QUADRA™ USER MANUAL

USB- & Battery-Powered Multi Frequency Electrical Impedance Spectroscopy Device

Table of Contents

Important Information

Copyright

Patents

The device and methods described in this document are covered by following patents: The Estonian Patent Office - KASULIKU MUDELI KIRJELDUS EE01312U1 – “Modular system for the measurement of the electrical impedance”; P201500014 – “Binaarse ergutusega impedantsi analüsaatori meetod ja seade”.

Disclaimer

Refer to EULA.TXT document in Quadra Software Package.

Abbreviations

DSP	Digital Signal Processor
POT	Digital Potentiometer
PGA	Programmable Gain Amplifier
OSC	Oscillator
I2C	Inter-Integrated Circuit Serial Bus
GUI	Graphical User Interface
ADC	Analog to Digital Converter
IO	Input Output
LED	Light Emitting Diode
HEX	Hexadecimal Number
GPIO	General Purpose Input Output
USB	Universal Serial Bus
AFE	Analog Front-End
RAM	Random Access Memory
MEX	Matlab dynamically linked executable
DFT	Discrete Fourier Transform

Introduction

This user manual contains specifications and instructions only for the Quadra device and its Windows based client software. Every application requires an application specific analog front-end, the instructions for analog front-ends are provided separately.

System Overview

Quadra device requires USB connection to a host PC for power supply (alt. battery charging) and data transmission, see Figure 1. The control commands and measurement data flow are controlled by *Quadra Control Panel* GUI that operates the device using a Microsoft *WinUSB* driver. In order to make impedance measurements, an application specific analog front-end is required. The front-end connects to measurement electrodes and provides signal conditioning for Quadra device.

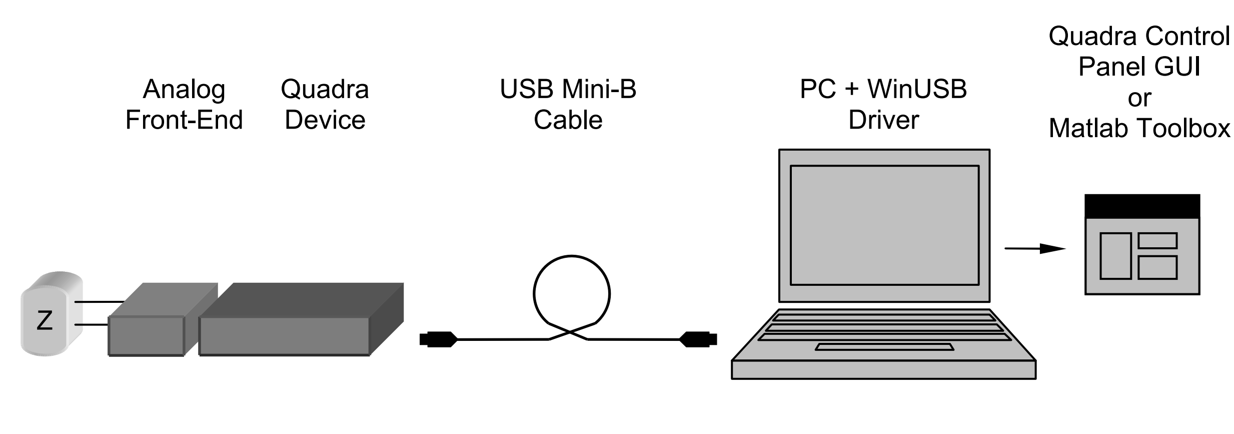


Figure 1 Components of Quadra based Impedance Acquisition System

Quadra is a real time electrical impedance spectroscopy device which is capable of measuring a spectrogram of 15 frequencies with speed of 1000 measurements per second. The compact enclosure includes all the circuitry required to generate spectrally sparse excitation voltage and to measure the response voltage and current (Figure 2). The measured response current and voltage time domain signals are used as input to calculate the spectra values for both module and phase at every frequency point. The calculated spectra will be transmitted to PC application for displaying and/or logging. To guarantee lower noise levels and to limit possibility of excitation current leak during the measurements the device has integrated battery with battery management hardware and software. In battery-powered mode, the ground and supply are disconnected from USB bus, the USB data and *SYNC* lines are optically decoupled.

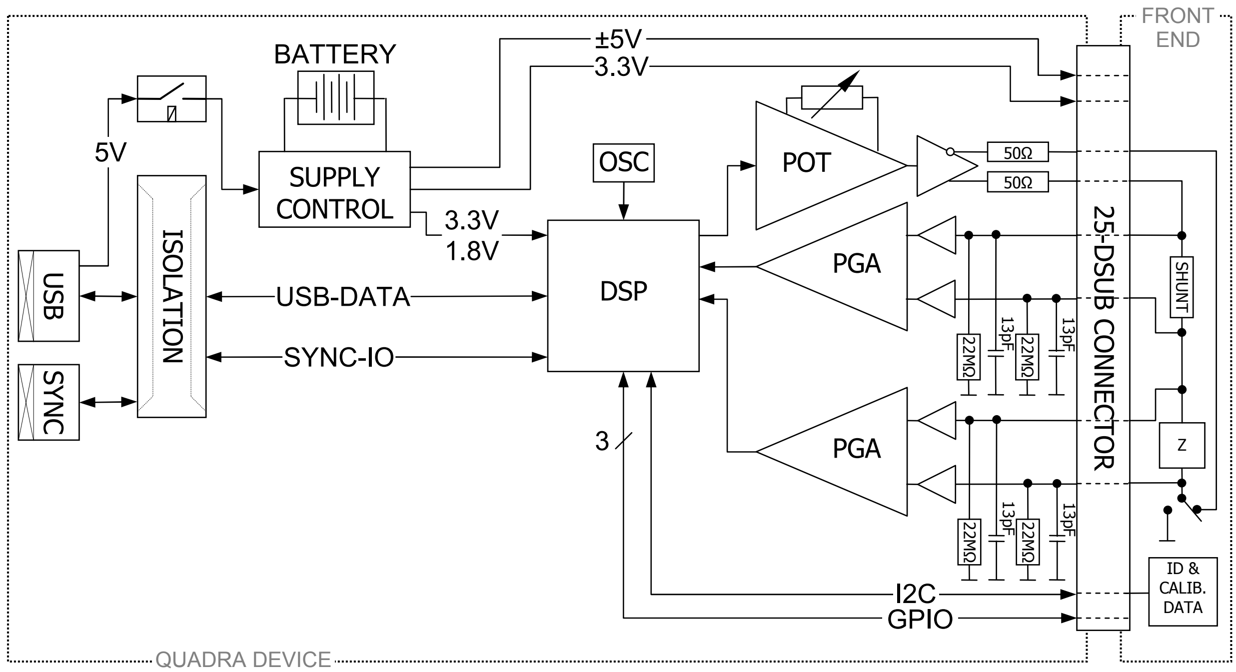


Figure 2 Quandra Internal and External Components

Device Specifications

Table 1 Measurement Parameters

Parameter	Value(s)
Impedance	Relative value of impedance. Module in units of ohms and phase in units of degrees.
Number of Frequencies in Spectrogram	15
Spectrogram Acquisition Period	1 ms; 1.8 s during Minimum Spectrogram Frequencies configuration.
Maximum Spectrogram Frequencies	1.0000 kHz, 2.0000 kHz, 3.0000 kHz, 7.0000 kHz, 11.0000 kHz, 17.0000 kHz, 23.0000 kHz, 31.0000 kHz, 43.0000 kHz, 61.0000 kHz, 89.0000 kHz, 127.0000 kHz, 179.0000 kHz, 251.0000 kHz, 349.0000 kHz
Minimum Spectrogram Frequencies	0.5580 Hz, 1.1160 Hz, 1.6741 Hz, 3.9062 Hz, 6.1383 Hz, 9.4866 Hz, 12.8348 Hz, 17.2991 Hz, 23.9955 Hz, 34.0401 Hz, 49.6651 Hz, 70.8705 Hz, 99.8883 Hz, 140.06697 Hz, 194.7544 Hz
Repeatability, Resolutions	0.1 %, 12-Bit ADC's, 16-Bit DFT references

Table 2 Technical Parameters

Parameter	Value(s)
Excitation Waveform	Binary Multi Frequency
Number of Excitation Channels	1
Excitation Channel Type	Differential, 50 Ω
Excitation Channel Voltage Level, Offset	0.4 Vpp to 7.5 Vpp, DC Offset 0 V
Number of Excitation Channel Voltage Level Steps	255
Number of Measurement Channels	2
Measurement Channels Type, Input Impedance	Differential, > 10 MΩ
Measurement Channels Input Range	3 Vpp @ PGA G=1
Measurement Channels Preamplifier Gains	1x, 2x, 5x, 10x
USB Bus Speed Settings, Standards	12 Mbps, Full Speed, USB 1.0, USB 2.0, USB 3.0
Power Consumption from USB Bus, Battery Duration	500 mA 2.5 W, 8 hours
Synchronization IO SMA Levels, Output Syncro Type	3.3 V CMOS, Output 1 ms Toggle, 5 V Tolerant, 50 Ω
Analog Front-End Digital IO	3x GPIO, I2C (400 kHz)
Analog Front-End Digital IO Levels	3.3 V CMOS, Not 5 V tolerant
Analog Front-End Digital & Analog Supply	3.3 V 150 mA, +5 V 150 mA, -5 V 100 mA

Installing Device Drivers

Requirements for host PC

Free USB 2.0 or 3.0 port required. Supported operating systems are Windows XP 32-bit SP2[2], Windows XP 64-bit SP3[2], Windows 7 32-bit, Windows 7 64-bit, Windows 8 32-bit, Windows 8 64-bit, Windows 10 32-bit, Windows 10 64-bit.

[2] Driver installation requires self-signed certificate. Contact Eliko if driver installer for Windows XP is required.

Before Install

Unpack the software package retrieved from Eliko's web page or from supplied memory stick. For driver installation all the required drivers and tools for all Windows versions are located at *Quadra Software Package v1.1\Windows Drivers*\ subfolder.

Installing Driver with Package Installer

1. Before installation, make sure that the device is not connected to PC USB port. Go to subfolder *Quadra Software Package v1.1\Windows Drivers* and start driver installation application *QuadraUSBDriverInstaller_v1.1.EXE*.

2. To start the driver installation, click *Next* on the driver installer dialog window.

Figure 3 Driver installer dialog

3. On the EULA window (Figure 4) select *I accept EULA* if you accept displayed license agreement. Click *Next* to continue with driver installation.

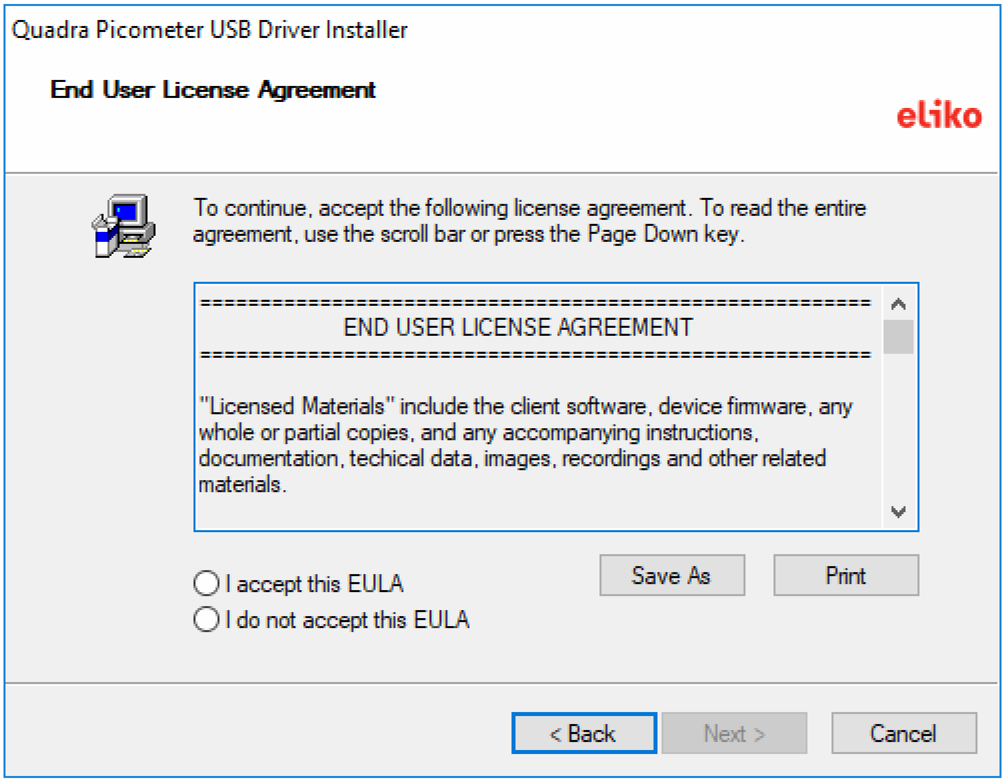


Figure 4 Driver EULA dialog

4. If driver installation was successful, the confirmation dialog (Figure 5) will appear. Click *Finish* to close driver installation application. Now the device can be connected to the PC. After connecting the device for the first time, Windows will finish up driver installation.

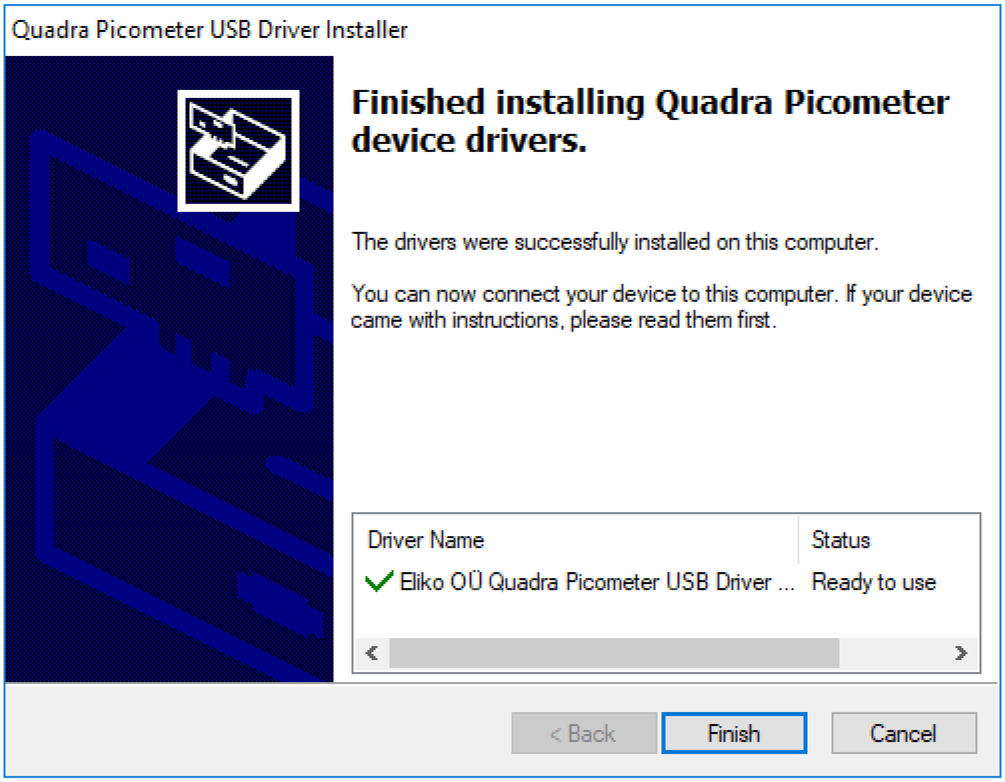


Figure 5 Driver installation confirmation dialog

NOTE:

The user can start Windows uninstaller program that can be used to uninstall the device driver. Locate *Windows Driver Package - Eliko OÜ Quadra Picometer USB Driver* under the Windows *Programs and Features* in *Control Panel* and choose *Uninstall/Change* from the context menu.

