MAN-MET16
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SIGENICS MET16 ANALYTICS MANUAL

USER GUIDE

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The MET16 is not intended for use on human subjects. Please read the grounding recommendations in this manual before in-vivo testing.

System Overview

This user guide describes the architecture, technical specification and usage of the MET16 16-Channel Micro-Electrode Tester System. The MET16 Analytic system can rapidly provide the end user with an analysis of each electrode in a microelectrode array.

In this manual, the term "Scan" is defined as a collection of test types along with their parameters to be performed on one or more electrodes. The MET16 can perform CV, EIS and Pulse measurements, and one or more of these test types can be included in a scan.

The MET16 system consists of:

a) The MET16 electrode analyzer
b) A multiconductor 0.75m long extension cable
c) A "populated Load Board", which may be used to verify of proper system operation
d) An "unpopulated Load Board", which does not have the R-C loads installed
e) A "Connector Board" to facilitate connection of the MET16 to a multi-electrode array
f) An Analytic software package to control the MET16

The MET16 software is controlled by a web browser and can utilizes many existing web-based technologies to allow remote control of the hardware, and facilitate easy sharing of the experimental data for internal and external review. The MET16 collects the "raw data" acquired during a scan in SI units using measurement methods familiar to electrochemists. Raw data is available in standard .csv format for user analysis or publication.

The Analytic software provides the user with an intuitive GUI to allow the user to set up the MET16 electrode scan parameters. An electrochemist exploring the detail of electrochemical reactions at the electrodes would use this package. Raw data acquired during the scans is available to the user in SI units.

The MET16 Electrode Analyzer Overview

The MET16 allows for *in vitro* and *in vivo* measurements of electrode characteristics. The MET16 can force a potentiostatic voltage on all working electrodes with respect to a reference electrode, and measure simultaneously the current in all 16 working electrodes. Standard CV (cyclic voltammetry) and EIS (electrochemical impedance spectroscopy) can be rapidly measured. In addition, the MET16 can apply a programmable biphasic current pulse to a working electrode and measure the resulting voltage excursion with wide bandwidth, allowing the charge capacity of stimulation electrodes to be calculated. The MET16 also supports cable compensation and automatic data sharing if desired by the user.

Electrochemical Measurement Overview

Electrochemical experiments examine the interaction of an electrode, the “working electrode”, with an electrolyte. The voltage vs. current vs. time response of the electrode are the parameters of interest. A second electrode connection must be made to the electrolyte using a “counter electrode” to provide a return for the current.

A two-electrode system

The simplest test setup consists of two electrodes immersed in an electrolyte. The two electrodes are:

1). The working electrode: The electrode under test.

2). The counter electrode: This electrode provides the return path for the current in the working electrode.

]

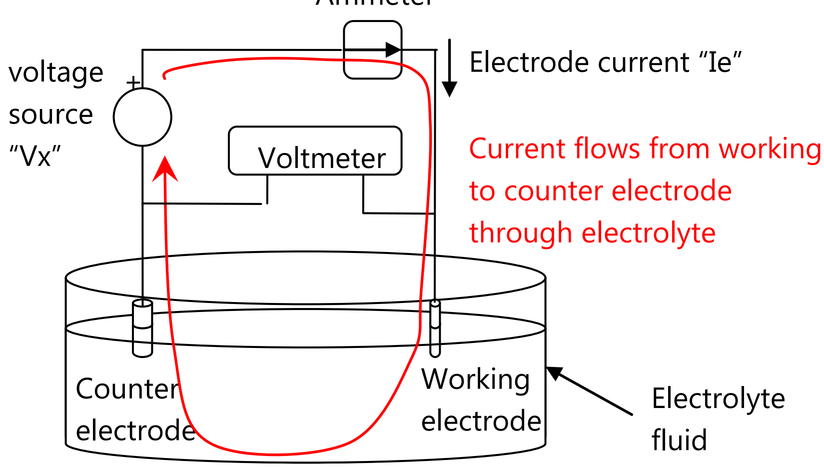


Figure 1. A two-terminal electrochemical measurement

To make a measurement, a voltage “Vx” is applied between the working and counter electrodes, and the resulting current “Ie” is measured vs. Vx and/or time. The measurement results depend upon both the working and counter electrode’s interaction with the electrolyte. Current from the working electrode into the electrolyte produce a current and time dependent voltage drop between the working electrode and the electrolyte – this is the voltage drop of interest. The same however is true at the counter electrode, and only the sum of these voltage drops can be measured as "Vx". Although the counter electrode properties will affect the results, the simplicity and safety of the measurement is an advantage, and the MET16 defaults to this method for in-vivo measurements.

A three-electrode system

A three electrode system is used to minimize the effects of the counter electrode properties upon the working electrode measurements. The three electrodes are:

1). The working electrode: The electrode under test.

2). The reference electrode: An electrode used to define the "0V" voltage reference against which the voltage at the working electrode is measured. This is usually a non-polarizable electrode, such as a silver-silver chloride electrode, as used in standard electrochemical measurements. Ideally, no current flows in the reference electrode.

3). The counter electrode: This electrode provides the return path for the current in the working electrode.

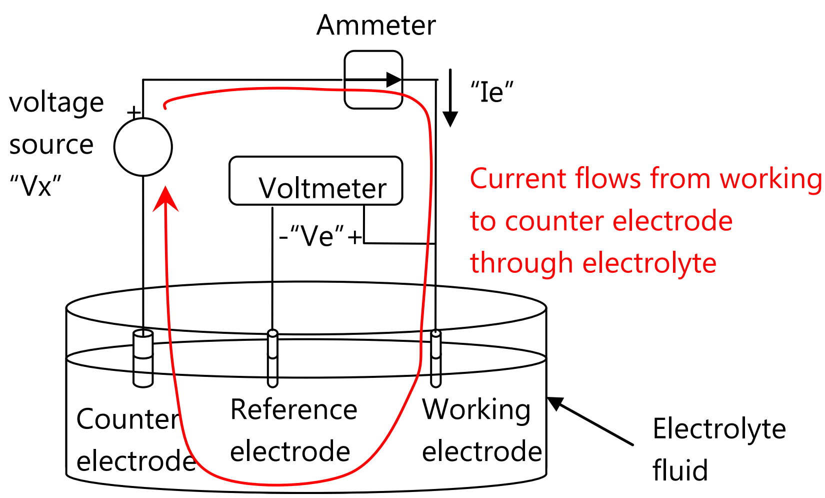


Figure 2. A three-terminal electrochemical measurement

The electrochemical measurement parameters of interest are the voltage between the reference and working electrode, "Ve" as a function of the current in the working electrode, and "Ie", as a function of time. Note that the voltage "Vx" which drives the current through the working and counter electrodes is of minimal interest.

The "Ground"

In most electronic systems, one circuit node is chosen as the zero-volt reference voltage for all other voltages in the system. This voltage is typically called "ground". In the figure above, note that none of the four circuit nodes have been named “ground”, so the diagram above represents a fully “floating” implementation of an idealized electrochemical test method.

In a real implementation, any one of the four nodes shown above could be named ground. In a typical potentiostatic instrument, the working electrode node is defined as ground. In the MET16 system, the counter electrode is defined as ground to facilitate simultaneous multi-channel measurements as well as provide safety and simplicity when performing in-vivo experiments.

A typical potentiostatic architecture

In a typical potentiostatic system, the potential of the reference is held constant. A fourth node is added to the three-electrode system and named “measurement ground”, and the counter electrode is driven to maintain the potential of the reference electrode at the measurement ground potential. A diagram of such a system is shown below. Note that the parameters of interest. “Ve” and “Ie”, are exactly the same quantities previously discussed, and it is only the electrical reference point which is altered.

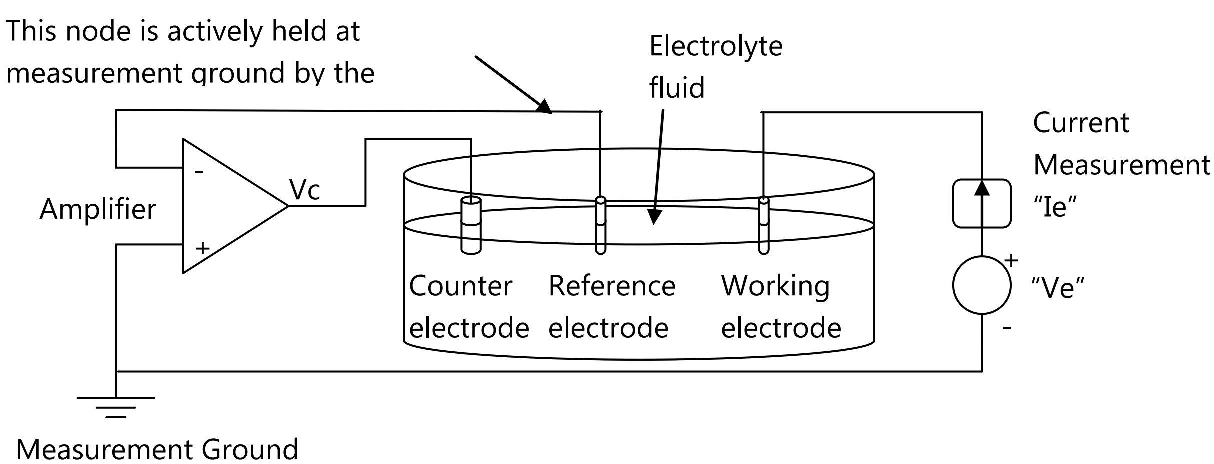


Figure 3. A typical potentiostatic architecture.

The potentiostat amplifier moves the voltage on its output, Vc, to whatever voltage is necessary to keep the difference at its inputs to zero. In the above diagram, since the amplifier positive input is held at measurement ground (0V), the counter electrode drives the electrolyte with whatever current is necessary to keep the Reference electrode voltage equal to 0V.

Since the Reference electrode potential is driven to 0V, the Working electrode excitation, Ve, is indeed the difference between the Working electrode potential and the

Reference electrode potential. “Ve” is referenced to measurement ground making it easier to generate with commonly used electronic circuits.

To generate a CV plot, a ramp wave is applied to Ve while the working electrode current is measured.

The MET16 potentiostatic architecture

The MET16 performs its potentiostatic measurements in a similar fashion by driving the electrolyte with the counter electrode to keep the reference at a known potential with respect to the working electrode. The MET16 however isolates the measurement ground node shown in the *previous* diagram to allow the counter electrode to be defined as the system ground, i.e. **ground**.

