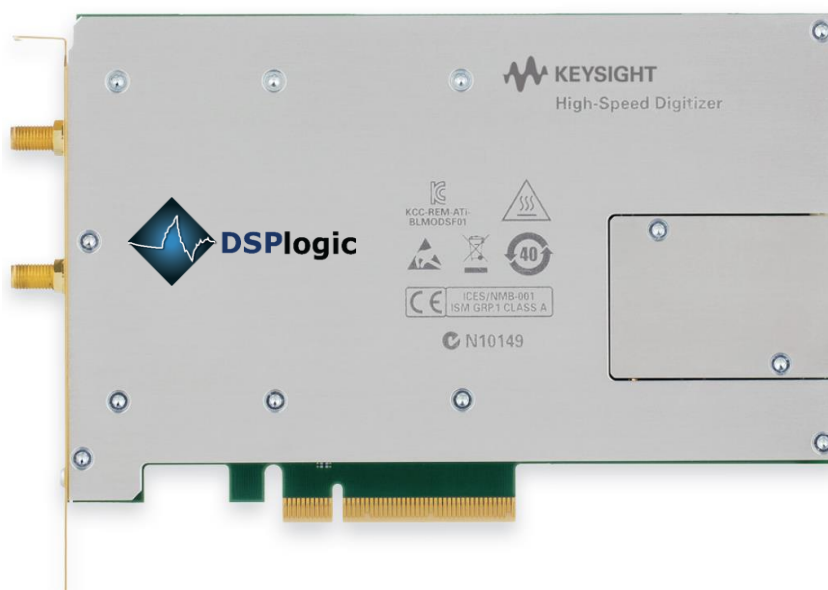




Wideband FFT Spectrometer

User Guide



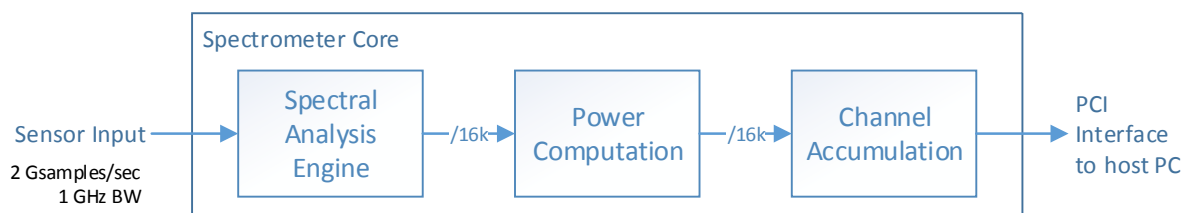
DSPlogic Inside



DSPlogic Innovation in a Keysight Quality Instrument

About Your Instrument

The Wideband FFT Spectrometer utilizes a custom “SpectroCore” hardware processor designed by DSPlogic to extract precise frequency information from the input signal in real-time.



The SpectroCore processor is hosted on the Keysight U5303a Digitizer that provides high quality analog-to-digital conversion and robust, portable drivers that allow an application to communicate with the SpectroCore processor through a high-speed PCI interface.

The U5303A host is configured with the following options:

Option	Description
DGT	Digitizer firmware
M02	256 MB (64 MSamples/ch) Acquisition memory
FDK	Custom firmware capability
INT	2 GS/s Interleaved channel sampling functionality
SR1	1 GS/s Sample rate
F10	Full Bandwidth

The spectrometer operates in interleaved mode with an input frequency range of DC to 1.3 GHz (typical). The input frequency range can be limited to 600 MHz using the on-board filter.

Getting Started

This section describes the steps required to install the host platform and enable the SpectroCore Processor.

Host Platform Startup

The U5303a host should be installed and verified following the manufacturer's instructions, as described in the "Startup Guide: Keysight U5303A PCIe High-Speed Digitizer," [1] which can be downloaded from

- <http://literature.cdn.keysight.com/litweb/pdf/U5303-90001.pdf>

These steps include:

1. Unpack and inspect the module
2. Install software, including:
 - a. Keysight IO Libraries Suite
 - i. www.keysight.com/find/IOsuite
 - b. Keysight MD2 High-Speed Digitizer Instrument Drivers
3. Install U5303a in a PC chassis
4. Verify operation of the U5303a

SpectroCore Installation

The SpectroCore custom real-time hardware processor core is enabled by loading the SpectroCore bit file into the Keysight host platform. The SpectroCore bit file is located in the PySpectro Demonstration Software distribution:

- `/pyspectro/bit/U5303ADPULX2FDK_uhsffts_32k_float_1_0_229.bit`

In order for the Keysight MD2 drivers to locate the SpectroCore, this file must be copied into one of the following folders, depending on which driver is being used:

- Windows 32-bit: `C:\Program Files (x86)\IVI Foundation\IVI\Drivers\AgMD2\Firmware`
- Windows 64-bit: `C:\Program Files\IVI Foundation\IVI\Drivers\AgMD2\Firmware`

SpectroCore API Reference

Communication with the instrument is done using Keysight's MD2 IVI-COM and IVI-C drivers that work in the most popular development environments including Python, Visual C/C++, C#, VB.NET, MATLAB, and LabVIEW. Please refer to Keysight's "AgMD2 IVI Driver Reference" [2] (installed during Keysight software installation) for detailed information on the driver API.

The MD2 drivers provide memory-mapped access to the SpectroCore configuration/status registers and the on-board DDR memory used to store the accumulated power measurements.

Enabling the SpectroCore

To connect to the instrument and enable the SpectroCore, use the `AGMD2 IIVIdriver.Initialize()` method. When calling this method, the `DriverSetup` option string must contain the `UserDpuA` flag, e.g.:

- `DriverSetup=UserDpuA=<SpectroCore Filename>.bit`

where `<SpectroCore Filename>` is the name of the *.bit file located in the `AgMD2\Firmware` directory.