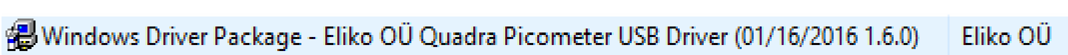


Figure 6 Quadra USB driver package in Programs and Features

Manual Driver Installation

The next steps are not required if driver was already successfully installed in previous steps.

Procedure for Windows 8 and Windows 10

1. To start with driver installation, connect the Quadra device to a USB port. At initial connection, Windows is unable to locate drivers for the device. Open device manager by typing *Device manager* in Windows *Start Screen*. Locate device named as *Quadra Picometer* under *Other devices* in the *Device Manager*. Right-click and choose *Properties* to open device properties window and on *General tab,* click *Update Driver* as shown on Figure 7. In the next dialog, select *Browse my computer for driver software* (Figure 8). Browse for the folder *Windows Drivers\Eliko Install Disk v1.6.0*\ in the Quadra software package (Figure 9). If driver installation finishes successfully, then the confirming dialog (Figure 10) will be displayed.

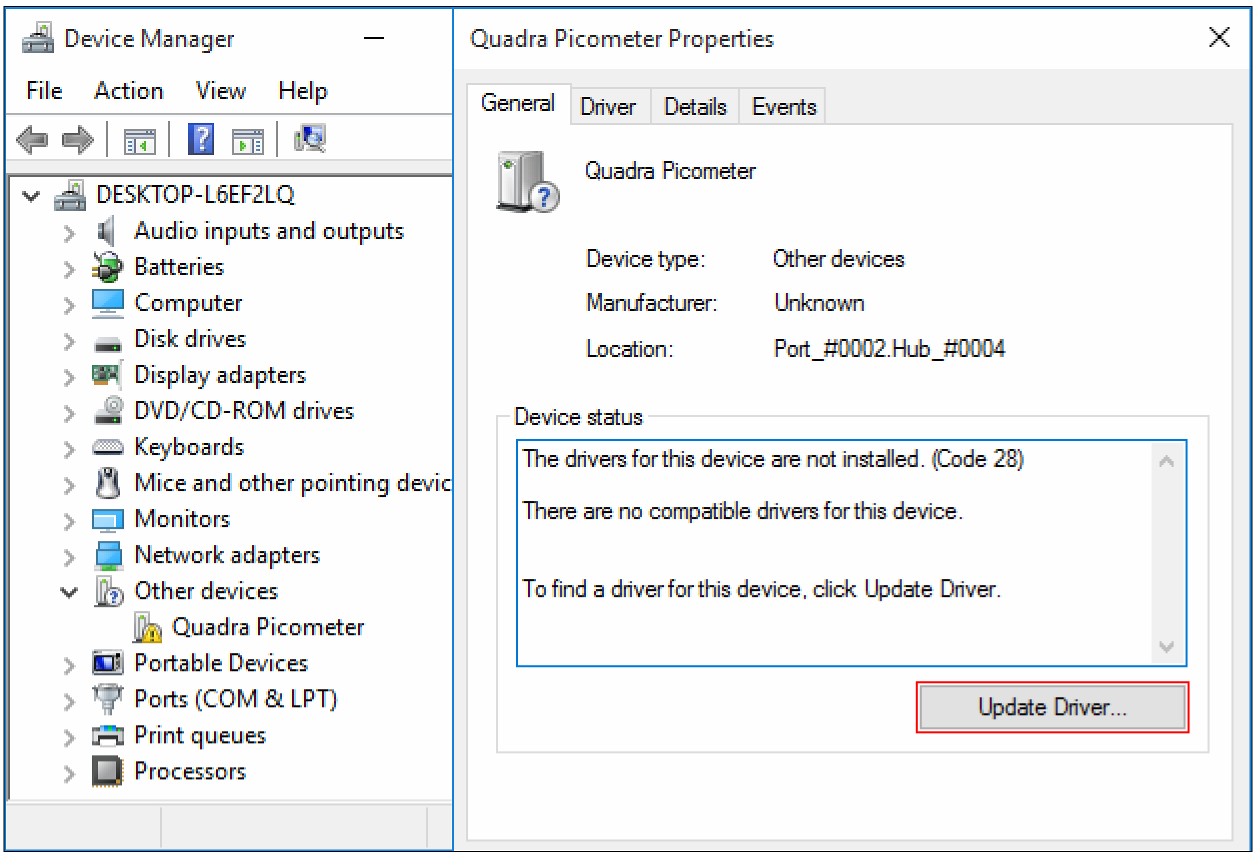


Figure 7 Update Device Drivers from Device Manager

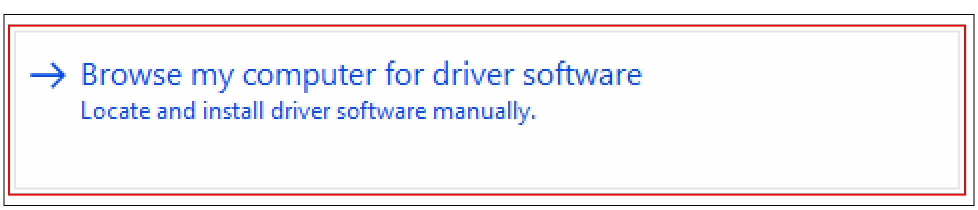


Figure 8 Select Driver Software Source

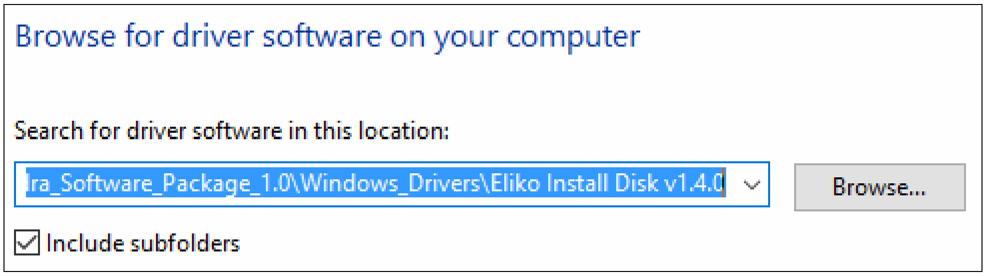


Figure 9 Select Device Drivers Folder

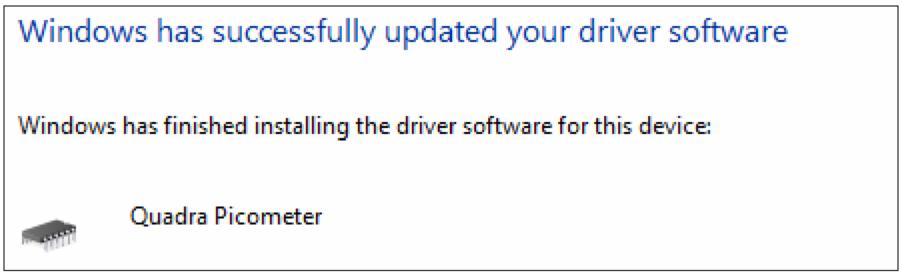


Figure 10 Device Driver Install Finished

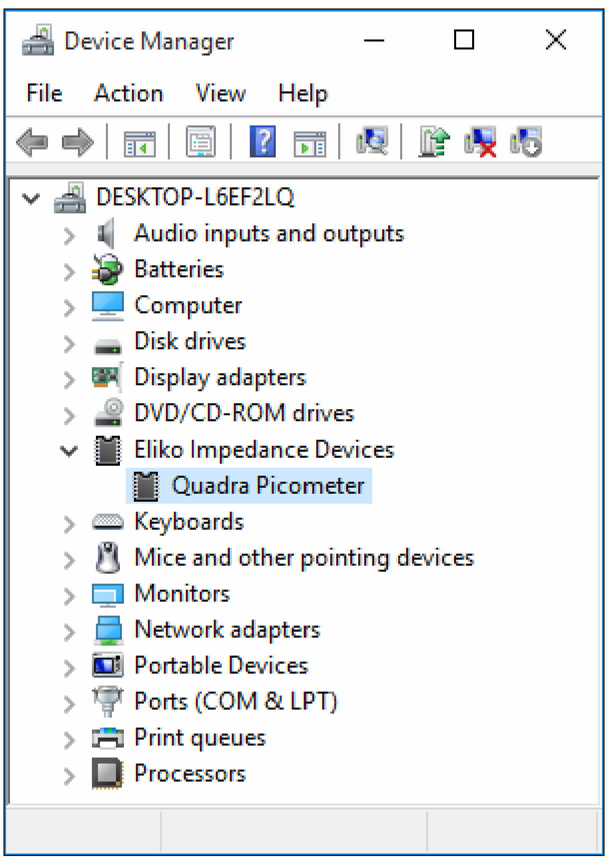


Figure 11 Device Ready Under Device Manager

Procedure for Windows XP and Windows 7

To start with driver installation, connect the Quadra device with PC USB port. At initial connection, Windows is unable to locate drivers for the device. Open *Device Manager* and under *Other devices* locate the Quadra device named as *Quadra Picometer* (Figure 12). Open device properties window and under *General tab* click *Update Driver…* or *Reinstall Driver…* as shown on Figure 13. On the first dialog, select *Browse my computer for driver software* and on Windows XP select *No, not this time* and *Install from list or specific location* (Figure 14). On the next dialog, browse for the folder *\Windows Drivers\Eliko Install Disk v1.6.0* in Quadra software package (Figure 15).

