate the activities of multiple NeuroMod tXES Stimulators for ultra high density tXES. The stimulators have been tested in configurations up to 91 channels operating simultaneously and independently.
- **Alternative Gels** - There are alternatives to Signs Gel from Parker Labs that are less expensive, easier to use, or simply preferred. The following

gels have been tested with the NeuroMod tXES Stimulator. These gels are recommended only for charge balanced waveforms.

- Spectra 360 (Parker Labs)
- Super Visc (Easy Cap)
- Electro-Gel (Electro-Cap)
- Ten20 (Weaver)
- **Duplicate Items** - any item in the NeuroMod tXES System can be ordered to augment the base kit. Commonly ordered items are extra electrodes, trigger cables for use of the NeuroMod tXES Stimulator in closed-loops systems, and additional consumables.
- **Software**
  - **Exotic Waveform Library** - A library of waveforms and Matlab functions to produce variants of those waveforms are available. The Matlab functions will produce any of the waveforms shown in Figure 1.
  - **Additional Licenses** - Additional seats for the tXES waveform generators and NeuroMod Controller Software are available.
- **Services and Support**
  - **Waveform Design** - Support for custom waveform design is in advanced tXES applications is available.
  - **Montage Design** - Support for the development of montages that position the NeuroMod tXES





Electrodes on the scalp is available.

- **Finite Element Modeling** - finite element models are used to understand the calculated current distribution in the brain during tES. The models of current distributions can be produced using stock male and female models from the Santa Fe Neurosciences library or with MRIs from user specified individuals. The current distributions are available for electrode montages with cephalic and extra-cephalic electrodes. The output format can be specified by the user.
- **tXES Training** - Basic training by video conference is included in the purchase of the stimulator. Additional and advanced training for the NeuroMod tXES system by phone, videoconference, or site visit are available.
- **Site Setup** - Onsite setup and training for the NeuroMod tXES System is available.
- **Maintenance Contracts** - The NeuroMod Stimulator is warrantied for two years from the date of delivery. The NeuroMod Electrodes are warrantied for 90 days from the date of delivery. Extended warranties beyond these periods are available through maintenance contracts. For maintenance contract details see Page XX.
- **Extended Technical Support** - during the period of warranty of the NeuroMod tXES Stimulator and Electrodes technical support is included in

the price of purchase. Technical support outside the period of the warranty is available as part of a maintenance contract or by the hour.

The experts at Brain Vision or Santa Fe Neurosciences are always happy to discuss the applications of the NeuroMod tXES System in your experimental paradigms to ensure that you have what you need to meet your goals. Please do not hesitate to contact us when you have questions, suggestions, or requests.

Brain Vision: [support@brainvision.com](mailto:support@brainvision.com)

Santa Fe Neurosciences: [neuromod@sfneuro.com](mailto:neuromod@sfneuro.com)



## NeuroMod tXES Hardware

**The components of the NeuroMod tXES Stimulator System are not fragile but can be irreparably damaged by drops, impacts, and rough handling.  
Please Handle with care.**

### The NeuroMod tXES Stimulator

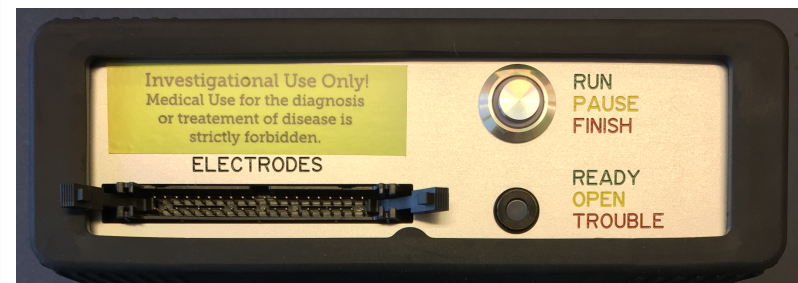
The NeuroMod tXES Stimulator is shown in Figure 2 and indicated with the letter A. The NeuroMod tXES Stimulator delivers user specified tES currents by measuring the impedance between the NeuroMod tXES Electrodes and generating the necessary voltage differences to drive the specified current between the electrodes. In this respect, the NeuroMod tXES stimulator is exactly the same as other tES stimulators. NeuroMod tXES Stimulator is also fully capable of common tDCS, tACS, and tRNS paradigms. However, the NeuroMod tXES Stimulator differs importantly in the method and variety of tES waveforms that can be generated and delivered. Unlike other tES stimulators, the NeuroMod tXES stimulator is not limited to specific types of tES by an internal function generator. Instead, the NeuroMod tXES Stimulator plays back waveforms that are stored in memory much like audio or video content on a smart phone, tablet, or computer. The NeuroMod tXES

Stimulator can deliver the waveforms on up to 16 fully independent channels that can playback the same or different waveforms simultaneously or in a specified temporal sequence. Thus, the user can do anything from multichannel tDCS to replicating the spatiotemporal sequence of events in electrophysiological recordings.

The front panel of the stimulator has a locking ribbon cable connector, a button for manual activation with status indication by color, and a LED indicator to show the status of electrodes (Figure 3).

**Locking Ribbon Cable Connector:** The ribbon cable connects to the NeuroMod tXES Stimulator to the Head Box that is described below. The ribbon cable is one meter

### NeuroMod tXES Stimulator Front Panel.



**Figure 3: NeuroMod tXES Stimulator Front Panel.** The locking ribbon cable connector is at bottom left. The manual activation button with illuminated status indicator is at top right. The electrode status indicator LED is at bottom right.



in length and can be extended by one meter without effecting the functioning of the NeuroMod tXES Stimulator. The locking ribbon cable connector has tabs on the left and right side that capture the ribbon cable when it is fully inserted. Push the tabs toward the center of the ribbon cable to lock the cable in place.

The ribbon cable and connector are keyed to ensure insertion in the proper orientation. Forcing the ribbon cable into the connector if the key is improperly aligned can damage the NeuroMod tXES Stimulator and change the distribution of tES currents on the electrodes. Please take a moment to examine the ribbon cable and connector prior to connection.



### NeuroMod tXES Stimulator Rear Panel.

Figure 5: NeuroMod tXES Stimulator Rear Panel.

The rear panel has the input for triggers at the far left, battery status indicator at middle left, the charger connector at center, the ethernet connector at middle right, and the power switch at far right.

### Front Panel: Stimulator Status Indicator



Figure 4: NeuroMod tXES Stimulator Status Indicator. The ring of color around the manual activation button on the upper right portion of the front panel indicates the status of the stimulator.

**Caution: Pressing and holding the manual activation button for 10 seconds will return the NeuroMod tXES Stimulator to factory settings. This will make the stimulator unusable. Please use this option only at the direction of technical support staff from Brain Vision or Santa Fe Neurosciences.**

### Manual Activation Button with Illuminated Status Indicator:

The button for manual activation of the NeuroMod tXES Stimulator is on the upper right of the front panel as shown in Figure 3. The manual activation button is surrounded by a lighted ring. The ring can be on of four colors; blue indicating that the stimulator booted properly and is ready, green indicating that the stimulator is in run mode and waveform playback is active, yellow indicating that the stimulator is paused and waiting for



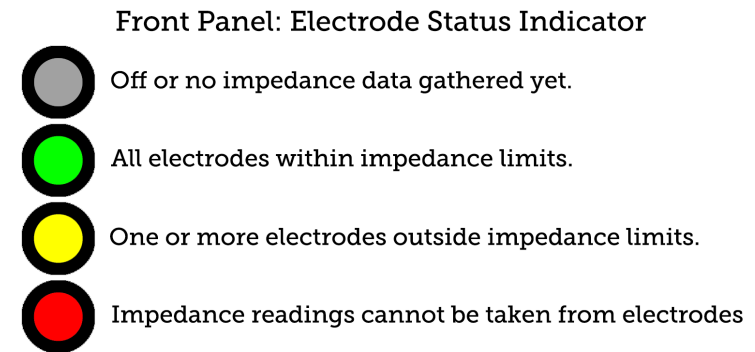


input, and red to indicate that playback of a waveform is finished. The indicator light is not illuminated when the NeuroMod tXES stimulator is off (Figure 4).