The `IIVIdriver.Initialize()` method returns a driver object that can be used to interact with the instrument using the `Agilent.AgMD2.Interop.AgMD2Ex3` interface.

Important: After connecting to the instrument, the `IAGMD2Acquisition.Mode` property must be set to `AgMD2AcquisitionModeUserFDK (0xF)`. As when changing any instrument settings, the `IAGMD2Acquisition.ApplySetup()` method must be called prior to initiating an acquisition.

Communicating with the SpectroCore

The SpectroCore API provides two interfaces: Measurement Control (SMCI) and Measurement Data (SMDI).

The Measurement Control and Measurement Data interfaces are accessed through the `AgMD2Ex3` instrument interfaces, including the following:

- `IAGMD2Acquisition`
- `IAGMD2AcquisitionUserControl`
- `IAGMD2Calibration`
- `IAGMD2Channels`
- `IAGMD2LogicDevices`

Details of the Measurement Control and Measurement Data interfaces are provided in the following sections. The PySpectro software also demonstrates a complete software implementation of the SpectroCore processor interface.

SpectroCore Measurement Control Interface

The SpectroCore Measurement Control Interface (SMCI) consists of a set of control and status registers located on the “DPUA” logic device found on the host platform. The `IAGMD2LogicDevice` interface must be queried to obtain the `IAGMD2LogicDevice` object corresponding to the DPUA device. This object is used to access the SpectroCore registers using the following methods:

- `IAGMD2LogicDevice.ReadRegisterInt32()`
- `IAGMD2LogicDevice.WriteRegisterInt32()`

In addition, the SMCI uses the `IAGMD2Calibration` and `IAGMD2AcquisitionUserControl` interfaces.

The following table identifies the registers that compose the SMCI.

Table 1 SpectroCore Measurement Control Interface – Memory map

Register Name	Register ID	Type	Offset
Main control	main_control	R/W	0x3300
Main status	main_status	R	0x3304
Measurement window	num_average	R/W	0x3308
Measurement count	msrmnt_count	R	0x330C

Instrument Calibration

Prior to acquiring any measurements, the instrument must be calibrated in accordance with manufacturer specifications using the `selfCalibrate()` method of the `AgMD2Calibration` interface.

Measurement Acquisition

A measurement acquisition is initiated using the `startProcessing()` method of the `IAGMD2AcquisitionUserControl` interface. The `ProcessingType` flag must be set to 0x1. Other processing types are ignored by the SpectroCore processor.

Two types of acquisitions are supported: one-shot measurement and continuous measurement. The type of measurement that is initiated depends on the `continuous_mode` field in the Main Control Register.

Acquisition status is provided by the Measurement Count register. The measurement count equals zero after the beginning of each acquisition, and is incremented at the completion of each measurement.

The `IAGMD2AcquisitionUserControl.StopProcessing()` method must be called to stop an acquisition. It must be called with the same `ProcessingType` flag (0x1) as the start command. In single-shot mode, the `StopProcessing()` method must be called after the single measurement is complete prior to starting a new acquisition. In continuous mode, the `StopProcessing()` method can be called at any time to stop the SpectroCore from writing new measurements to acquisition memory.

Main Control Register

The main control register is composed of the fields shown in Table 2. This register should not be modified during an acquisition.

Table 2 SMCI: Main control register fields

Field	Data type	# Bits	Bit range	Description
continuous_mode	Bool	1	[0:0]	0 = Single-shot mode 1 = Continuous mode
disable_polyphase	Bool	1	[1:1]	0 = Polyphase filter algorithm enabled 1 = Polyphase filter algorithm disabled
reset	Bool	1	[31:31]	1 = Reset SpectroCore 0 = Remove SpectroCore from reset

Main Status Register

The Main status register is composed of the fields shown in Table 3. The occurrence of a memory indicates that both software and the PySpectro core tried to access acquisition memory at the same time. (See Section “Memory Sharing” for additional information.)

Table 3 SMCI: Main status register fields

Field	Data type	# Bits	Bit range	Description
memory_error	Unsigned	8	[7:0]	0 = No measurement memory error 1 = Measurement memory error occurred

Measurement Window Register

The measurement window register is composed of the fields shown in Table 4. This register determines the number of 32-kFFT results to accumulate in the SpectroCore.

The length of the measurement window, and the resulting measurement update period is

$$T_{msr} \text{ (seconds)} = (num_averages_m1 + 1) * 32768 / 2.0e9.$$

Table 4 SMCI: Measurement window register fields

Field	Data type	# Bits	Bit range	Description
num_averages_m1	Unsigned	32	[31:0]	Number of FFTs to accumulate minus one.

Measurement Count Register

The measurement count register indicates the number of measurements that have occurred since the last StartProcessing command. This register can be read at any time during a continuous-mode acquisition.

Table 5 SMCI: Measurement Count Registers

Field	Data type	# Bits	Bit range	Description
msrmnt_count	Unsigned	32	[31:0]	Number of measurements that have occurred since the last StartProcessing command.

SpectroCore Measurement Data Interface

The SpectroCore Measurement Data Interface (SMDI) provides access to measurement data stored in memory onboard the host U5303a. This section describes how read measurement data from the SpectroCore processor. The PySpectro demonstration software also demonstrates usage of this interface.

Memory Sharing

On the U5303a, access to acquisition memory is time-shared between the SpectroCore processor and software access through PCI, as shown in Figure 1. The SpectroCore requires exclusive access to memory for approximately one FFT window (16.4 us) during each measurement accumulation window. In continuous mode, the SpectroCore processor performs this write access at regular intervals of $N \times 16.4$ microseconds, where N is the number of FFTs accumulated, resulting in a small duty cycle for any significant number of accumulations. The SpectroCore is capable of internally accumulating millions of FFTs, minimizing interface throughput requirements.