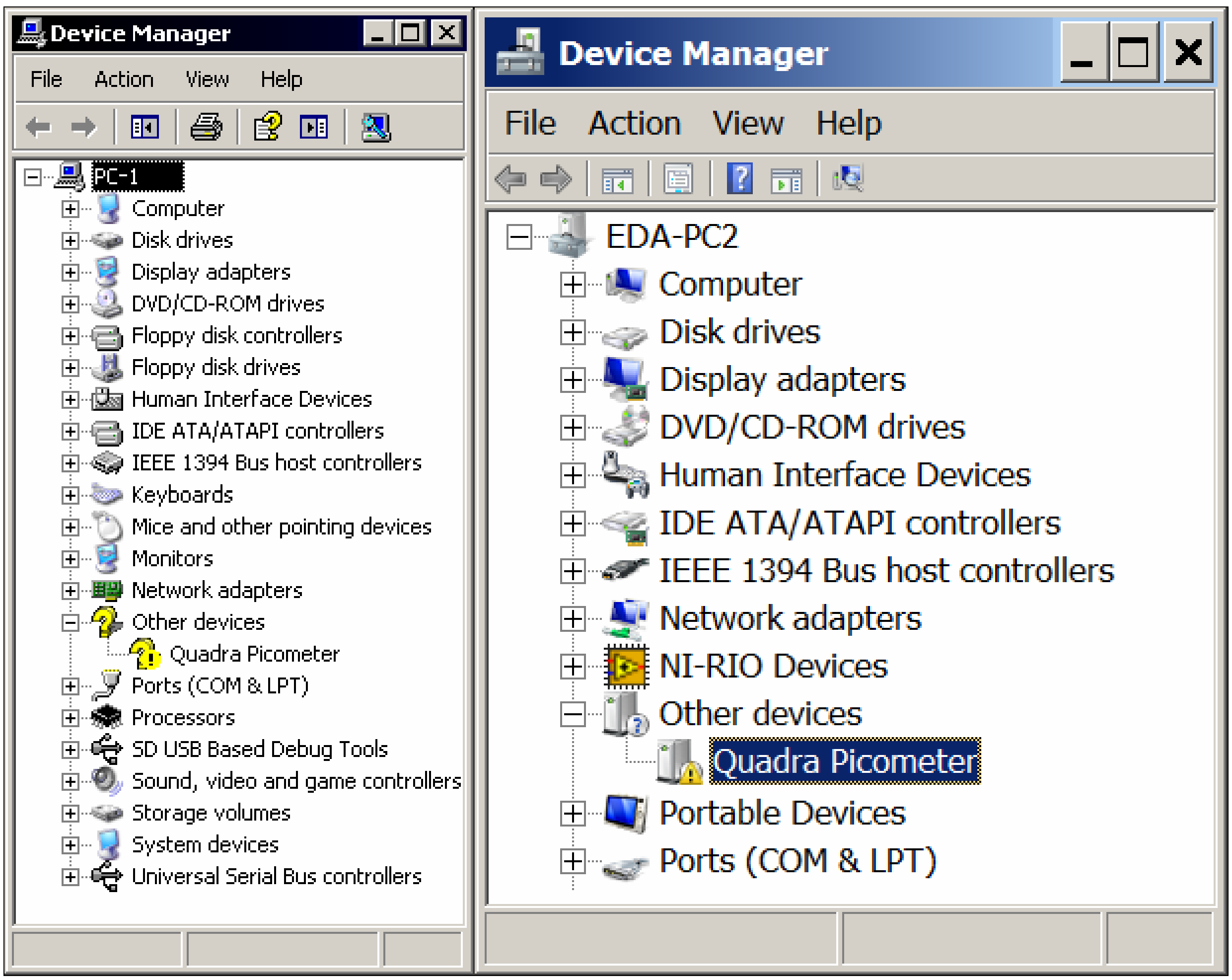


Figure 12 Windows XP and Windows 7 Device Manager

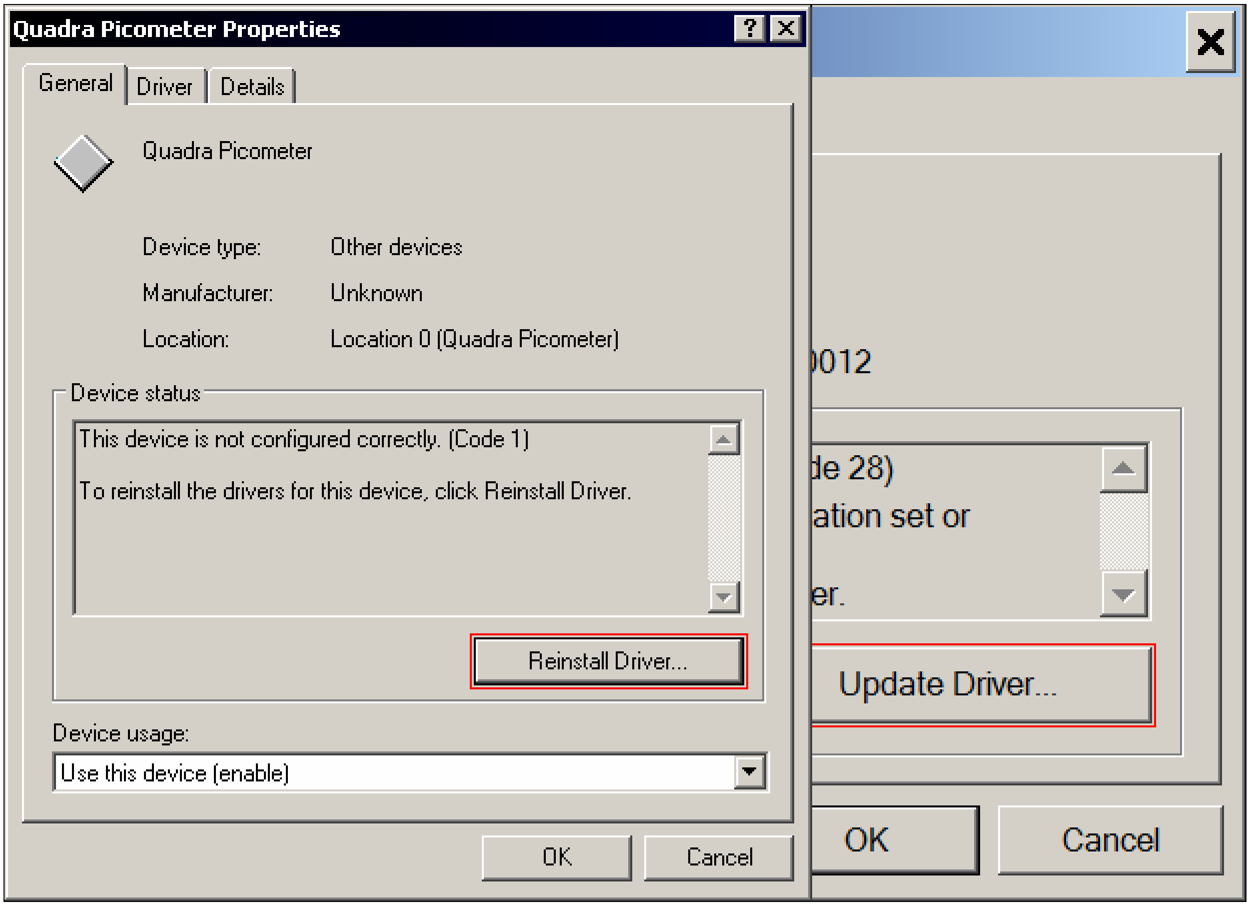


Figure 13 Update Device Driver

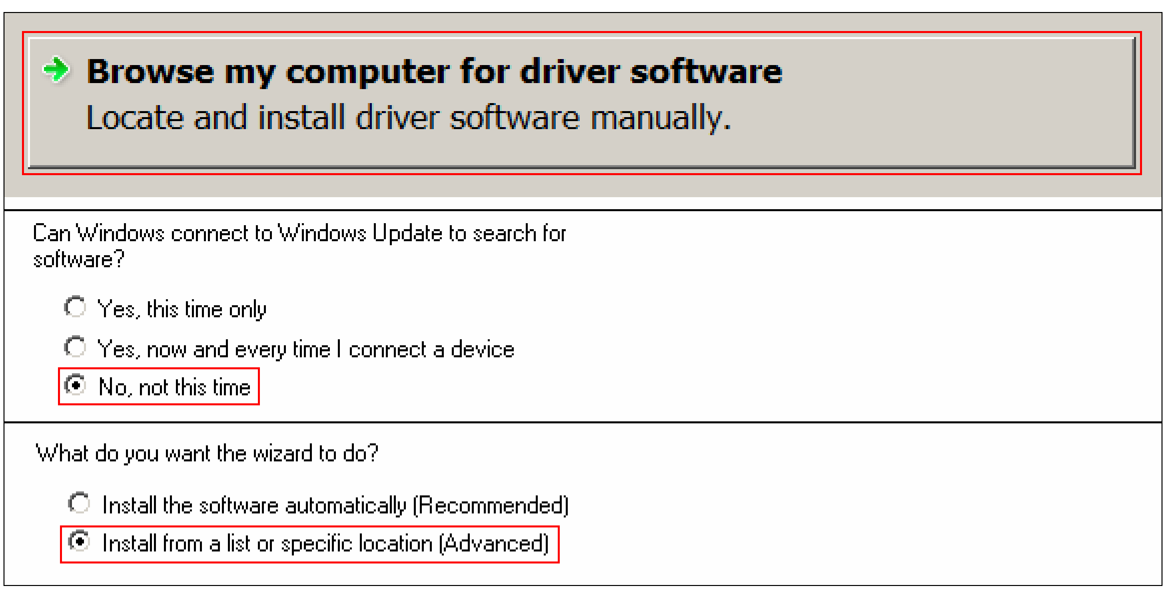


Figure 14 Select Driver Software Source

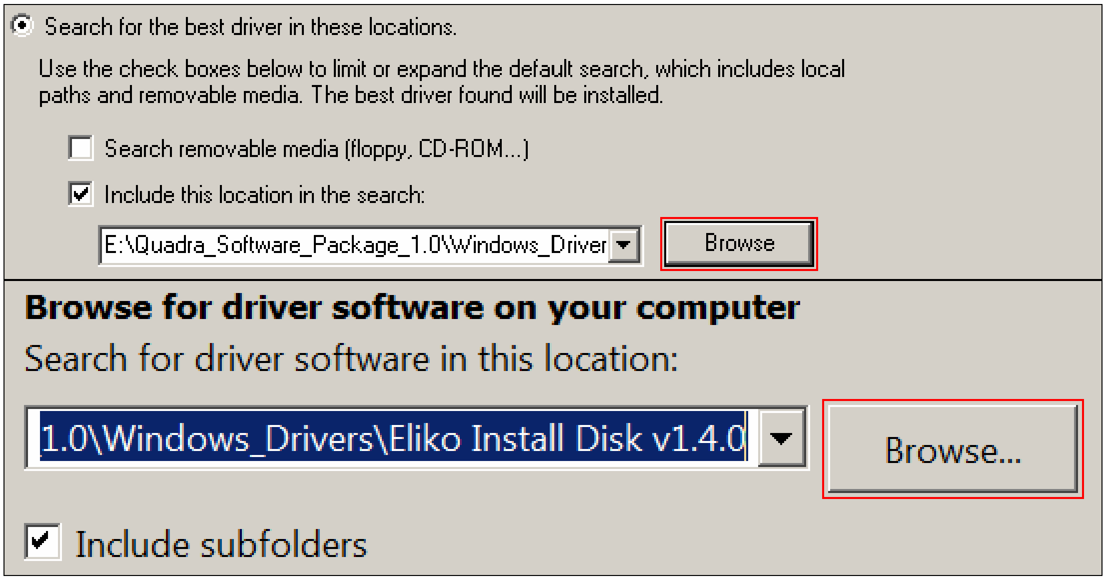


Figure 15 Select Device Drivers Folder

During the installation, Windows may prompt security warning where user must click *Install this driver software anyway* (or *Yes* in Windows XP) to continue with driver install. When Windows has finished installing the drivers then the Quadra device should appear in *Device Manager* as *Quadra Picometer* under category *Eliko Impedance Devices* (Figure 17).

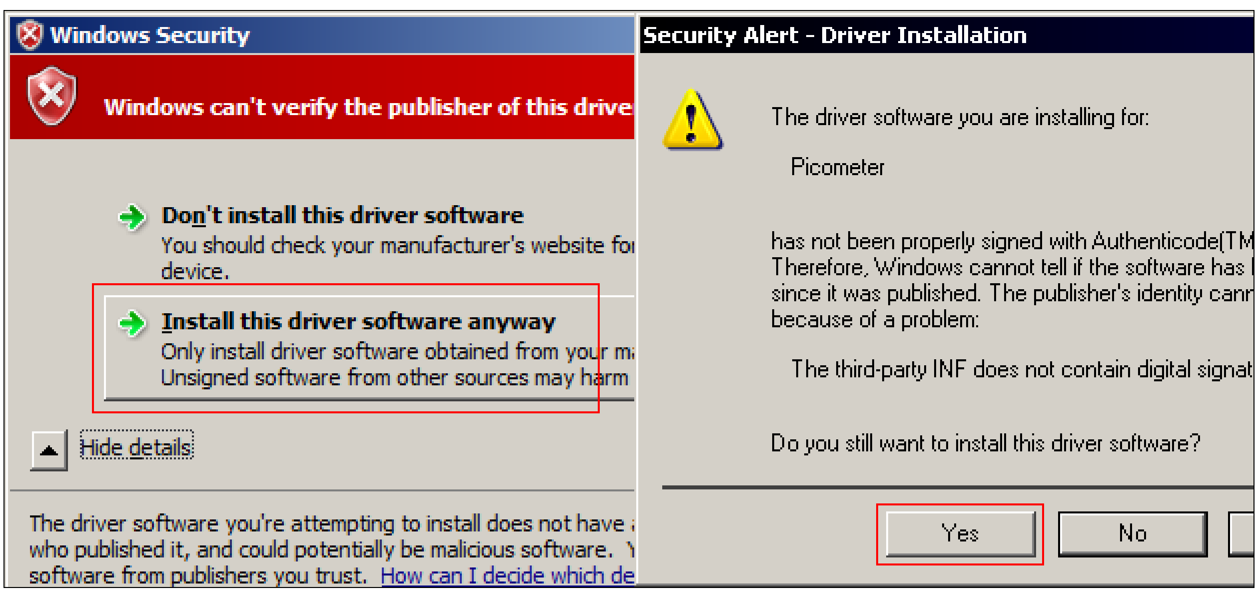


Figure 16 Security Warnings

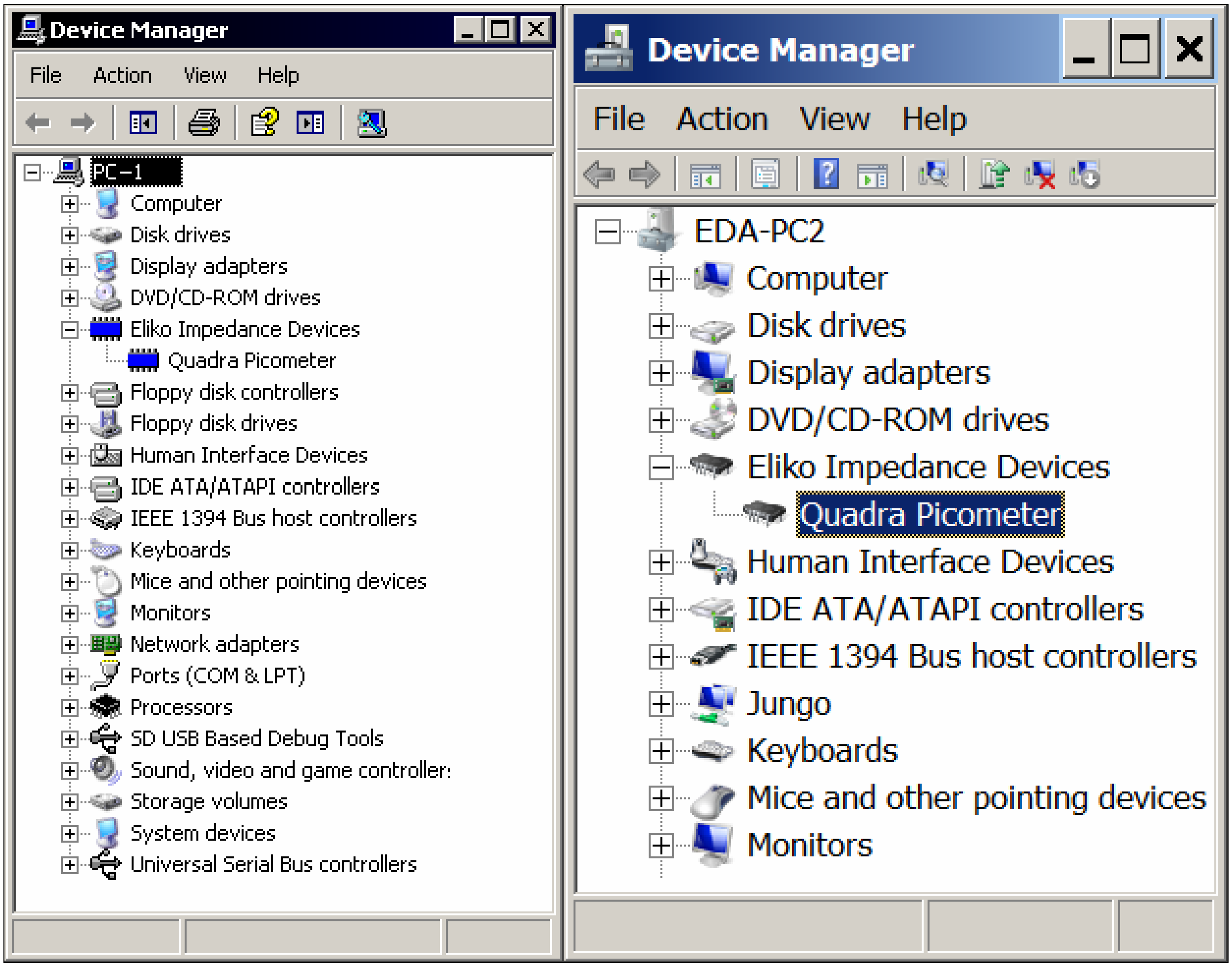


Figure 17 Device Drivers Installed

Device Connectors

Figure 18 Connectors and indicators on the front and back panel.

USB Connector

Mini-B type USB connector is located on the front panel. USB connection is used to provide power supply to the device and for charging the internal battery (Figure 18, *USB)*. Independently of the power supply modes (internal battery or USB), the USB bus data lines are used to transmit measurement data, receive control commands and configuration data. The USB bus channel speed is 12 Mbps (Full Speed) and the data rate can be up to 1.6 Mbps during active measurement mode. The USB controller on DSP side has a data buffer for storing measurement data for 64 ms. In case a delay longer than 64 ms occurs in data reception by PC host, some loss can be expected. When connected to PC, the device automatically switches to USB bus supply. To switch device to battery supply, follow the steps in p. 15.

Synchronization Input-Output Connector

Synchronization Input-Output SMA connector *(SYNC-IO* on Figure 18) operates by default as output, the SYNC-IO signal is toggled after every 1 ms during active measurement mode. This 1 ms toggle period is synchronous with the excitation signal generation and measurement channel's ADC buffer sampling. Therefore, this SYNC-IO can be used to get synchronization according to impedance spectra acquisition periods. The SYNC-IO can also be configured as input, which enables to switch the device to active measurement mode when the input is set high, similarly to selecting external triggering (p.14 in section "Using Control Panel Application" of this manual). During the period when input is kept high, the measurement runs continuously, and when the input is set low, the measurement is terminated immediately. Synchronization Input-Output level is 3.3 V and the input is 5 V tolerant.

Analog Front-End Connector

DSUB-25 type connector located on the back panel of Quadra device (Figure 18, Figure 19) provides all necessary analog inputs and outputs, supply and digital IO lines that are required to connect and operate an analog front-end. Standardized DSUB allows to connect application specific front-end setups and customize the input of Quarda device for different measurements. The connector pin-out is listed in Table 3.