**Ready:** Upon turning the NeuroMod tXES Stimulator on the lighted ring will turn blue when the stimulator has booted properly and is ready for input.

**Running:** When the NeuroMod tXES Stimulator is playing back a waveform in response to manual input, software input, or external triggers the light will turn green. The running of any waveform can be paused by pressing the manual activation button or pressing the pause button in the NeuroMod tXES Stimulator Control Software described below. When the stimulator has been paused during a run pressing the manual activation button, the pause button in software, or the run button in software will resume the playback of the waveform.

**Paused:** A yellow light surrounding the manual activation button of the NeuroMod tXES stimulator indicates that the unit is paused. When in Paused mode the stimulator is waiting for input. One way to place the stimulator is placed into Paused mode by pressing the manual activation button or software buttons during run status as described above. The NeuroMod tXES Stimulator is also in Paused mode when waiting for an external trigger to initiate the playback of a waveform. The use of external triggers for inclusion of the NeuroMod tXES Stimulator is discussed in detail below.



**Figure 5: NeuroMod tXES Electrode Status Indicator.** The status indicator will not be illuminated when the NeuroMod tXES Stimulator is off and will remain in this state until the impedance readings are taken after the user initiates the playback of a waveform. Green indicates that the impedance readings for all electrodes are under the threshold set by the user. Yellow indicates that at least one electrode is over the impedance limit. Red indicates that impedance readings cannot be taken and waveform playback will not be initiated.

**Finished:** The lighted indicator surrounding the manual activation button will be red when the stimulator has finished running a waveform that has been setup in the software to run once or for a specific length of time. Note: When the stimulator has been setup in software to run waveforms each time an external trigger is detected it will return to Paused mode, not Finished, after a waveform run is completed. When the stimulator is in Finished mode a single button press will return it to Ready.



**NeuroMod tXES Electrode Status Indicator LED:** At the bottom right of the front panel of the stimulator is an LED indicating the status of the NeuroMod tXES Electrodes (Figure 5). Each of the, up to 16, channels on the NeuroMod tXES Stimulator has two electrodes. The impedance across those electrodes is measured independently for each channel. The LED will be green when the measured impedances of all electrodes on all active channels are under the limit set by the user, typically 30 kOhms. The LED will change to yellow when the impedance across any electrode pair on any active channel in the tES montage rises above the threshold specified by the user. If the NeuroMod tXES Stimulator cannot obtain impedance readings, detects a problem with the electrodes, or with sending the waveform to the electrodes, the status indicator will turn red.

The rear panel of the NeuroMod tXES Stimulator is depicted in Figure 6. The rear panel has the connector for input of external triggers, the battery status indicator, the battery charging connector, the ethernet connector, and the power switch.

**Trigger Input Connector:** The NeuroMod tXES Stimulator can be externally triggered. The external trigger port is designed to incorporate the stimulator into real-time, closed-loop systems where neuromodulation can be delivered in response to a behavioral, physiological, or neurological state. The TTL pulse must be between 3.2 and 10 volts, at least 1 mA, and at least 10

ms in duration. All triggering and waveform playback operations in the NeuroMod tXES Stimulator are based on a single clock. Moreover, waveforms that are assigned to a trigger are preloaded into volatile memory. These factors allow the stimulator to deliver the waveforms with a 2 ms delay across all active channels. The stimulator has no variance in the onset of waveforms across channels or across multiple triggering events (see Weisend et al., 2017 in Appendix I). The stimulator has three independent trigger lines that can be used to control

**Caution: TTL pulses that exceed 10 Volts and improperly wired trigger cables can damage the NeuroMod tXES Stimulator. Please consult Brain Vision or Santa Fe Neurosciences if you intend to design your own TTL pulse or build your own trigger cable.**

three different wave forms. Multiple waveforms can be delivered simultaneously or inputs from multiple devices can be used in a single stimulation paradigm. The trigger lines can be used alone or in combination using a Boolean ‘or’ function where a trigger on line 1 or 2, 2 or 3, 1 or 3, or any line will elicit the playback of a waveform that is resident in memory. Thus, input from EEG or from behavioral performance can elicit playback of the same waveform. Similarly, two different waveforms both of which are set to trigger on 1 or 2 can be delivered



simultaneously. This unprecedented temporal reliability and flexibility using external triggers are among the most innovative features of the NeuroMod tXES Stimulator.

The trigger input is optically isolated inside the stimulator to prevent any risk of the subject being shocked with power line voltages. Thus, it is not necessary to disconnect devices that send triggers to the NeuroMod tXES Stimulator from wall power.

**Battery Status Indicator:** The battery status indicator is not illuminated when the battery is well charged enough to run 2 hours of continuous tDCS at 2 mA per channel across a 10 kOhm resistor (Figure 7). When the charge in the battery falls below this threshold, the light will be illuminated in yellow. When the charge remaining in the

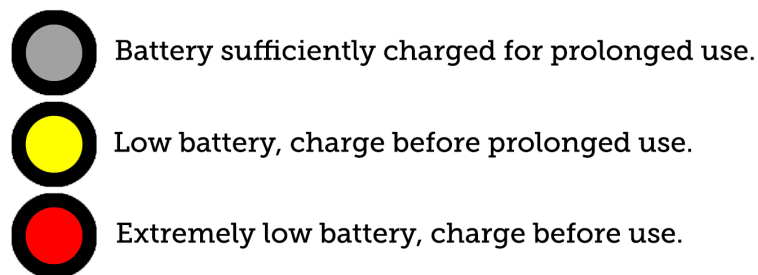
battery will not support 30 minutes of tDCS at 2 mA per channel across a 10 kOhm resistor the battery status indicator will be illuminated in red.

**Battery Charging Connector:** The three pronged connector receives input from the Tenenergy 1.0 Amp Smart Charger that is provided with your NeuroMod tXES Stimulator. If you choose to charge the stimulator with a different charger please contact the technical support staff at Brain Vision or Santa Fe Neurosciences to discuss your options. The smart charger prevents overcharging of the battery. The connector from the charger has a locking collar that holds the charger connector securely to the NeuroMod tXES Stimulator. Lock the collar onto the connector to ensure proper charging of the stimulator.

The battery charging port is physically disconnected from the hardware inside the stimulator when the power switch is activated to prevent any risk of the subject being shocked with power line voltages. Thus, it is good practice, but not necessary, to disconnect the NeuroMod tXES stimulator from the charger during use with human subjects.

**Ethernet Connector:** A standard ethernet cable is used as the main interface with the NeuroMod tXES Stimulator. The ethernet cable connection provides a connection to the NeuroMod Controller Software graphical user interface (GUI) on an external computer. The GUI is necessary to setup the stimulator but not necessary to run the stimulator. When not connected to an external

#### Rear Panel: Battery Status Indicator



**Figure 7: Battery Status Indicator.** The LED is unlit when the NeuroMod tXES Stimulator has enough charge for prolonged use. The indicator will turn to yellow when insufficiently charged for prolonged use and red when the charge is so low that the stimulator cannot be used.



computer with the ethernet cable the stimulator will perform based on the settings from the previous session. The ethernet port on the NeuroMod tXES Stimulator is NOT optically isolated. Thus, if the user chooses to monitor the performance of the stimulator using the NeuroMod Controller Software GUI on a computer that is plugged into the wall socket or an uninterruptible power supply (UPS) during stimulation it is necessary to use an in line optical ethernet isolator to protect the human subject from power line voltage.

