



# NMR Precision Teslameter PT2026

## User's Manual

Version 1.3

(Revision 1.0)

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## REVISION HISTORY

v. 1.0 r. 1.0	August 2015	First release
v. 1.1 r. 1.0	January 2016	Mention MFC API coding example Update definition of *IDN? output Add warning about NMR signal averaging Explain effect of NMR pulse parameters Add description of back panel Update specifications Miscellaneous editorial changes
v. 1.2 r. 1.0	March 2016	Change description for new recording file format API is now in LabVIEW 2015 SP1 format
v. 1.3 r. 1.0	June 2016	Add description of “Probe Info” button Update installation procedure for signed installer Fix numbering of help bullets

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# **GETTING STARTED**

## **1-Introduction**

The Precision Teslameter PT2026 is a magnetometer, used to very precisely measure the flux density (“field strength”) of strong magnetic fields.

The PT2026 relies on Nuclear Magnetic Resonance (NMR) as measurement technique. NMR is unique in magnetometry due to its unrivalled precision and accuracy, and practically total lack of drift.<sup>1</sup> For these reasons, NMR magnetometers are widely used as a secondary magnetic-field standard, serving as reference to calibrate other magnetometers. They are also routinely used in scientific and industrial applications that need to measure, map, monitor or regulate magnetic fields with extreme precision.

It is important to note that NMR magnetometry also has limitations. Most importantly, the magnetic field gradients in the volume to be measured must be close to zero. In addition, NMR is best suited for measuring strong magnetic fields. Finally, NMR is a relatively slow measurement technique.

The contents of this manual are as follows:

- Chapter 2- “Quick Start Guide” and Chapter 3- “Overview” provide information to get started;
- Chapter 4- “Software User Interface” explains how to use the software;
- Chapter 5- “LabVIEW Instrument Driver” and Chapter 6- “Host Interfaces” explain how to write instrument control software;
- Chapter 7- “Key Specifications” lists the key instrument characteristics; and
- Chapter 8- “NMR Magnetometers” provides technical background information on NMR magnetometers.

Updates to the software and instrument firmware are posted on the Metrolab website, [www.metrolab.com](http://www.metrolab.com), and can be downloaded free of charge. The firmware in the PT2026 Main Unit can be upgraded in the field. The easiest way to

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<sup>1</sup> See Chapter 7-Key Specifications for details.

be notified of updates is to sign up for our electronic newsletter, on the News page of our site.

We hope the PT2026 will help you perform your magnetic field measurements easily and accurately. If you have problems and your reseller cannot help you further, the Metrolab team is ready to help. Even if you don't have problems, we are always interested in knowing more about how our instruments are used. Feel free to contact us at any time at [contacts@metrolab.com](mailto:contacts@metrolab.com).