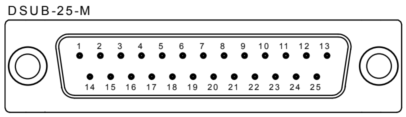


Figure 19 Analog Front-End Connector

Table 3 Analog Front-End Pin-Out

Pin Number	Direction	Function
1	Passive	GND
2	Analog Input	U_P_SENSE
3	Analog Input	U_P_GUARD
4	Analog Input	U_N_GUARD
5	Analog Input	U_N_SENSE
6	Passive	GND
7	Analog Input	I_P_SENSE
8	Analog Input	I_P_GUARD
9	Analog Input	I_N_GUARD
10	Analog Input	I_N_SENSE
11	Passive	GND
12	Analog Output	Excitation Signal Positive
13	Analog Output	Excitation Signal Negative
14	Passive	GND
15	Passive	GND
16	Analog Supply	-5 V, 100 mA
17	Passive	GND
18	Analog Supply	+5 V, 150 mA
19	Digital Input Output	User GPIO 1
20	Digital Input Output	User GPIO 2
21	Digital Input Output	User GPIO 3
22	Passive	GND
23	Digital Input Output	I2C Bus Serial Data IO SDA
24	Digital Input Output	I2C Bus Serial Clock IO SCL
25	Digital Supply	+3.3 V, 150 mA

Device Indicators

On the device front panel are located four LED indicators for different functions (Figure 18, *B, BSY, ERR/ACK, RDY*). All four LED's are controlled by DSP software where every LED indicator signals one or multiple events and conditions.

Table 4 LED Indications

LED Indicator	Indication Mode	Description
RDY	On constant green.	DSP is powered and DSP firmware has booted up.
	Off.	DSP firmware encountered critical error during normal operation or DSP firmware did not boot.
ERR/ACK	On constant red.	DSP firmware encountered critical error during normal operation. DSP firmware operation is halted.
	On for period of 125 ms.	Acknowledges that received control command execution was successful.
	Toggled twice with periods of 125 ms.	During active measurement DSP USB controller transmit buffer overflow has occurred and 40 ms of data has lost.
	Toggled four times with periods of 125 ms.	Indicates that the last received control command execution failed or the latest data transfer at I2C bus has failed. To get the specific error event the user must send control command (*GET STATUS*) that requests device software version string with device error flags.
BSY	On constant orange.	Indicates that DSP is operating in active measurement mode and some of the time-consuming control command executions are disabled because DSP is busy with data processing.
	Off.	Indicates that DSP is in idle mode.
B	On constant green.	Indicates that battery charging has completed and device is currently running on USB bus power.
	On constant red.	Indicates that device is operating on battery supply.
	On constant orange.	Indicates that battery is charging and device is operating on USB bus supply.
	Red toggling with periods of 400 ms.	Indicates that battery is low and in any moment the device will switch back to USB bus supply.
	Toggling between red and orange with periods of 800 ms.	Indicates fault condition on battery management unit.

QUADRA Control Panel Software

The *Quadra Control Panel* is a standalone Windows application which is used to control the main functions of Quadra device and to display or log the measurement data. The *Quadra Control Panel* application can be found in Quadra software package under */Quadra Software Package v1.0/Quadra Control Panel/*. *QuadraControlPanel.exe* is a lightweight executable with dynamic link library that does not require any installation. Multiple instances of these programs can run in parallel on the same PC, so that multiple *Quadra* devices can be used concurrently for multi-channel applications (p. 14 in section "Using Control Panel Application" of this manual).

⚠ This application expects that the dynamic link library *PicometerCtrl.dll* is located in the same directory as the executable.

System Requirements

Table 5 System Requirements

Hardware / Software	Requirement
Operating System	Windows XP 32-bit SP2, Windows XP 64-bit SP3, Windows 7 32-bit, Windows 7 64-bit, Windows 8 32-bit, Windows 8 64-bit, Windows 10 32-bit, Windows 10 64-bit
CPU	Pentium 4 1.5 GHz minimum
Memory	256 MB RAM minimum
Hard Drive	500 KBytes minimum
Graphics Hardware	DirectX 9.0c compatible video card, 3D Hardware Accelerator - 64MB of memory minimum
Screen Resolution	(1280 × 800) px minimum
Display DPI Settings	Scaling 100% 96 dpi
Disk File System	NTFS

Using Control Panel Application

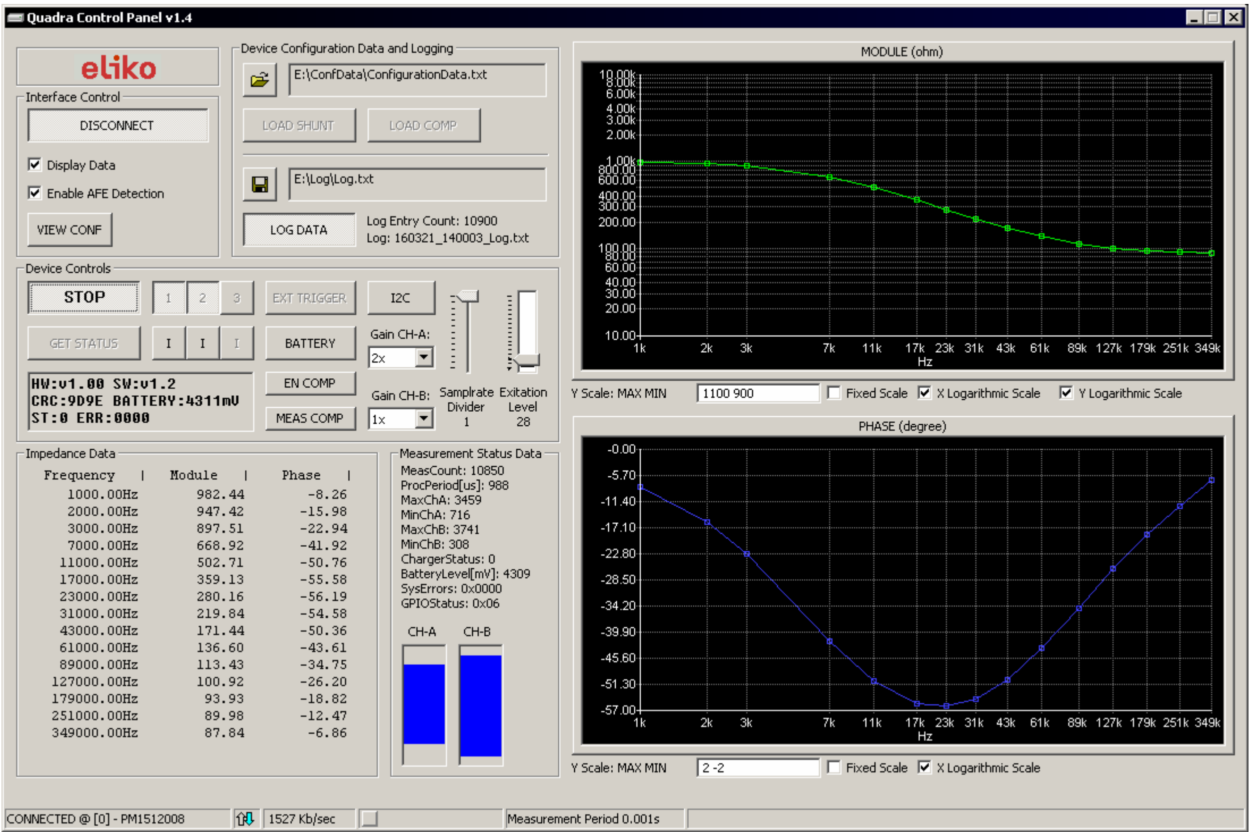


Figure 20 Quadra Device Control Application

The Quadra control application GUI layout is divided into groups of controls and data plotting regions. The *Interface Control* group controls the connection state with device and the real time data updating in the GUI window. The group *Device Control* includes all controls that set the operating mode and configuration of the device.

Starting and Stopping Measurements

1. Before starting the Quadra application (*QuadraControlPanel.exe),* connect Quadra device with PC USB port. When using the device for the first time, check that the device appears correctly in the *Windows Device Manager*.

2. Start the application, press control *CONNECT DEVICE* in *Interface Control* group and wait for one second while the application initializes Quadra with default configuration. After successful initialization, the *Frequency* data column in *Impedance Data* group and

GPIO State indicators *1*, *2*, *3* in *Device Controls* are updated. If the device is not connected or the device drivers are not installed, an error message is displayed on status bar *ERROR [01167] – The device is not connected*.

3. To switch Quadra device to active measurement press control *START* in *Device Controls* group. Right after that the device starts with continues measurements and measurement data is transmitted back to *Quadra Control Panel* application for plotting. During the active measurement some of control commands are enabled - some controls disabled.

4. *Display Data* checkbox in *Interface Controls* group can be used to disable or enable measurement data updating. Every 50th received spectra is displayed while measurement period is 1 ms.

5. To stop active measurement, click the control with caption *STOP* in *Device Controls* group.

6. Before disconnecting Quadra from USB, click the control *DISCONNECT* in *Interface Control* group to stop the communication and release the USB bus resources.

Loading Configuration Data

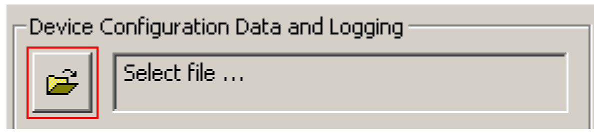
The specific characteristics of an analog front-end (shunt impedance and input impedance compensation values) can be read from a text file and loaded to Quadra device RAM. The loaded data can be viewed using *VIEW CONF* in *Device Controls* group. The configuration data must be formatted in text file according to this example:

```
COMP\r\n
1000000000.0 1000000000.0 1000000000.0 1000000000.0 1000000000.0 1000000000.0
1000000000.0 1000000000.0 1000000000.0 1000000000.0 1000000000.0 1000000000.0
1000000000.0 1000000000.0 1000000000.0 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01\r\n
SHUNT\r\n
1000.1 1000.1 1000.1 1000.1 1000.1 1000.1 1000.1 1000.1 1000.1 1000.1 1000.1
1000.1 1000.1 1000.1 1000.1 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2
1.2 1.2 1.2
```

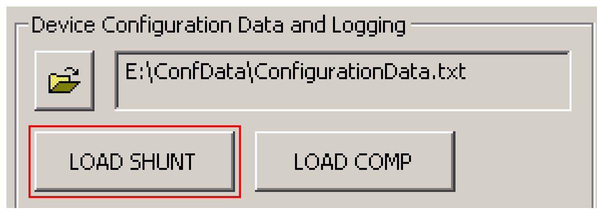
The first line contains keyword '*COMP*' indicating that next text line contains input impedance compensation values in float format, where first 15 values ('*1000000000.0*' in the example) are real part values and last 15 values ('*0.01*') are imaginary part values. The text line containing keyword '*SHUNT*' indicates that next text line contains shunt impedance compensation values in float format, where first 15 values ('*1000.1*' in the example) are real part values and last 15 values ('*1.2*') are imaginary part values.

Before loading input impedance compensation or shunt impedance compensation values, the *Quadra Control Panel* application must be connected to the device.

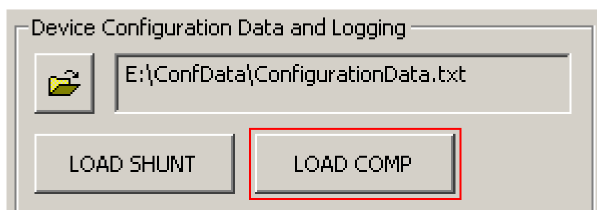
7. Using file browse control in *Device Configuration Data and Logging* group select the configuration data text file.



8. To load shunt impedance complex values to device RAM press *LOAD SHUNT* control in *Device Configuration Data and Logging* group and confirm if the control command execution was acknowledged by ERR/ACK LED.



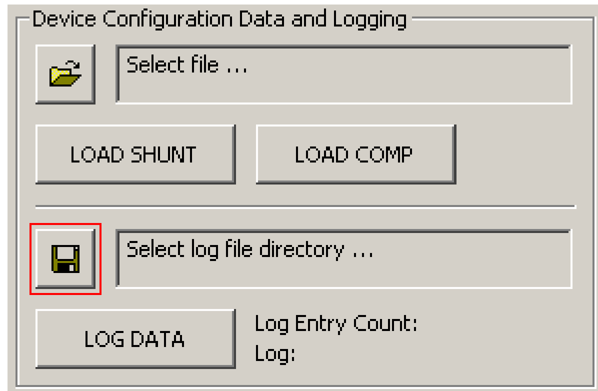
9. To load input impedance compensation values to device RAM press *LOAD COMP* control in *Device Configuration Data and Logging* group and confirm if the control command execution was acknowledged by ERR/ACK LED.



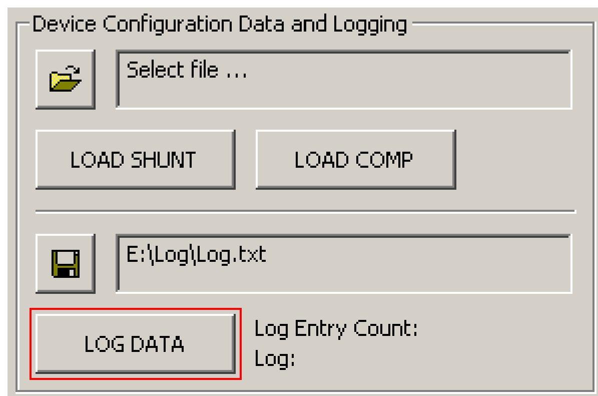
Logging Measurement Data

Regardless, if Quadra device is in active measurement mode or not, the logging can be configured and started. When logging is started, the actual data is recorded once active measurement is started as in p. 3.

10. Using file save control in *Device Configuration Data and Logging* group, define log file location and insert log file name suffix. The *Quadra Control Panel* application will add prefix with date and time to log file name when *LOG DATA* control is activated.



11. To activate measurement data logging toggle control *LOG DATA* in *Device Configuration Data and Logging* group. At this point, the log file is created with current date and time in log file prefix. To end data logging toggle that same control.