**Caution: The ethernet port on the NeuroMod tXES stimulator is NOT optically isolated. If the ethernet cable is connected to a computer that is plugged into a wall socket or an uninterruptible power supply during stimulation an in-line optical ethernet isolator is required.**

**Power Switch:** A keyed, locking switched is used to power the NeuroMod tXES Stimulator on and off. The keyed mechanism ensures that the stimulator cannot be accidentally turned on and off. In addition, only those who have access to the keys can power the stimulator on and off. The keys should be removed the locking mechanism when the stimulator is on or off to prevent mechanical damage to the power switch.

### NeuroMod tXES Head Box

The NeuroMod tXES Head Box is shown in Figure 2 and indicated with the letter B. The head box connects to the NeuroMod tXES stimulator with a ribbon cable. The electrodes are plugged into 16 connectors that are at the top of the unit.

**Electrode Connectors:** The top of the NeuroMod tXES Head Box has the electrode connectors shown in Figure 8. The connectors have 4 pins and a key tab to ensure that the electrodes are plugged in properly. The electrode connectors hold the NeuroMod tXES Electrodes firmly in place. Use care to hold the electrode connectors firmly when inserting or removing the electrodes.

**Ground Connector:** The ground connector on the NeuroMod tXES Head Box ties into the ground for the NeuroMod tXES Stimulator. The ground connector is useful for 1) visualizing the output of the stimulator with an oscilloscope and 2) tying the grounds together for multiple pieces of equipment, i.e. EEG or other physiological recording equipment to guard against noise from drift based on multiple grounds. If the user would like this capability please contact Brain Vision or Santa Fe Neurosciences for a ground cable.

**Locking Ribbon Cable Connector:** The ribbon cable connects to the NeuroMod tXES Head Box to the stimulator (Figure 9). The ribbon cable is one meter in length and can be extended by one meter without

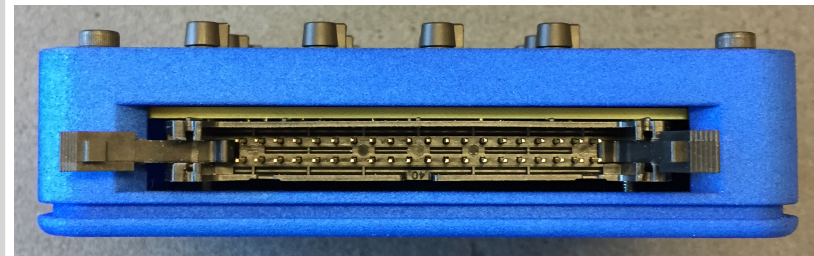






**Figure 8: Top of the NeuroMod tXES Head Box.**  
The head box has connectors for up to 16 electrodes and a ground cable.

effecting the functioning of the NeuroMod tXES Stimulator. The locking ribbon cable connector has tabs on the left and right side that capture the ribbon cable when it is fully inserted. Push the tabs toward the center



**Figure 9: Side of the NeuroMod tXES Head Box.**  
The locking ribbon cable connector on the side of the NeuroMod tXES Head Box is identical to that on the NeuroMod tXES stimulator. Note the key to guide proper insertion and the locking mechanism on the lateral edges of the connector.

of the ribbon cable to lock the cable in place.

The ribbon cable and connector are keyed to ensure insertion in the proper orientation. Forcing the ribbon cable into the connector if the key is improperly aligned can damage the NeuroMod tXES Head Box and change the distribution of tES currents on the electrodes. Please take a moment to examine the ribbon cable and connector prior to connection.

### **NeuroMod tXES Electrode Assemblies**

The NeuroMod tXES Electrode assemblies are shown in Figure 2 and are marked with the letter C. The electrodes make the connection between the NeuroMod tXES head box and the research participant. The NeuroMod tXES Electrode Assembly can be seen in Figure 10. The

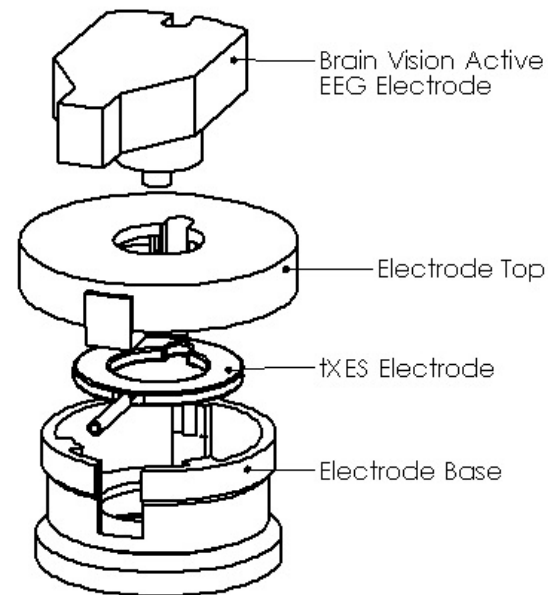


NeuroMod Electrode Assembly consists of a nonconducting base, a conductive electrode, and a non conductive top that holds the assembly together. The electrode assembly is filled with gel to make contact between the skin and the conductive electrode. The wires attached to the electrode terminate in a connector that can be inserted into any position on the NeuroMod tXES Head Box. The electrode base can be inserted into an EEG cap for holding the electrode assembly against the scalp in the standard EEG positions approximated by the electrode cap.

Additional questions on the NeuroMod tXES hardware can be answered by experts at Brain Vision or Santa Fe Neurosciences.

Brain Vision: [support@brainvision.com](mailto:support@brainvision.com)

Santa Fe Neurosciences: [neuromod@sfneuro.com](mailto:neuromod@sfneuro.com)



**Figure 10: NeuroMod tXES Electrode Assembly.** The assembly comes in three parts. The non-conductive electrode base, the conductive electrode, and the non-conductive electrode top. The base is filled with conductive gel to make contact between the electrode and the skin. The top holds the electrode into the base and provides a port for filling the electrode base with gel. In some electrode tops, the Brain Vision EEG electrode can be placed into the fill port for co-localized stimulation and recording.