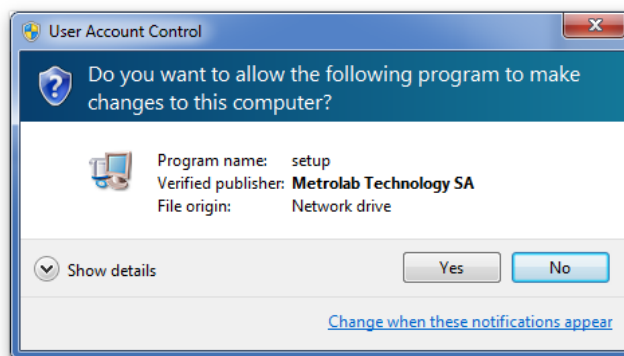


# GETTING STARTED

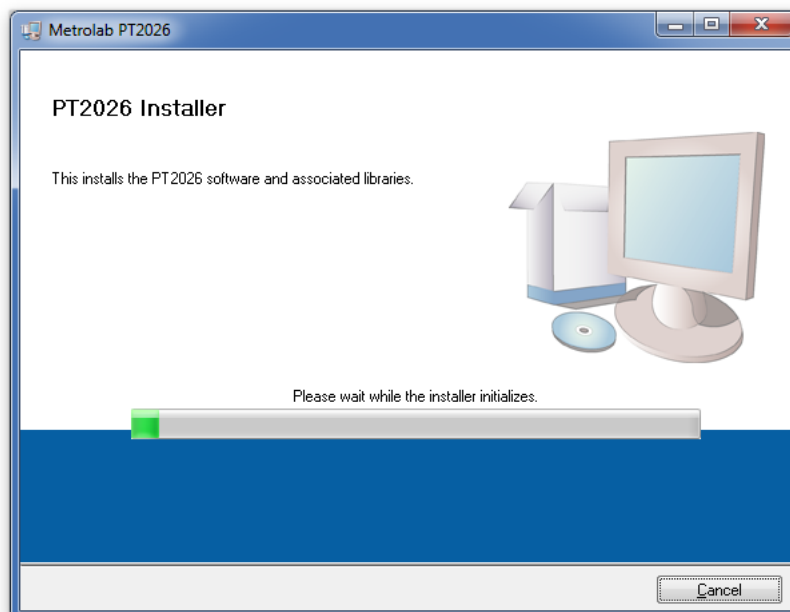
## 2-Quick Start Guide

### 2-1 SOFTWARE INSTALLATION – WINDOWS

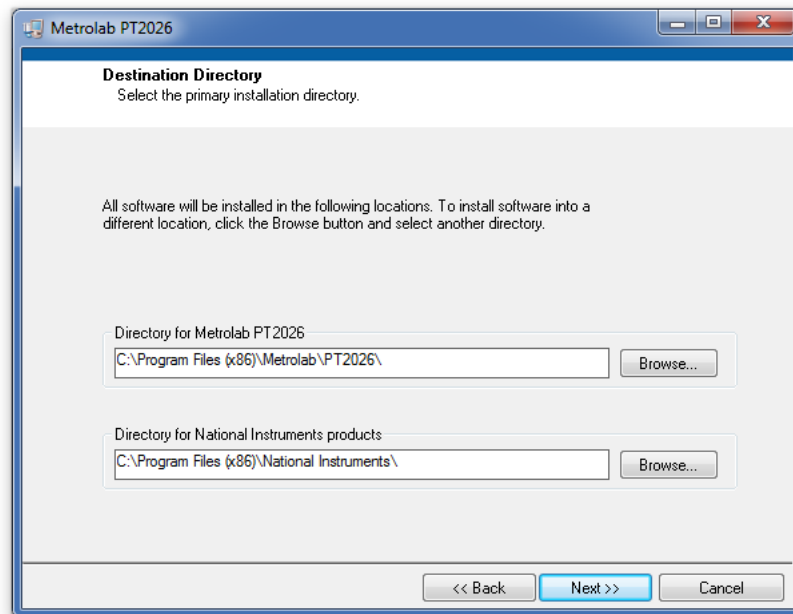
- Insert the installation CD.
- Execute the PT2026 installation program:  
\\Metrolab PT2026 Windows Installer\setup.exe
- Windows will display a security alert. Allow the installation program to execute by clicking “Yes”:



- You should briefly see the installation program's splash screen:

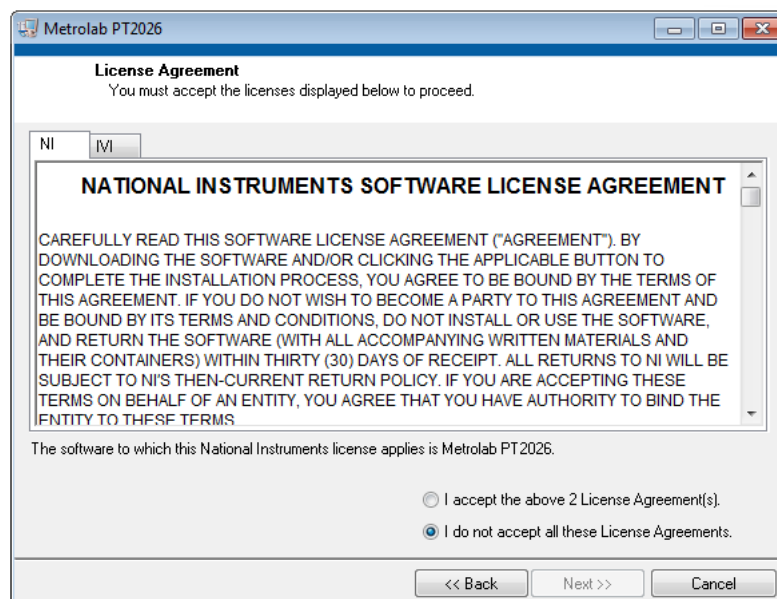


followed by a screen proposing destination directories for the Metrolab software and National Instruments components:

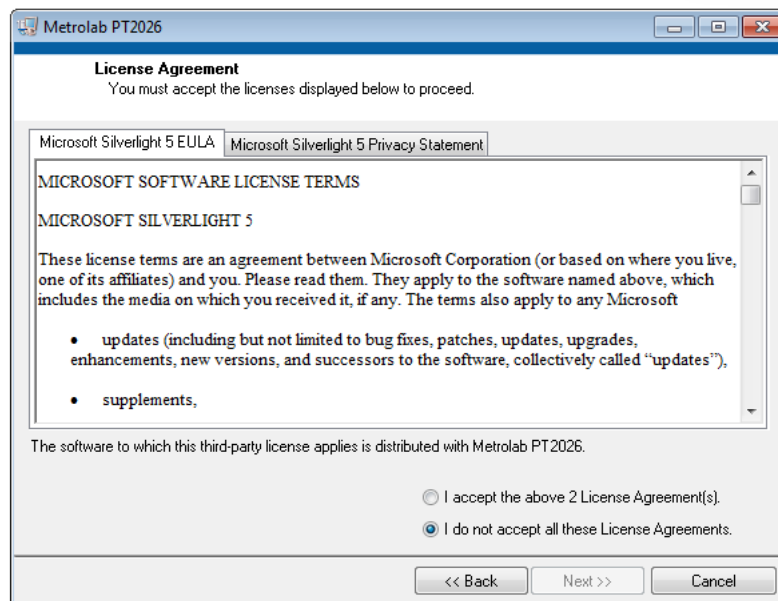


Normally you should accept the defaults. Click “Next”.

- You will now see a screen with license agreements for the National Instruments components:

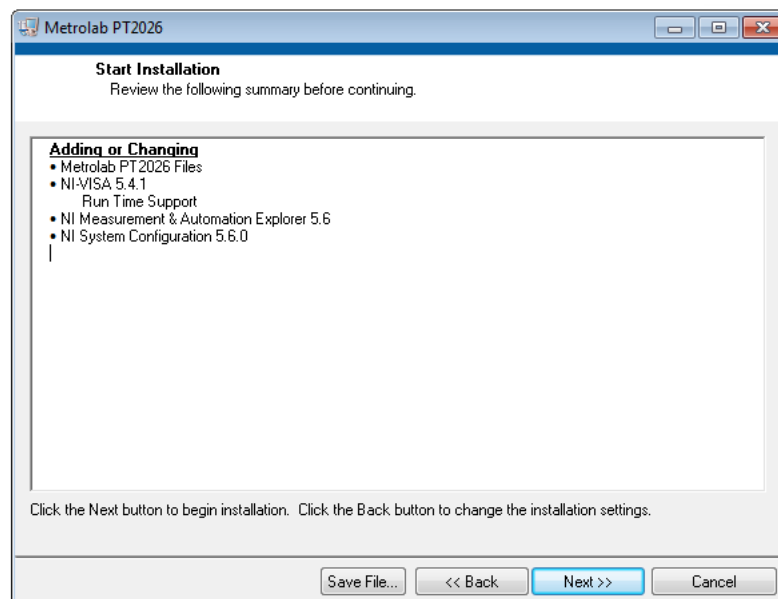


Ticking the “I accept...” check box will enable the “Next” button. Click “Next” to display a screen with license agreements for the Microsoft Silverlight component:

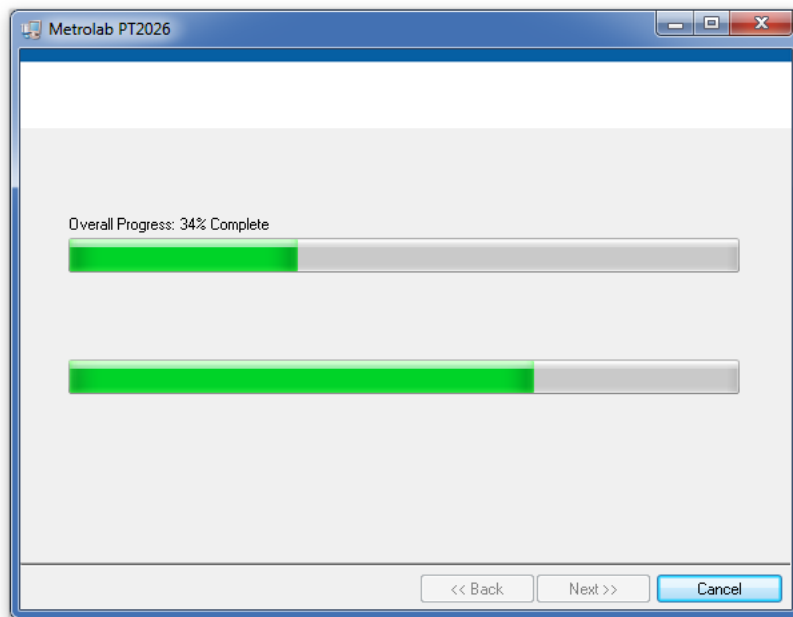


Once again, ticking the “I accept...” check box will enable the “Next” button.  
Click “Next”.

