KHU MARK 2.5 - USER MANUAL

Contents

I. System descriptions

Similar to KHU Mark2 system for Electrical Impedance Tomography measurement, the KHU Mark 2.5 has two separate units, one for power supply and one for EIT data acquisition.

Current KHU Mark 2.5 is a 16- channels system with integrated calibration. Impedance measurements controller and calibration are PC-controlled through a software called **EIT_Mark2.exe**. It is currently only available for Windows (64 and 32 bits).

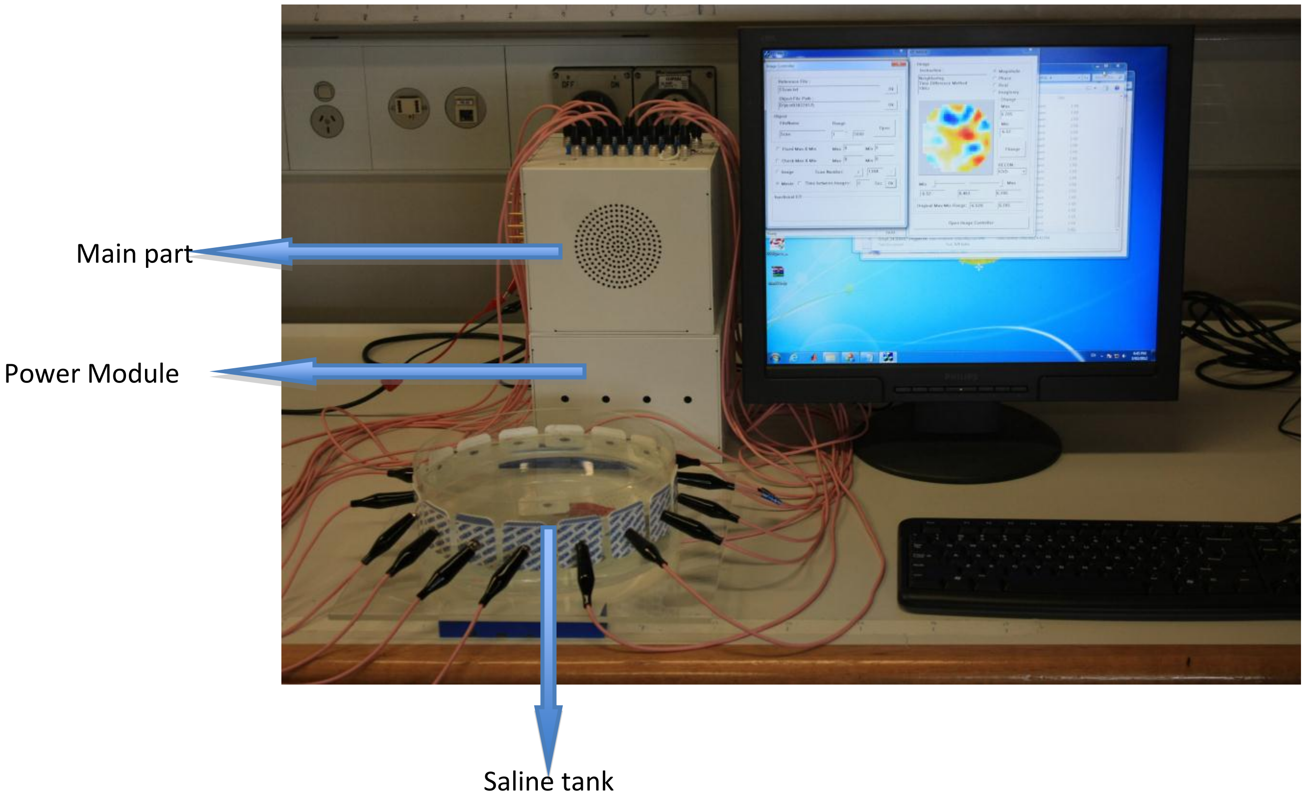


Figure 1 KHU MARK 2.5 system

Main KHU Mark2.5 unit consists of 16 parallel IMMs (Impedance Measurement Modules), an analogue backplane, a digital backplane and a DSP mainboard. Analogue backplane is used to switch the IMMs between current injection and voltage measurement. Digital backplane communicates between the IMMs and DSP. Each IMM consists of a CCS(constant current source) , CCS Calibration circuits, ADC (12 bits resolution), Voltage amplifier circuits and an FPGA as the central control unit for each IMM.

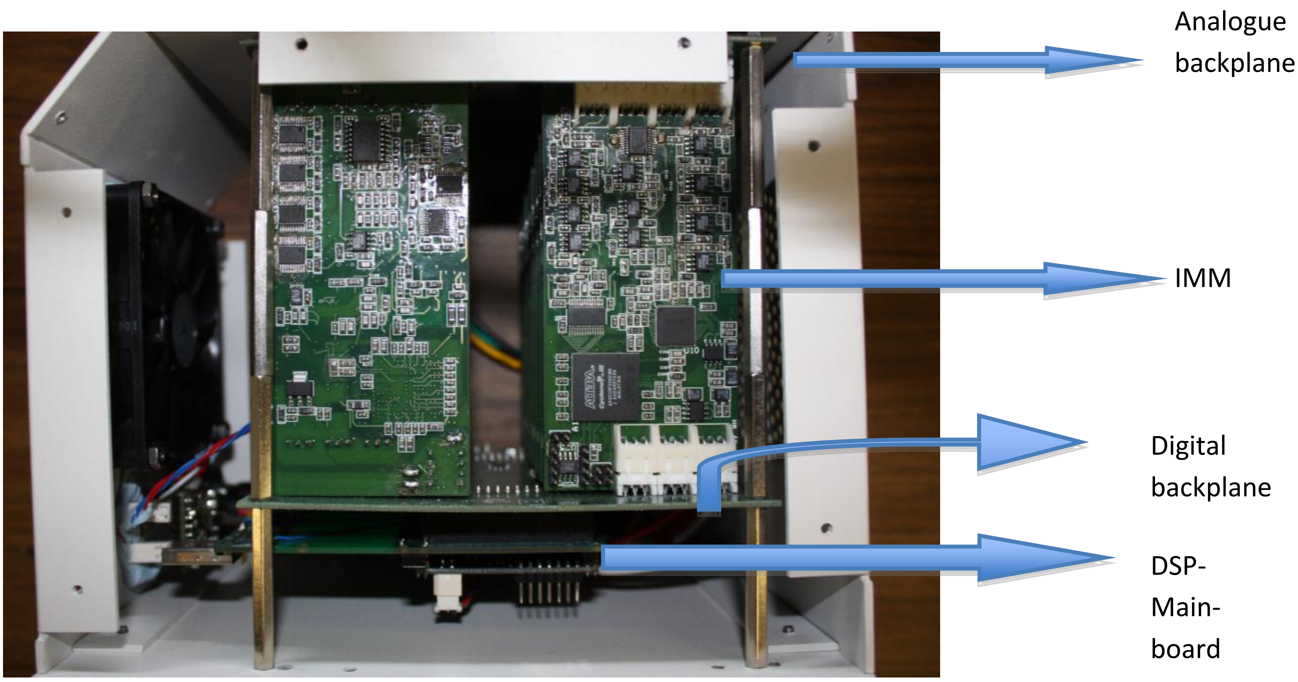


Figure 2 KHU MARK 2.5 main unit

II. Electrical characteristics

1. Power

The KHU Mark 2.5 is medically (?) electrically isolated to avoid electrical shock in clinical settings. The power unit provides three different types of powers to the main unit:

- ±5 VDC at 2A (max) for the analogue backplane
- + 3.3VDC at 6A (max) for the digital backplane
- +5 VDC at 1A (max) for the DSP main-board

If the power is not functional, the following sequence should be used to provide power for the main unit of the KHU Mark 2.5 system:

- Step 0, connect main unit to PC through USB port
- Step 1, turn the ±5 VDC (2A max) on for the analogue backplane
- Step 2, turn the +3.3 VDC (6A max) on for the digital backplane
- Step 3, turn the +5 VDC (1A) max on for the DSP main-board

When turning off the system while on lab power supply, turn off each unit in the reverse order of turning on.

2. Signals

- 16 parallel channels.
- 1 GND electrode
- Max current injection from each channel is 1mA
- **Contact impedance (to be completed)**
- Trigger signal: TTL at +3.3 V, high impedance matching (~100 kΩ)
- Operating frequencies: 10 Hz, 50 Hz, 100 Hz, 1kHz, 5kHz, 10Khz, 50KHz, 100KHz, 250 kHz and 500 kHz.
- The actual digital output frequencies are 11.25 Hz, 56.25 Hz, 112.5 Hz, 1.125 kHz, 5.625 kHz, 11.25 kHz, 56.25 kHz, 112.5 kHz, 247.5 kHz and 450 kHz.

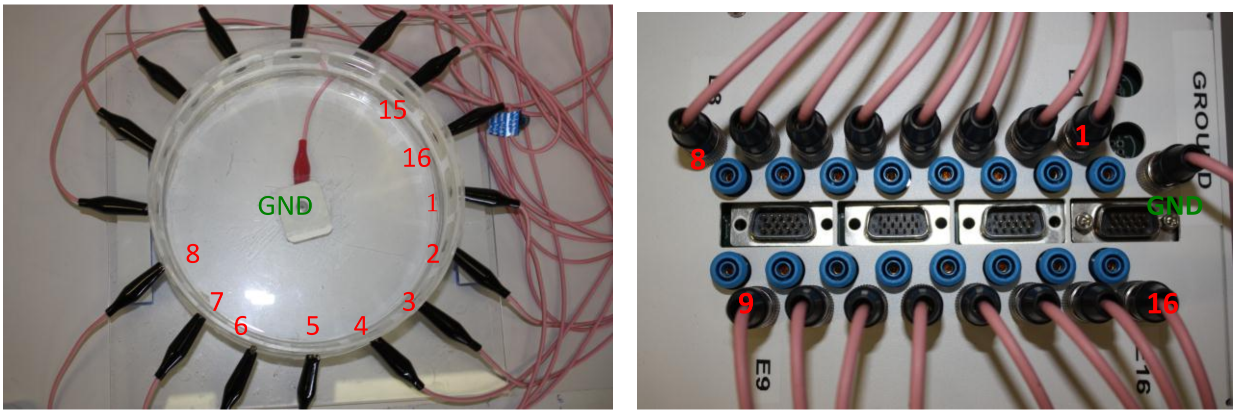


Figure 3 Electrodes placements on simulation tank and KHU Mark 2.5

III. Installation

1. USB Driver installation

USB driver of the KHU Mark 2.5 should be installed through the following steps:

1. Uninstall any preinstalled USBXPress driver

2. Run the executable USBXPress.exe. This should create and copy files to a folder at C:\SiLabs\MCU\USBXPress

In case there is no "SIUSBXp.dll" in C:\WINDOWS\system, copy SIUSBXp.dll from C:\SiLabs\MCU\USBXpress\USBXpress_API\Host to C:\WINDOWS\system

3. Run C:/SiLabs/MCU/USBXpress/Driver/Preinstaller.exe

4. Connect the system (MARK 2.5) to USB port

5. When the windows popup asking for new driver, add the path C:/SiLabs/MCU/USBXpress/Driver to find driver

6. Done. Windows should report driver for device installed properly.

Note that only the most current USBXPress driver (version < 3.5) would work in a Windows 7, 64 bits.

2. Setup KHU Mark2.5

i. Connect the power unit to the main unit (power should be off)

ii. Connect the main unit to PC via USB port

iii. Connect power unit to power plug (make sure power button is still off)

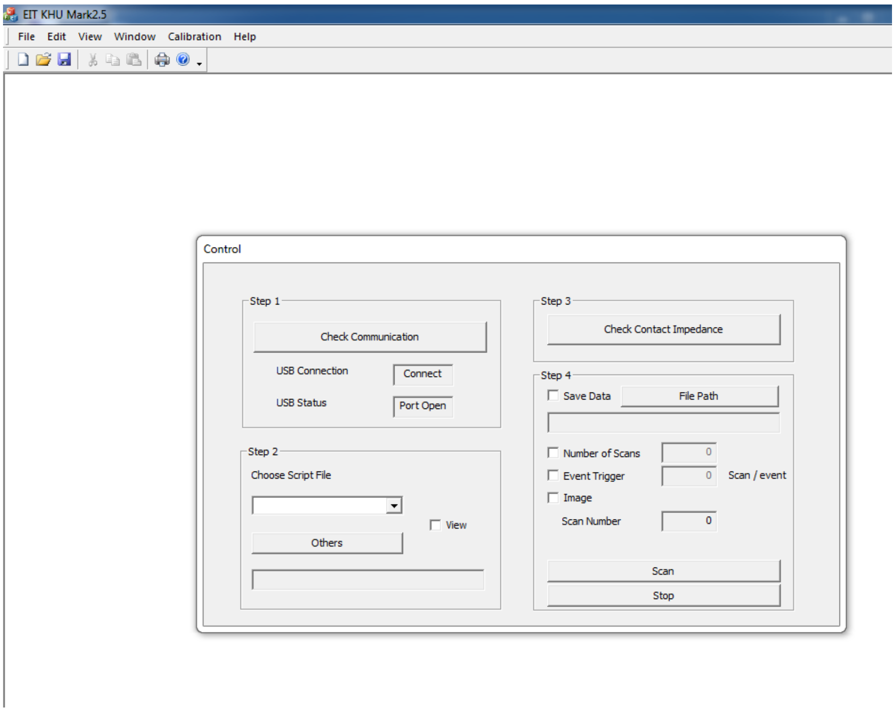
iv. Turn power on

v. Open the controlling software **EIT_Mark2.exe**

IV. Operation manual

3. Normal mode – Single frequency

i. EIT_Mark2 main window should look like this.



ii. Follow the steps on the main control dialog to setup the projections prior to scanning:

a. **Step 1**. Check communication, make sure the USB connection is **Connected** and USB port status is **Open**

b. **Step 2**. Load the correct script file with desired frequency, projection protocol, amplitude and all the calibrations are **ON**. An example script file is included below.