## NeuroMod tXES Software

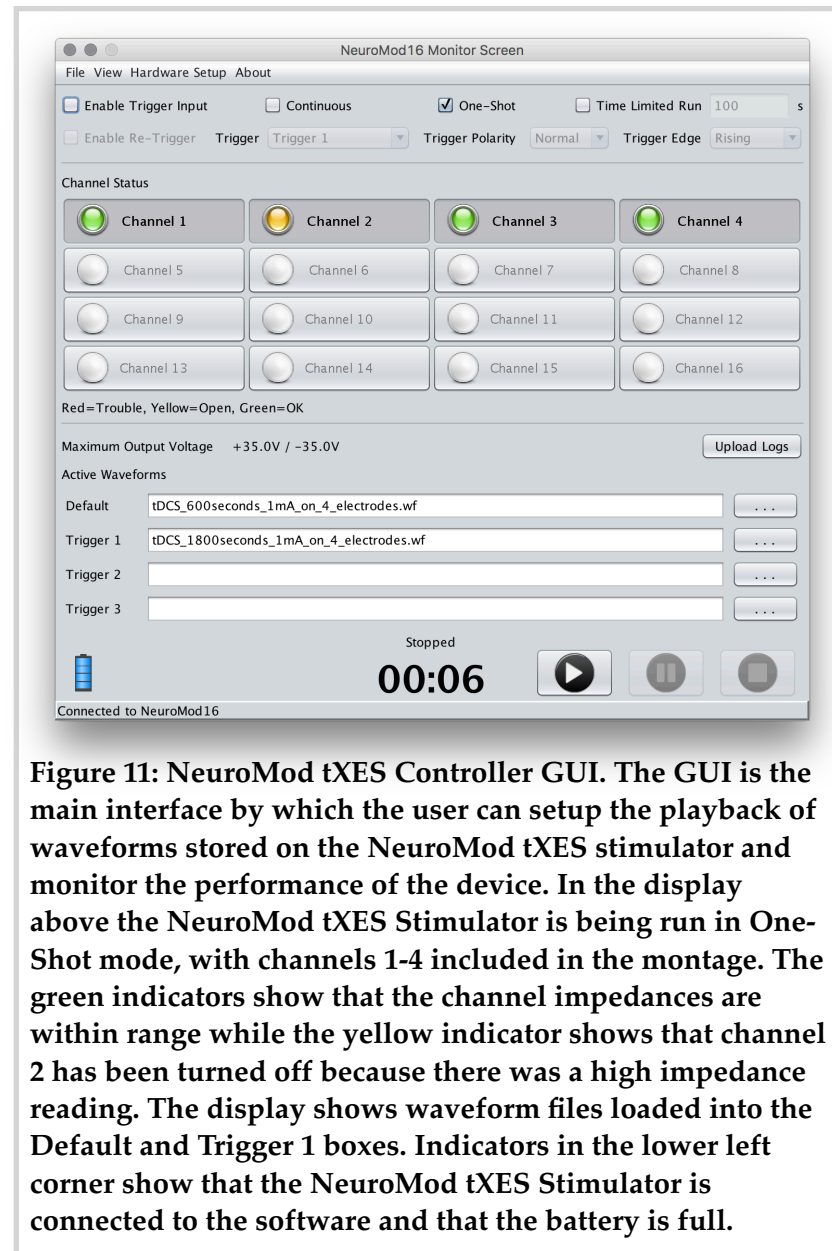
The NeuroMod tXES Software consists of three parts; 1) The NeuroMod tXES Controller graphical user interface (GUI) that is used to setup the stimulation protocol and monitor the performance of the NeuroMod tXES Stimulator, 2) a package of standard tDCS, tACS, and tRNS waveforms, and 3) Matlab scripts that allow the user to create custom tDCS, tACS, and tRNS scripts.

### The NeuroMod tXES Controller GUI

The NeuroMod tXES Controller GUI can be seen in Figure 11. The GUI is the main interface by which the user can setup the playback of the waveforms stored on the NeuroMod tXES Stimulator and monitor the performance of the device during stimulation. The GUI has a menu bar with drop down choices and three sections of content arranged from top to bottom. The top section sets the options for playback of the waveform. In the center section the user selects the channels to deliver the tES waveforms. The bottom section allows the user to select the waveforms for playback, upload stimulation logs, and start, stop, or pause the stimulator.

**NeuroMod tXES Controller GUI - Stimulation Settings (Top Box):** The top box determines how the waveform playback can be initiated and repeated.

- Enable Trigger Input: When this box is *unchecked*, TTL



**Figure 11: NeuroMod tXES Controller GUI.** The GUI is the main interface by which the user can setup the playback of waveforms stored on the NeuroMod tXES stimulator and monitor the performance of the device. In the display above the NeuroMod tXES Stimulator is being run in One-Shot mode, with channels 1-4 included in the montage. The green indicators show that the channel impedances are within range while the yellow indicator shows that channel 2 has been turned off because there was a high impedance reading. The display shows waveform files loaded into the Default and Trigger 1 boxes. Indicators in the lower left corner show that the NeuroMod tXES Stimulator is connected to the software and that the battery is full.



pulses on trigger lines will not activate the playback of a waveform. When this box is *checked*, the NeuroMod tXES Stimulator enters Pause mode when the Hardware or software Play buttons are pressed and waits for the specified trigger to initiate playback of the specified waveform. Checking this box also un.masks the Enable Re-Trigger check box.

- Enable Re-Trigger: When this box is *unchecked*, the NeuroMod tXES stimulator enters Pause mode when the Hardware or software Play buttons are pressed and waits for the specified trigger to initiate playback of the specified waveform. The specified waveform will be played back once, the stimulator will move to finished mode, and additional triggers will be ignored. When the box is *checked*, the NeuroMod tXES stimulator enters Pause mode when the Hardware or software Play buttons are pressed and waits for the specified trigger to initiate playback of the specified waveform. The specified waveform will be played back once, the stimulator will return to Pause mode, and additional triggers will initiate additional playback of the specified waveform.
- Trigger: The waveform specified in the box labeled “Trigger 1” can be triggered by a TTL pulse on Trigger Line 1 or by combinations of triggers as specified in the drop down menu.
  - Trigger 1: Initiates playback of the specified waveform with TTL pulses on Trigger Line 1.
  - Trigger 2: Initiates playback of the specified waveform with TTL pulses on Trigger Line 2.
  - Trigger 3: Initiates playback of the specified waveform with TTL pulses on Trigger Line 3.
  - Trigger 1 or 2: Initiates playback of the specified waveform with TTL pulses on Trigger Lines 1 or 2.
  - Trigger 1 or 3: Initiates playback of the specified waveform with TTL pulses on Trigger Lines 1 or 3.
  - Trigger 2 or 3: Initiates playback of the specified waveform with TTL pulses on Trigger Lines 2 or 3.
  - Any Trigger: Initiates playback of the specified waveform with TTL pulses on Trigger Lines 1, 2, or 3.
- Trigger Polarity: Normal detects TTL pulses that have a zero baseline and rise to 3.2 V or more. Inverted detects TTL pulses that have a 5 V baseline and decrease to 1.8 V or less.
- Trigger Edge: Rising detects the leading edge of a TTL pulse. Falling detects the trailing edge of a TTL pulse.
- Continuous: When this box is *unchecked*, the waveform is played back once in response to a Trigger or the hardware or software Play buttons. When this box is *checked*, a waveform is played back continuously in response to pressing the hardware or software play buttons until it is stopped manually by pressing the hardware or software Stop buttons.





- One-Shot: When this box is *unchecked*, the NeuroMod tXES Stimulator is placed in Continuous mode. When the box is *checked*, the stimulator plays back the specified waveform once in response to a Trigger or the hardware or software Play buttons.
- Time Limited Run: When this box is *unchecked*, the length of the continuous run is unlimited and terminated only by the pressing of the hardware or software Stop buttons. When this box is *checked*, a number must be entered into the box to the right of the checkbox. The number specifies the number of seconds for continuous delivery of the waveform. The waveform will be delivered continuously for the specified length of time. At any time during this time-limited, continuous playback pressing the hardware or software Stop buttons will terminate the delivery of the waveform.
  - tACS should be delivered using a time-limited, continuous delivery of a sine wave.
  - tRNS should be delivered using a time-limited continuous delivery of a vector of random numbers.

### NeuroMod tXES Controller GUI - Channel Status

**(Center Box):** The center box determines which channels are active or inactive and displays the status of the active channels via colored circular indicators.

- Virtual Channel Selector Buttons: Channels can be activated or inactivated by pressing the virtual button

with the numbers 1 through 16. The activated channels have black text and borders. Inactive channels have gray text and borders.

- In the activated channels there is a circular colored indicator that indicates the status of the activated channel. The indicator will only show a color after the playback of a waveform has been initiated.
  - Green Indicator: Impedance across this channel is within the limit on the settings page, 30 kOhms by default. The specified waveform will be delivered on this channel.
  - Yellow Indicator: Impedance across this channel is outside the limit on the settings page. The specified waveform will not be delivered on this channel.
  - Red Indicator: Impedance readings cannot be taken on this channel. The specified waveform will not be delivered on this channel. Please contact the experts at Brain Vision or Santa Fe Neurosciences to help resolve this issue.
- Inactivated channels will not play back the selected waveforms. Impedance readings will not be taken on inactive channels.
- The number of channels that can be activated is determined by the version of the stimulator that was purchased. With a 2, 4, or 8-channel stimulators any two, four, or eight channels can be activated. With 16-channel stimulators all channels can be activated.