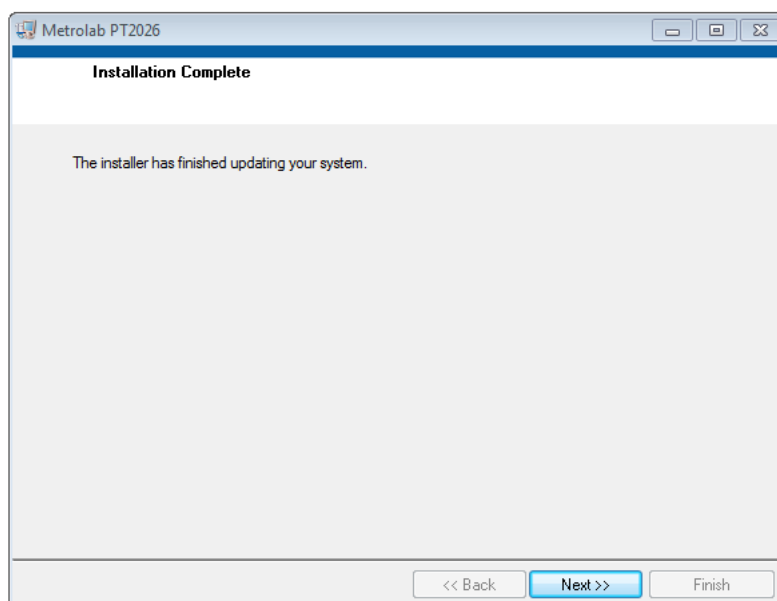
- You will now see the installation summary:



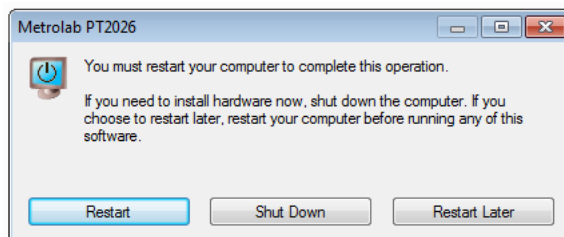
- Click “Next” to start the installation:



- The installation should complete normally. Click “Next”.



- You must now restart your computer:



## 2-2 BASIC HARDWARE INSTALLATION

- Plug the probe, power, and USB cables into the back panel. If you intend to use the Ethernet interface, also plug in an Ethernet cable:



For details on the back panel, please see Section 7-1, “Back Panel”.

- Plug the PT2026 power plug into a wall socket, the USB cable into your computer, and (optionally) the Ethernet cable into an Ethernet switch connected to your network.



### CAUTION

- ⇒ Make sure you have performed the software installation (see Section 2-1) before powering on the PT2026.
- ⇒ Treat the probe connectors with care. They have very tight tolerances, and crushing them, or even dropping them on the floor, may deform the shell, making it difficult or impossible to plug in the probe.
- ⇒ When plugging in the probe, make sure the connector is perfectly aligned with the socket; otherwise it will jam.
- ⇒ To unplug the probe, you must grasp the sleeve and pull straight back to release the locking mechanism.
- ⇒ To unplug the female plug of the Probe-Extension / MUX cable from a MUX6026 multiplexer, press the ring at the base of the socket to release the locking mechanism.