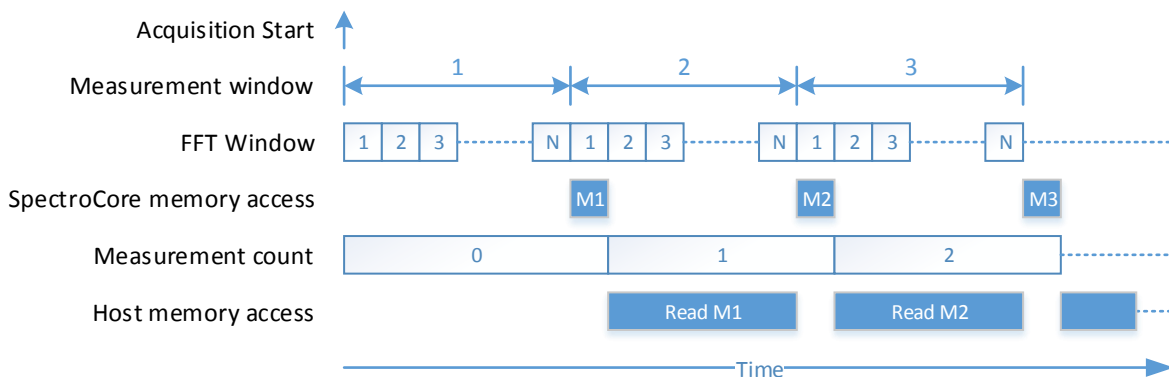


Figure 1: Acquisition memory - shared access timing.

In continuous mode, time sharing can be performed by software polling of the Measurement Count register. Whenever a new measurement is detected, software should take control of acquisition memory, read the measurement results, then return control to the SpectroCore processor prior to the next SpectroCore write interval. If the SpectroCore tries to access memory and is blocked by software, a `memory_error` will be raised in the main status register.

In continuous mode, the minimum number of accumulations achievable without memory access conflict depends on the capabilities of the user software, the OS under which it runs, and the performance of the PCI interface.

There are two memory banks connected to the DPUA IAgMD2LogicDevice, identified as “DDR3A” and “DDR3B”. To access DDR memory controls, the use DPUA’s IAgMD2LogicDeviceMemoryBanks interface to obtain a IAgMD2LogicDeviceMemoryBank reference for each of the “DDR3A” and “DDR3B” memory banks.

To arbitrate memory access, software must set the AccessMode property of the IAgMD2LogicDeviceMemoryBank interface in accordance with the following table. DDR3A and DDR3B are arbitrated independently.

Table 6 SMDI: DDR Memory IAgMD2LogicDeviceMemoryBank.AccessMode property

Field	Data type	# Bits	Bit range	Description
AccessMode	Unsigned	32	[31:0]	0x00000000: SpectroCore has access to memory. Software should not access memory over PCI. 0x00000001: Software has access to memory over PCI. SpectroCore cannot write measurements to memory.

Reading Measurement Data

When the measurement count indicates that a new measurement is available, and software has taken control of acquisition memory (DDR3A or DDR3B), the measurement can be read using the ReadIndirectInt32() method of the IAgMD2LogicDevice interface for DPUA.

In order to perform spectral measurements efficiently, the SpectroCore processor writes the measurement results to both acquisition memory banks (DDR3A and DDR3B) in the order in which they are computed. Therefore, after reading from DDR3A and DDR3B, the data must be rearranged to put the spectral measurements in normal frequency order.

A total of 16,384 channels (FFT bins) are available for each measurement. Half are stored in DDR3A and other half in DDR3B. To read all channels, two calls to the ReadIndirectInt32() method are required, with arguments set as follows:

- Id (Integer) = BUFFER_ID (from Table 7)
- StartAddress (Integer) = 0
- NumElements (Long) = 8192

Table 7 SMDI: BUFFER_ID for DDR Access using ReadIndirectInt32()

DDR Bank	BUFFER_ID
DDRA	28
DDRB	30

The measurements are stored in acquisition memory using single-precision floating point format. Although the result of the ReadIndirectInt32() method vector of 32-bit integers, the contents must be re-interpreted (without changing the stored value) as 32-bit floating-point.

The mapping to rearrange memory contents to FFT bins is fixed and should be mapped to a table to optimize performance. Please refer to the PySpectro software documentation for details on the memory to FFT bin mapping.

PySpectro Demonstration Software

The PySpectro Demonstration Software illustrates the use of the SpectroCore processor as hosted on the Keysight U5303a digitizer. PySpectro consists of the following three components:

- Spectrometer Driver
- PySpectro Core Application
- PySpectro GUI

The Spectrometer Driver is a low-level implementation of the SMCI and SMDI interfaces described in this document. The PySpectro Core is a high performance, multi-threaded spectral measurement acquisition and logging application. It can be used programmatically, or can be controlled through the PySpectro Graphical User Interface.

PySpectro is written in Python with well documented source-code. It has been tested on Windows 32 and 64 bit platforms, but should also work on other platforms supported by the Anaconda Python distribution.

PySpectro Core Application

The PySpectro Core application is a high performance, multi-threaded spectral measurement acquisition and logging application that interfaces with the Wideband FFT Spectrometer.

The PySpectro Core (`pyspectro.applib.core.PySpectroCore`) class provides non-blocking interfaces to manage instrument connections, control acquisition and log data. An event interface can be used to monitor data transfers and changes in instrument state. User callbacks are also supported for data processing, state change handling and 1 PPS heartbeat processing. Supporting classes for the PySpectro Core include:

- Instrument connection management
 - `pyspectro.applib.connection.ConnectionManager`
- Acquisition control
 - `pyspectro.applib.acq_control.AcquisitionControlInterface`
- Data logging
 - `pyspectro.applib.datalogger.SpectrumDataLogger`

The PySpectro Core can be accessed directly from Python code or may be controlled by the GUI.