In an animal experiment, the animal is typically “grounded” by a head screw, head connector, wrist strap, metal surroundings and a faraday cage. These connections are also often connected to an earth ground. All these connections to the animal serve as the counter electrode in the MET16 electrochemical cell. For this reason, the MET16 defines the counter electrode as “ground”, allowing other instrumentation such as neural recording equipment, to be simultaneously connected to the subject during an experiment.

The users of microelectrode arrays often use a different nomenclature than electrochemical researchers, but the principles of the two and three terminal measurements remain the same. A microelectrode array contains multiple “working electrodes”, one or more “reference electrodes”, and one or more “ground electrodes”. The array’s ground electrode actually corresponds to the electrochemical counter electrode.

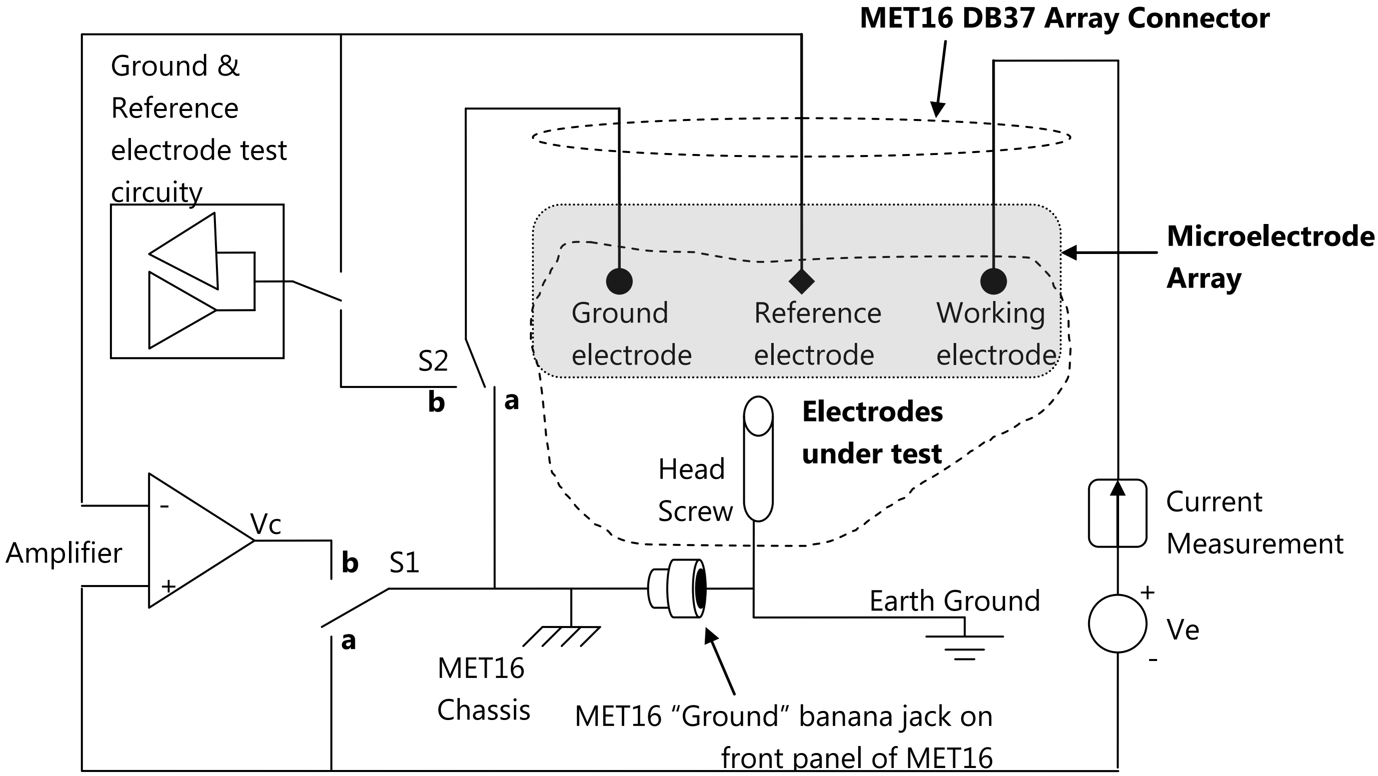


Figure 4. MET16 potentiostatic architecture.

1). True potentiostatic three-terminal measurement (Potentiostatic Mode in GUI Scan Settings)

In Figure 4 above, when the integrity of the ground electrode and reference electrode are assured, switch S1 is placed in the **b** position and switch S2 is placed in the **a** position to configure the system as a true potentiostat. In this configuration, the front panel banana jack Ground on the MET16 need not be connected to the test cell if the ground electrode is functional. The MET16 banana jack ground could also be connected to the head screw as shown in the diagram above, which connects the ground electrode and head screw in parallel so they both function as the counter electrode.

Note that if the reference electrode becomes disconnected during a three-terminal potentiostatic measurement, the amplifier goes open loop, which may result in the electrolyte being driven with a large voltage as the loop tries unsuccessfully to maintain the electrolyte voltage, therefore care should be taken to ensure the reference electrode connection is intact.

2). Two terminal measurement (Grounded Mode in GUI Scan Settings)

Referring again to Figure 4, for in-vivo experiments, connect the head screw to the MET16 Ground front panel banana jack. The MET16 software GUI ignores the reference electrode potential and sets switches S1 and S2 in the **a** position to make a two-terminal measurement. This method may result in a small voltage offset in the working electrode voltage measurement as compared to a true potentiostatic measurement because of the voltage drops between the electrolyte and the head screw/ground electrode, but this default method is used for these reasons:

- Additional safety if the integrity of ground and reference electrodes is unknown
- Less noise since the impedance of a head screw is usually low
- Compatibility with a typical neural recording experimental setup, where the test subject could be "grounded" at multiple points (head screw, metal table, head connector, ground electrode, wrist strap etc.)

Note that a true potentiostatic measurement can be performed in-vivo as in 1) above, but the integrity of the ground and reference electrodes in the array must first be verified to ensure the safety of the measurement.

MET16 Block Diagram

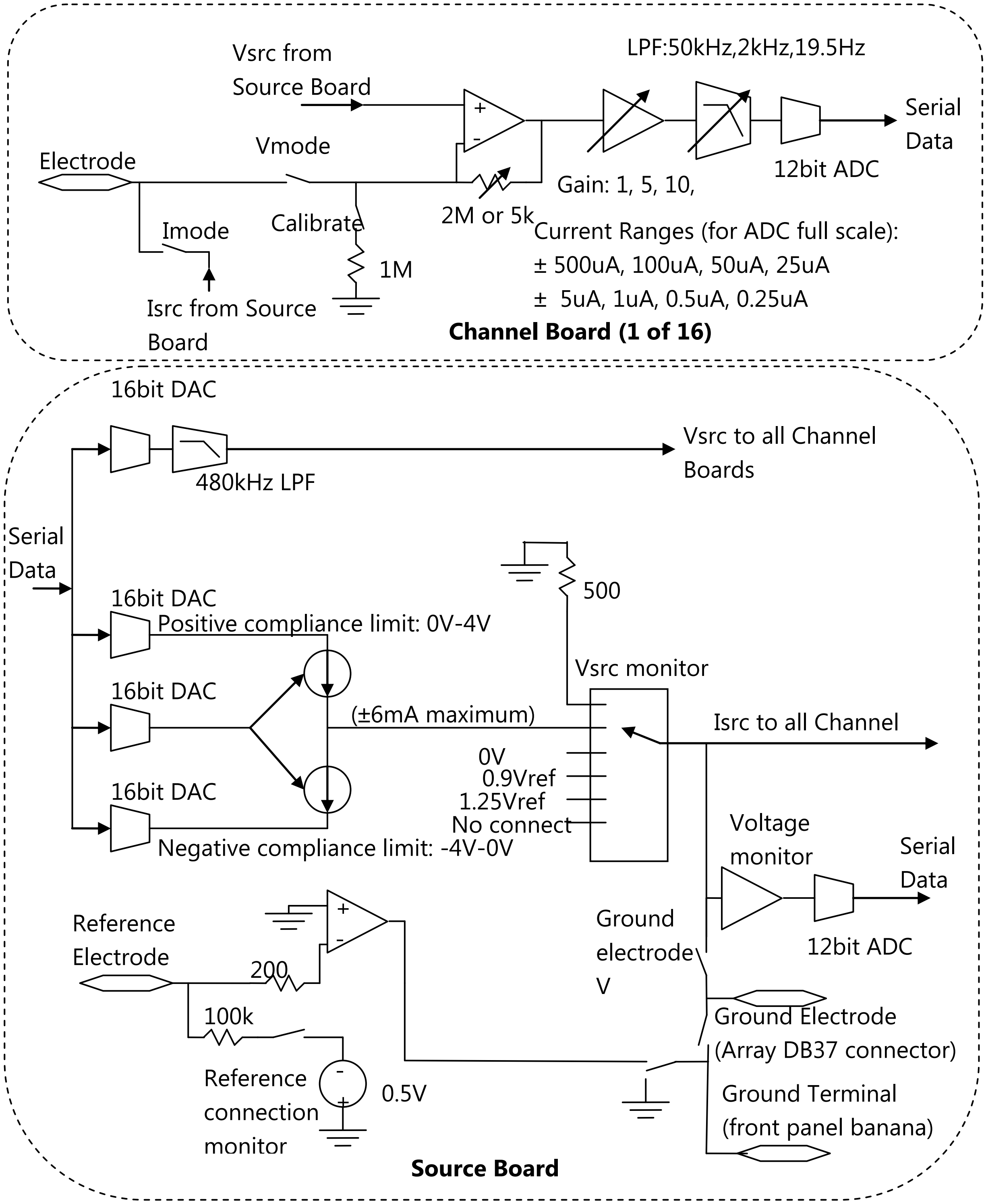


Figure 5. The MET16 Functional Block Diagram.

MET16 Theory of Operation

The MET16 contains 16 Channel Boards. A microprocessor on the motherboard controls each channel board and collects their acquired data in parallel via sixteen high-speed serial interfaces. Each Channel Board is connected to one electrode via a guarded connection to the DB37M front panel connector. Each Channel Board applies a voltage, "Vsrc" (corresponding to "Ve" in Figure 4) to its electrode, and can measure the current flowing in the electrode. The Channel Boards use the "force voltage, sense current" modality to acquire data for the CV and EIS curves. A Calibrate relay connects a precision 1M resistor to the electrode input to allow the MET16 to self-calibrate against three precision voltage references. During a CV or EIS sweep, data from the ADC converters on all of the Channel Boards is collected simultaneously by the microcontro ller on the motherboard, resulting in dramatically short electrode array scan times.