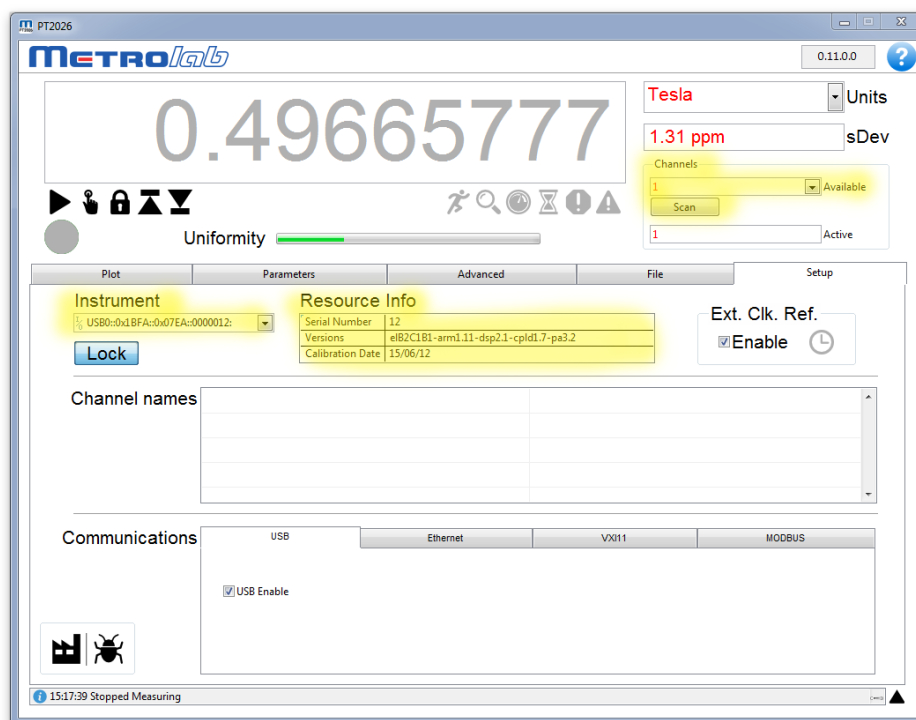
## 2-3 START-UP

- Power on the PT2026 by pressing the power switch on the front or rear panel (the two are equivalent). If the PT2026 does not power up, try holding the power button a little longer.
- Start the PT2026 software from the Windows Start Menu:  
Metrolab > PT2026 > Metrolab PT2026
- Place the probe in your magnet:

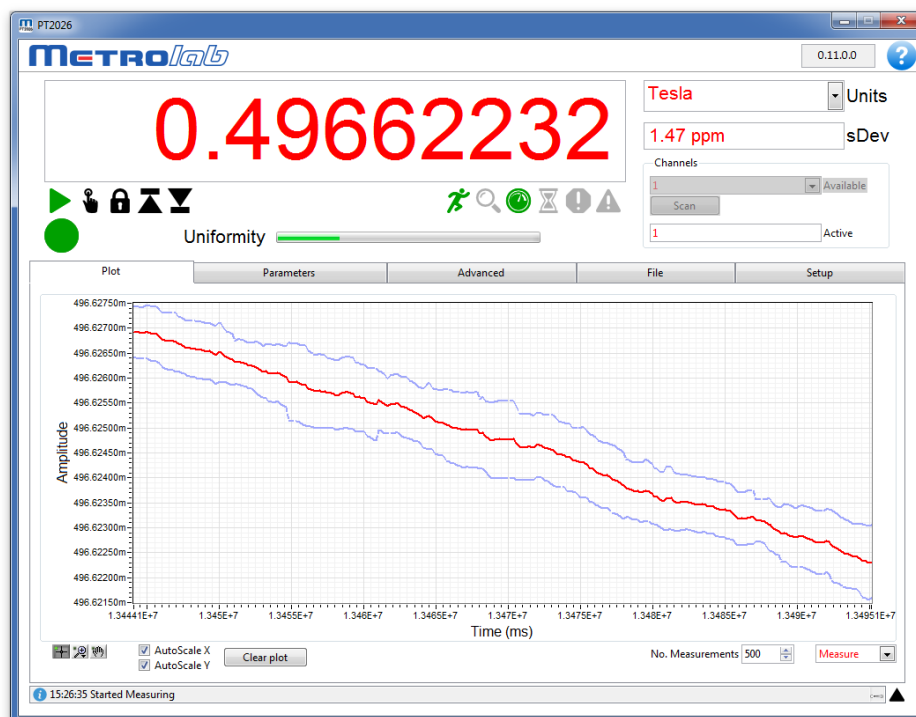


- In the PT2026 software window, click on the “Setup” tab to select the corresponding screen. With the Instrument pull-down menu, select the VISA resource name that corresponds to your PT2026. This name should look something like “USB0::0x1BFA::0x07EA::xxxxxxx::INSTR”, where “xxxxxxx” represents the serial number written on the back panel of your instrument. Verify that the software has been able to connect to your

PT2026, and that the PT2026 has been able to connect to your probe:

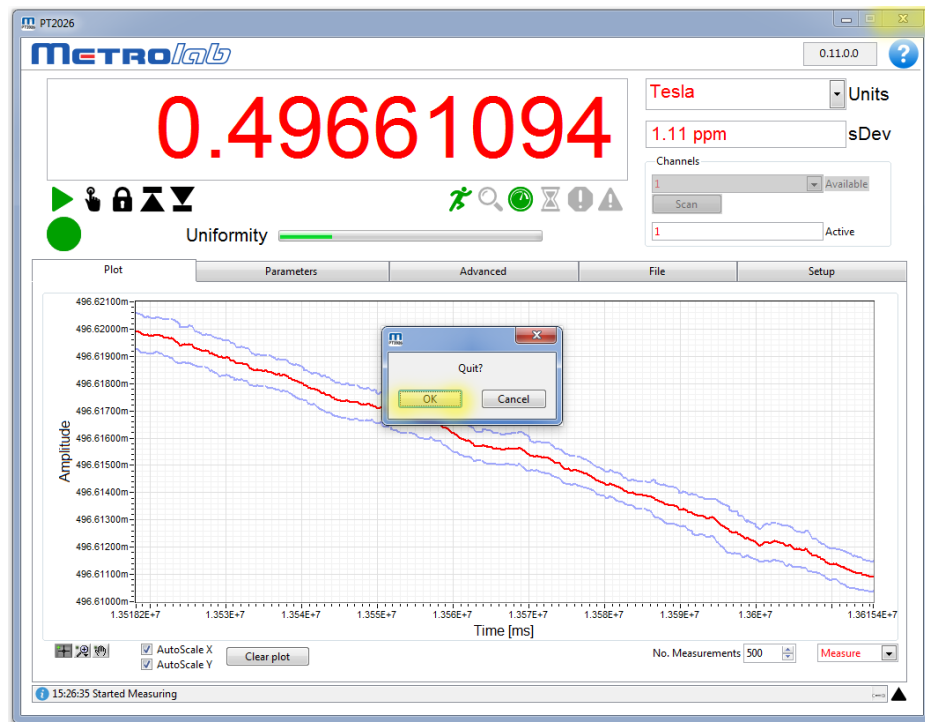


- Using the corresponding tab, return to the Plot screen and click the Measure arrow. The Search Progress bar should show the probe range being swept, searching for the NMR resonance, until your magnetic field value is reached and the instrument starts measuring:



## 2-4 SHUT-DOWN

- To stop the software, close the PT2026 window and confirm the “Quit?” dialog:



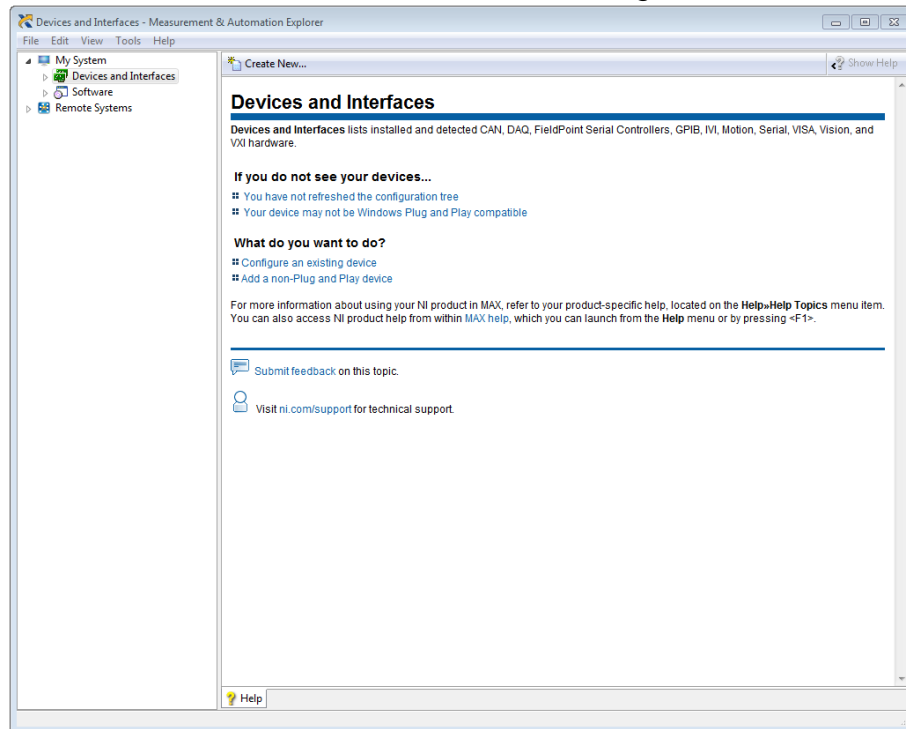
- Power off the PT2026 by pressing the power switch on the front or rear panel (the two are equivalent).