PySpectro GUI

The PySpectro GUI provides a convenient way to get started collecting measurements from the Wideband Spectrometer. It uses the PySpectro Core to interact with the instrument and provides the following features:

- Connection management
- Spectral Display
 - Power vs. Frequency display
 - Zoom, pan, and select data points during continuous acquisition
 - Highlight frequency bin using mouse to display bin power
 - Auto-scale
 - Units in dBm, dB-FS, or FS (raw)
- Acquisition Control
 - Start/Stop Acquisition
 - Single-shot or continuous mode
 - Acquisition window duration setting (in seconds or number of FFT averages)
 - Algorithm selection (FFT or Polyphase Filter Bank)
- Input Settings
 - Full scale input range (FSR) adjustment
 - Input voltage offset adjustment
 - Enable bandwidth limiting filter (600 MHz)
- HDF5 Measurement Data Logging
 - Stores measurement data in HDF5 format
 - Supports both one-shot and continuous acquisitions.
 - Continuously log measurements during continuous acquisitions (Limited to first N measurements of each acquisition).
- Calibration
 - Initiate instrument calibration
 - Calibration required notification
- Acquisition monitoring
 - Board and ADC temperatures
 - Number of acquisitions (total for instrument session)
 - Number of measurements (current acquisition)
 - Dropped measurement detection

An example screenshot of the PySpectro GUI is shown in Figure 2. The spectral display shows a measurement of a 20 MHz sine wave input using the Polyphase Filter Bank (PFB) algorithm.

Figure 3 shows the measurement using the FFT algorithm, demonstrating the superiority of the PFB.