The Source Board supplies the forcing voltage, Vsrc, to all Channel Boards simultaneously. This voltage is generated by a DAC followed by a low pass Filter, and applies a potentiostatic voltage between -2V and 2V to the electrodes with respect to the reference electrode.

The MET16 can also force current, and measure the voltage on a single selected electrode. This modality is used for measuring the rapid voltage response of a stimulating electrode to a fast current pulse. Since the Pulse measurements can happen very rapidly, there is no need for the MET16 to process Pulse measurements in parallel. To make this measurement, first all Channel Boards are disconnected from their electrodes by opening the Vmode and Imode relays, then the selected Channel Board is connected to the Isrc bus by closing its Imode relay. The Source Board applies a programmable magnitude and duration current pulse on the Isrc bus while measuring the changing electrode voltage with the Source Board "Voltage monitor" ADC. The GUI offers the option of either measuring a single pulse with a 4uS time resolution, or making time-interleaved measurements on 8 pulses for 0.5uS time resolution.

The current source and sink on the Source Board has positive and negative compliance limits to protect the electrodes under test. In addition, a multiplexer on the Source Board allows the Source Board ADC to measure three reference voltages as well as Vsrc for MET16 self-calibration.

Calibration

Calibration is actually a two-step process: the first step is done at the factory, and the second is done automatically if necessary immediately prior to the user's scan.

1). At the factory, each MET16 is calibrated to allow measured data to be converted into accurate SI units. The gain and offsets of each of the 16 channel boards inside the MET16 are individually measured to produce a set of calibration files which are then applied real-time to subsequent experimental data collection so that experimental data can be saved in accurate SI units. If required, Sigenics can remotely recalibrate your MET16.

2). Before every CV or EIS measurement in a scan, the MET16 software checks the local PC for the existence of a second type of calibration file, called the "zero baseline" file which must correspond EXACTLY to the type of measurement about to be made with EXACTLY the same parameter settings. If this zero baseline file is not present, the MET16 does a "dry run" of the requested test with the electrodes automatically disconnected to generate this zero baseline file. *If a user runs a particular scan for the first time, the MET16 will therefore take twice as long to complete the initial first-time scan.*

Cable Compensation

Cable and/or other stray capacitance and leakage on the electrode connecting wires will cause measurement inaccuracies. This is because the stray capacitance and any leakage of the interconnect cabling appears in parallel with the electrode being measured. ***Cabling and wires should be kept as short as possible when measuring small electrodes.*** Running measurements of all the electrode cabling or wires with the electrodes "dry" or disconnected at the distal end will give the user a measure of the impedance of the interconnecting wires alone. If the observed effect of the cabling is significant, the user may decide to have the MET16 automatically compensate for the effects of the cabling.

The MET16 system allows the user to perform a "Cable Compensation" to correct for cable wiring effects. The MET16 performs and stores a set of cable-only measurements and "subtracts" these baseline measurements in real-time, from any subsequent experimental measurements.

Prior to performing the cable compensation, the user must set up the cabling with the electrode array disconnected from the distal end of the cabling. Alternatively, the cable compensation can be performed with a new and dry electrode array in air connected to the cabling. The MET16 system requires that the measurement parameters used during any compensated electrode measurement are exactly identical to the parameters used during the cable compensation measurement.

The cable and experimental setup must remain exactly the same during the compensation measurement and the subsequent compensated electrode measurement, otherwise inaccurate electrode data may be collected.

Analytic Software Architecture

The analytic software consists of:

1). Google Chrome web browser.
2). Node.exe web server.
3). HTML and javascript files to implement the GUI and manage the lower-level .exe programs.
4). Master.exe, cvcal.exe, eiscal.exe and other command line executables which run to interface directly with the MET16 firmware and hardware via a USB port.
5). .json files which hold scan configuration and parameter settings for a particular experiment.
6). .csv files containing native and cable compensation information for the MET16.
7). .csv files containing electrode data collected by the MET16.
8). Firmware within the MET16 hardware.

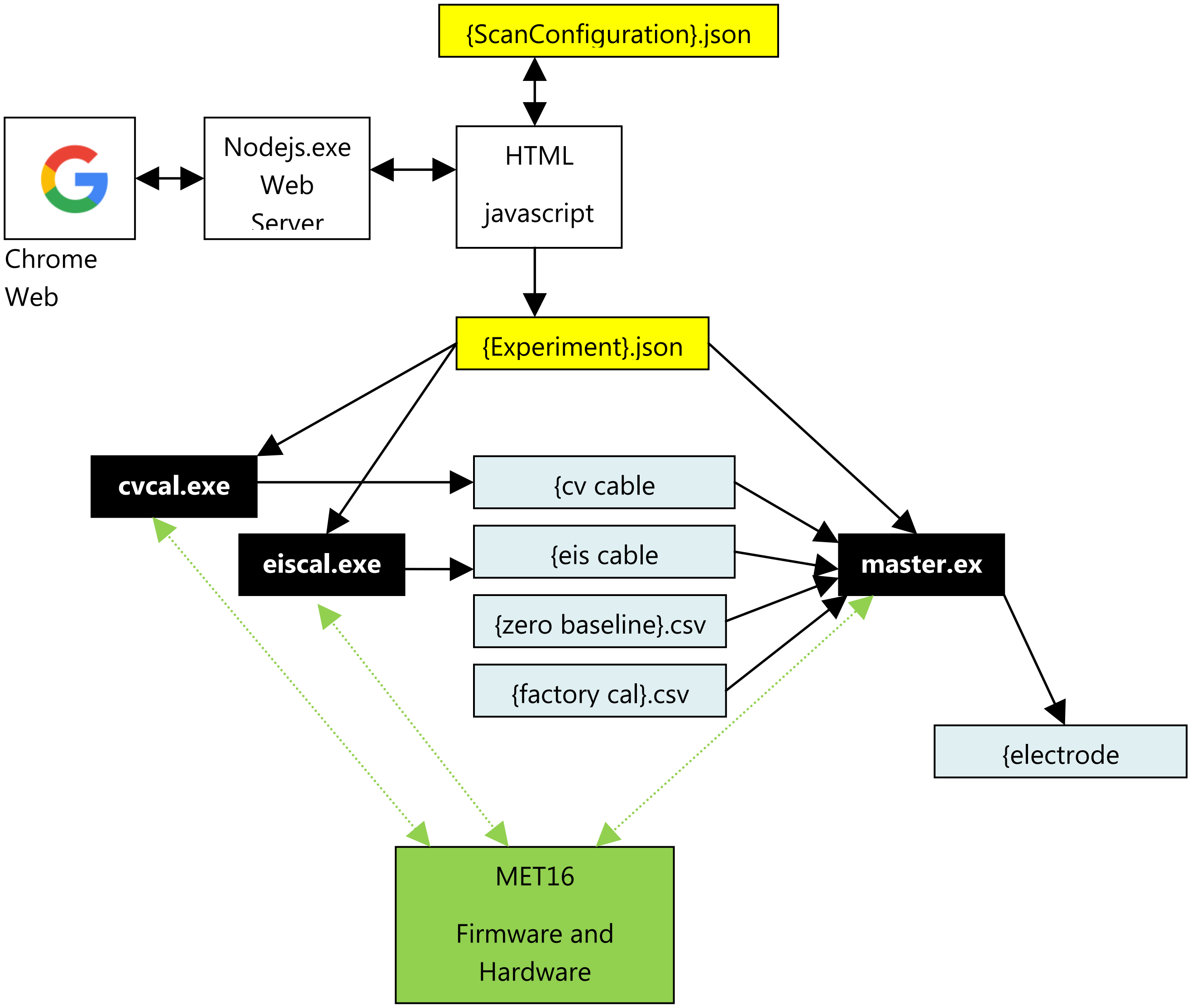


Figure 6. Software Architecture

The GUI is implemented in HTML and displayed in the Chrome web browser via the node.exe web server. The website code interprets the user input and creates or modifies the {ScanConfiguration}.json file, which remembers the user-selected settings. When the "Start Scan" GUI button is pushed, the website code creates {Experiment}.json, and runs the command-line statement "*master.exe {Experiment}.json*". master.exe also uses the calibration .csv files as input to produce calibrated data as {electrode data}.csv files. The {factory cal}.csv file is always used by master.exe, and if cable compensation is used, the {cv cable comp}.json and/or {eis cable comp}.csv files are also used. Note that cvcal.exe and eiscal.exe must be run prior to the experiment with cables attached to generate the .csv compensation files needed for cable compensation.

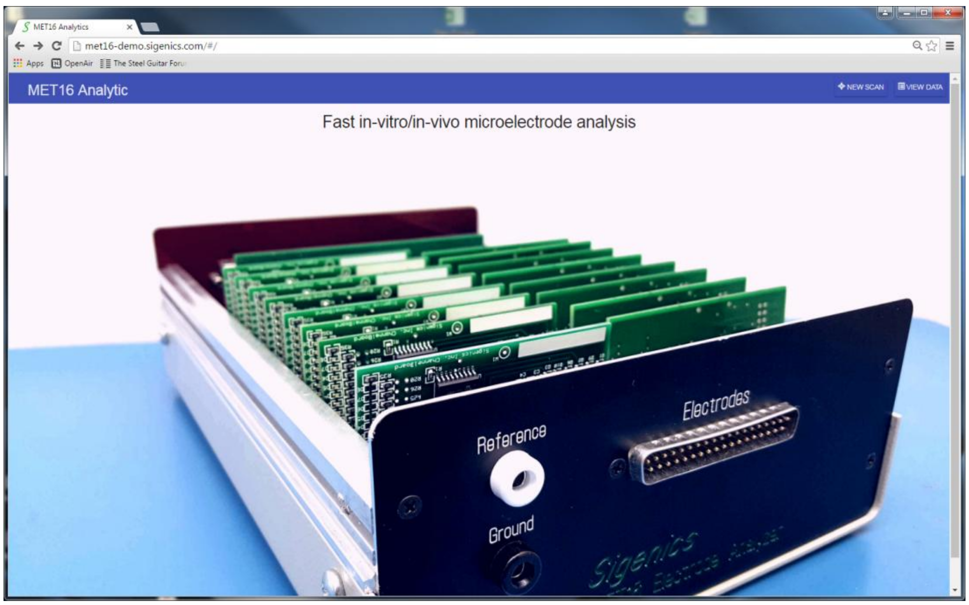
Web-Based Software

A demo of the software, controlled by your browser with no installation required, may be found at: http://met16-demo.sigenics.com/#/

A ***Scan*** is a data collection consisting of one CV, one EIS and/or one Pulse test, occurring in that order. For example, a Scan could consist of (CV,EIS,Pulse) or only (CV) or only (CV,Pulse) etc.