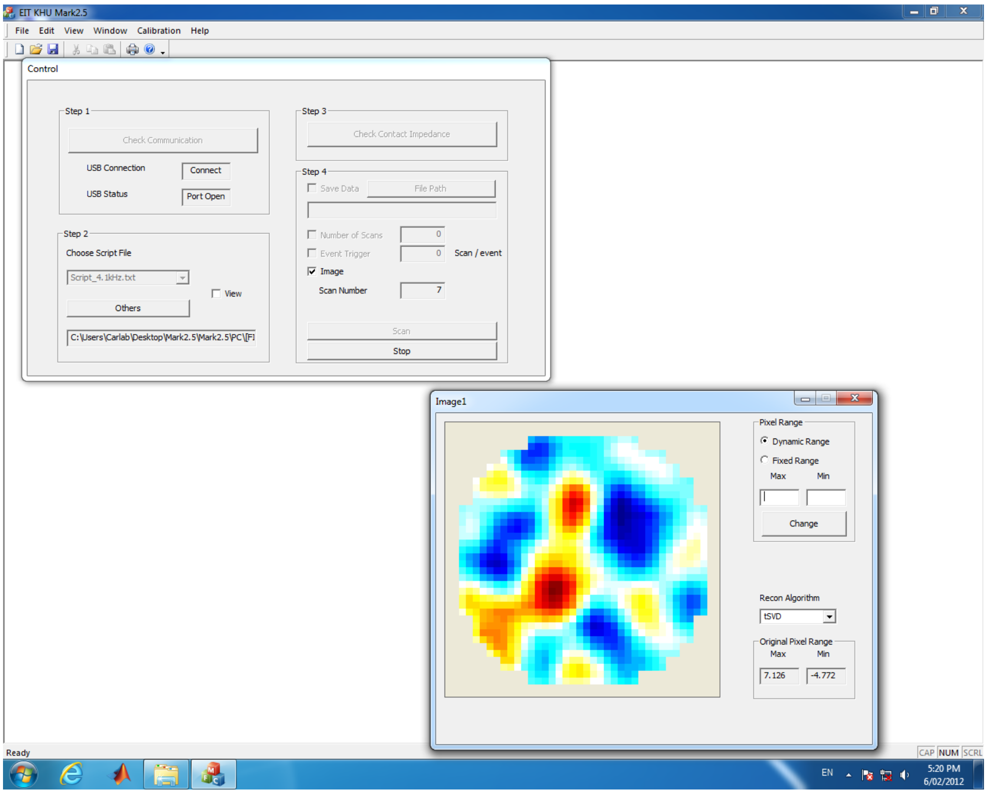
```
%Date 10/22/2010
%Comment :
#include "projection\projection_7.50kHz.txt"
 start
      setting
      Channel            16 // Number of channel
      Average            64 // Number of average
      Freq               1  // Number of frequency
      TimeInfoHigh       0  // Delay between projections (High byte)
      TimeInfoMid        7  // Delay between projections (Mid byte)
      TimeInfoLow        0  // Delay between projections (Low byte)
      InjDelayHigh       0  // Delay from the press of Start button to
                               the start first scan (High byte)
      InjDelayLow        60 // Low byte of the above quantity
stop
calibration
      DCOffset    ON
      OutputImpedance   ON
```

```
        Amplitude   ON
        Voltmeter   ON
        Protocol    2DNeighboring_mV
stop
scan
        projection1
        projection2
        projection3
        projection4
        projection5
        projection6
        projection7
        projection8
        projection9
        projection10
        projection11
        projection12
        projection13
        projection14
        projection15
        projection16
stop
end
```

c. **Step 3** Check contact impedance – Make sure that the voltage is not overflowed.

d. **Step 4**
   - Check the appropriate boxes to Save data (in appropriate File Path)
   - Check the box for Number of Scan and specified and the desired number of scans
   - In normal mode, the Event Trigger box should be left unchecked.
   - Check the Image box to view real time images. If this option is checked, during data acquisition, images are concurrently reconstructed. Typically, the first 5 scans contains transient noise and therefore are discarded (not saved). The reconstruction algorithm uses the first saved frame of data as its homogeneous or baseline data. Subsequent scans are reconstructed against the homogeneous data. Notably, the reconstruction software assumes that the object is circular, with the first electrode at 3 o'clock and electrodes are arranged clockwise.

e. **Step 5 -** Click **Scan** to start scanning, if the Image box is checked, it should look like this



4. Normal Mode – Multi-frequency

a. Multi-Frequency mode

One main difference of KHU MARK 2.5 from KHU Mark1 is that each IMM has independent current source so that each channel can independently generate current waveform. One option is the Multi-frequency mode. As you are able to check in a projection file, injecting one frequency at one pair of channels and another frequency at the other pair of channels at the same time. Due to the fundamental method of wave generation, we have harmonic problem at Multi- frequency mode. In order to minimize this effect, it is recommended to use one pair and the other pair at the opposite end such as 1 and 16 for one frequency, 8 and 9 for the other.

Due to the limitation of bits of demodulation frequency (6-bit), it is not possible to produce concurrently produce two frequencies that have a ratio (f1/f2) of more than 50.

Multi-frequency mode can be selected in the **projection.txt** file. An example is shown in the following figure.

```
projection1
%	Ch	Amp	Freq	Gain
	1	600uA	50kHz	x10
	2	Null	Null	x10
	3	Null	Null	x10
	4	Null	Null	x10
	5	Null	Null	x10
	6	Null	Null	x10
	7	Null	Null	x10
	8	-600uA	10kHz	x10
	9	600uA	10kHz	x10
	10	Null	Null	x10
	11	Null	Null	x10
	12	Null	Null	x10
	13	Null	Null	x10
	14	Null	Null	x10
	15	Null	Null	x10
	16	-600uA	50kHz	x10
end
projection2
%	Ch	Amp	Freq	Gain
	1	-600uA	50kHz	x10
	2	600uA	50kHz	x10
	3	Null	Null	x10
	4	Null	Null	x10
	5	Null	Null	x10
	6	Null	Null	x10
	7	Null	Null	x10
	8	Null	Null	x10
	9	-600uA	10kHz	x10
	10	600uA	10kHz	x10
	11	Null	Null	x10
	12	Null	Null	x10
	13	Null	Null	x10
	14	Null	Null	x10
	15	Null	Null	x10
	16	Null	Null	x10
end
```

b. Mixed-Frequency mode

The other option of independent current source is Mixed Frequency mode. It is possible to generate the waveform by mixing three frequencies together in one channel. The ratio of frequencies in each mix is fixed at 1:5:10. Accordingly, there are four combinations from the range of operating frequency such as 10Hz, 50Hz, 100Hz (called as MIXED1), 1kHz, 5kHz, 10kHz (called as MIXED2), 10kHz, 50kHz, 100kHz (called as MIXED3), 50kHz, 250kHz, 500kHz(called as MIXED4).