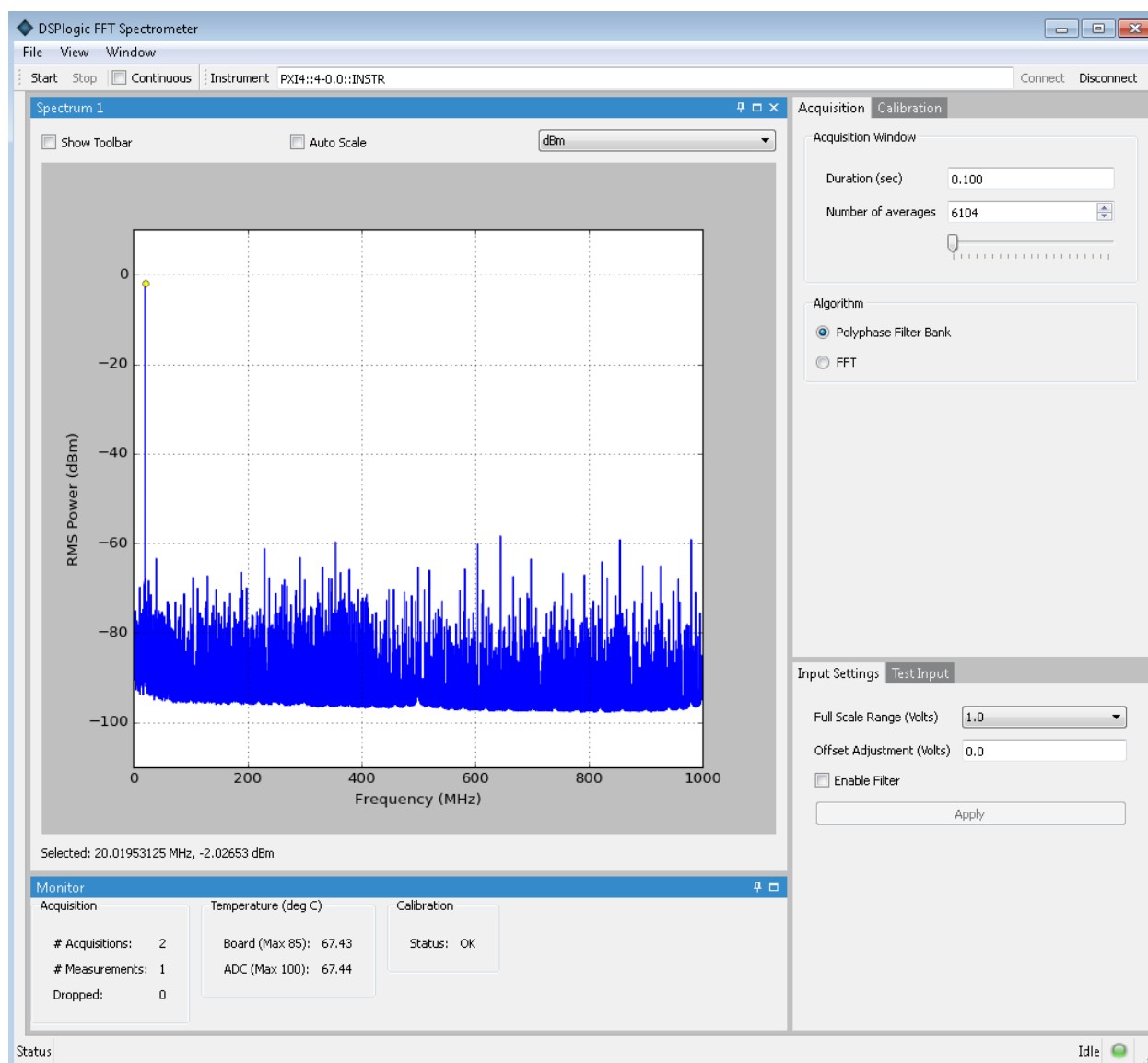


Figure 2 PySpectro GUI

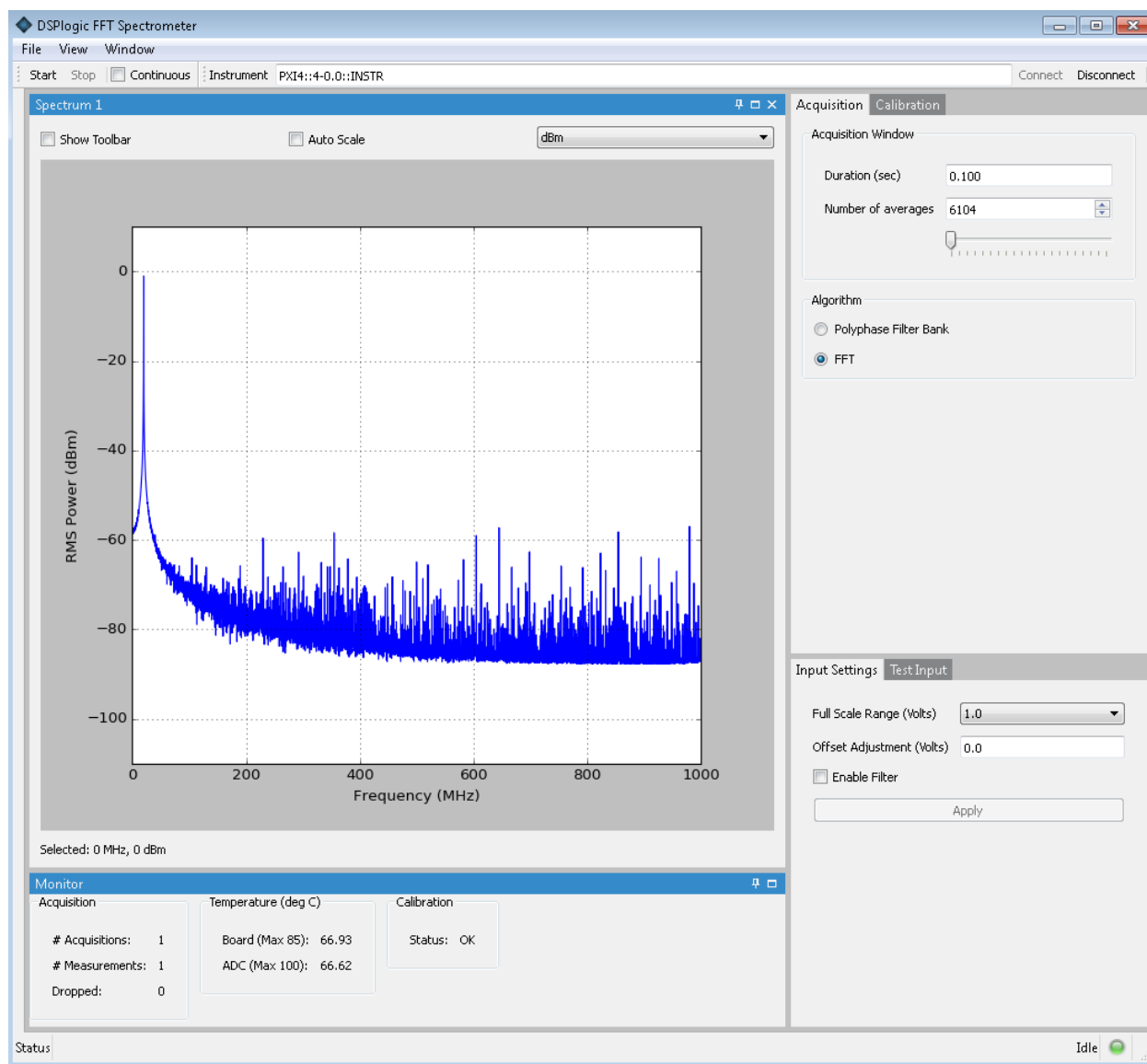


Figure 3 Pyspectro GUI (FFT Algorithm)

PySpectro Installation

The PySpectro installation wizard automatically installs the PySpectro Demonstration Software, including the prerequisite Python interpreter and all required python packages. The Python interpreter is a local installation dedicated to PySpectro to avoid conflicts with other versions of Python that may already be installed. The wizard is also designed to work without an internet connection

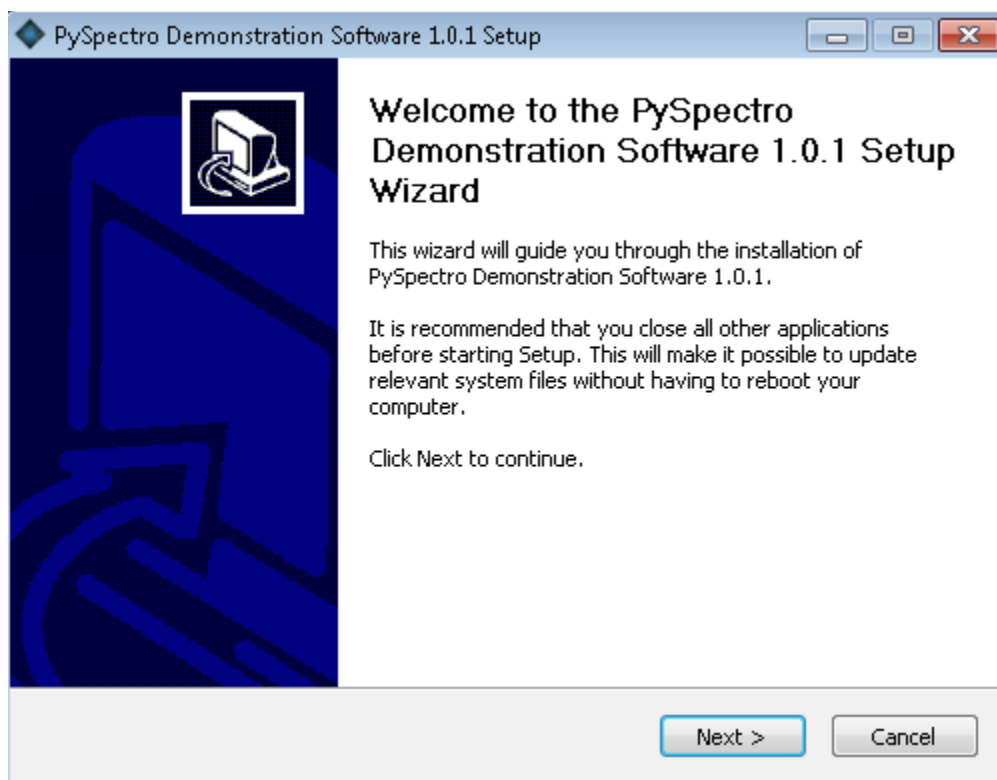
Important: The Keysight IO Library Suite and MD2 drivers must be installed prior to running the PySpectro installation wizard executable. These packages are also included in the DVD, as shown in the following table. After installing the Keysight IO Library Suite and MD2 drivers, verify their operation and instrument communications using the Keysight SFP program.