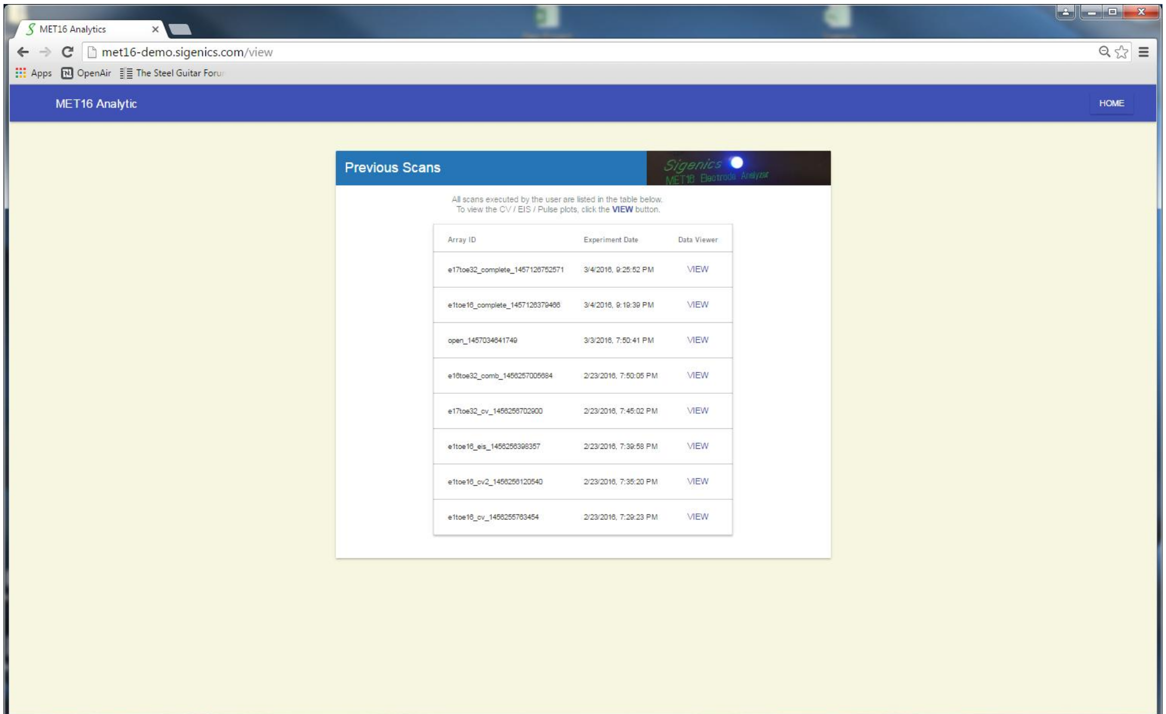
A Scan Configuration is a .json file which describes which of the three tests are to be run, and holds the parameters to be used for each test.

Home Page



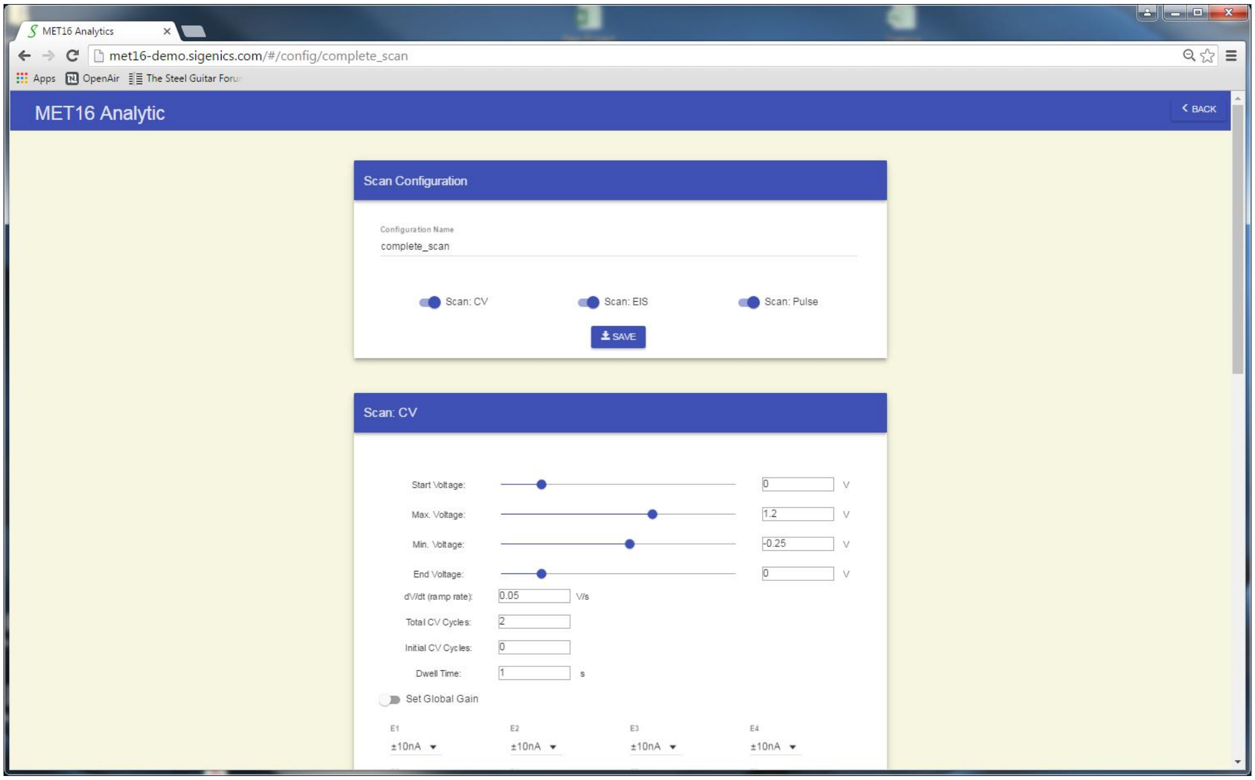
On the Home Page, the user has the option of either New Scan or View Data.

View Data



On the View Data page, the user selects data from a previous Scan, and the data is displayed. This page gives the user a basic data view immediately after a Scan to verify the integrity of the experiment. Since data is saved in .csv files, it may be displayed in many different ways using other software packages, such as Excel.

New Scan



On the New Scan page, the user has the option to create a new Scan Configuration or edit an existing one. After the desired Scan Configuration is selected, the user selects which of the 16 electrodes are to be included in the Scan. Note that the electrode selection is not stored in the Scan Configuration.

After the Scan Configuration and electrode selections are made, the user hits the "Scan" button to start the new Scan.

Establishing a Remote Connection

When the user launches the MET16_analytics.exe, it starts the Nodejs.exe web server on port 3000 on your PC (localhost). MET16_analytics.exe then opens your browser and directs it to localhost:3000 and your browser will display the MET16 GUI.

Nodejs.exe can serve the MET16 GUI to multiple browsers at the same time, so if you opened a second browser window and manually directed it to localhost:3000, a second GUI window would open up and control the same MET16 hardware. You can fully control the MET16 from either browser window, but naturally cannot start a new scan from either browser window if a scan is currently running.

Nodejs.exe runs as long as there are one or more browsers connected to port 3000. If you close all browser windows, there are no longer any open connections to port 3000 and Nodejs.exe will terminate itself, thereby restoring you PC to its initial state.

To establish a remote connection to Nodejs.exe from any computer on your local network:

1). First determine the local network IP address of the MET16 PC connected to the MET16. Running IPconfig from the command prompt on the MET16 PC will give you the address. Let's say for example, your local IP address is 10.0.0.123.

2). Launch the MET16 GUI on the MET16 PC. This will launch Nodejs.exe and start serving the MET16 GUI on port 3000 of the MET16 PC.

3). Open a browser on a remote PC or a smartphone connected to your local network. Direct this browser to port 3000 on the MET16 PC by typing the MET16 PC's address followed by :3000, for example 10.0.0.123:3000.

The smartphone or remote PC will launch another MET16 GUI. You can now control the MET16 or view data from any open MET16 GUI.

4). Closing the browser on the remote PC or smartphone will not shut down the MET16 GUI, since the browser on the MET16 PC is still open. You can disconnect or reconnect multiple remote PC's or smartphones at will.

If you close the browser on the MET16 PC, but a remote PC or smartphone is still connected to port 3000, the MET16 GUI will continue to run. The MET16 GUI will terminate only when ***all*** browser windows have disconnected from port 3000.

Note: The MET16 GUI can only be started from the MET16 PC, but can be terminated from any device if that device is running the last browser connected to port 3000.

A connection can be made from anywhere using a standard VPN connection from outside to the local network of the MET16 PC.

Installation

The MET16 software is typically installed by clicking a link sent to the user from Sigenics. *The software is locked to a specific MET16 serial number*, but multiple computers can run the same MET16 software to control that MET16. The "root" folder of the installation package is called "met16….". The user can choose the directory where this root folder is installed, but for proper operation the software must be free to read and write files in the installation folder. Some versions of windows restrict access to C:\. The Desktop, a D: drive or other user folder on the C: drive are good options for installation locations.