NOTE: If the number of channels activated is greater than the capability of the stimulator, waveforms will be delivered only on the channels with the lowest numbers.

### NeuroMod tXES Controller GUI - Waveforms and

**Stimulator Status (Bottom Box):** The bottom box shows the selected waveforms and the status of the stimulator.

- The upper left corner shows the maximum voltage output of the stimulator,  $\pm 35$  V by default. This describes the upper limit of the voltage and is not a measure of the voltage across the electrodes.
- The upper right corner has a software button that uploads the stimulation logs to the directory specified in the settings.
- The Active Waveforms shows the files that are specified for playback.
  - Default: The waveform in this box will be played back when the Enable Trigger Input option is not selected and the hardware or software Play buttons are pressed. The waveform will play back in One-Shot or Continuous mode as specified.
  - Trigger 1: The waveform in this box will be played back when the Enable Trigger Input or Enable Re-Trigger in response to a TTL pulse on Trigger Line 1 or with an alternative trigger as specified in the description above. The waveform will play back in One-Shot or Continuous mode as specified.
  - Trigger 2: The waveform in this box will be played back when the Enable Trigger Input or Enable Re-Trigger in response to a TTL pulse on Trigger Line 2. The waveform will play back in One-Shot or Continuous mode as specified.
  - Trigger 3: The waveform in this box will be played back when the Enable Trigger Input or Enable Re-Trigger in response to a TTL pulse on Trigger Line 3. The waveform will play back in One-Shot or Continuous mode as specified.
- Waveforms are specified in each box by depressing the virtual “...” button and navigating to the waveform file, highlighting it with a single click, and pressing the Open button.
- A battery status indicator is located in the lower left corner.
- A connection status message is shown in the lower left border.
  - “Not Connected” indicates that the GUI is not interacting with the NeuroMod tXES stimulator. No waveforms can be delivered by pressing the software Play, Pause, or Stop buttons. The hardware Play, Pause, Stop button on the NeuroMod device will deliver the waveform with the options that were set in the previous session.
  - “Connected to NeuroMod16” indicates that the GUI has found and is communicating with the



NeuroMod tXES Stimulator. The hardware and software Play, Pause, and Stop buttons have similar functionality.

- A timer in the center bottom shows the time elapsed in the replay of a waveform. A message displaying the message HV On will flash when the stimulator is engaged in or paused during playback of a waveform.
- Bottom Right has the software Play, Pause, and Stop

**If the stimulator becomes unresponsive to the hardware or software Pause or Stop buttons, stimulation can be terminated in three ways.**

- 1) Turn the Power Switch to the off position.**
- 2) Disconnect the ribbon cable from the front of the stimulator.**
- 3) Disconnect the ribbon cable from the Head Box.**

buttons.

- Play: Initiates the replay of the specified waveform in the Default box or places the stimulator in to Pause mode to await a trigger depending on the specifications at the top of the NeuroMod tXES software GUI window.
- Pause: Pauses the waveform playback on the first press. A second press resumes playback of the

waveform.

- Stop: Stops the playback of the waveform or terminates waiting for a trigger and places the NeuroMod tXES Stimulator in Finished mode.

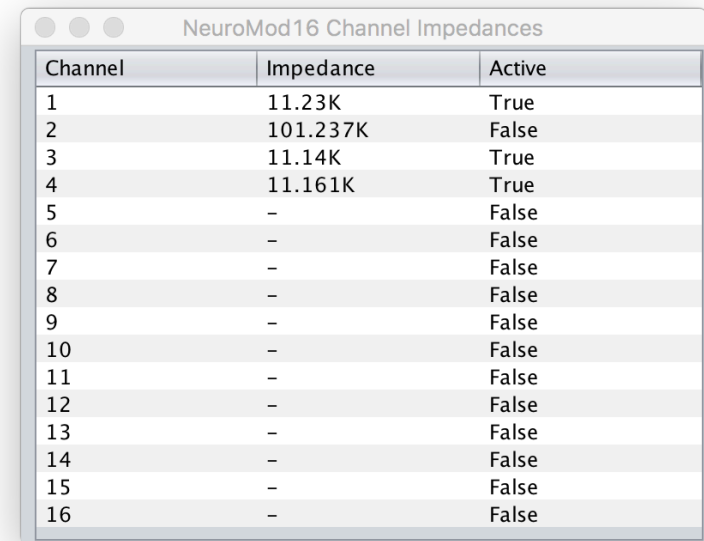
**Drop down options in the Menu Bar:** The choices in the drop down menus will be represented with the syntax top level > lower level and followed with a description of the effects of selecting an option. For quick reference the information will be presented in a bulleted list.

- File > Save Configuration: Selecting this option saves the options that are selected in a file called “gizmo.cfg”.
  - This configuration file is updated automatically on exit of the NeuroMod tXES Controller GUI.
  - This configuration file must be present in the same directory from which the GUI is launched.
- Starting the NeuroMod tXES Controller GUI without a configuration file in the same directory will cause an inability to connect with the stimulator via the ethernet port.
- Configuration files that are specific for individual experiments can be stored in different directories. For example, a directory entitled “MyExperiment1” containing the controller software and configuration file will open a GUI with the settings for experiment 1. A separate directory, “MyExperiment2”, with a second copy of the GUI and configuration file will



open a GUI with the settings for experiment 2.

- **File > Exit:** Selecting this option closes the NeuroMod tXES controller software.
  - The configuration file is updated automatically upon exit of the GUI.
  - If the ethernet port is disconnected while the GUI is active and the NeuroMod tXES Stimulator is on, the user will need to reconnect the ethernet cable then exit and restart the GUI to connect with the stimulation device.
- **View > Channel Impedances:** Selecting this option brings up a window that shows the channels, the measured impedances, and the status of the channel. This can be seen in Figure 12.
- **View > Waveform List:** Selecting this option brings up a menu that shows the waveforms that are stored on the device and provides options Ok, Add, Delete, Refresh, Clear, and Cancel.
  - **View > Waveform List > Ok:** Selecting this option places the selected waveform into the Default box on the GUI.
  - **View > Waveform List > Add:** Selecting this option allows the user to add waveforms to the memory on the NeuroMod tXES Stimulator.
    - The password for the NeuroMod tXES Stimulator is required to add waveforms.