Table 8 – PySpectro Software DVD Contents

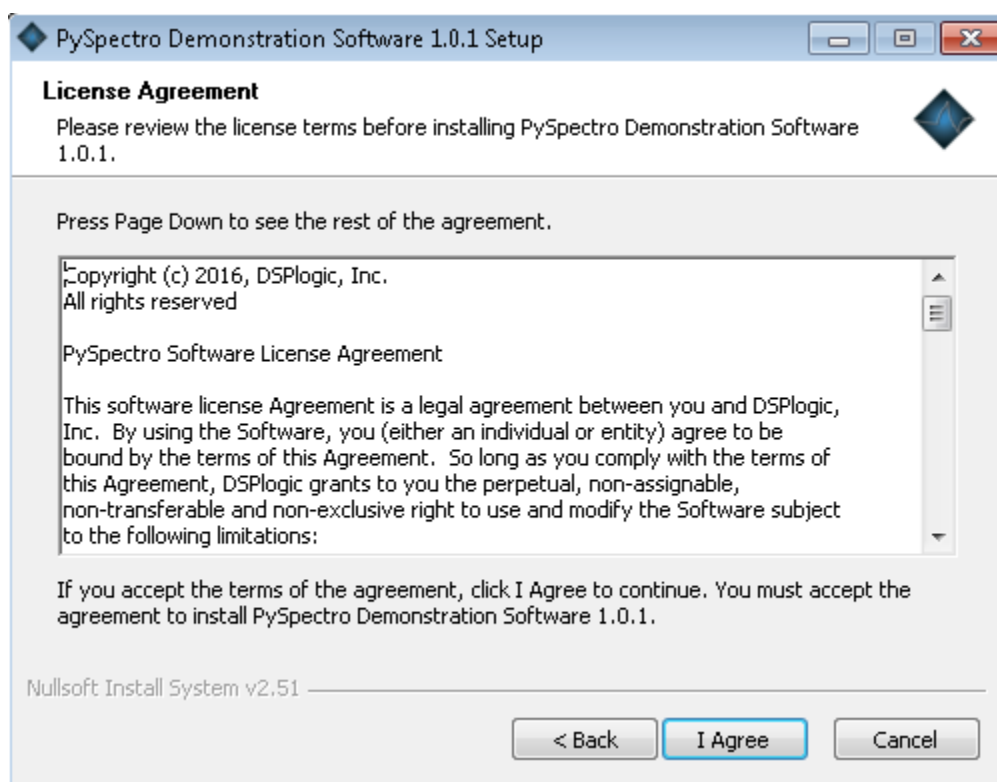
Package	Description
IOLibSuite_17_2_20818_0.exe	Installer for Keysight IO Libraries Suite
MD2_Software_CD_1.12.6	Installer for Keysight MD2 Drivers
PySpectro_1.0.1.exe	Installer for PySpectro Demonstration software

PySpectro Installation Wizard

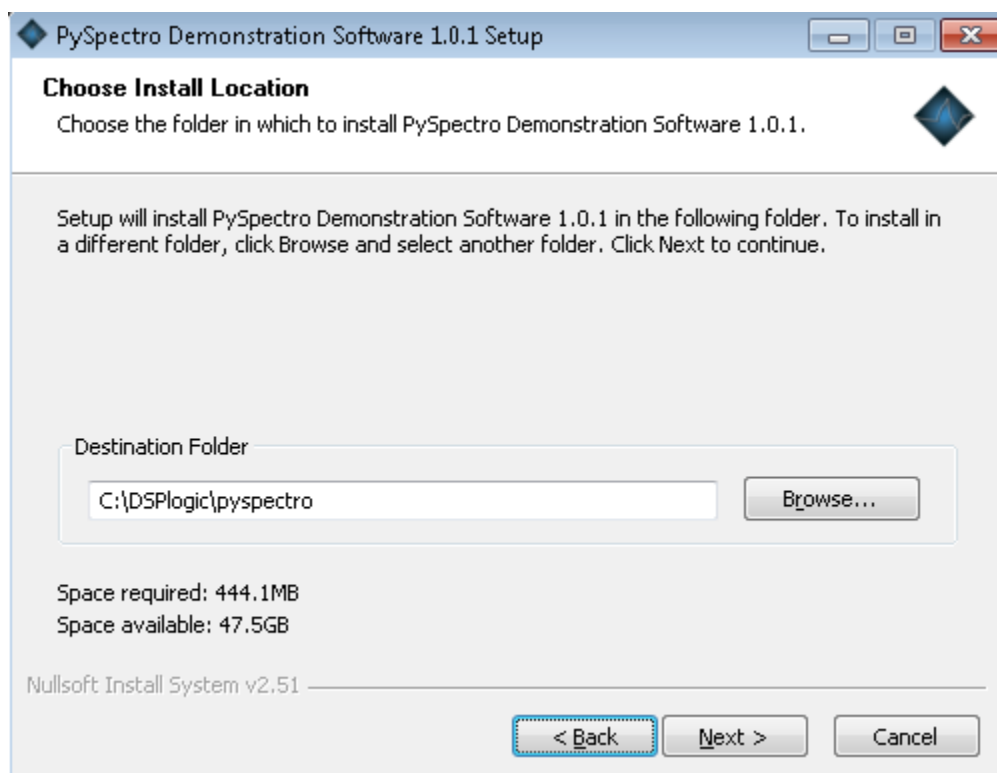
1. Run PySpectro_1.0.1.exe, click “Next”