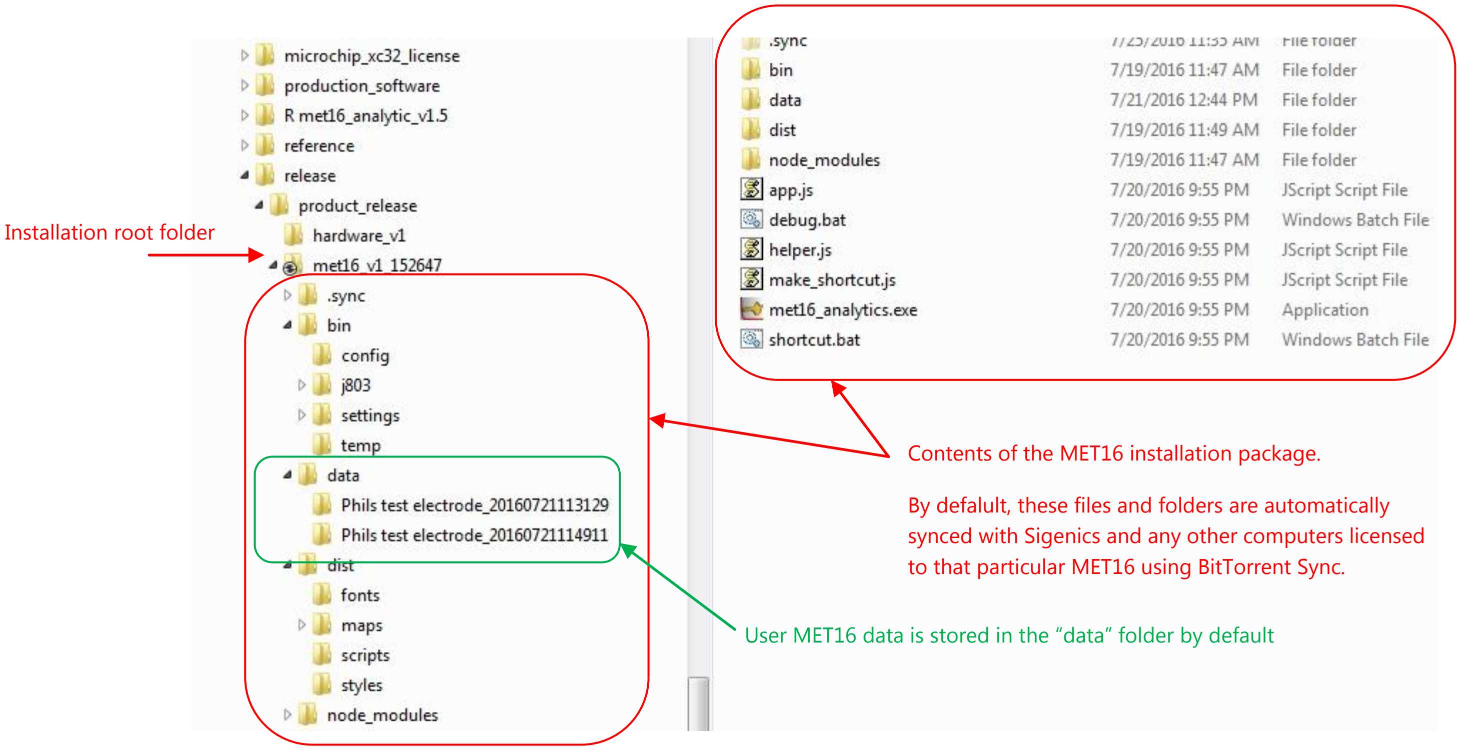


Figure 7. MET16 Installation Folder Structure

Data Sharing

The MET16 installation also installs a commercial peer-to-peer sharing program called BitTorrent Sync, and the installation root folder is shared by default. This allows any computers licensed to run your MET16 *as well as Sigenics* to access to **all** files in the installation root directory. For example, if you installed your MET16 software on both a laptop PC and a desktop PC, new MET16 measurements you make on the laptop PC would automatically show up on your desktop PC. This sharing also allows Sigenics to update your software and well as help you debug any issues you may have while making electrode measurements. Note that Sigenics does not share data between MET16's with different serial numbers!

You can restrict sharing in one of two ways:

1). Turn off or uninstall BitTorrent Sync. This will break the link between all user computers and Sigenics computer.

2). You can place your data storage folder outside the installation root directory, and it will become invisible to BitTorrent Sync.

API Description

The MET16 software is highly customizable for advanced users. The MET16 "API" does not consist of a set of calls to a dll or other program; the MET16 operation is simply determined by the human-readable .json format files passed in a command line to an executable called master.exe.

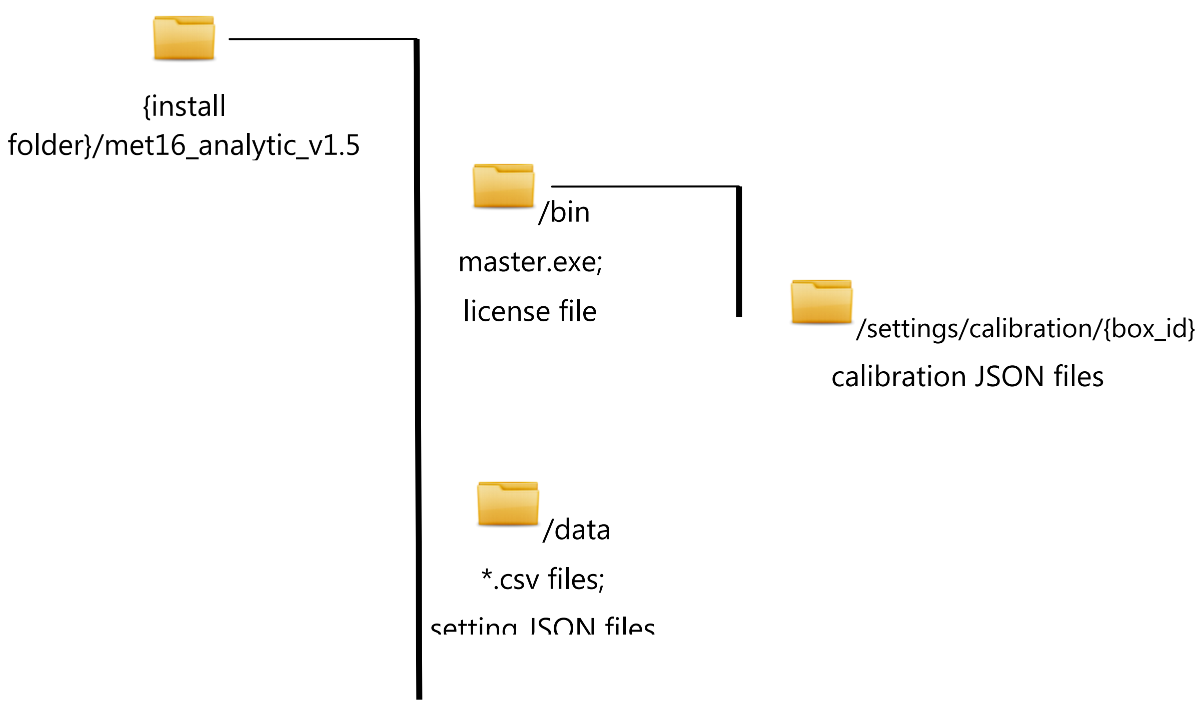


Figure 8. MET16 Software Folder Structure

The executable master.exe is located in the \bin folder in the folder where the application was installed, e.g.

```
{install folder}\met16_analytic_v1.5\bin
```

As indicated by Figure 6, master.exe also reads calibration and license files located inside the "/bin" folder. This is why you must "cd" into the "/bin" folder in step 2 below, before invoking master.exe.

Master.exe ***must*** be run from an open Command Prompt window whose directory must be preset to the \bin folder location. This Command Prompt window must remain open while the experiment is running.

The .json settings file does not need to be in the \bin folder, but if it is not, you must specify the path to the .json file in the command line of master.exe so it can find it.

There are many json examples inside "/data" folder, as well as an EIS example in the next section of this document. For each experiment performed by the MET16 GUI, a corresponding json file is stored on the local machine. Use the examples provided to generate your own custom json files.

To run the master.exe on Windows, follow the steps below:

1. Prepare your "settings.json" file, and note the location of this file
2. Open a Command Prompt window
3. Change directory:

   ```
   cd {your MET16 software install folder}\met16v1.5\bin
   ```

4. From this \bin folder, invoke the "master.exe" executable with its parameter being the "setting.json" filespec. Note that if settings.json is not in the \bin folder, you must specify the path to settings.json so master.exe can find it, like:

   ```
   master.exe C:\user\Myjson\settings.json
   ```

5. Leave the console window open until the experiment is completed. Once the experiment has started, progress information will be displayed in that console window. After the experiment is done, master.exe will save data files in the "/data" folder and exit.

   To programmatically control MET16 via common programming languages such as Python or MATLAB, the procedure is very similar. For example:

   Python code:

   ```
   os.chdir("C:\\user\\met16_analytic_v1.5\\bin")
   subprocess.call(["master", "setting.json"])
   ```

   MATLAB code:

   ```
   cd("C:\\user\\met16_analytic_v1.5\\bin")
   system("master", "setting.json")
   ```

The output data files are saved in plain CSV format, which can be imported, plotted and analyzed by most modern data analysis software.

JSON File Example

Here is an example JSON file (setting.json) to run EIS experiment at 1kHz:


```
{
    "arrayName": "airof_1447863759670",
    "dataFolder": "airof_1447863759670",
    "date": "11/18/2015, 10:22:39 AM",
    "selectedElectrodes": [
        0,
        1,
        2,
        3,
        4,
        5,
        6,
        7,
        8,
        9,
        10,
        11,
        12,
        13,
        14,
        15
    ],
    "experiments": {
        "CV": false,
        "EIS": true,
        "Pulsing": false
    },
    "eissetting": {
        "eis": {
            "single": true,
            "singleFreq": 1000,
            "startFreq": 1,
            "endFreq": 10000,
            "ppd": 1,
            "autoGain": true,
            "useCache": false
        },
        "freq_obj": [
            {
                "freq": 1000,
                "eis": {
                    "biasV": 0,
                    "endV": 0,
                    "amplitude": 0.08,
                    "cycles": 10,
                    "dwellTime": 0,
                    "dT": 0.0000078125,
                    "tableLength": 128
                },
                "adc": {
                    "filter": 0,
                    "initCycles": 2,
                    "nStep": 1,
                    "totalSamples": 1024
                }
            }
        ]
    }
}
```

Scan Profile Parameter Description

When creating or editing a scan, the user selects which of the three tests are to be included in the Scan, and parameters are shown only for the specific tests to be included in the Scan. For example, if the user wants to run only the CV and Pulse tests, the parameters for the EIS test are not shown. The parameters are described below.

CV Parameters

The CV test sweeps the electrode voltage linearly between two voltage limits at a specified ramp rate and records the electrode current. The user first sets the current gain range of each electrode channel. When the CV Scan begins, a “Start Voltage” is first applied to the electrode for a “Start Voltage Dwell Time”. The CV then begins with a specified number of “Equilibration CV Cycles” to create a stable chemical equilibrium around the electrode. Data is not taken during the Equilibration CV Cycles. Finally CV data is taken for a selected number of “Recorded CV Cycles”, and the electrode is left at the “End Voltage”. This sequence is shown below.