In terms of GIC, the current output is connected to the GIC for smallest frequency, for example GIC3 for MIXED4.

To select mixed-frequency mode, a mixed combination (e.g MIXED1) should be entered in place of frequency in a **projection.txt** file, as shown in the following figure.

```
projection1
%       Ch      Amp     Freq    Gain
        1       600uA   MIXED1  x10
        2       Null    Null    x10
        3       Null    Null    x10
        4       Null    Null    x10
        5       Null    Null    x10
        6       Null    Null    x10
        7       Null    Null    x10
        8       Null    Null    x10
        9       Null    Null    x10
        10      Null    Null    x10
        11      Null    Null    x10
        12      Null    Null    x10
        13      Null    Null    x10
        14      Null    Null    x10
        15      Null    Null    x10
        16      -600uA  MIXED1  x10
end
projection2
%       Ch      Amp     Freq    Gain
        1       -600uA  MIXED1  x10
        2       600uA   MIXED1  x10
        3       Null    Null    x10
        4       Null    Null    x10
        5       Null    Null    x10
        6       Null    Null    x10
        7       Null    Null    x10
        8       Null    Null    x10
        9       Null    Null    x10
        10      Null    Null    x10
        11      Null    Null    x10
        12      Null    Null    x10
        13      Null    Null    x10
        14      Null    Null    x10
        15      Null    Null    x10
        16      Null    Null    x10
end
```

5. Biopotential triggering mode

a. Triggering signal requirements

- TTL interface (3.3 VDC)
- 5ms pulse width
- 1 Hz

b. Parameters

Inj Frequency	No Average	TimeInfo	TimeSlot	Max Frame/s
10 kHz	1	0-0-127	1 (corr. 20 ms)	50
50 kHz	1	0-0-127	1 (corr. 20 ms)	50

c. Procedures

i. Follow all the steps for normal operation mode
ii. Check the Event Trigger box
iii. Specify the number of Scans/trigger. If number of Scans/trigger is not specified, the default value is 1.
iv. Press Start to start scanning.

6. Users configurable parameters (in script.txt and projection.txt)

a. Script file

Users can change following quantities in the script.txt file:

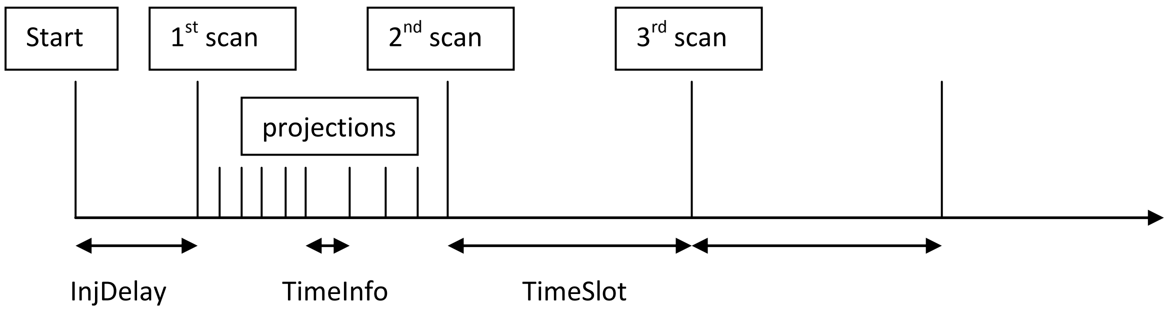
-*Average*: Number of averages taken per voltage measurement**.** Minimum average is 1 and maximum is 64 and averages must be power of 2.

-*Frequency*: Number of frequencies to be used in each projection. This quantity should be 1 for single frequency measurement, 2 for multi-frequency mode and 3 for mixed-frequency mode.

-*TimeInfoHigh and TimeInfoLow*: Delay between projections**.** This is a 16 bits value. The first (HIGH) byte is specified in TimeInfoHigh while the second (LOW) byte is specified in TimeInfoLow.

-*InjDelayHigh and InjDelayLow*: Delay from the press of Start button (in the control dialog) to the start of the first scan**.** Similar to TimeInfo, it is a 16-bit value, specified by InjDelayHigh for the HIGH byte and InjDelayLow for the LOW byte.

The following diagram shows the timing of the system:



The InjDelay in real time min value is 80us and maximum is 360 us. Note that the values specified in the script.txt file for InjDelay and TimeInfo are digital values, not real time values.

The order of the projections can also be changed in script file.

b. Projection file

Each projection file contains the injection and measurement information for each projection, which should like this:

```
projection1
%   Ch Amp    Freq   Gain
    1  600uA  50kHz  x10
    2  Null   Null   x10
    3  Null   Null   x10
    4  Null   Null   x10
    5  Null   Null   x10
    6  Null   Null   x10
    7  Null   Null   x10
    8  Null   Null   x10
```

```
    9  Null   Null   x10
    10 Null   Null   x10
    11 Null   Null   x10
    12 Null   Null   x10
    13 Null   Null   x10
    14 Null   Null   x10
    15 Null   Null   x10
    16 -600uA 50kHz  x10
end
projection2
%   Ch Amp    Freq   Gain
    1  -600uA 50kHz  x10
    2  600uA  50kHz  x10
    3  Null   Null   x10
    4  Null   Null   x10
    5  Null   Null   x10
    6  Null   Null   x10
    7  Null   Null   x10
    8  Null   Null   x10
    9  Null   Null   x10
    10 Null   Null   x10
    11 Null   Null   x10
    12 Null   Null   x10
    13 Null   Null   x10
    14 Null   Null   x10
    15 Null   Null   x10
    16 Null   Null   x10
End
```

Typically, there are 16 projections for each frame, which are described in the projection file.

The users can change the injection pair, current injection frequency and the gain of each projection. The sequence of injection can also be changed as consequence.

Current injection amplitude and frequency can be changed in the projection file. Injection current amplitude ranges from 0 to1023 (digital value to be input): 0 digital value corresponds to 30 uA actual current amplitude, 1023 digital value corresponds to 1000 uA.