When a new log is created, the log file contains ASCII text log header and measurement data columns. If the keywords *OnExtTrigger*, *OnBattery*, *CompensationState*, *MeasureCompState* in log header are set as one, then these options were enabled when logging was started. The keywords *Frequencies*, *Shunt*, *CompValues* contain the configuration data values that were used at the beginning of measurements.

```
LogName=                LogName.txt
Created=                2015 11.09 12:06:32
ApplicationVersion=     v1.4
DeviceDescription=      HW:v1.00 SW:v1.2 CRC:A811 BATTERY:4220mV ST:0ERR:0000
DeviceSerial=           PM1512008
AFEDescription=         Single shunt, R(Z1), 1kohm, S/N: 5
FrequencyDivider=       1
ExcitationLevel=        96
GainCH-A=               1x
GainCH-B=               1x
OnExtTrigger=           0
OnBattery=              0
CompensationState=      0
MeasureCompState=       0
Frequencies=                        1000.00Hz,      2000.00Hz,      3000.00Hz,
7000.00Hz,      11000.00Hz,      17000.00Hz,      23000.00Hz,      31000.00Hz,
43000.00Hz,      61000.00Hz,      87000.00Hz,    127000.00Hz,    177000.00Hz,
247000.00Hz,  349000.00Hz\r\n
Shunt(re...im...)=                 1000.10,     1000.10,     1000.10,     1000.10,
1000.10,      1000.10,      1000.10,      1000.10,      1000.10,      1000.10,
1000.10,      1000.10,      1000.10,      1000.10,      1000.10,         1.20,
1.20,           1.20,         1.20,           1.20,          1.20,         1.20,
1.20,         1.20,        1.20,        1.20,         1.20,        1.20,         1.20,
1.20\r\n
CompValues(re...im...)=
1000000000.00,1000000000.00,1000000000.00,1000000000.00,1000000000.00,1000000
000.00,1000000000.00,1000000000.00,1000000000.00,1000000000.00,1000000000.00,
1000000000.00,1000000000.00,1000000000.00,1000000000.00,   0.01,         0.01,
0.01,          0.01,          0.01,          0.01,          0.01,          0.01,
0.01,          0.01,          0.01,          0.01,          0.01,          0.01,
0.01\r\n
```

The log header is followed by the data columns which are positioned in a way that the log importing to *Excel* program would be straightforward. The data columns contain the following data:

`Count`	Contains the count of measured impedance spectra where one acquisition period is defined by variable 'PPeriod', which in most cases is ~1 ms. If the count step is >1, then it indicates data loss. Also indicated on status bar with number of impedance spectra lost (named as 'MeasCount'). 
`Module(ohm)1...15`	Contains the impedance module values in number of ohms for all 15 frequencies.
`Phase(degree)1...15`	Contains the impedance phase values in number of degrees for all 15 frequencies.
`PPeriod(us)`	Contains the time period in number of microseconds that was spent by DSP during last impedance spectrum acquisition (named 'ProcPeriod').
`Max-A`	Contains the maximum value of the time domain buffer from which the impedance was calculated. In case this variable is set to value 4095 then it indicates that this ADC channel input signal was clipping and the impedances calculated during that are invalid.
`Min-A`	Contains the minimum value of time domain buffer from which the impedance was calculated. In case this variable is set to value 0 then it indicates that this ADC channel input signal was clipping and the impedances calculated during that are invalid.
`Max-B`	Same description as variable 'Max-A'.
`Min-B`	Same description as variable 'Min-A'.
`SysErr`	Contains the system error flags combined value. If this variable is zero then no errors were detected.
`GPIO`	Contains three bit fields that indicate the states of user GPIO's 1, 2 and 3. When bit 3 is set, then GPIO1 is in high state; if bit 2 is set, then GPIO2 is in high state and if bit 1 is set, then GPIO3 is in high state.
`Battery`	Contains the current battery voltage value in number of mV. Value is updated after a period of 1 second.
`ChargeStatus`	Battery charger status code, where value 0 indicates that battery is full, value 2 indicates that battery is charging and value 4 indicates battery fault. If value 4 does not clear away on USB supply then the device requires service.

Keyword SysErr error bit fields description:

`Bit0:`	Value 1 indicates that some of the received control commands were unknown or execution failed because of incorrect arguments.
`Bit1:`	Value 1 indicates that during active measurement the impedance data buffer overflowed causing data loss.
`Bit2:`	Value 1 indicates that during impedance data calculations the numeric saturation was detected. Indicates software problem or incorrect configuration data.
`Bit3:`	Value 1 indicates error within data acquisition driver software.
`Bit4:`	Value 1 indicates for I2C bus communication error.
`Bit5:`	Value 1 indicates that device requires service.
`Bit6-Bit15:`	Reserved

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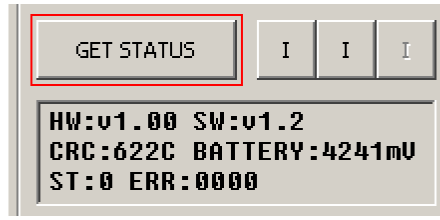
Reading Device Current Version and Status String

12. Press *GET STATUS* in *Device Controls* group to request the version and status string from the device (the device must be connected, see p. 2). This control command clears all the internal error flags to zero.



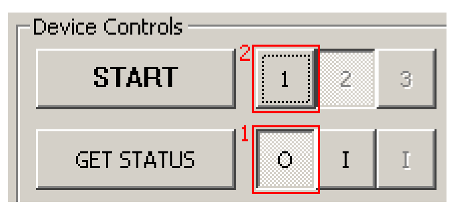
The received version and status string contains the following fields:

`HW:v1.00`	- This field contains the Quadra device hardware version number.
`SW:v1.2`	- This field contains the Quadra device firmware version number.
`CRC:622C`	- This field contains the Quadra device software CRC checksum value in HEX.
`BATTERY:4241mV`	- This field contains the current battery voltage value in mill volts.
`ST:0`	- This field contains battery charger status code, which values are described in p. 11 with keyword *ChargeStatus*.
`ERR:0000`	- This field contains the internal error flags in HEX format. Bit fields are described in p. 11 with keyword *SysErr*.

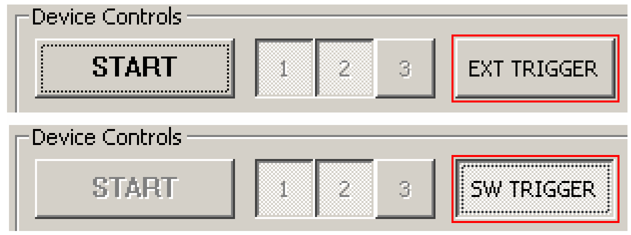
Controlling User GPIO's

When *Quadra Control Panel* application is connected to the device, which is in idle operating mode, the user GPIO state indicators *1*, *2* and *3* are automatically updated if one of the states has changed. During the measurement, the GPIO state indicators are updated only if data update is enabled. User GPIO's are configured as input by default.

13. To configure selected user GPIO as output, click the control *I* under the selected GPIO state indicator (1) in *Device Controls* group. The GPIO control caption changes to *O,* indicating output configuration. To manually toggle between output states, press the activated GPIO state indicator (2) in *Device Controls* group. If GPIO state control is checked as *2* then this input/output is at high state.



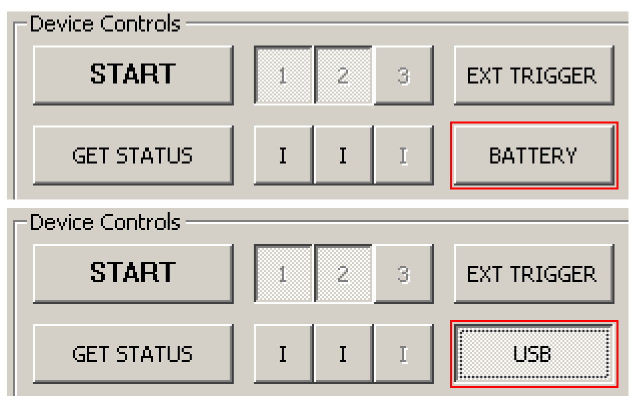
Selecting External Trigger



14. To enable triggering the active measurement from external signal click the *EXT TRIGGER* control in *Device Controls* group. This control command configures the *SYNC-IO* as input that starts and stops the active measurement. The high input signal starts active measurement and low input stops the active measurement. When external trigger is enabled, the software measurement control is disabled. In case of multiple devices, *SYNC-IO* are connected in parallel, so that all the devices can be switched to active measurement mode with random delay of several microseconds. This setup enables to use multiple Quadra devices for multi-channel applications.

⚠ To avoid inconsistency between the control state and actual external trigger configuration, it is required that switching from external trigger to software trigger is done while *SYNC-IO* input is low.

Enable Battery Supply



15. By default, the Quadra device is operating on USB bus supply. To switch from USB bus supply to battery supply, click the control *BATTERY* in *Device Controls* group. After the control command is acknowledged, the device is switched to battery supply and battery LED *B* is set red. Device continues to operate on battery supply until battery gets on critical level or USB is disconnected.

Configure Input Impedance Compensation

Quadra can perform additional impedance data processing that enables to remove input impedance Z_{input} from the measured impedance $Z_{parallel}$, (Figure 21). This option enables to decrease the influence of device's input impedance in final impedance spectra. To compensate this influence the open input impedance must be measured or loaded from configuration text file as described in p. 9.

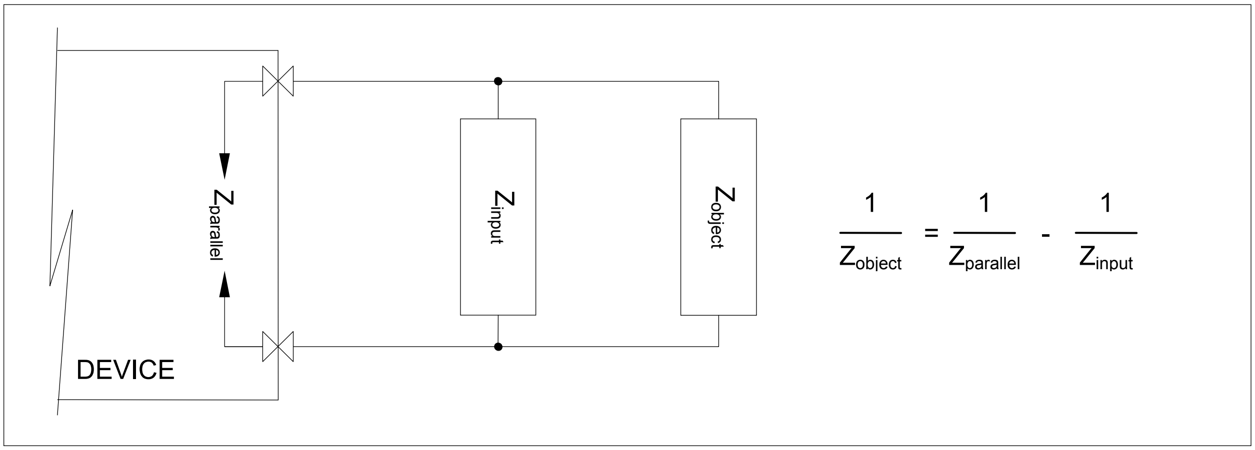
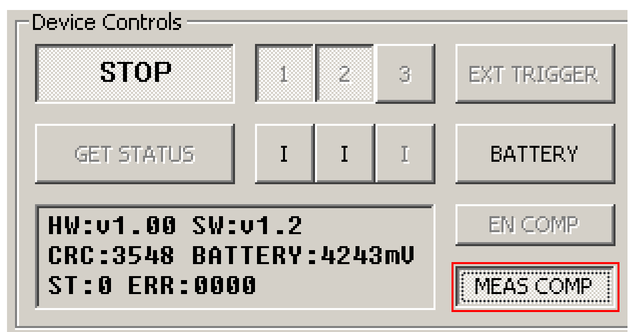
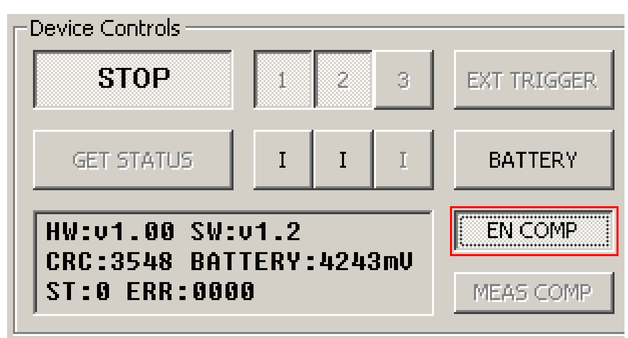


Figure 21 Impedance Measured by Device

16. In order to measure open input impedance, activate *MEAS COMP* control in *Device Controls* group. The input impedance values in DSP RAM are updated only if active measurement mode is enabled like described in p. 3. In order to get correct open input impedance, the analog front-end must be attached and terminals that connect to electrodes must be disconnected.



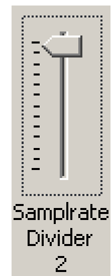
17. The input impedance compensation values measured, as shown in p. 16 (or loaded as shown in p. 9), can be used when compensation processing is made active. To enable input impedance compensation, activate control *EN COMP* in *Device Controls* group.



Configuring Sampling Rate Divider

The set of Quadra spectra frequency points can be shifted to lower frequencies by modifying DSP internal frequency dividers that are used by sampling rate generators. The frequency point values can be divided with these factors: 1, 2, 4, 6, 8, 10, 12, 14, 16, 20, 24, 28, 32, 40, 48, 56, 64, 80, 96, 112, 128, 160, 192, 196, 224, 256, 320, 384, 448, 512, 640, 768, 896, 1024, 1280, 1536, 1792.

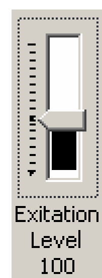
18. To switch device impedance spectra frequencies to desired lower frequency range, slide *Samplingrate Divider* control downwards (*Device Controls* group). Frequency values list in *Impedance Data* group is updated accordingly. When lower frequency range is selected, the impedance spectra acquisition period also increases from 1 ms up to 1.8 seconds at lowest frequency set. This control can be used only when device is running in idle mode.



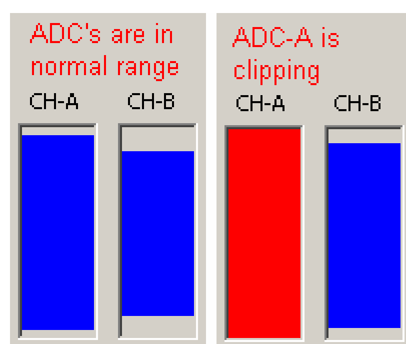
⚠ If sampling rate divider is configured with value higher than 192, the *SYNC-IO* output pulse width will be set to 1 ms. This is a hardware limitation.

Configure Excitation Voltage Level

19. To configure excitation output voltage levels between range of 0.4 Vpp to 7.5 Vpp, slide the *Excitation Level* track bar control in *Device Controls* group until desired voltage level is reached or until input signals start to clip. One step of track bar move will increase or decrease excitation voltage level in step of ~28 mV.



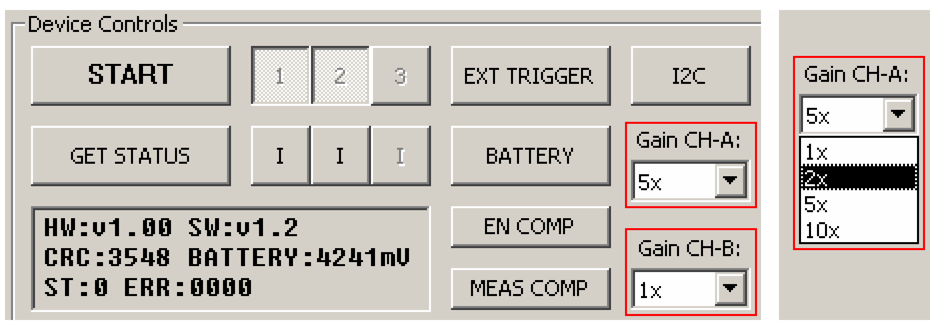
During the active measurement it is recommended to adjust excitation level so that ADC channels A and/or B use 90% of the ADC input range. Also, ADC input clipping must be avoided because during clipping all the acquired impedance spectra are invalid. The ADC input range can be verified from the indicators located in *Measurement Status Data* group. In case one of the inputs signal level is too low the calculated impedance values may also be incorrect. To add gain for input with low signal level use the corresponding gain configuration control *Gain CH-A* or *Gain CH-B* in *Device Controls* group as described in p. 20.



Configure Input Channels Gain

In some measurement situations, the input signal level of the channel might clip while other channel signal level is too low. To balance signal levels for both channels decrease excitation level so that signal clipping disappears. For the channel that has too low signal level, increase input gain so that approximately 90% of the channel range is used.

20. To change gain for specific input channel, open up drop down menu from *Gain CH-A* or *Gain CH-B* control in *Device Controls* group and select desired gain multiplier value. When drop down menu closes the gain values for the device are immediately updated. The changes of signal levels can be tracked only if active measurement is enabled as described in p. 3.