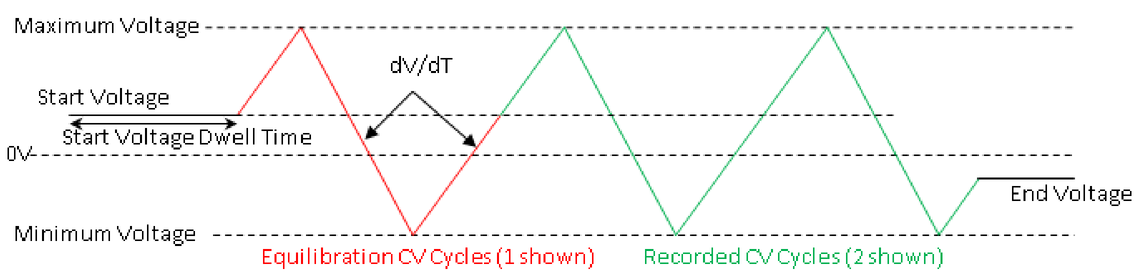


Figure 9. CV parameter diagram.

CV Parameters List:

- Current Range for each Channel (individual gains or common gain)
- Start Voltage
- Maximum Voltage
- Minimum Voltage
- End Voltage
- dV/dT Ramp Rate
- Start Voltage Dwell Time
- Equilibration CV Cycles
- Recorded CV Cycles

EIS Parameters

The EIS test applies a small (80mVpp typical) voltage sinusoid to each electrode and measures the electrode current. The Scan Profile determines how many and at which frequencies this measurement is performed. An FFT is performed inside the MET16 to extract the current amplitude and phase from the measured data at each frequency. The MET16 also automatically adjusts the current range for each channel. This autorange feature takes a preliminary measurement and saves the autorange settings. These settings may be used to speed subsequent EIS Scans, or they may be regenerated each time an EIS Scan is performed.

EIS Parameters List:

- Single Frequency? (T/F)
- Use saved previous autorange settings? (T/F)
- Start Frequency
- End Frequency
- Points per Decade
- Save as background impedance
- Subtract background impedance

Pulse Parameters

The Pulse test applies biphasic currents to each electrode sequentially and measures the time voltage response of the electrode to the current excitation. The pulse can be anodic or cathodic first, and the sequence and nomenclature for the applied current pulse and voltage response is shown below. To increase the effective time resolution of the ADC measuring the voltage response to current, ADC samples are taken from 8 successive pulses and interleaved.

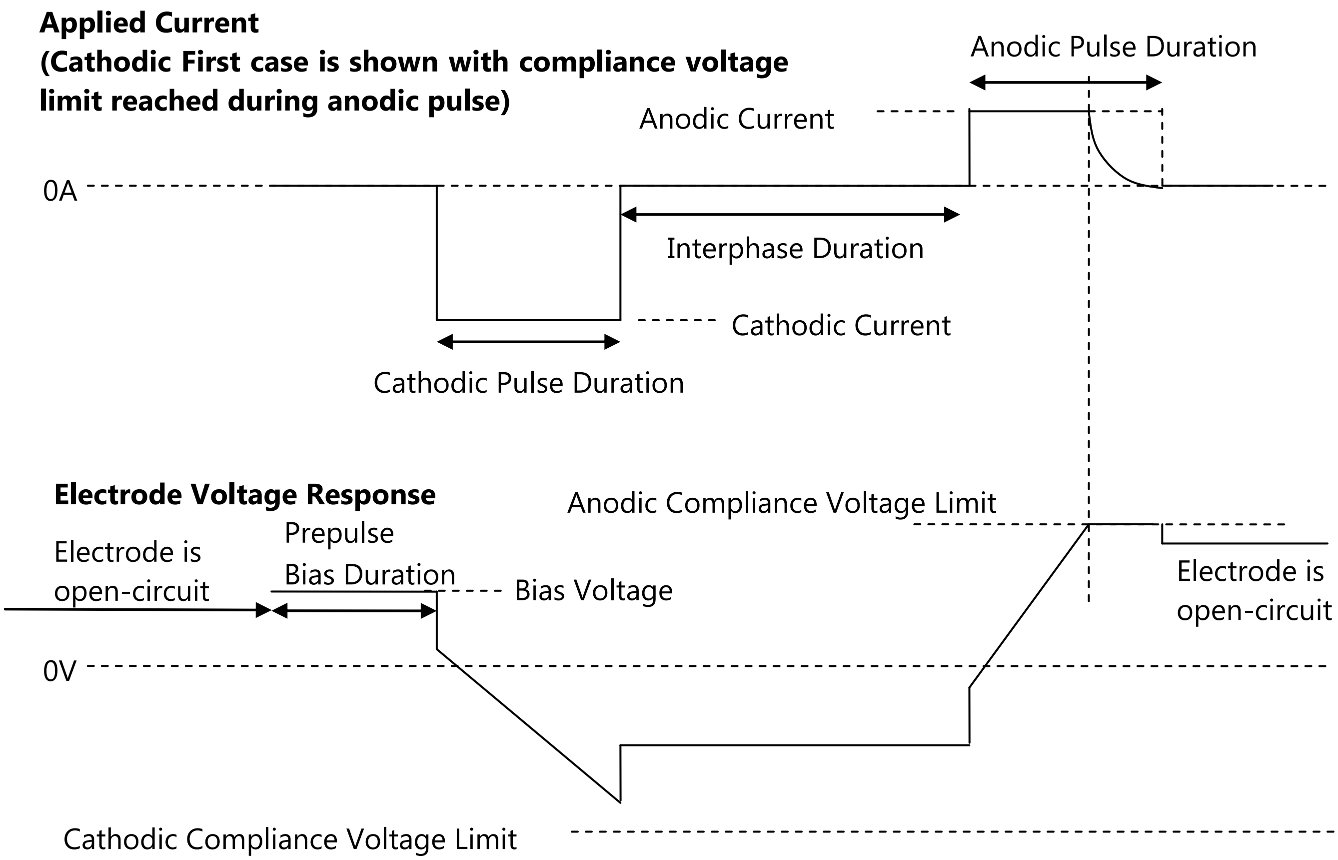


Figure 10. Pulse Parameter diagram

Pulse Parameters List:

- Cathodic First? (T/F)
- Anodic Compliance Voltage Limit
- Cathodic Compliance Voltage Limit
- Bias Voltage (must be inside compliance limits)
- Prepulse Bias Duration
- Interphase Duration
- Anodic Current

- Anodic Pulse Duration
- Cathodic Current
- Cathodic Pulse Duration

Pulse Artifacts

Because of the wideband nature of the test pulse applied to an electrode and the sensitivity of the instrument, measurement artifacts or interference may be visible in the output data, particularly when high impedance or small electrodes are being tested. Two effects may be visible:

1). Spikes from the charge injection of the current switches at the phase transitions of the current pulse waveform may be present. The magnitude of these spikes will vary with the voltage on the electrode as well as with the anodic and cathodic compliance voltage settings. In addition, interference from the internal MET16 digital logic or other external interference, such as light dimmers of radio stations, may also be visible in the output data.

2). Slower than expected risetimes due to the approximately 200pF of capacitance present on the current distribution pathway inside the MET16.

Note: In CV and EIS modes, the capacitance is different and compensated for by the calibration routine.

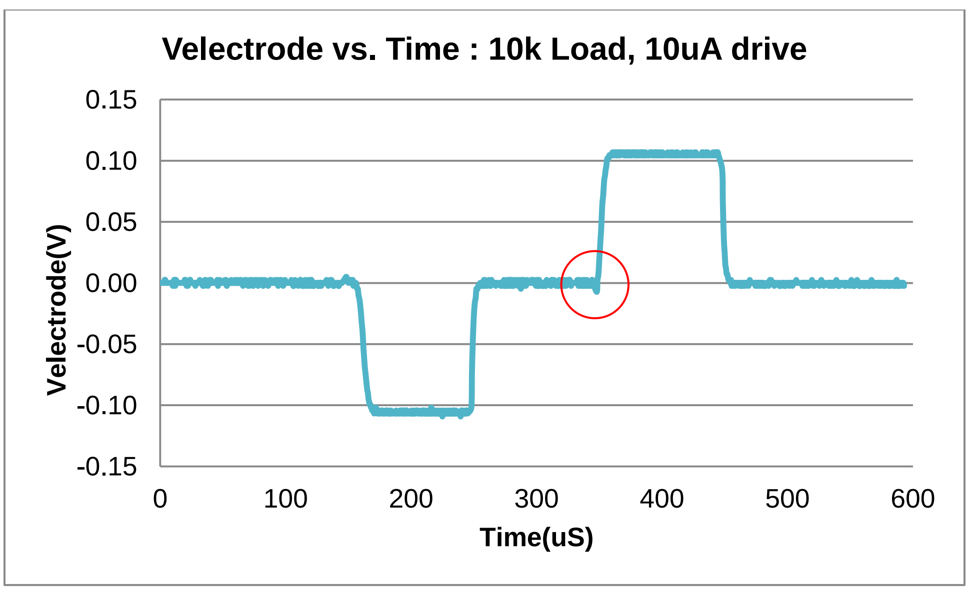


Figure 11. 10uA into a 10k resistor load

A small voltage spike artifact is circled in the waveform above.

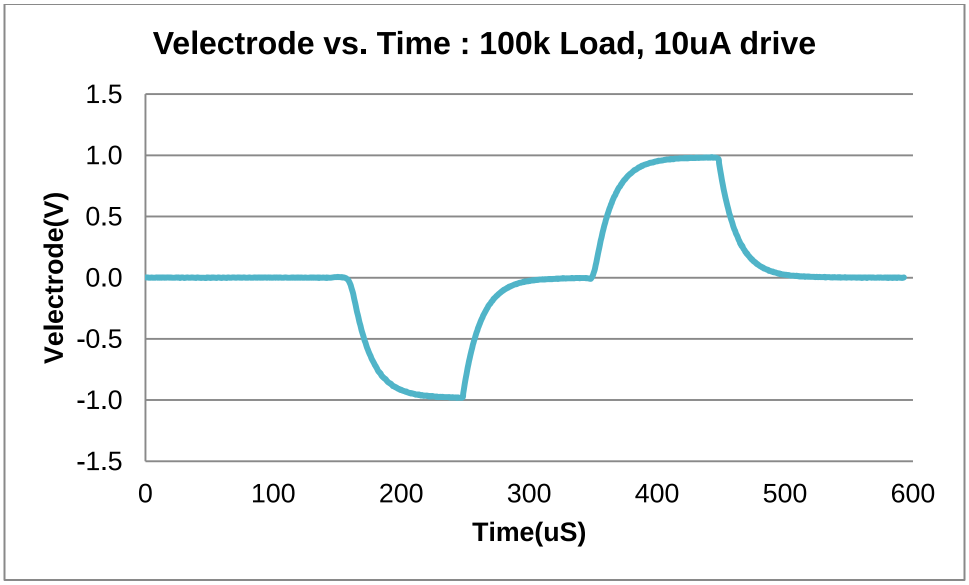


Figure 12. 10uA into a 100k resistor load

With small pulse current settings, larger electrode impedances and larger voltage swings, the 200pF internal MET16 capacitance becomes more evident, manifesting itself as slow exponential rise and fall times.