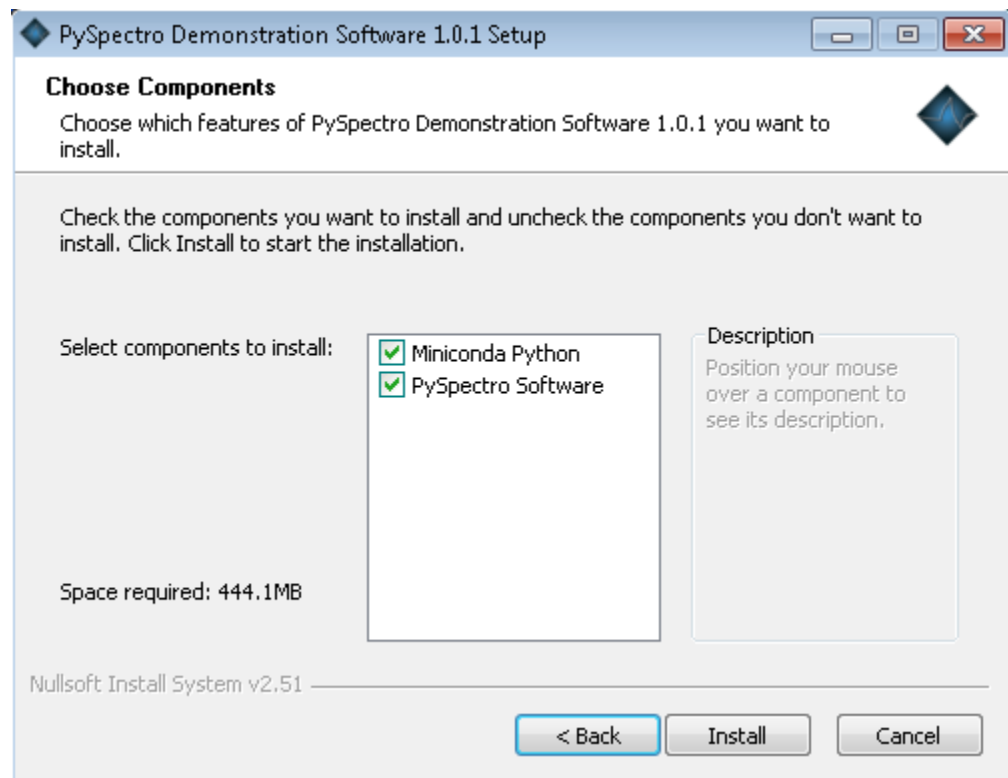
2. Review and accept the licensing agreement



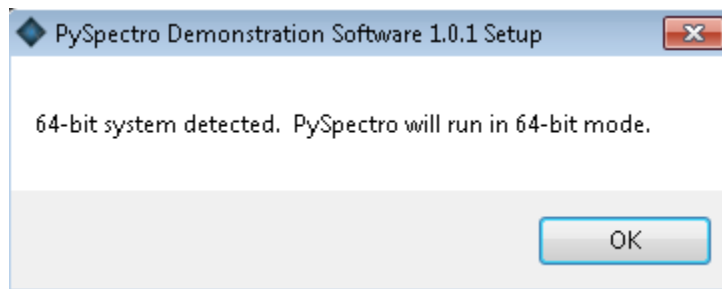
3. Select the destination folder, click Next