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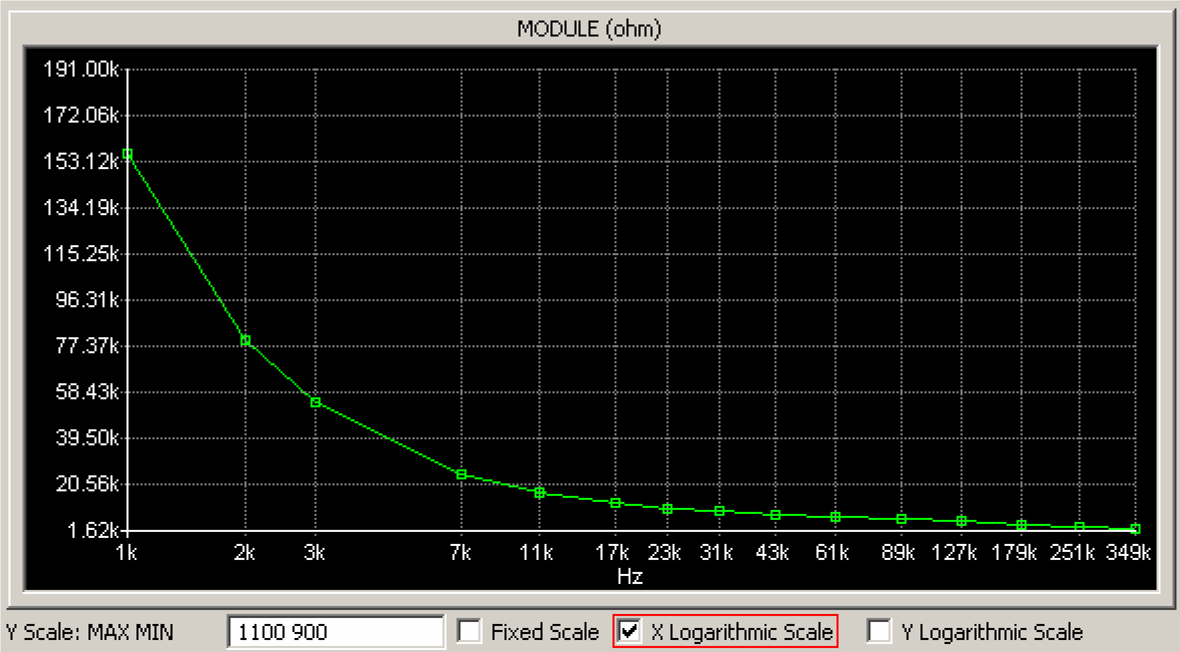
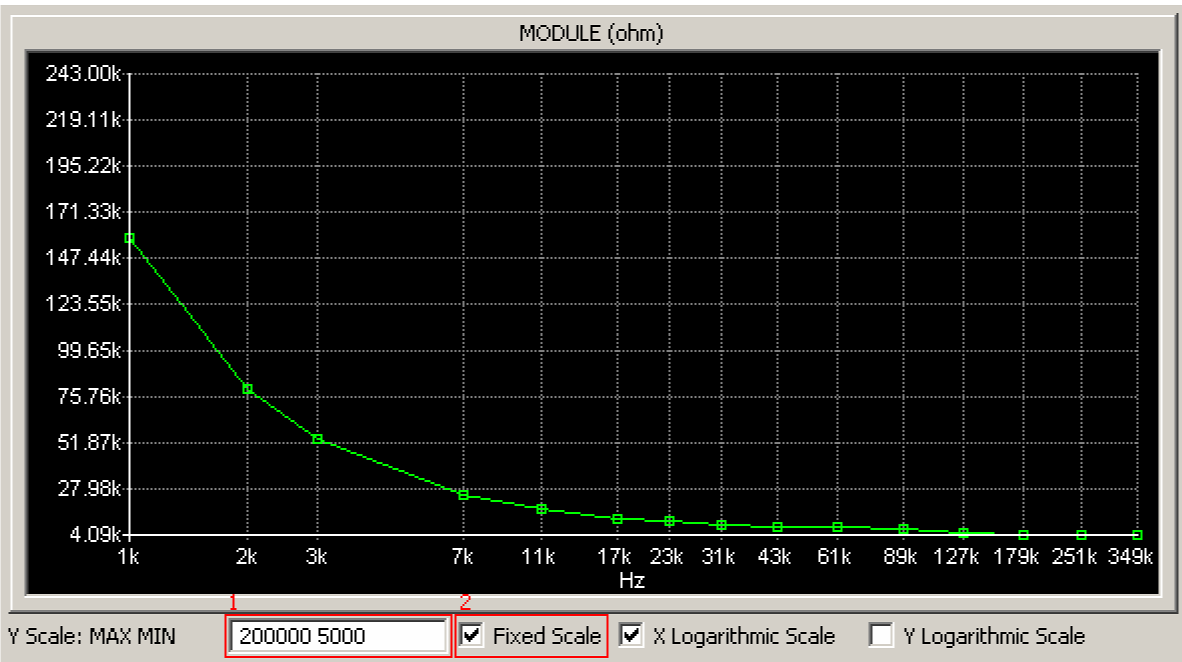
Configure Plot Areas

21. To draw X axes in logarithmic scale, check the *X Logarithmic Scale* control under the plot area, for linear scale uncheck the control.

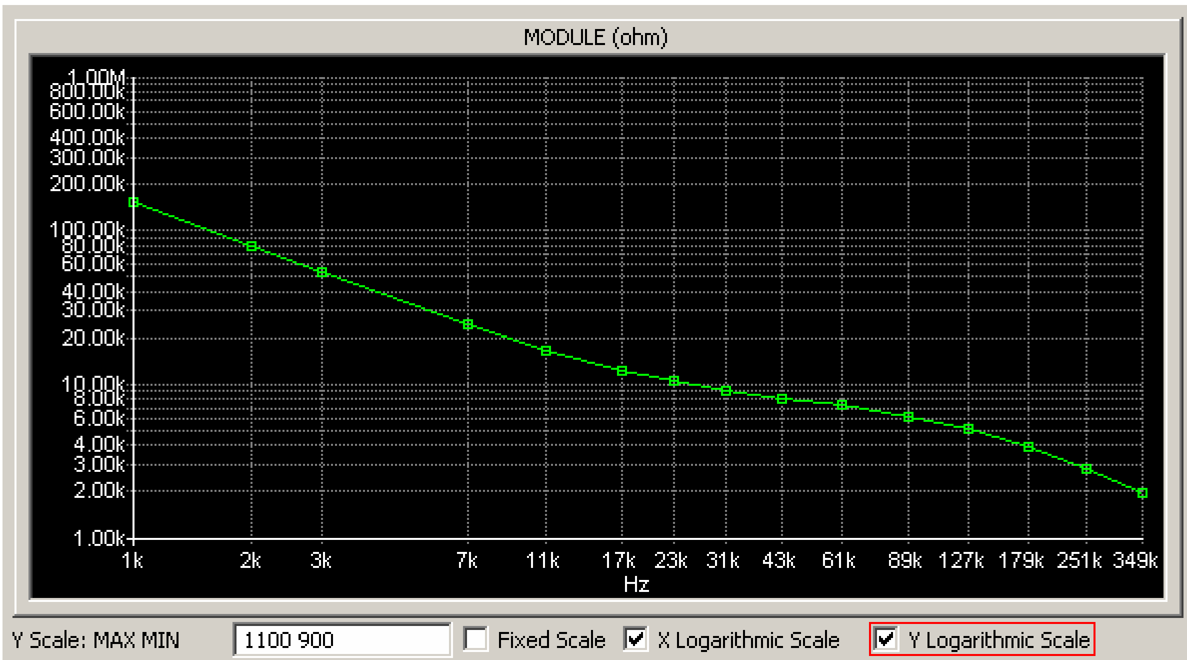


22. To draw Y axes with fixed scale, insert the Y scale maximum value in Ohms or degrees and Y scale minimum value in Ohms or degrees with space between the two values to the editable control under the plot area. Check the *Fixed Scale* control to enable the fixed Y scale.



⚠ Fixed Y axes scale is usable only when Y axes linear scale is used. When fixed scale is applied the configured minimum and maximum values are rounded upward and downward for maximum and minimum values.

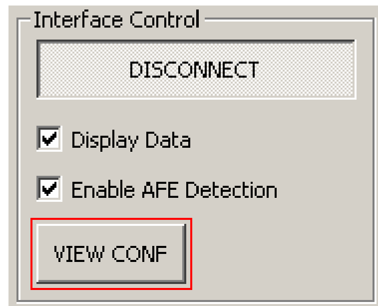
23. To draw Y axes with logarithmic scale, check the *Y Logarithmic Scale* control. In this scale, the actual maximum and minimum values are automatically recalculated to fit within decade boundaries.

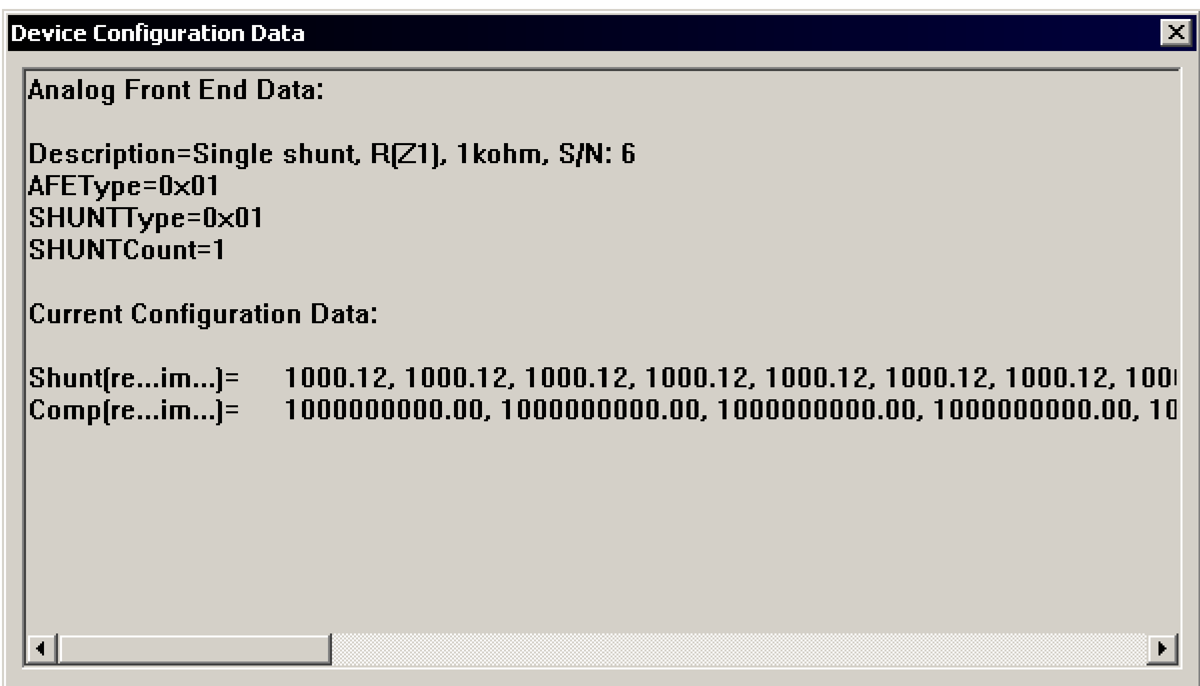


View Configuration Data

When *Quadra Control Panel* application is connected with Quadra device and initialization is completed, the current configuration data can be viewed in *Device Configuration Data* window. Displayed data contains the connected analog front-end description, type, shunt type and shunt count value that was read from the analog front-end interface when it was connected. The data also includes the shunt and compensation complex values that are currently used by Quadra device during the impedance measurement. Shunt values are calculated based on the selected frequencies and data read from analog front-end or the values are directly copied from external configuration file like described in p. 8.

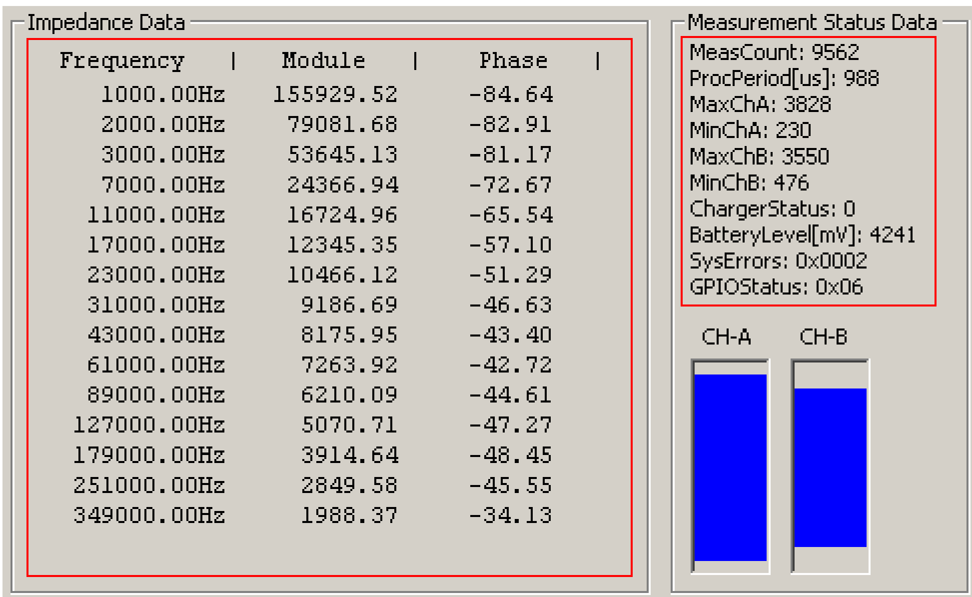
24. To open up *Device Configuration Data* child window click control *VIEW CONF* in *Interface Control* group. The data in *Device Configuration Data* child window edit control is dynamically updated when new shunt or compensation values are loaded from text configuration file or from the attached analog front-end.





Numeric Data Display

During measurement, the impedance data is updated in *Impedance Data* group with the update period of 50 ms (while divider is set to 1). At the same time, the status data is updated in *Measurement Status Data* group. All the data fields in *Measurement Status Data* group are same that are described in p. 11. Clicking right mouse button within the *Impedance Data* group area copies the displayed impedance spectra values as text to Windows clipboard.



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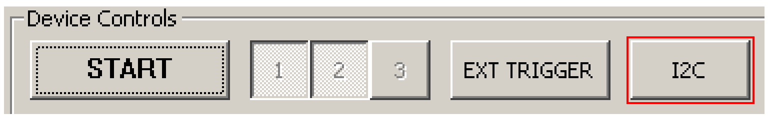
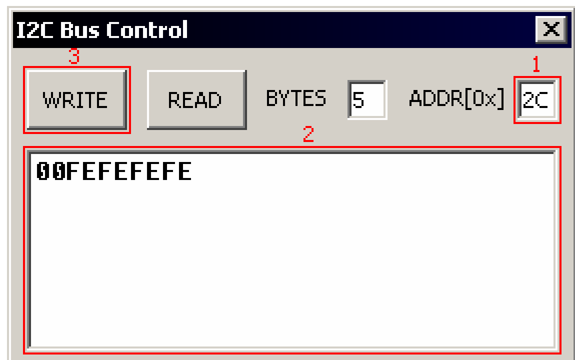
I2C Bus Control

Quadra Control Panel application includes I2C bus controls that enable to send or receive raw binary data from the I2C slave device attached to the bus. This interface can be used to control any custom made analog front-end that includes controller with I2C slave interface. The maximum number of data bytes that can be read or written is limited to 90 bytes.