Channel	Impedance	Active
1	11.23K	True
2	101.237K	False
3	11.14K	True
4	11.161K	True
5	-	False
6	-	False
7	-	False
8	-	False
9	-	False
10	-	False
11	-	False
12	-	False
13	-	False
14	-	False
15	-	False
16	-	False

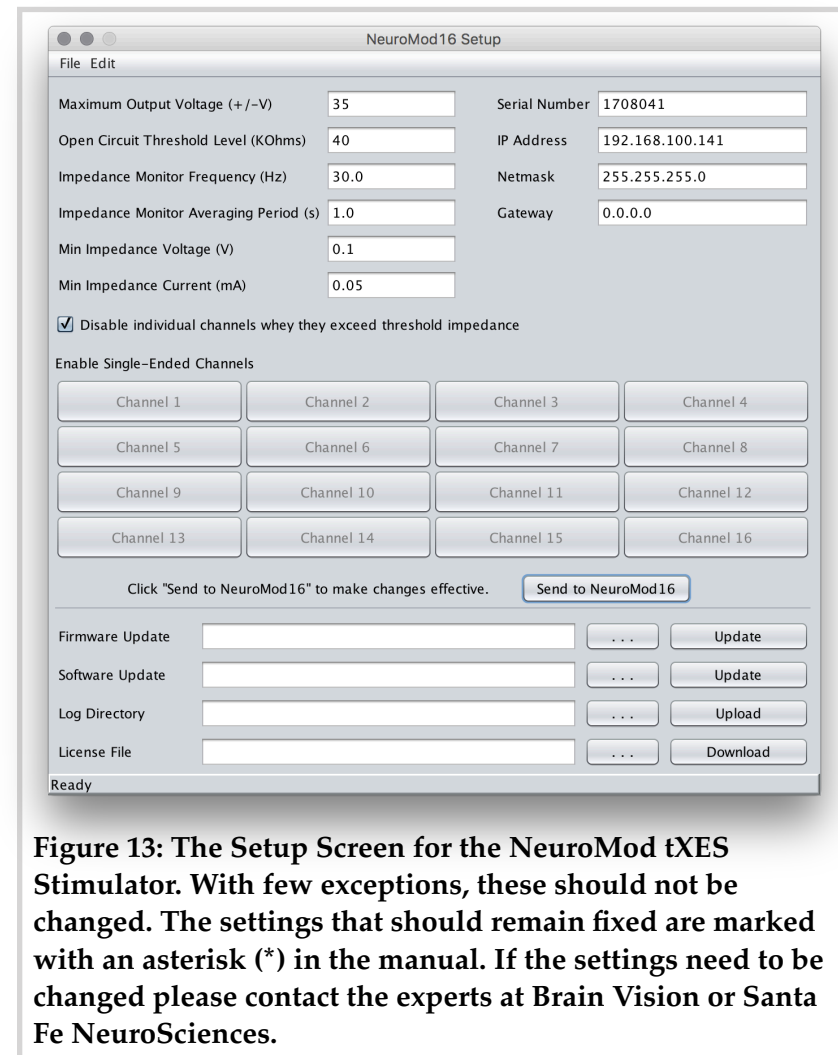
**Figure 12: Display of channel impedances.** The left column shows the channel number, the center shows the impedance measured across the channel, and the right column shows the status of the channel. True indicates that the channel is active and on. False indicates that the channel was not selected as part of the montage or that the channel has been turned off as a result of high impedance. In the display above, Channels 1-4 have been turned on and channel two has been deactivated as a result of a high impedance measurement.

- When the correct password is entered, a window is displayed with directory and file information.
- The user can navigate to the directory where the waveforms are stored and select 1 or more files to



be added to the memory on the stimulator.

- View > Waveform List > Delete: Selecting this option removes the selected waveform from the memory of the NeuroMod tXES Stimulator.
- View > Waveform List > Refresh: Selecting this option refreshes the list of waveform files that are stored on the stimulator.
- View > Waveform List > Clear: This option clears the selected waveform and allows the user to select a different waveform for placement in the Default box on the GUI.
- View > Waveform List > Cancel: Selecting this option cancels the selection of a new waveform for the Default box in the GUI and closes the window showing the waveforms stored on the NeuroMod tXES Stimulator.
- Hardware Setup > Setup Screen: Selecting this option brings up a window that allows the user access to advanced settings. Changing the factory settings can effect the functioning of the NeuroMod tXES stimulator. The settings that should be changed only in consultation with the experts at Brain Vision or Santa Fe Neurosciences are marked below with an asterisk (\*). These advanced settings can be seen in Figure 13.



**Figure 13: The Setup Screen for the NeuroMod tXES Stimulator. With few exceptions, these should not be changed. The settings that should remain fixed are marked with an asterisk (\*) in the manual. If the settings need to be changed please contact the experts at Brain Vision or Santa Fe NeuroSciences.**

\* Changing this setting can negatively effect the performance of the NeuroMod tXES Stimulator. Please contact the experts at Brain Vision or Santa Fe Neurosciences before making any changes.



- \* Hardware Setup > Setup Screen > Maximum Output Voltage\*: This setting determines the voltage range of the device. The default setting is  $\pm 35$  V. The maximum capacity of the system is  $\pm 40$  V. However, this pushes the electronics of the system to their maximum capacity. Prolonged use at the voltage maxima may reduce the lifetime of the electronics and the battery life. If you change this value it should decrease, not increase above  $\pm 35$  V.
- \* Hardware Setup > Setup Screen > Open Circuit Threshold Level (kOhms): This setting determines the impedance value that will be considered an open circuit, i.e. a bad or disconnected electrode. The user can determine the value that is appropriate for their experiments. However, the user should keep in mind that the equation  $V=IR$  (where V is voltage, I is current, and R is resistance or impedance) sets limits for the current that can be delivered at high impedances. For example, 35 V across a 30 kOhm impedance means the maximum current that can be delivered is the voltage/impedance or 1.167 mA. At the  $\pm 35$  V maximum it is critical to get impedances under 17.5 kOhms to ensure a 2 mA current will be delivered on a channel.
- \* Hardware Setup > Setup Screen > Impedance

Monitor Frequency (Hz): This setting determines the number of impedance readings that are taken each second while a waveform is being delivered. High numbers (greater than 100) negatively impact the performance of the stimulator in changing the current at specified times. Low values cause increased variance in the impedance reading during subject movement.

- \* Hardware Setup > Setup Screen > Impedance Monitor Averaging Period (s): This setting determines the period over which the impedance readings are averaged to assess the quality of the connection between the electrodes and the skin. The default setting of 1 causes the impedance to be evaluated each second. An impedance reading above the user determined threshold deactivates the channel. Similarly, a setting of 5 evaluates the impedance after 5 seconds. The functional effect of this setting is to evaluate the impedance over the specified period of seconds and shut down the channel to ensure the safety of the subject.
- \* Hardware Setup > Setup Screen > Min Impedance Voltage (V): This setting determines the voltage at which samples are excluded from the impedance calculation. When the current specification is near

\* Changing this setting can negatively effect the performance of the NeuroMod tXES Stimulator. Please contact the experts at Brain Vision or Santa Fe Neurosciences before making any changes.





zero; as in a sine wave that is crossing the zero line, a zero voltage specification for a waveform that has a built in pause or delay, or tRNS specification where the mA are near the zero line;  $V=IR$  can give a zero in the numerator of the equation. This causes an error that dramatically underestimates the impedance and can cause volatility in the impedance calculation. Excluding samples below a minimum voltage prevents this error.

- \* Hardware Setup > Setup Screen > Min Impedance Amperage (mA): This setting determines the current at which samples are excluded from the impedance calculation. When the current specification is near zero; as in a sine wave that is crossing the zero line, a zero voltage specification for a waveform that has a built in pause or delay, or tRNS specification where the mA specification is near zero;  $V=IR$  can give a divide by zero error that dramatically overestimates the impedance calculation and may shut down a channel improperly. Excluding samples below a minimum amperage prevents this error.
- Hardware Setup > Setup Screen > Disable Individual Channels When They Exceed Threshold Impedance: When this box is *checked* individual channels with impedances higher than the Open Circuit Threshold

are turned off and tES continues on channels where the impedance is below the open circuit threshold. This changes the tES montage. When the box is *unchecked* tES stops on all channels when impedance on any channel exceeds the Open Circuit Threshold.