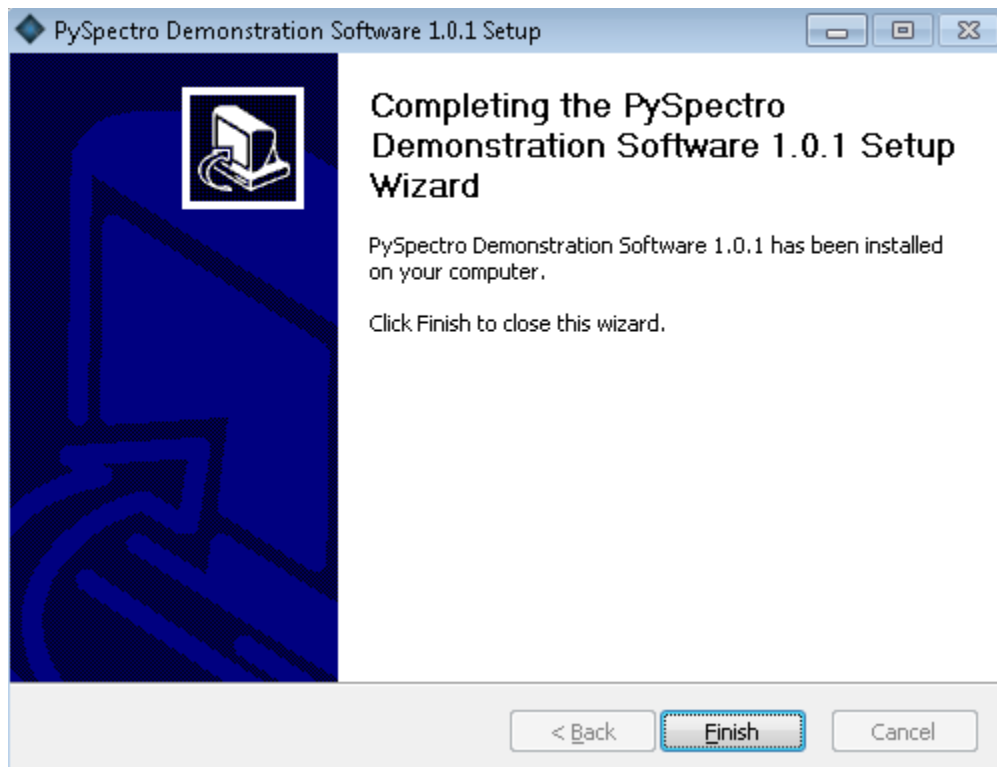
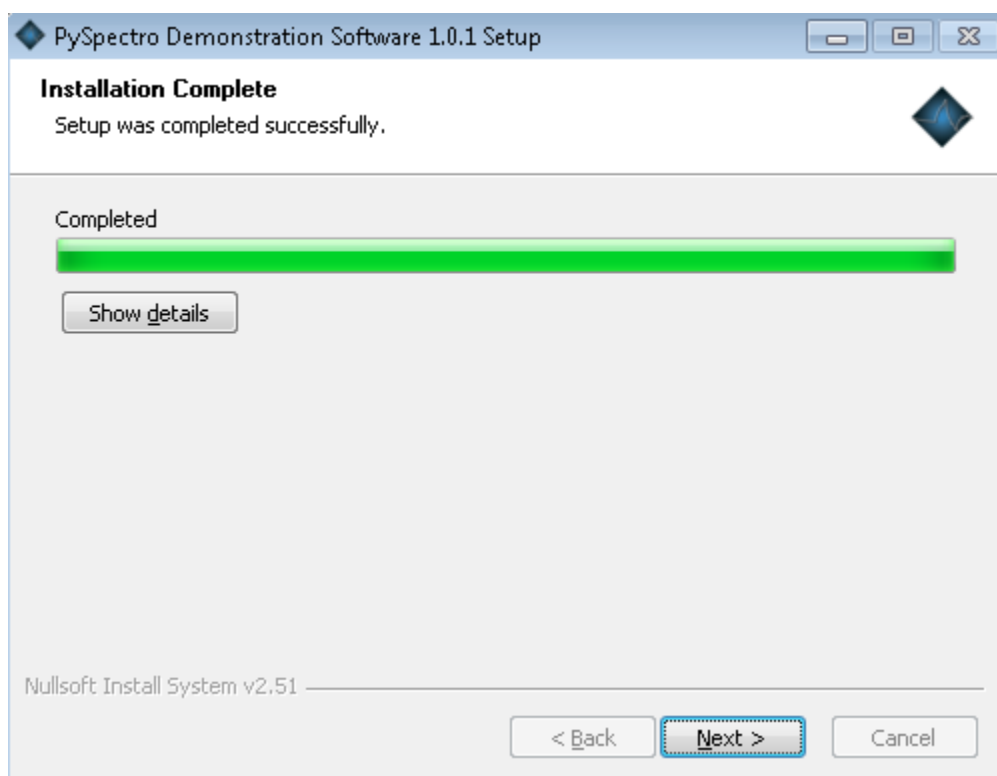
4. Select components to install (**Be sure to select all components**) and click Next



5. The Wizard will automatically detect whether to install the 32-bit or 64-bit version, click OK.



6. Wait for the installation to complete, click Next, then Finish

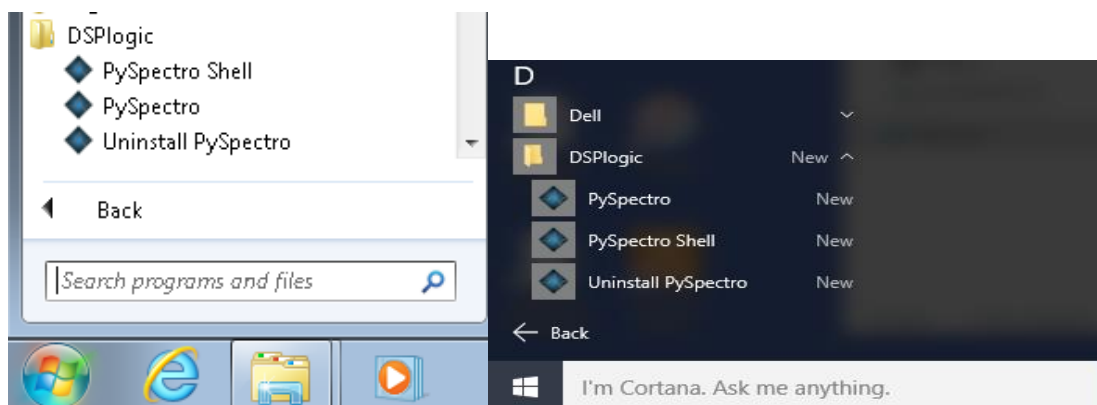


Running the PySpectro software

To run PySpectro GUI, use the Start Menu item:

- Start Menu > DSPlogic > PySpectro

as shown in the following figure (left: Windows 7, right: Windows 10)



In addition, the PySpectro software package can be accessed directly from the Python interpreter. To simplify this process, the “PySpectro Shell” menu item will open a command window and configure it for use with PySpectro.

```
python
C:\DSPlogic\pyspectro>C:\Windows\system32\cmd.exe "/K" "C:\DSPlogic\pyspectro\python\Scripts\activate.bat" "C:\DSPlogic\pyspectro\python"
Activating environment "C:\DSPlogic\pyspectro\python"...

[python] C:\DSPlogic\pyspectro>python
Python 2.7.11 |Continuum Analytics, Inc.| (default, Feb 16 2016, 09:58:36) [MSC
v.1500 64 bit (AMD64)] on win32
Type "help", "copyright", "credits" or "license" for more information.
Anaconda is brought to you by Continuum Analytics.
Please check out: http://continuum.io/thanks and https://anaconda.org
>>> import pyspectro
>>> pyspectro.__version__
'1.0.1'
>>>
```

References

1. Keysight Technologies, Inc., “Startup Guide: Keysight U5303A PCIe High-Speed Digitizer,” <http://literature.cdn.keysight.com/litweb/pdf/U5303-90001.pdf>
2. Keysight Technologies, Inc., “AgMD2 IVI Driver Reference,” Compiled help file, installed with AgMD2 drivers.