The gain is a digital value, specified the voltage gain of each voltage measurement. Minimum gain is 0 (which doesn’t mean a gain of 0). Maximum value for gain is 255.

$$G_{actual} = \frac{40 * G_{digital}}{200}$$

V. Data format

Data obtained in each scan is recorded in an **XXScan.txt** file, saved in the folder specified in the File Path field (see Normal Operation – Single Frequency section). A part of a typical **XXScan.txt** would look like this:

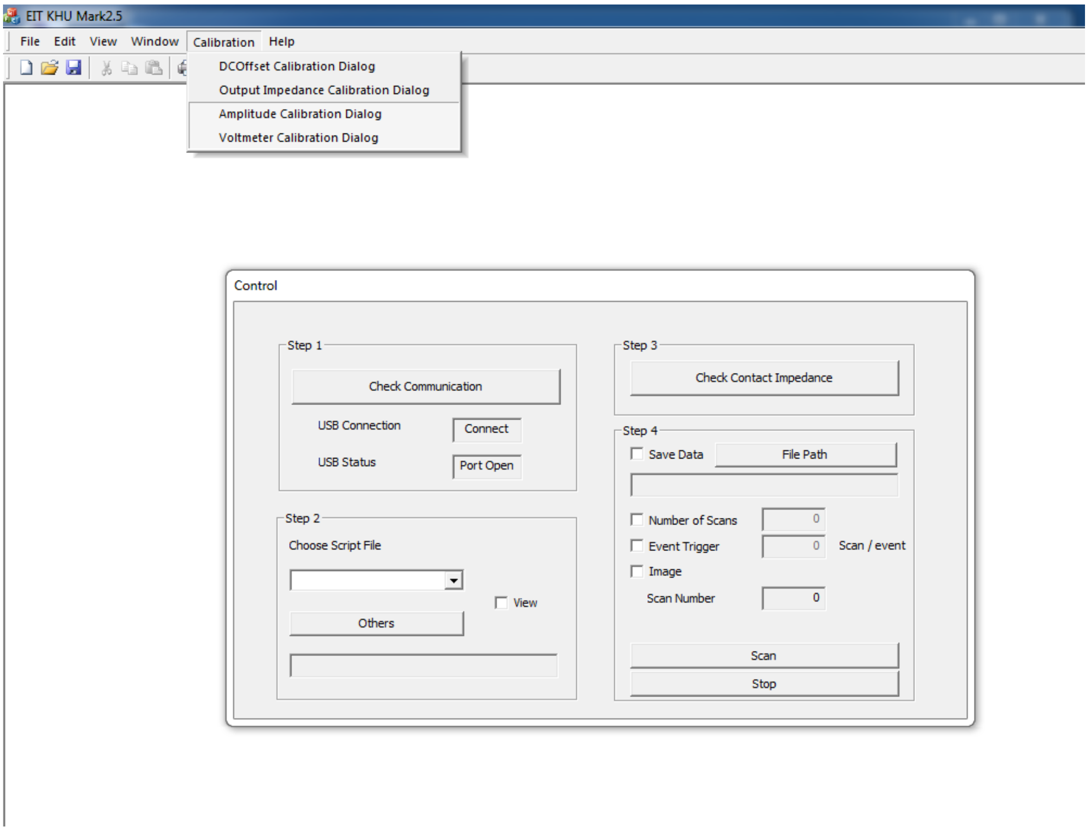
```
0	1	-26937.000000	30554.000000
1	1	26563.000000	-30857.000000
2	1	3798.000000	-1742.000000
3	0	-1352.000000	1217.000000
4	0	-1540.000000	-235.000000
5	1	1545.000000	1705.000000
6	0	-2219.000000	183.000000
7	0	2701.000000	-2473.000000
8	0	-933.000000	-218.000000
9	0	566.000000	-595.000000
10	0	151.000000	983.000000
11	0	841.000000	-1982.000000
12	0	-1714.000000	1780.000000
13	0	-298.000000	48.000000
14	1	-0.000000	-0.000000
15	1	27005.000000	-30445.000000
```

Each text file contains the data of each full frame, typically consists of 16 projections for single frequency measurement mode. The above is data obtained from one projection.

- The first column is the number of measurement: 0 is the measurement between electrodes 16 and 1, 1 is measurement between electrodes 1 and 2 and so on.
- The second column contains binary values indicating whether the corresponding voltage measurement is saturated (1) or not (0). Voltage measurements are usually saturated at the measurements involving the current injection electrodes.
- The third column contains the real values of the corresponding measurements
- The fourth column contains the imaginary values of the corresponding measurements.

In the current version of the EIT software, if multi-frequency mode is selected (specified in **projection.txt** file), the data is stored for the lowest frequency first (16 measurements x 16 projections), a blank line, then the data for the second lowest frequency (16 measurements x 16 projections) and so on. In total, there are 16 measurements x 16 projections x N number of frequencies.

VI. Calibration procedures



You need to connect USB first before calibration. Also, make sure that the cables are connected for calibration.

For DC offset calibration and Output Impedance calibration, the cables should be connected to the corresponding blue port with ground electrode unconnected (as shown in picture).

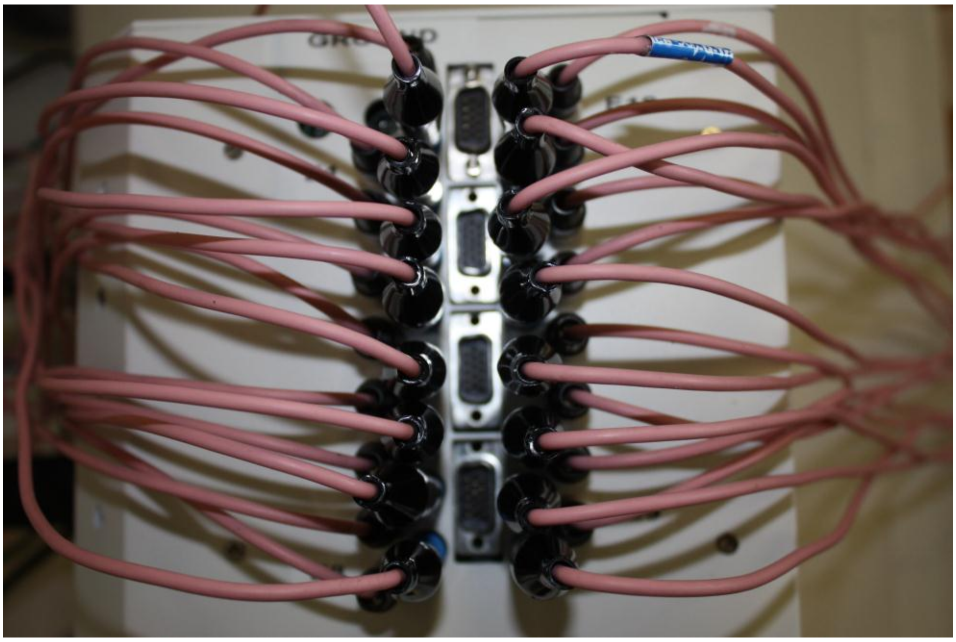


Figure 4 Cables configuration for DC offset and Output Impedance calibrations

For Amplitude calibration and Voltmeter calibration, the cables should be connected to the **Resistor Phantom** through the circular connection rings at the side of the main unit (as shown in the picture).