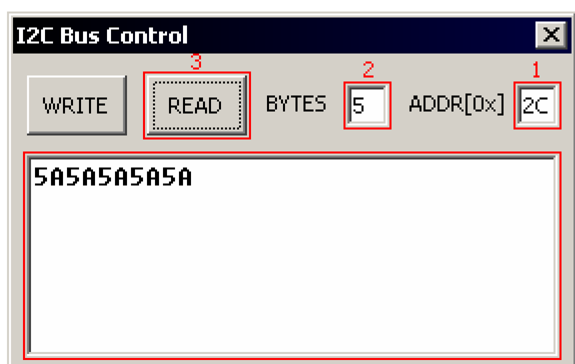
25. To open I2C bus control dialog toggle *I2C* control in *Device Controls* group.



26. To send specific bytes to I2C slave device, insert the I2C slave address to field *ADDR* (1) in hexadecimal format. Then insert the data bytes as hexadecimal string to edit field (2) and click the control *WRITE* (3) which sends the inserted data bytes to I2C bus. The hexadecimal string must contain even number of characters without spaces and the string must include only hexadecimal characters *0123456789ABCDEF*.
    To verify if writing was successful, click the *GET STATUS* control in *Device Controls* group and check if *I2C bus communication* error flag is cleared, described in p. 12.



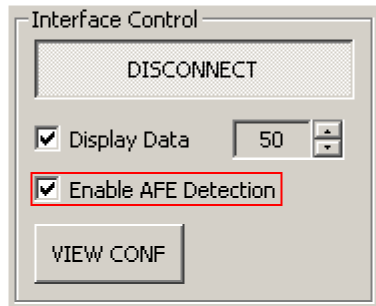
27. To receive specific number of bytes from I2C slave device, insert slave address to *ADDR* (1) field in hexadecimal format. Then insert the desired number of bytes in *BYTES* (2) field and then click *READ* (3) control. If I2C slave device responds without errors, then the received bytes are placed into edit field in hexadecimal format.



Analog Front-End Detection

This program enables to use automatic analog front-end detection. When the analog front-end is attached to Quadra device, the front-end data is read, interpolated according to selected frequencies and then the shunt impedance values in Quadra device are updated. For automatic detection of the analog front-end, interface's GPIO 3 input is used.

28. To enable automatic analog front-end detection and automatic update of shunt values, check the *Enable AFE Detection* control in *Interface Control* group. When this control is set, then the configuration data is read from the attached front-end and Quadra device shunt values are updated. To confirm that the configuration data and shunt data were updated, this data can be viewed by clicking *VIEW CONF* control, see p. 24. Analog front-end detection is enabled by default.



⚠ While the automatic analog front-end detection is enabled, GPIO 3 cannot be used.

⚠ While attaching an AFE module, the module detection may fail. To force AFE detection, click one of the GPIO direction controls once, like described in p. 13.

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Setup Verification with Example Impedance

This tutorial explains the common setup procedures for verifying impedance measurement with optimal repeatability.

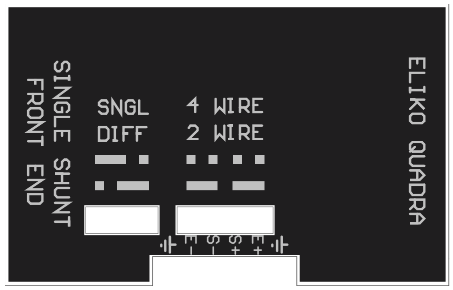


Figure 22 Single Shunt Front-End Top Cover

This tutorial assumes that device drivers are installed and Quadra device is connected with USB port.

1. Attach the single shunt front-end to Quadra device front-end connector. The front-end (Figure 22) is included in the device box.

2. Using the front-end jumpers, configure the front-end for single-ended 2-wire measurements.

3. Attach the included impedance demo board (Figure 23) into the front-end input terminals with button positioned upward. Fasten the terminal screws.

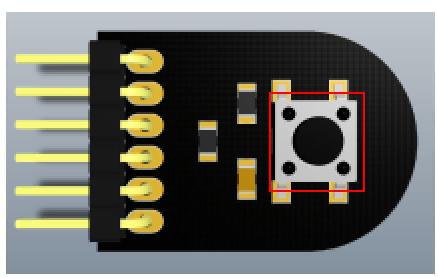


Figure 23 Impedance Demo Board

4. Start the *QuadraControlPanel.exe* application. On the control panel, click the *CONNECT DEVICE* control in *Interface Control* group and wait while the Quadra device is initialized.

5. Switch the device to measurement mode by clicking *START* control in *Device Controls* group. The measurement is started and impedance data is displayed on control panel window with refresh rate of 50 ms.

6. For 1 kΩ impedance, the MODULE and PHASE plots should look similar to examples on Figure 24.

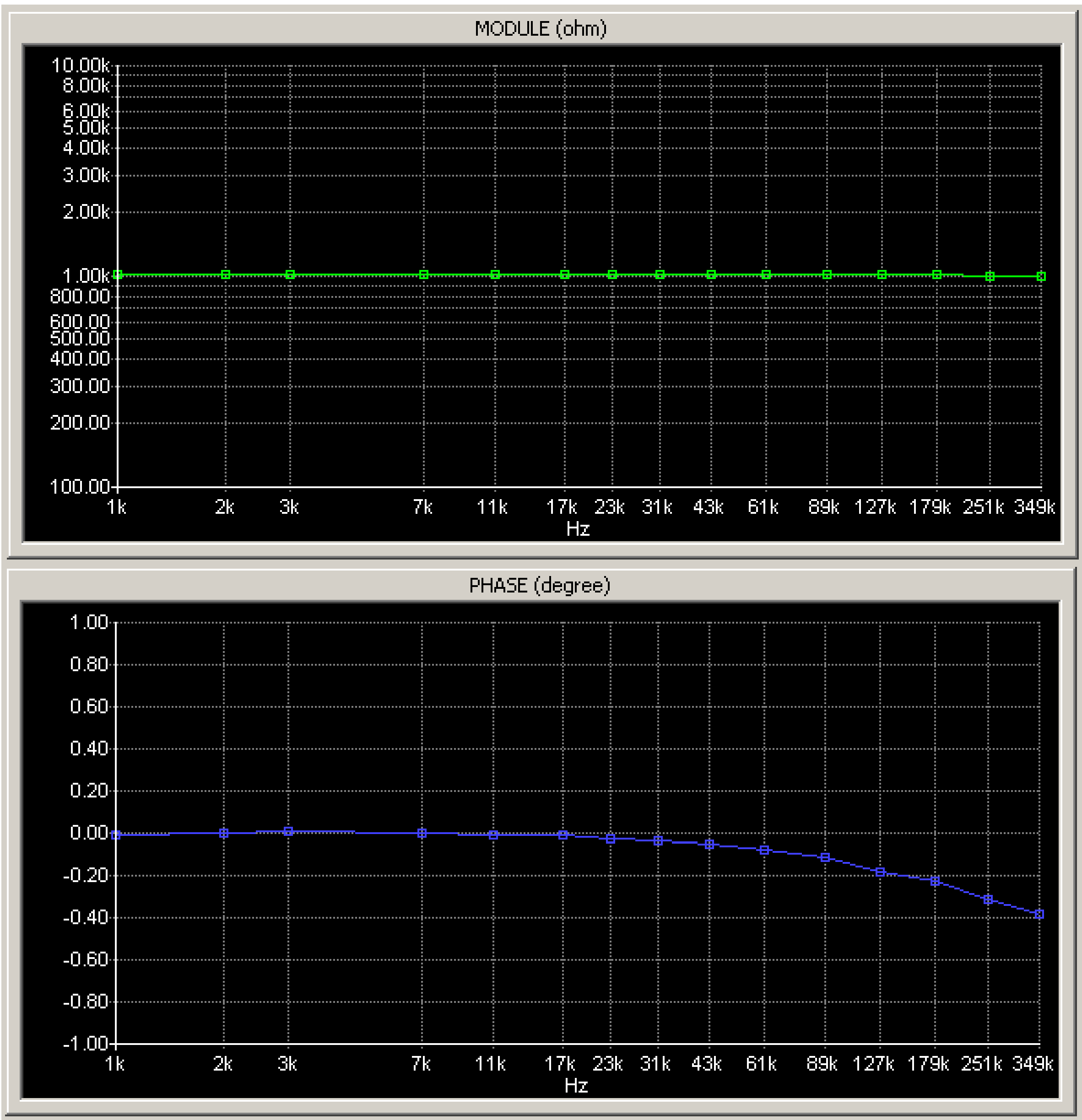
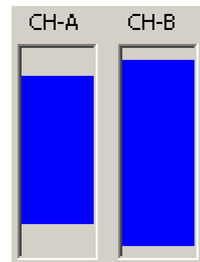


Figure 24 1 kΩ resistor impedance (button on the demo board is not pressed)

7. Press and hold down the button on the demo board to switch to the second impedance circuit.

8. Decrease excitation level from value 90 to 30 using *Excitation Level* track bar control in *Device Controls* group, refer to p. 19. Excitation level is correct if CH-B signal is not clipping (level indicator is not red) and ~90% of the level indicator is filled.

9. To add gain for input channel CH-A, use the *Gain CH-A* control in *Device Controls* group, refer to p. 20. From drop down menu select gain value of 2x and check if ~80% of CH-A level indicator is filled.



10. The measured impedance of the second circuit is similar to examples on Figure 25.

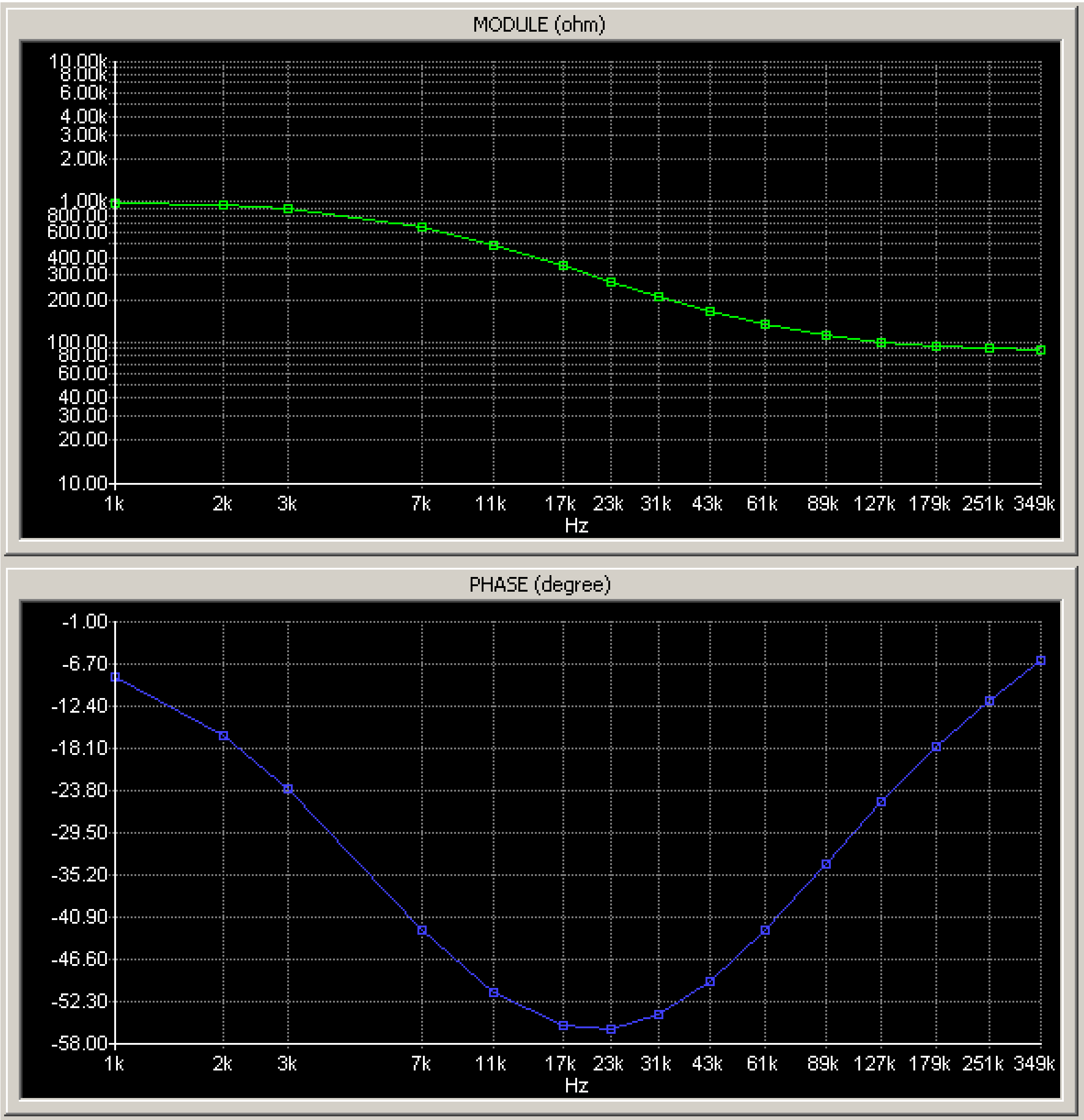


Figure 25 RC Circuit Impedance (button on the demo board is pressed)

Matlab Toolbox Application

Quadra software package includes Matlab MEX executable command line application that enables to send control commands and continuously capture receiving data from the device. This application handles control commands, error management and data buffering in independent thread. For 32-bit Matlab call *\Quadra Software Package v1.0\Matlab Toolbox\x86\PicometerControl.mexw32* and for 64-bit Matlab call *\Quadra Software Package v1.0\Matlab Toolbox\x64\PicometerControl.mexw64*.

The 32-bit version of this toolbox application is compiled with Matlab v7.5.0 (R2007b) with Microsoft Visual C++ 2005 and tested with Windows XP and above. The 64-bit version is compiled on Matlab v7.5.0 (R2007b) with Microsoft Visual C++ 2005 compiler and tested with Windows XP and above.

Using Matlab Toolbox Application

This toolbox application has common command line interface to send control commands to the device and to capture receiving data. For all the commands, the common Matlab function is *PicometerControl* that must have first input string format argument for command and one or more input-output arguments to exchange data and commands. On the Matlab command line the interface access call is similar to regular Matlab function call:

```
[RET1, RET2, ...] = PicometerControl('COMMAND', ARG2, ARG3, ...)
```

To run the toolbox application, the user must have *PicometerControl.mexw64* or *PicometerControl.mexw32* copied to active workspace directory.