- \* Hardware Setup > Setup Screen > Serial Number: The serial number of your device should match the label on the top of the NeuroMod tXES Stimulator. The Serial Number is linked to the licensing information and should not be changed.
- \* Hardware Setup > Setup Screen > IP Address: The NeuroMod tXES Stimulator communicates with an attached computer via a ethernet port. The address of the device is set to 192.168.100.1XX, where XX are the last two numbers of the serial number. If this number needs to be changed as a result of a conflict with another network device, please contact the experts at Brain Vision or Santa Fe Neurosciences for assistance.
- \* Hardware Setup > Setup Screen > Netmask: The Netmask should be set to 255.255.255.0 and should not be changed.
- \* Hardware Setup > Setup Screen > Gateway: The Gateway should be set to 0.0.0.0 and should not be

\* Changing this setting can negatively effect the performance of the NeuroMod tXES Stimulator. Please contact the experts at Brain Vision or Santa Fe Neurosciences before making any changes.



changed.

- **Hardware Setup > Setup Screen > Enable Single Ended Channels:** Selecting this option for any channel delivers the specified waveform on only the electrode with the white wire and the black wire is inert. In Single Ended mode, it is the responsibility of the user to balance the positive and negative currents across the electrodes. The single ended mode is useful for advanced applications such as replicating the high density tES paradigms or current steering using multiple electrodes. Improper use of this option can damage the NeuroMod tXES device and increase the risk to the subject. Please consult with the experts at Brain Vision or Santa Fe Neurosciences before use.
- **Hardware Setup > Setup Screen > Send to NeuroMod16:** Any changes to the settings in any field on the Settings Page must be sent to the NeuroMod tXES Stimulator before they will become effective. Please use this button only when you are certain you want to make changes to the settings.
- **\* Hardware Setup > Setup Screen > Firmware Update:** When a firmware update is required this can be used in collaboration with the experts at Brain

Vision or Santa Fe Neurosciences.

- **\* Hardware Setup > Setup Screen > Software Update:** When a software update is required this can be used in collaboration with the experts at Brain Vision or Santa Fe Neurosciences.
- **Hardware Setup > Setup Screen > Log Directory:** The user should set the directory where log files should be stored when uploaded. The directory should be selected by pressing the “...” button and navigating to the directory, highlighting it with a single click, and pressing the Open button.
- **\* Hardware Setup > Setup Screen > License File:** When a license update is required this can be used in collaboration with the experts at Brain Vision or Santa Fe Neurosciences.
- **Hardware Setup > Restart NeuroMod16:** Selecting this option restarts the internal software on the NeuroMod tXES Stimulator. This will terminate the delivery of all waveforms or wait modes for triggers. This is sometimes necessary after a software upgrade and under rare circumstances where the stimulator does not respond as expected.
- **About > Version:** Selecting this option displays hardware and software information that is useful if

\* Changing this setting can negatively effect the performance of the NeuroMod tXES Stimulator. Please contact the experts at Brain Vision or Santa Fe Neurosciences before making any changes.





troubleshooting is required. The information includes GUI build date, GUI version, Application Date and Time, Application Version, Operating System Date and Time, Device Serial Number, and Hardware Serial Number.

Additional questions on the NeuroMod tXES Software can be answered by experts at Brain Vision or Santa Fe Neurosciences.

Brain Vision: [support@brainvision.com](mailto:support@brainvision.com)

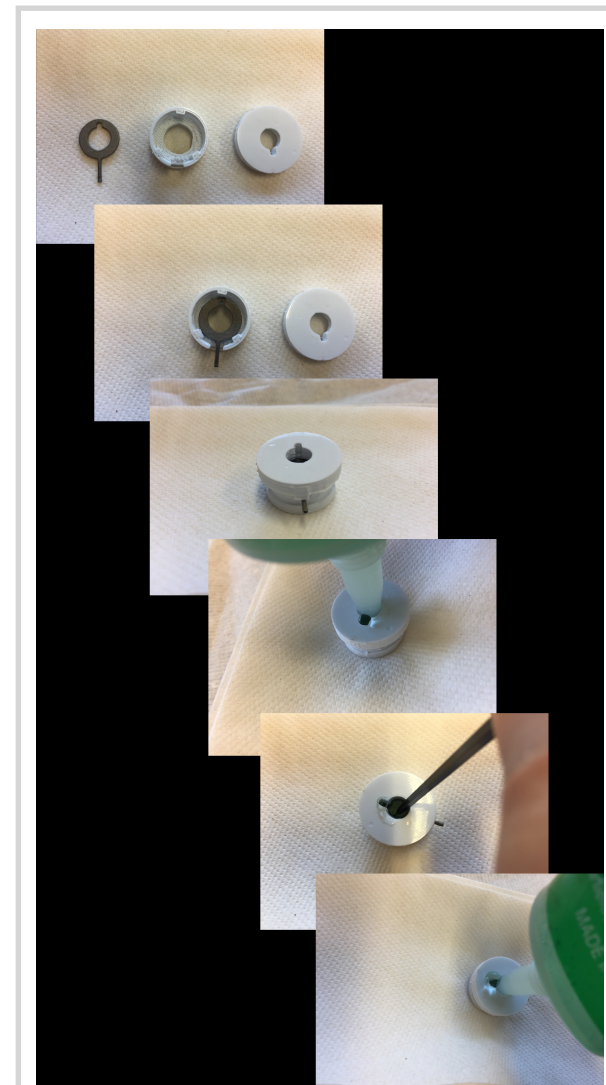
Santa Fe Neurosciences: [neuromod@sfneuro.com](mailto:neuromod@sfneuro.com)



## **NeuroMod tXES Electrode Use**

The NeuroMod tXES Electrodes can be seen in Figure 10. To apply the electrodes use the instructions below with the illustrations in Figure 14.

- Clean the skin where the electrodes will be applied with an alcohol wipe.
- Place the electrode base into the a retention device (electrode cap, Surgelast, Santa Fe Neurosciences Electrode Retainer).
- Place the electrode in the base.
- Put the electrode top in place.
- Fill the electrode assembly with conductive gel.
- Ensure that the gel fills the entire electrode assembly and area of the skin interface by moving the gel around to the inner edges of the electrode base with a cotton tipped applicator, blunt syringe needle, or similar.
  - The goal is to move the spread the gel without abrading the skin.
  - The use of instruments with sharp edges is discouraged.
- Refill the electrode assembly until gel exits the relief slot in the electrode top.
- Check the impedance using the NeuroMod tXES

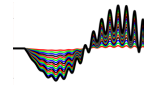


**Figure 14: Setup of the NeuroMod tXES Electrodes. See detailed instructions for assembly and filling with gel in the text.**



Stimulator or other impedance checking device.

- High impedances can typically be corrected with moving increasing the homogeneity of gel at the skin interface (removing air bubbles).
- Impedances typically get lower with time. Gelling the electrodes early in the visit of the research subject is advantageous.

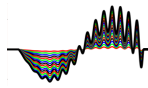


## NeuroMod tXES Electrode Maintenance

The NeuroMod tXES Electrodes require regular cleaning and maintenance to prolong their useful life time.

- With maintenance the electrodes can be used indefinitely.
- Without maintenance the electrodes will fail unpredictably after 6 to 10 uses in unbalanced waveforms like tDCS or tRNS.
- In tDCS and tRNS parallel waveforms with inverted polarities (anodal and cathodal) should be created. After each use the waveform with an inverted polarity should be run while the electrodes are immersed in the same gel used during stimulation to recondition the electrodes. The electrodes should be thoroughly cleaned in immersed briefly in alcohol prior to reuse.
- In tACS the waveform is typically balanced and only cleaning and brief immersion in alcohol is necessary to properly maintain electrodes.





## NeuroMod tXES Waveform Creation

There are 4 Matlab functions that are provided for the user to create or view the contents of a waveform file. The waveforms can create tDCS, tACS, or tRNS waveforms.