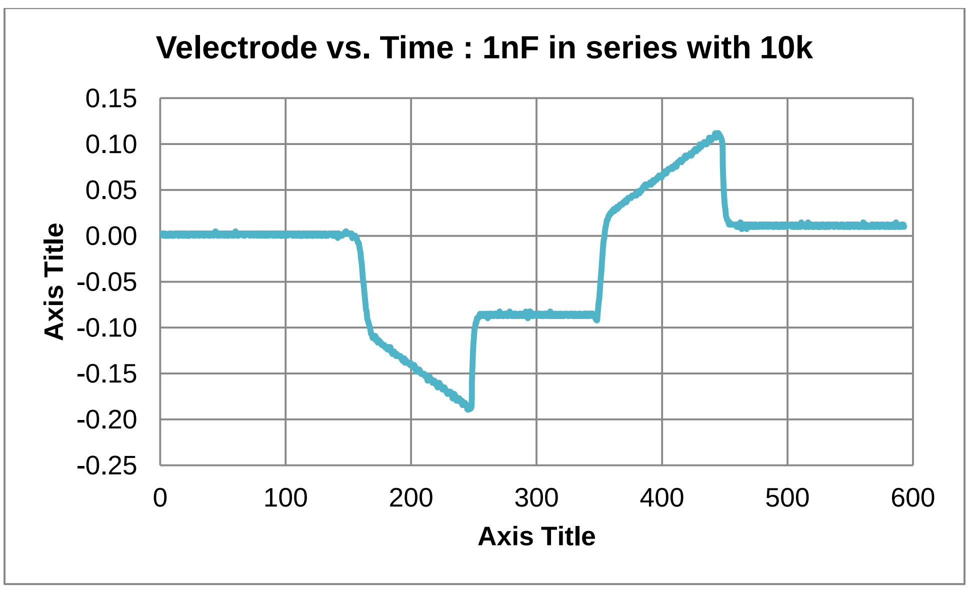


Figure 13. 10uA into a simulated "small electrode" consisting of 1nF in series with 10k

In the figure above, a series RC circuit load simulating a small electrode is driven with the biphasic current pulse. The result is a fairly good representation of the expected voltage response to the current pulse, however the effects of MET16 internal capacitance can still be seen on the fast rising and falling edges of the voltage waveform.

Recommended Measurement Setup

The setup of the measurement can affect the accuracy of MET16 measurements. More importantly, improper grounding of equipment could defeat the MET16's built in safety isolation and compromise safety.

The MET16 chassis is connected to the banana jack "Ground" connection on the front panel. This ground should be connected to the animal in an in-vivo experiment.

As a MET16 safety feature, both the USB (computer) ground and the external power supply ground are isolated from the MET16 chassis and from each other. **DO NOT connect the USB or power supply ground to the MET16 Chassis.** Acceptable and unacceptable grounding arrangements are shown below:

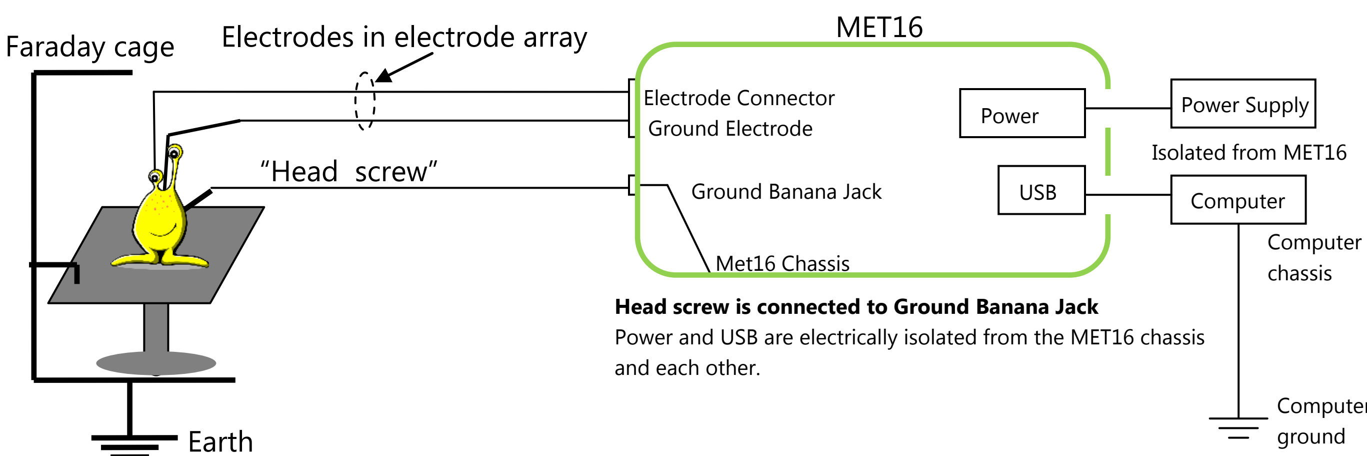


Figure 14. Best

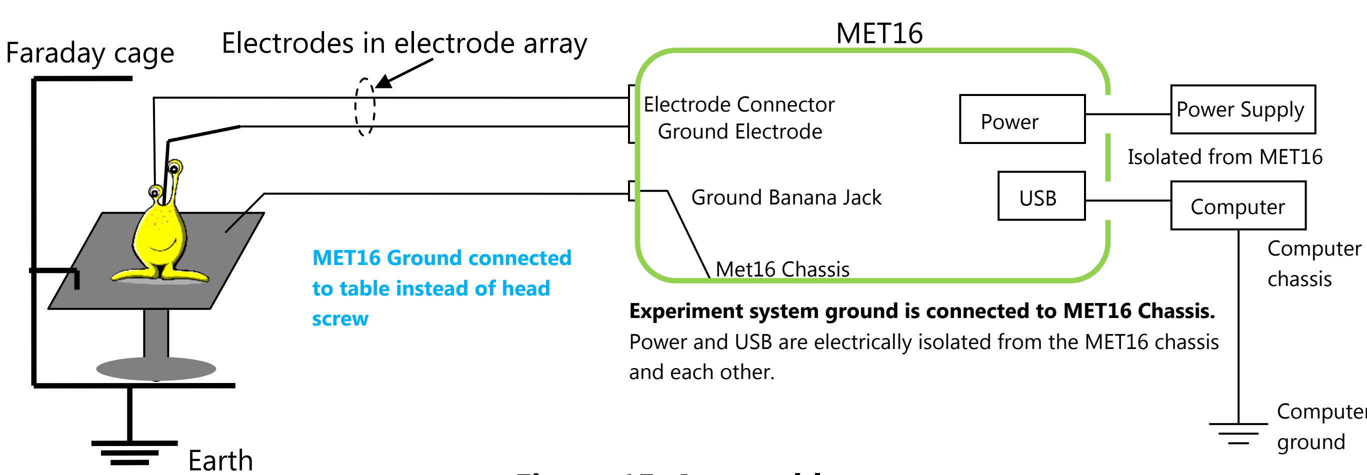


Figure 15. Acceptable

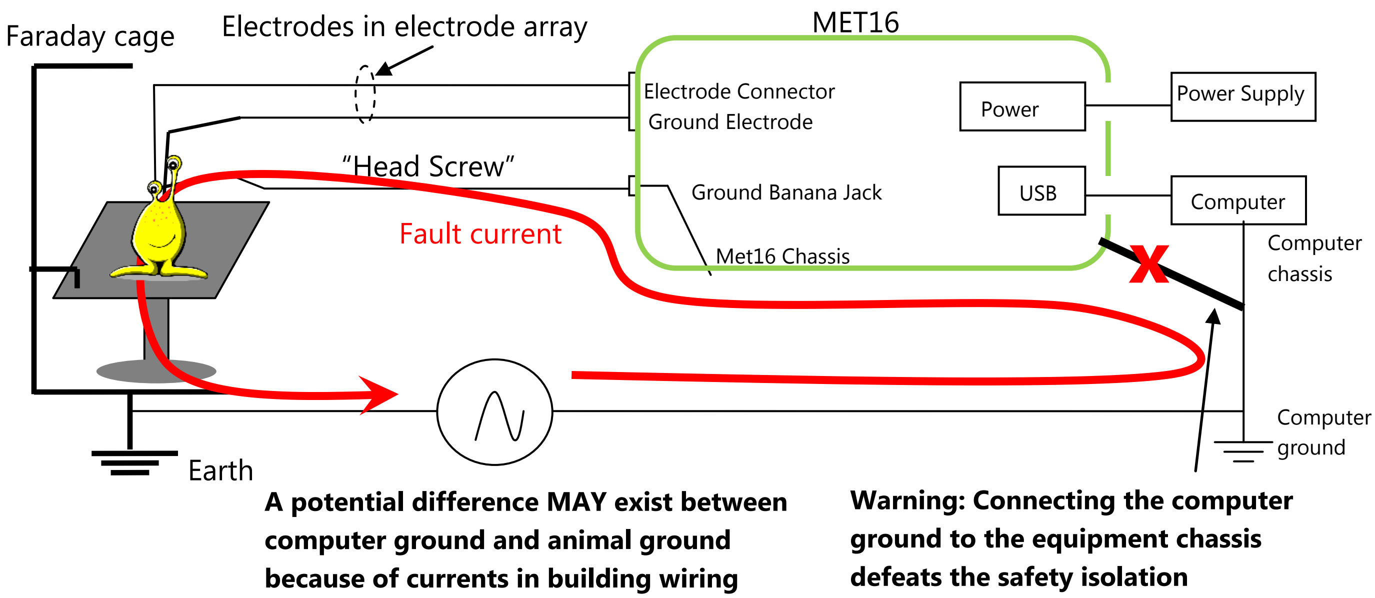


Figure 16. Potentially Unsafe

MET16 Instrument Specifications

Table 1. CV and EIS current measurement ranges.

Gain Index	Channel Current Range Full Scale	Resolution	Accuracy
0	±500uA	244nA	±1uA (0.2% FS)
1	±100uA	48.8nA	±200nA (0.2% FS)
2	±20uA	9.76nA	±40nA (0.2% FS)
3	±4uA	1.95nA	±8nA (0.2% FS)
4	±1.25uA	0.61nA	±2.5nA (0.2% FS)
5	±250nA	122pA	±0.5nA (0.2% FS)
6	±50nA	24.4pA	±100pA (0.2% FS)
7	±10nA	4.88pA	±20pA (0.2% FS)
Definition of Full Scale (FS) range and resolution: The Channel and Source boards use 12 bit ADC converters. The digital range of these converters is 0-4095 in unsigned binary. A level shifter precedes each ADC to make the 0V level nominally 2048 counts. The FS range is the distance in volts or amps between the 0 and 4095 ADC count values. For example, if the FS range is ±500uA, then 0 counts corresponds to -500uA and 4095 counts corresponds to +500uA. The resolution at this range is therefore 1000uA/4096=244nA per ADC count.			