Toolbox commands

COMMAND	DESCRIPTION	ARG2	ARG3	RET1	RET2
Connect	Matlab toolbox software initializes data buffers and USB port. After the USB initialization the device serial number and device status string are acquired and printed out.[1]	-	-	-	-
GetDevInfo	This command returns the device's serial number, hardware and software version numbers with status data. Sending this command will automatically clear all internal error flags.	-		String array: "Device[0] S/N:_BLANK_ HW:v1.00 SW:v1.2 CRC:3AE8 BATTERY:4224mV ST:0 ERR:0000" Device[#] - device index number at the USB bus, S/N:######### - device serial	

			number, HW:v#.## - device hardware version number, SW:v#.# - device embedded software version number, CRC:#### - embedded software image CRC checksum, BATTERY:####mV - integrated battery voltage level, ST:# - battery charger unit status code where value 0 indicates that battery is full, value 2 indicates that battery is charging and value 4 indicates battery fault. ERR:#### - Internal error flags, where every set bit fields indicates error: Bit0: Value 1 indicates that some of the received control command was unknown or execution failed because of incorrect arguments. Bit1: Value 1 indicates that during active measurement the impedance data buffer overflowed causing data lost. Bit2: Value 1 indicates that during impedance data calculations the numeric saturation was detected. Indicates software problem or incorrect configuration data. Bit3: Value 1 indicates error within data acquisition driver software. Bit4: Value 1 indicates for I2C bus communication error. Bit5: Value 1 indicates that device requires service. Bit6-Bit15 Reserved.
GetConfData	This command retrieves current device configuration data from the device memory. The data includes number of frequencies in spectra, frequency bin values, shunt impedance complex values and compensation complex values.	-	4 variable structure: FrequencyCount: [1 uint16] - Number of used frequencies, FrequencyBins: [15x1 uint16] - Numeric array of frequency bins - to get frequency value use: (FrequencyBins(n) * 1000) / SamplingrateDivider, ShuntComplexValues: [15x1 single[2]] - Shunt impedance complex values, CompensationComplexValues: [15x1 single] - Input compensation impedance complex values.
GetShuntData	This command retrieves shunt complex values from attached analog front-end and interpolates the shunt values according to the used frequency range. When shunt values have acquired, then send	Double[2] array of 1x15 frequency values in units of Hz. The same frequency values must be selected that the device is using, for that calculate frequencies accordingly: (FrequencyBins(n) * 1000) / SamplingrateDivider.	Double[2] complex array of 1x15 shunt impedance values.

	'SetShuntVal' command to load these values to device memory.				
Start	This command sets device to active measurement mode. In this mode the user application must send 'GetData' command within 100 ms period when 100 spectra are acquired to avoid data lost.	-	-	-	-
Stop	Command sets device to idle operating mode. When switching to this mode the user application should suspend sending the 'GetData' command.	-	-	-	
GetData	This command must be sent only when device is in active measurement mode. This command retrieves specified count of impedance spectra data along with additional measurement status data. All the data is stored as structure array. To avoid data loss this command must be sent periodically within the period before the internal data buffer starts to overflow. The internal buffer length is 500 impedance spectra while sampling rate divider is set to 1, that gives impedance acquisition period of 1 ms and buffer length of 500 ms. * For divider 2 the buffer length is 500 -> 1000 ms (single acquisition period of 2 ms). * For divider 1792 the buffer length is 500 -> 896000 ms (single acquisition period of 1792 ms).	Number of impedance spectra's to retrieve.		12 variable structure array of 100 impedance spectra's: SysErrors: [100x1 uint16] - Internal error flags, refer to ERR:#### in 'GetDevInfo' command return. MeasurementCycleCount: [100x1 uint32] - Impedance spectra count, if this number increment is more than one then it indicates data loss. MeasurementCyclePeriod: [100x1 uint32] - Internally measured single impedance spectra acquisition period in number of microseconds. MaxChA: [100x1 uint16] - CH-A maximum value, if value is 4095 then this measurement channel is clipping and impedance values are invalid. MinChA: [100x1 uint16] - CH-A minimum value, if value is 0 then this measurement channel is clipping and impedance values are invalid. axChB: [100x1 uint16] - CH-B maximum value, if value is 4095 then this measurement channel is clipping and impedance values are invalid. MinChB: [100x1 uint16] - CH-B minimum value, if value is 0 then this measurement channel is clipping and impedance values are invalid. ImpedanceModule: [100x15 single[2]] - Single array of impedance module values in ohms at all 15 frequencies from FrequencyBins(1) to FrequencyBins(15). ImpedancePhase: [100x15 single[2]] - Single array of impedance phase values in degree at all 15 frequencies from FrequencyBins(1) to FrequencyBins(15). BatteryLevel: [100x1 uint16] - Battery level	

				ChargerStatus: [100x1 uint16] - Battery charger status code, refer to ST:# in 'GetDevInfo' command return. GPIOState: [100x1 uint16] - Integer where three lower bit fields indicate the states of user GPIO's 1, 2 and 3. When bit 3 is set then GPIO 1 is in high state, bit 2 is set GPIO 2 is in high state and if bit 1 is set then GPIO 3 is in high state.	
SetGPIO	This command configures user GPIO's direction, sets or clears output GPIO state and at the same time it retrieves current GPIO's direction and states info.	Three lower bits of the value configure the user GPIO's directions: |X|X|X|X|X|GPIO-1-DIRECTION|GPIO-2-DIRECTION|GPIO-3-DIRECTION| GPIO-X-DIRECTION=1 Output GPIO GPIO-X-DIRECTION=0 Input GPIO	Three lower bits of the value configure the output user GPIO states: |X|X|X|X|X|GPIO-1-STATE|GPIO-2-STATE|GPIO-3-STATE| GPIO-X-STATE=1 GPIO is High GPIO-X-STATE=0 GPIO is Low	Three lower bits of returned byte indicate the user GPIO's direction configuration as described in ARG2.	Three lower bits of returned byte indicate the user GPIO's states as described in ARG3.
SetShuntVal	This command loads array of shunt impedance complex values to device memory where it will be used on impedance spectra calculations during active measurement mode.	Double[2] array of 1x15 shunt impedance complex values. Array values from index (1) to (15) must hold shunt impedance values for frequency points of FrequencyBins(1) to FrequencyBins(15).		-	
SetCompVal	This command loads array of input compensation impedance complex values to device memory where it will be used on compensation calculations (if enabled) during active measurement mode.	Double[2] array of 1x15 input compensation impedance complex values. Array values from index (1) to (15) must hold compensation impedance values for frequency points of FrequencyBins(1) to FrequencyBins(15).		-	
SetCompensation	Sending this command with two arguments enables or disables input impedance compensation calculations and enables to record measured impedance as input compensation impedance. WARNING - if ARG2 and ARG3 is set to 'On' then impedance values are invalid.	Expected string values are: 'On' - input impedance compensation calculations are enabled. 'Off' - input impedance compensation calculations are disabled.	Expected string values are: 'On' - measured impedance will be recorded in input compensation impedance table in device RAM. This method is an alternative to 'SetCompVal' command. 'Off' - input compensation impedance table recording is disabled.	-	

SetExcitationLevel	This command sets the output excitation level.	Value from 0 to 255 sets the excitation level. With the level value the output excitation can be adjusted between range of 0.4 Vpp to 7.5 Vpp with single step of 28 mV.		-	
SetInputGain	If the signal level of one of the measurement input channels is too low then this command can be used to add additional gain for specific channel.	To set channel A gain. Expected string values are: '1x' - No gain. '2x' - Gain of 2. '5x' - Gain of 5. '10x' - Gain of 10.	To set channel B gain. Expected string values are: '1x' - No gain. '2x' - Gain of 2. '5x' - Gain of 5. '10x' - Gain of 10	-	
SetExternalTrigger	This command enables to configures SYNC-IO to operate as input that can be used to switch device to active measurement mode when set high and to idle mode when set to low. WARNING - To disable external trigger send 'SetExternalTrigger' command with 'Off' argument only when SYNC-IO input is low, otherwise this command is ignored and flag 0 will be set in internal error flags.	Expected string values are: 'On' - Device can be set to active measurement mode from SYNC-IO input. 'Off' - Device can be set to active measurement mode with 'Start' command.		-	
SetBatterySupply	This command is sent to switch device power source between USB bus and battery power.	Expected string values are: 'On' - Switch device to battery supply. In this supply mode the PC USB supply and grounds are isolated from device. 'Off' - Switch device to USB bus supply. In this supply mode the depleted battery is charging.		-	
SetSamplingDivider	With this command the device internal sampling rate generator can be configured to generate lower sampling rate frequency that shifts the impedance spectra' to lower frequencies.	Sampling rate divider value. Expected values are: 1, 2, 4, 6, 8, 10, 12, 14, 16, 20, 24, 28, 32, 40, 48, 56, 64, 80, 96, 112, 128, 160, 192, 196, 224, 256, 320, 384, 448, 512, 640, 768, 896, 1024, 1280, 1536, 1792 Selecting another frequency divider will result in different frequency values on which the impedance spectra is measured, refer to page 51. Selecting any value greater than one will increase impedance spectra acquisition time by 1 ms × SamplingDividerValue.		-	
Disconnect	Matlab toolbox program releases device USB resources and clears internal control and data buffers.	-	-	-	-

[1] When device is successfully connected then the expected output on Matlab console is:

```
############################################################################
#                                                                          #
#   QUADRA(TM) Impedance Data Acquisition Toolbox v1.0 for 64-bit Matlab   #
#   Picometer series devices                                               #
#   (C) Copyright Eliko OÜ 2004 - 2016                                     #
#                                                                          #
############################################################################

    Picometer device USB connection initialized...
    Device[0] S/N:PM1512001
    HW:v1.00 SW:v1.2 CRC:3AE8 BATTERY:4224mV ST:0 ERR:0000
```

[2] This is numeric array format, where single means single precision 32-bit floating point numbers and double means double precision 64-bit floating point numbers.

Example Commands Implementation

To measure specified number of impedance spectra with Matlab script refer to example file at *\Quadra Software Package v1.0\Matlab Toolbox\Examples\ZRecord.m*.

To measure and plot impedance data continuously refer to Matlab GUI example script file at *\Quadra Software Package v1.0\Matlab Toolbox\Examples\ZReader.m*.

Frequencies Listing

Divider	Frequency (Hz)														
Value	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1000	2000	3000	7000	11000	17000	23000	31000	43000	61000	89000	127000	179000	251000	349000
2	500	1000	1500	3500	5500	8500	11500	15500	21500	30500	44500	63500	89500	125500	174500
4	250	500	750	1750	2750	4250	5750	7750	10750	15250	22250	31750	44750	62750	87250
6	166.666	333.333	500.000	1166.66	1833.33	2833.33	3833.33	5166.66	7166.66	10166.6	14833.3	21166.6	29833.3	41833.3	58166.6
8	125	250	375	875	1375	2125	2875	3875	5375	7625	11125	15875	22375	31375	43625
10	100	200	300	700	1100	1700	2300	3100	4300	6100	8900	12700	17900	25100	34900
12	83.3333	166.666	250.000	583.333	916.666	1416.66	1916.66	2583.33	3583.33	5083.33	7416.66	10583.3	14916.6	20916.6	29083.3
14	71.4285	142.857	214.285	500.000	785.714	1214.28	1642.85	2214.28	3071.42	4357.14	6357.14	9071.42	12785.7	17928.5	24928.5
16	62.5000	125.000	187.500	437.500	687.500	1062.50	1437.50	1937.50	2687.50	3812.50	5562.50	7937.50	11187.5	15687.5	21812.5
20	50	100	150	350	550	850	1150	1550	2150	3050	4450	6350	8950	12550	17450
24	41.6666	83.3333	125.000	291.666	458.333	708.333	958.333	1291.66	1791.66	2541.66	3708.33	5291.66	7458.33	10458.3	14541.6
28	35.7142	71.4285	107.142	250.000	392.857	607.142	821.428	1107.14	1535.71	2178.57	3178.57	4535.71	6392.85	8964.28	12464.2
32	31.2500	62.5000	93.7500	218.750	343.750	531.250	718.750	968.750	1343.75	1906.25	2781.25	3968.75	5593.75	7843.75	10906.25
40	25	50	75	175	275	425	575	775	1075	1525	2225	3175	4475	6275	8725
48	20.8333	41.6666	62.5000	145.833	229.166	354.166	479.166	645.833	895.833	1270.83	1854.16	2645.83	3729.16	5229.16	7270.83
56	17.8571	35.7142	53.5714	125.000	196.428	303.571	410.714	553.571	767.857	1089.28	1589.28	2267.85	3196.42	4482.14	6232.14
64	15.6250	31.2500	46.8750	109.375	171.875	265.625	359.375	484.375	671.875	953.125	1390.62	1984.37	2796.87	3921.87	5453.12
80	12.50	25.00	37.50	87.50	137.50	212.50	287.50	387.50	537.50	762.50	1112.50	1587.50	2237.50	3137.50	4362.50
96	10.4166	20.8333	31.2500	72.9166	114.583	177.083	239.583	322.916	447.916	635.416	927.083	1322.91	1864.58	2614.58	3635.41
112	8.92857	17.8571	26.7857	62.5000	98.2142	151.785	205.357	276.785	383.928	544.642	794.642	1133.92	1598.21	2241.07	3116.07
128	7.81250	15.6250	23.4375	54.6875	85.9375	132.812	179.687	242.187	335.937	476.562	695.312	992.187	1398.43	1960.93	2726.56
160	6.25	12.50	18.75	43.75	68.75	106.25	143.75	193.75	268.75	381.25	556.25	793.75	1118.75	1568.75	2181.25
192	5.20833	10.4166	15.6250	36.4583	57.2916	88.5416	119.791	161.458	223.958	317.708	463.541	661.458	932.291	1307.29	1817.70
196	5.10204	10.2040	15.3061	35.7142	56.1224	86.7346	117.346	158.163	219.387	311.224	454.081	647.959	913.265	1280.61	1780.61
224	4.46428	8.92857	13.3928	31.2500	49.1071	75.8928	102.678	138.392	191.964	272.321	397.321	566.964	799.107	1120.53	1558.03
256	3.90625	7.81250	11.7187	27.3437	42.9687	66.4062	89.8437	121.093	167.968	238.281	347.656	496.093	699.218	980.468	1363.28
320	3.12500	6.25000	9.37500	21.8750	34.3750	53.1250	71.8750	96.8750	134.375	190.625	278.125	396.875	559.375	784.375	1090.62
384	2.60416	5.20833	7.81250	18.2291	28.6458	44.2708	59.8958	80.7291	111.979	158.854	231.770	330.729	466.145	653.645	908.854
448	2.23214	4.46428	6.69642	15.6250	24.5535	37.9464	51.3392	69.1964	95.9821	136.160	198.660	283.482	399.553	560.267	779.017
512	1.95312	3.90625	5.85937	13.6718	21.4843	33.2031	44.9218	60.5468	83.9843	119.140	173.828	248.046	349.609	490.234	681.640
640	1.56250	3.12500	4.68750	10.9375	17.1875	26.5625	35.9375	48.4375	67.1875	95.3125	139.062	198.437	279.687	392.187	545.312
768	1.30208	2.60416	3.90625	9.11458	14.3229	22.1354	29.9479	40.3645	55.9895	79.4270	115.885	165.364	233.072	326.822	454.427
896	1.11607	2.23214	3.34821	7.81250	12.2767	18.9732	25.6696	34.5982	47.9910	68.0803	99.3303	141.741	199.776	280.133	389.508
1024	0.97656	1.95312	2.92968	6.83593	10.7421	16.6015	22.4609	30.2734	41.9921	59.5703	86.9140	124.023	174.804	245.117	340.820
1280	0.78125	1.56250	2.34375	5.46875	8.59375	13.2812	17.9687	24.2187	33.5937	47.6562	69.5312	99.2187	139.843	196.093	272.656
1536	0.65104	1.30208	1.95312	4.55729	7.16145	11.0677	14.9739	20.1822	27.9947	39.7135	57.9427	82.6822	116.536	163.411	227.213
1792	0.55803	1.11607	1.67410	3.90625	6.13839	9.48660	12.8348	17.2991	23.9955	34.0401	49.6651	70.8705	99.8883	140.066	194.754

NOTES

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Indoor use only.

Do not dispose, contains battery element.

Read the user manual completely and carefully for proper use.

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