### General Notes:

- The function numSubplots is required to use the functions described below. Please obtain the function from <https://www.mathworks.com/matlabcentral/fileexchange/26310-numsubplots-neatly-arrange-subplots> before use.
- The format of the waveform files is a four column matrix in CSV format. The first column gives the times when the amplitude of the current should be updated. The second column gives the channel numbers. The third column gives the values in mA for the stimulation waveform. The fourth column contains a vector of zeros. The time and amplitude vectors must be repeated for each channel. Please consult with the experts at Brain Visions or Santa Fe Neurosciences before attempting to create your own waveforms.

Brain Vision: support@brainvision.com

Santa Fe Neurosciences: neuromod@sfneuro.com

**NeuroModTACSWaveform.m:** tACS waveforms can be created with user specifications using this Matlab function.

Example: `NeuroModTACSWaveform(10,0,0,10,2,4,'/Users/mydata/mywaveforms/')` will create a 10 Hz sine wave that starts and stops at full strength because the rise and fall times are zero. The length of the waveform will be 10 seconds. The peak amplitude will be  $\pm 2$ mA. The current will be divided across 4 electrodes. The waveform and image depicting the waveforms will be stored in the `Users/mydata/mywaveforms` directory.

- Format: function [] = NeuroModTACSWaveform (stimFreq, riseTime, fallTime, durationAtMax, maxAmplitude, montageN, saveDir)
- Inputs:
  - stimFreq: the frequency of the tACS (Hz)
  - riseTime: the time over which the amplitude of stimulation increases from zero to maximum (seconds)
  - fallTime: the time over which the amplitude of stimulation falls from maximum to zero (seconds)
  - durationAtMax: the duration of stimulation at maximum amplitude (seconds)
  - maxAmplitude: the amplitude of stimulation at maximum (mA)



- montageN: the number of channels the current will be divided across (integer from 1-16)
- saveDir: directory where waveform files will be saved ('text')
- Outputs:
  - File and figure saved to saveDir
- Notes:
  - Large waveforms negatively effect the performance of the NeuroMod tXES Stimulator. It is preferred to specify a small number of cycles of a sine wave at relatively high fidelity (100 points) and repeat the sine wave for a specified number of seconds instead of creating a large waveform with many cycles of the sine wave.
  - tACS sine waves with very large numbers of points may exceed the 25  $\mu$ A resolution of the NeuroMod tXES device. Thus, the waveform will not change until the threshold is exceeded.
  - The NeuroMod tXES Stimulator defines the amplitude of the tACS waveform from baseline to peak similar to the Soterix stimulators. This is unlike the NeuroConn stimulator that defines the amplitude of the waveform from peak to peak.
  - The number of subplots in the image will reflect the number of channels that have been included in the stimulation montage.

**NeuroModTDCSWaveform.m:** tDCS waveforms can be created with user specifications using this Matlab function.

Example: NeuroModTDCSWaveform(15,15,1800,2,4,'/Users/mydata/mywaveforms/') will create a DC waveform that rises to maximum over 15 seconds and falls to zero over 15 seconds. The length of the stimulation at maximum current will be 1800 seconds. The peak amplitude will be +2mA. The current will be divided across 4 electrodes. The waveform and image depicting the waveforms will be stored in the Users/mydata/mywaveforms directory.

Format: function [] = NeuroModTDCSWaveform (riseTime,fallTime,durationAtMax,maxAmplitude,montageN,saveDir)

- Inputs:
  - riseTime: the time over which the amplitude of stimulation increases from zero to maximum (seconds);
  - fallTime: the time over which the amplitude of stimulation falls from maximum to to zero (seconds);
  - durationAtMax: the duration of stimulation at maximum amplitude (seconds);
  - maxAmplitude: the amplitude of stimulation at maximum (mA);
  - montageN: the number of channels the current will



be divided across (integer from 1-16)

- saveDir: directory where waveform files will be saved ('text')
- Outputs:
  - File and figure saved to saveDir
- Notes:
  - The NeuroMod tXES device changes the amplitude of the waveform only when instructed. Thus, the rise and fall of the waveform is specified with changes to the amplitude over time. However, there is no need to specify changes over the time of peak stimulation amplitude. Thus, the file size for tDCS waveforms does not necessarily vary with the length of stimulation.
  - The NeuroMod tXES Stimulator defines the tDCS and tACS waveforms similarly - from baseline to peak. This is similar to the Soterix stimulators but unlike the NeuroConn stimulator that defines tDCS from baseline to peak but tACS from peak to peak.
  - The number of subplots in the image will reflect the number of channels that have been included in the stimulation montage.

**NeuroModTRNSWaveform.m:** tRNS waveforms can be created with user specifications using this Matlab function.

Example: NeuroModTRNSWaveform(1,1,10,2,4,'/Users/mydata/mywaveforms/') will create a random noise waveform that rises to maximum over 1 second and falls to zero over 1 second. The length of the stimulation at maximum current is possible will be 10 seconds. The peak amplitude will be +2mA. The current will be divided across 4 electrodes. The waveform and image depicting the waveforms will be stored in the Users/mydata/mywaveforms directory.

Format: function [] = NeuroModTRNSWaveform(riseTime,fallTime,durationAtMax,maxAmplitude,montageN,saveDir)

- Inputs:
  - riseTime: the time over which the amplitude of stimulation increases from zero to maximum (seconds);
  - fallTime: the time over which the amplitude of stimulation falls from maximum to to zero (seconds);
  - durationAtMax: the duration of stimulation at maximum amplitude (seconds);
  - maxAmplitude: the amplitude of stimulation at maximum (mA);
  - montageN: the number of channels the current will be divided across (integer from 1-16)
  - saveDir: directory where waveform files will be saved ('text')



- Outputs:
  - File and Figure saved to saveDir
- Notes:
  - Large waveforms negatively effect the performance of the NeuroMod tXES Stimulator. It is preferred to specify a short noise vector (10000 points) and repeat the noise vector for a specified number of seconds instead of creating a large waveform with long vectors of random noise.
  - tRNS waves with very small changes from one point to the next in the vector may exceed the 25  $\mu$ A resolution of the NeuroMod tXES device. Thus, the waveform will not change until the threshold is exceeded.
  - The NeuroMod tRNS Stimulator defines the amplitude of the tACS waveform from baseline to peak similar to the Soterix stimulators. This is unlike the NeuroConn stimulator that defines the amplitude of the waveform from peak to peak.
  - tRNS waveforms are created at 1000 samples per second using the Matlab function randn. The maximum value in the random noise vector is scaled to the maximum specified current. All other values in the noise vector are scaled by the same factor.
  - The number of subplots in the image will reflect the number of channels that have been included in the

stimulation montage.

**NeuroMod tXES Waveforms:** Custom Matlab scripts are available to create pulsed, windowed, multifrequency, evoked response based, and other waveforms. The user can also program the waveforms that conform to the tXES .wf format. The format of the waveform files is a four column matrix in CSV format. The first column gives the times when the amplitude of the current should be updated. The second column gives the channel numbers. The third column gives the values in mA for the stimulation waveform. The fourth column contains a vector of zeros. The time and amplitude vectors much be repeated for each channel. Please consult with the experts at Brain Visions or Santa Fe Neurosciences before attempting to create your own waveforms.

**NeuroModWaveformPlotter.m:** This Matlab function plots the contents of any waveform file.

Example: NeuroModWaveformPlotter('User / myData / myWaveforms', 'myWaveform')

Format: function [] = NeuroModWaveformPlotter (saveDir, waveform2plot)

- Inputs:
  - saveDir: directory where waveform files will be saved ('text')
  - waveform2plot: the waveform file to plot without the .wf extension ('text')





- Outputs:
  - Image saved to saveDir
- Notes:
  - Waveforms can be viewed but not created using this function.
  - Matlab will overwrite previous images of a waveform with the image shown with this function.
  - The number of subplots in the image will reflect the number of channels that have been included in the stimulation montage.