Table 2. MET16 specification table.

Specification	Values	Notes
CV		
Voltage scan rate	1.45uV/s to 12.2V/S	Fully programmable.
Voltage Sweep Range	±2V	Note larger dV/dT is possible by using voltage steps greater than 122uV, and maximum dV/dT is limited by CV filter corner.
Minimum voltage step	122uV	
Minimum time Step	5uS	
Maximum time Step	42S	
Current and voltage accuracy	0.5% maximum at any gain setting with dV/dT<300V/S	
Timing accuracy	±0.05%	
EIS		
Frequency Range	0.1Hz-10kHz	
Excitation	10mVpp-100mVpp	Sinusoidal Amplitude
CV & EIS Filtering		
Excitation Filter	73kHz	
Sampling Filter	12kHz, 2kHz, 19.5Hz	Programmable

Pulse Stimulation current range Current amplitude resolution Current accuracy Compliance limits Compliance limit resolution Pulse width time resolution Timing accuracy	 ±300uA, ±3mA, ±6mA 3nA, 30nA, 60nA ±2% ±4V 61uV 4uS on a single pulse or 0.5uS on 8 pulses using interleaved sampling ±0.05%	 Programmable
Output Voltage Electrode output voltage	 +/- 4V w.r.t. Reference terminal or +/- 5V w.r.t. the Ground terminal	 Programmable compliance limits from +/- 0V to +/- 4V in 61uV steps
Safe Operating Range Voltage isolation between MET16 Ground terminal and USB ground Voltage isolation between MET16 Ground terminal and AC power ground Electrode and Reference terminal voltage	 5000Vrms minimum 707 VDC minimum +/- 5V w.r.t. MET16 Ground	The supplied power supply module was type tested and safety certified using the dielectric strength test voltages listed in Table 6 of IEC 60601-1:2005.

Electrode Connection Accessories

The MET16 comes with three accessories to facilitate its connection to the user's electrodes under test:

1). A 2.5 foot (0.75m) DB37 M-F extension cable

2). A "Connector Board" which breaks out the DB37 connections to accessible labeled electrode terminals.

3). A "Load Board" containing a simulated electrode array so the user can verify proper operation of the MET16. Populated and unpopulated Load Boards are supplied with the MET16.

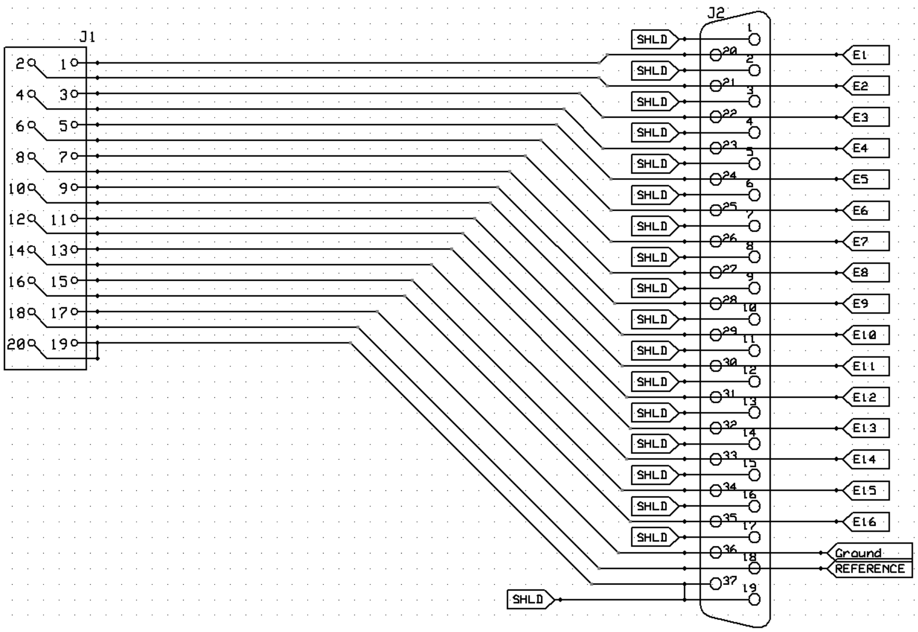


Figure 17. Connector Board Schematic

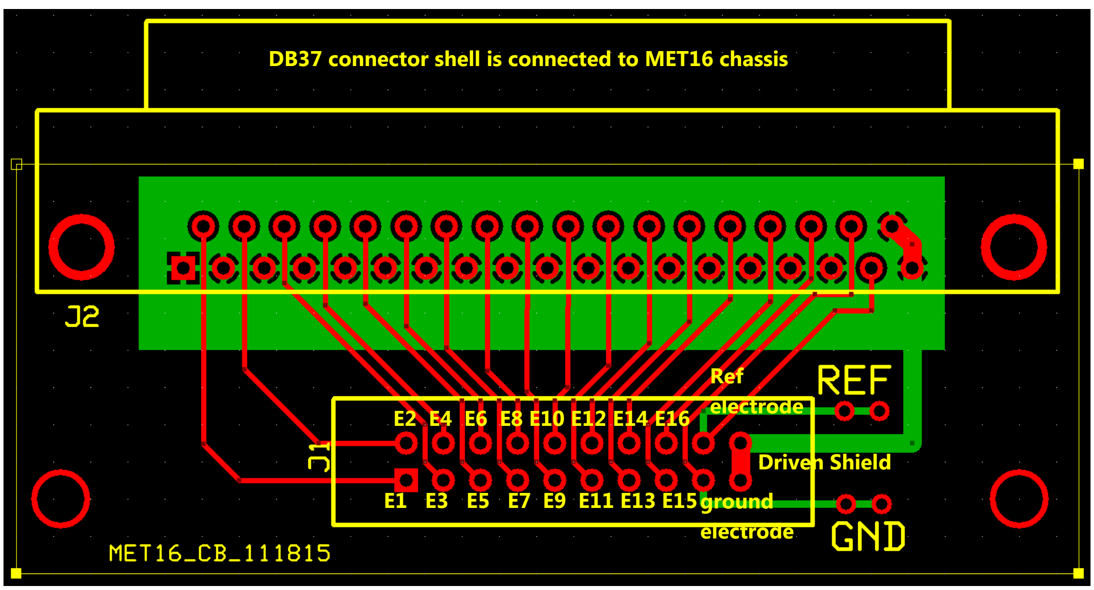


Figure 18. Connector Board Layout

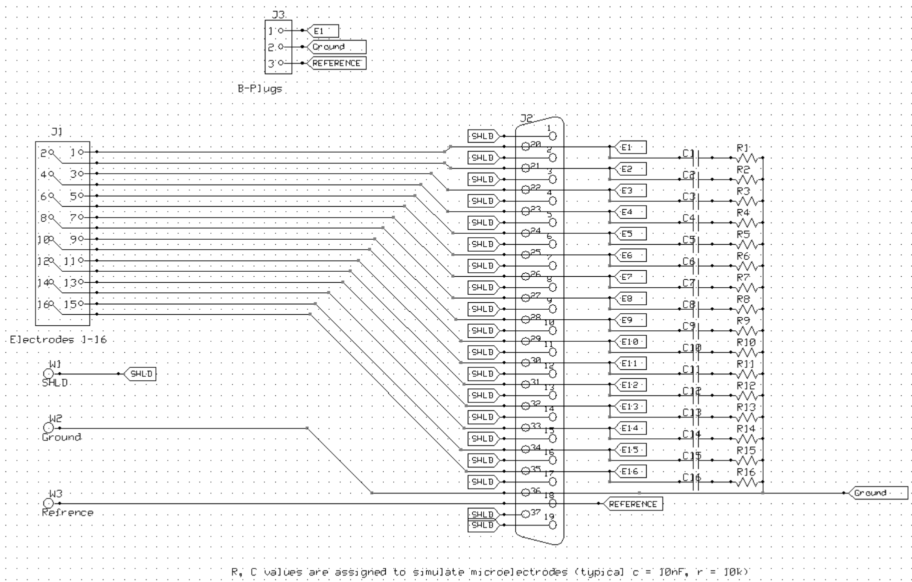


Figure 19. Load Board Schematic

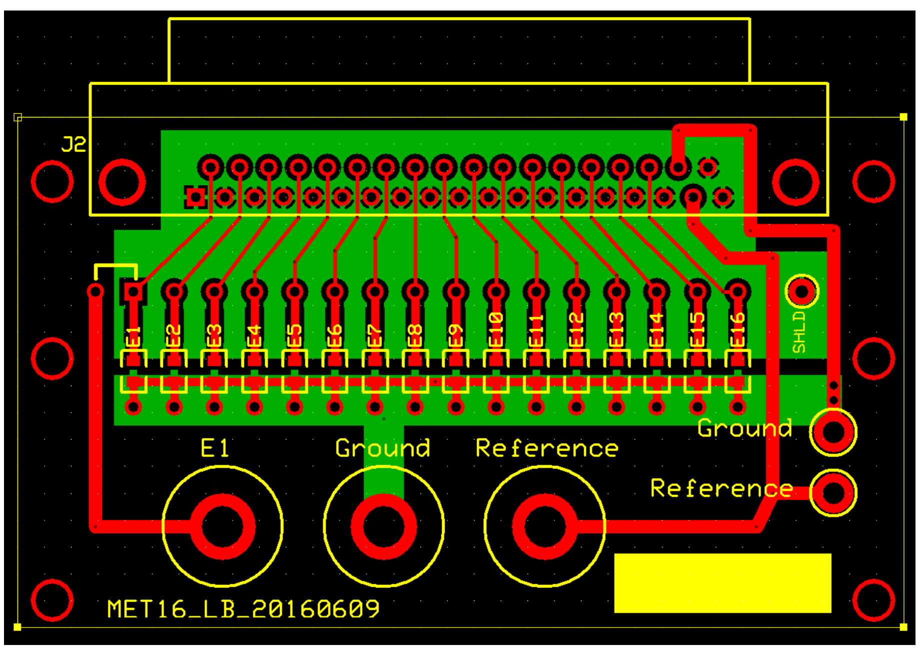


Figure 20. Load Board Layout (available with or without R-C loads installed)