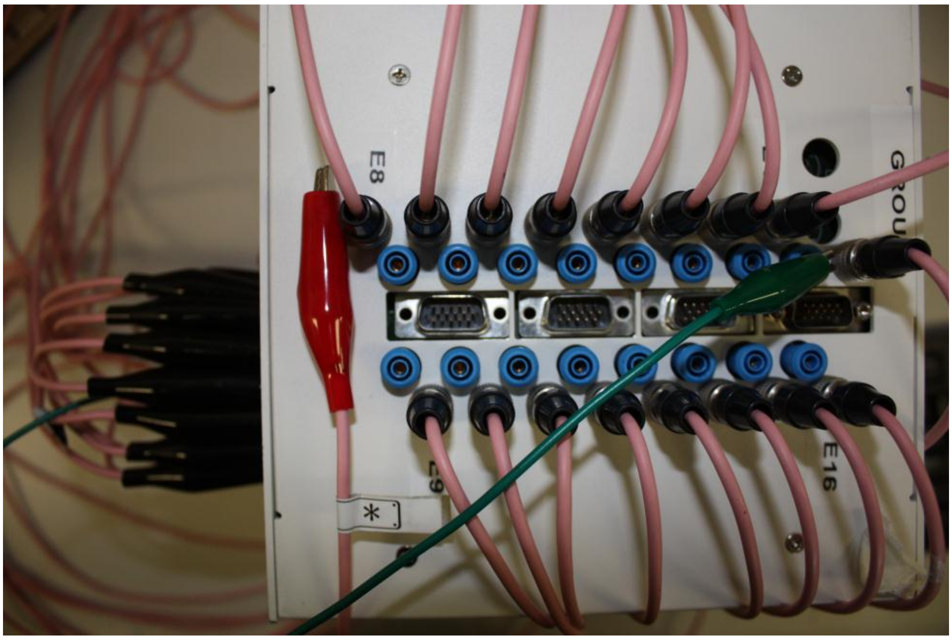


Figure 5 Cables configuration for amplitude calibration

For Amplitude calibration, the ground electrode should be unconnected. The connection at the centre of the **Resistor Phantom** should be connected to the blue port of the first channel for voltage measurement.
In Voltmeter calibration mode, the ground electrode cable should be connected to the centre of the **Resistor Phantom.**

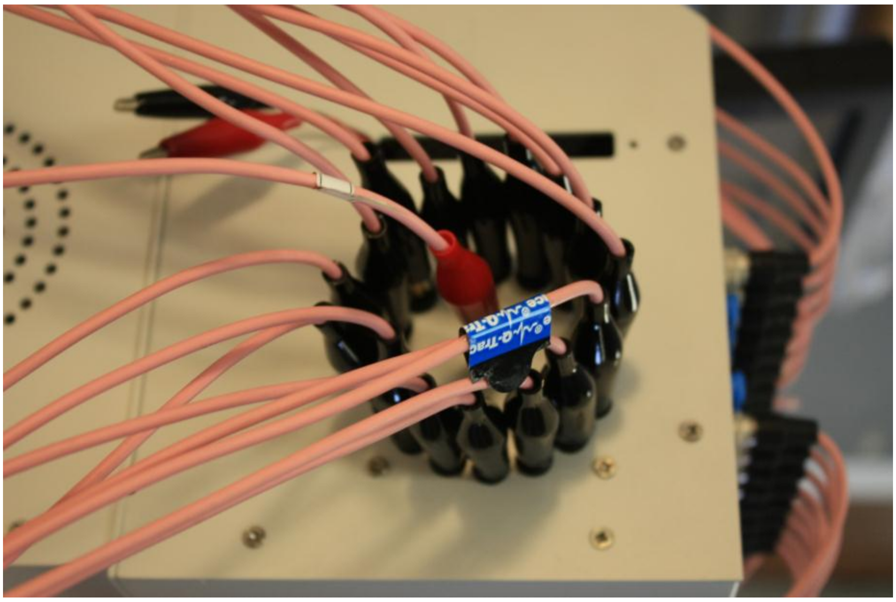
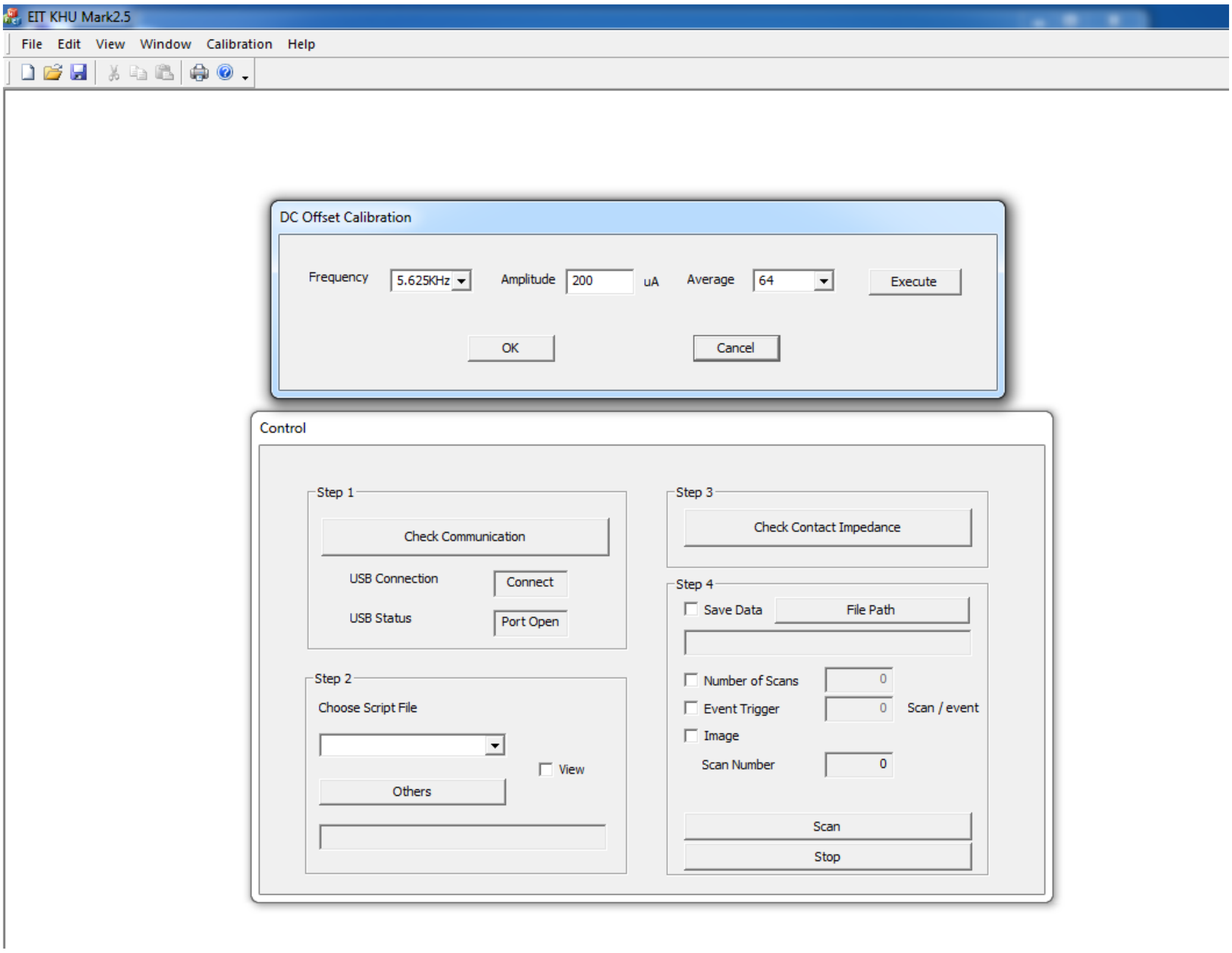


Figure 6 Cables configuration for Voltmeter calibration

1. DC offset calibration



ii. Select frequency you want to calibrate.

iii. Set current amplitude of waveform. Default value is 200uA. It is recommended for you to set 200 as amplitude to avoid voltage saturation.

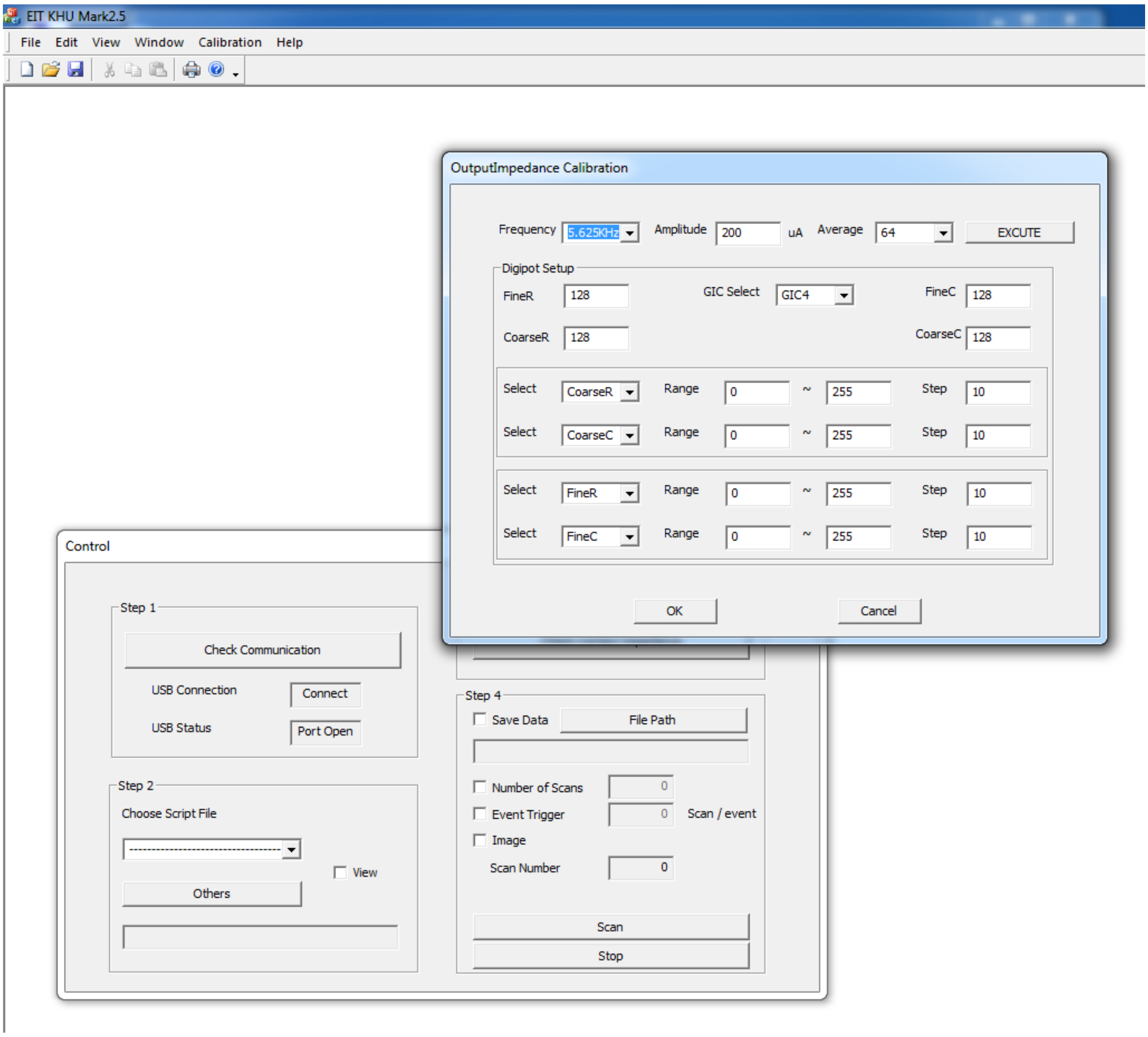
iv. Select Average number you want.

v. Make sure the cables are arranged appropriately (as shown above).

vi. Press the Execute.

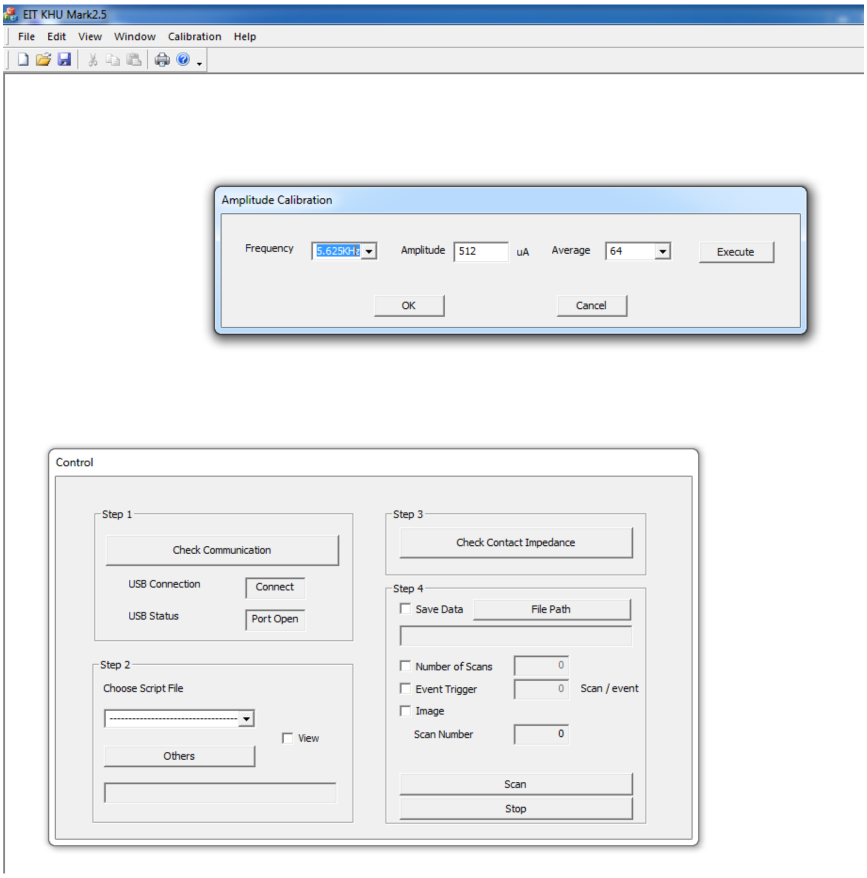
vii. Once the program report calibration finished. Check the saved log at *RootLocation\[FINAL_SYDNEY]EIT_Mark25_20120202\Release\Calibration\eit4\DCOffset\(CalibratedFrequency)KHz\DCOffset.txt* to make sure calibration is successful.

2. Output Impedance calibration



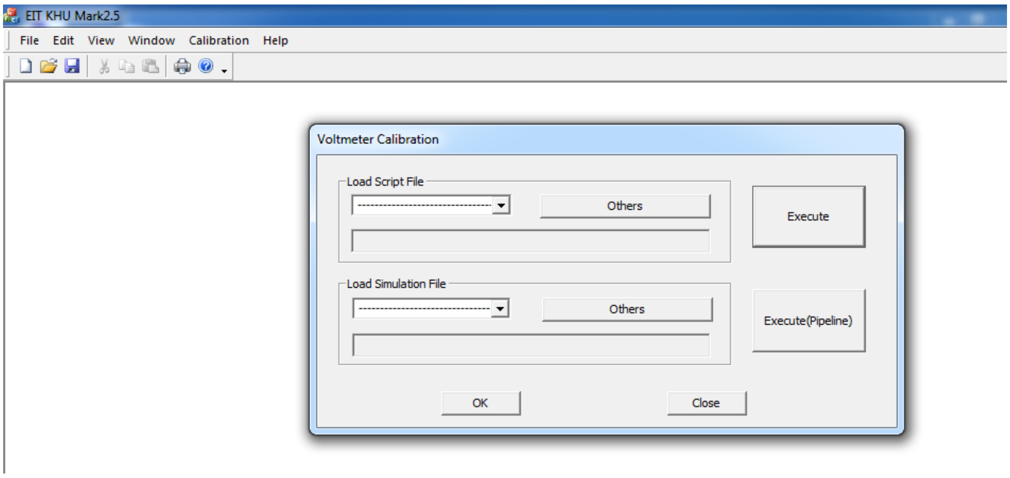
i. Select frequency you want to calibrate then GIC is changed automatically for the frequency range selected.
ii. Set current amplitude of waveform. Default value is 200uA. It is recommended for you to set 200 as amplitude to avoid voltage saturation.
iii. Select Average number you want.
iv. Do not change the value of any other boxes.
v. Make sure the cables are arranged appropriately (as shown above).
vi. Press the Execute.
vii. Once the program report calibration finished. Check the saved log at *RootLocation\[FINAL_SYDNEY]EIT_Mark25_20120202\Release\Calibration\eit4\OutputImpedance\(CalibratedFrequency)KHz\OutputImpedance.txt* to make sure calibration is successful.

3. Amplitude calibration

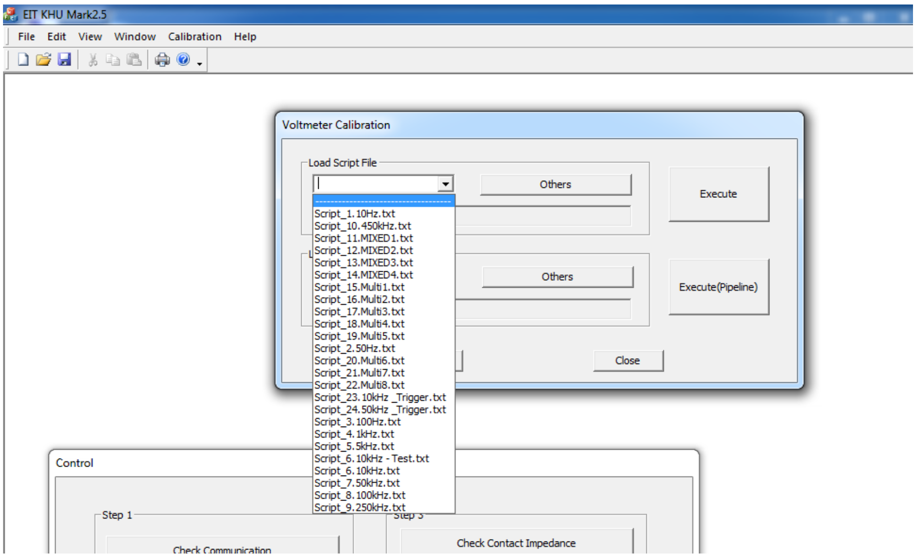


i. Select the frequency
ii. Set current amplitude of waveform. Default value is 512uA.
iii. Select Average number you want.
iv. Make sure the cables are arranged appropriately (as shown above).
v. Press the Execute.
vi. Once the program report calibration finished. Check the saved log at *RootLocation\[FINAL_SYDNEY]EIT_Mark25_20120202\Release\Calibration\eit4\Amplitude\(CalibratedFrequency)KHz\Amplitude.txt* to make sure calibration is successful.

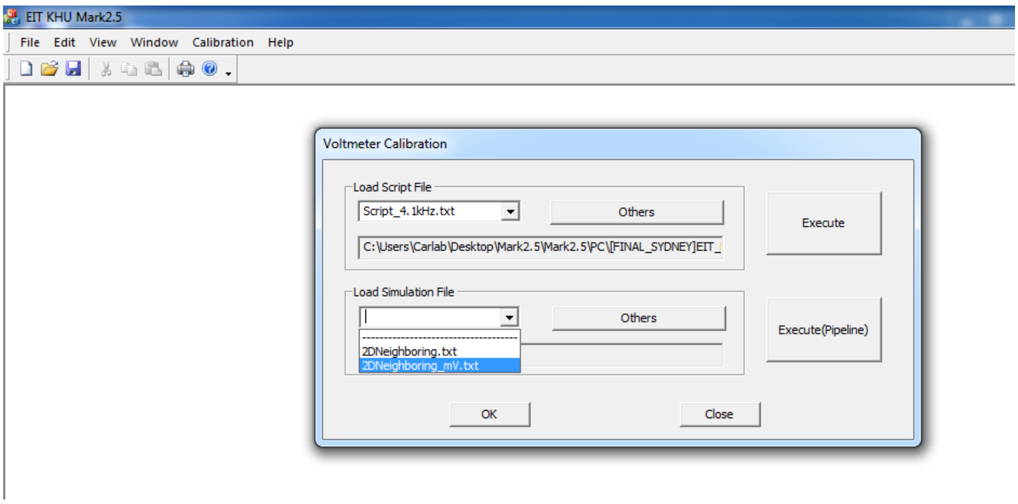
4. Voltmeter calibration



i. Load the *script.txt* with the desired frequency and protocol.



ii. Load the simulation file to be used (2Dneighboring.txt for measurement in V or 2Dneighboring_mV.txt for measurements in mV(recommended)



iii. Make sure the cables are arranged appropriately (as shown above).

iv. Press the Execute for manual projection or Execute (Pipeline) for pipelining. Pipelining is the default setting of all normal scan, for which reason, we recommend using Execute(Pipeline) for calibration.
v. Once the program report calibration finished. Check the saved log at *RootLocation\[FINAL_SYDNEY]EIT_Mark25_20120202\Release\Calibration\eit4\Voltmeter\2DNeighboring(_mV)\ 2DNeighboring(_mV)_Script_(frequency)Hz_MagnitudeFacto.txt* to make sure calibration is successful.