## 2-5 CONNECT VIA ETHERNET

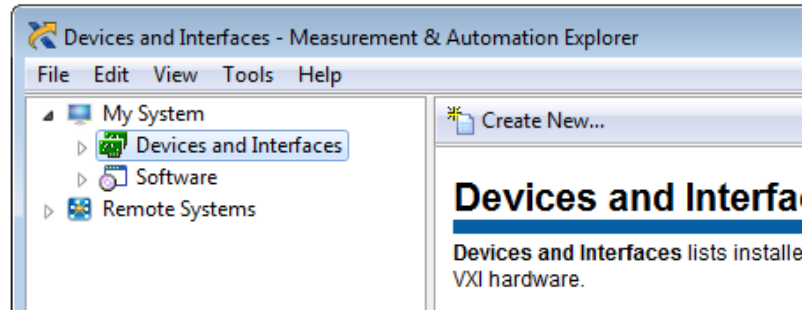
To connect to the PT2026 via Ethernet, you must first create a network instrument entry for the PT2026 in the VISA database. Use the National Instruments utility, “Measurement & Automation Explorer” (MAX) to do this:



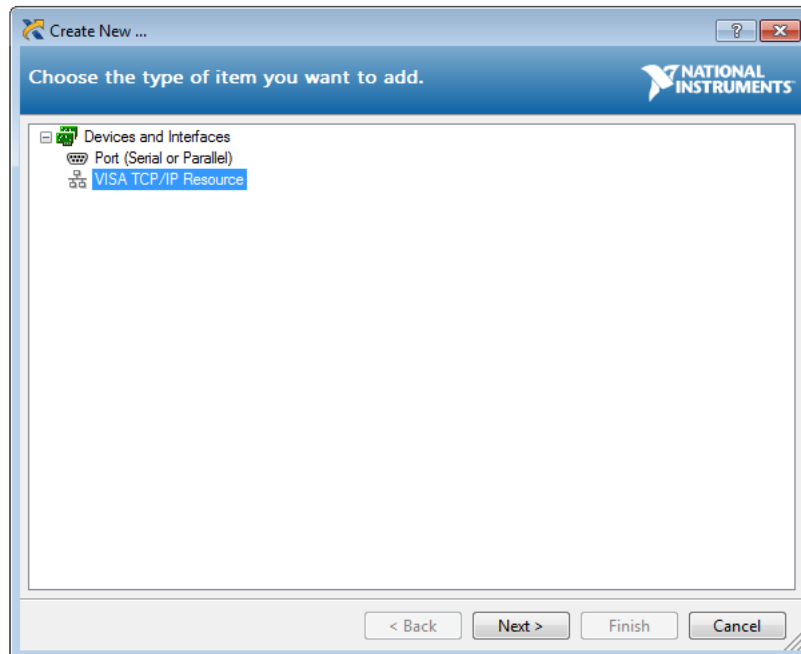
- Launch MAX: Windows Start Menu > All Programs > NI MAX:



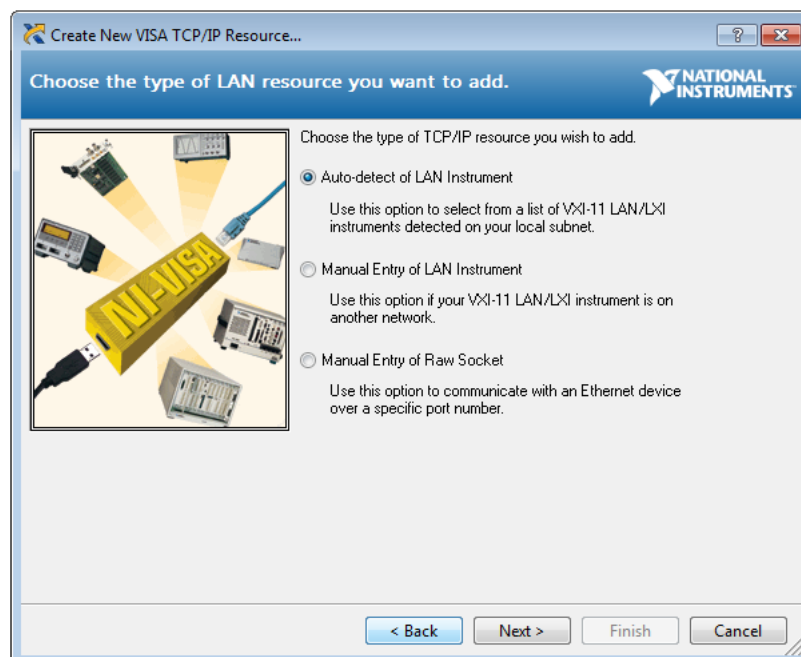
- Select “System > Devices and Interfaces” in the left-hand column, and click on “Create New...”:



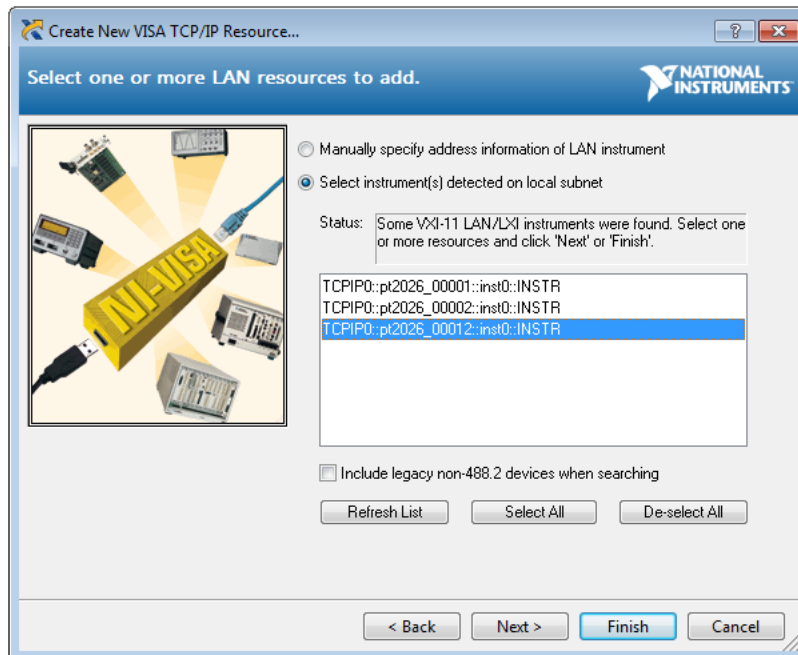
- In the resulting dialogue window, select “VISA TCP/IP Resource” and click “Next”:



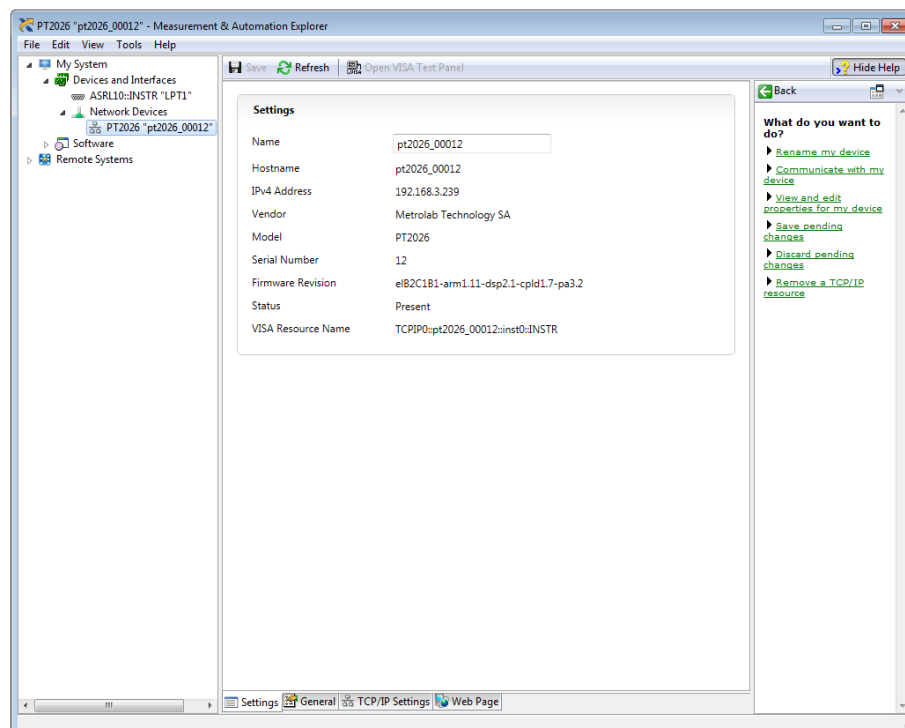
- In the subsequent dialogue, Select “Auto-detect of LAN Instrument” and click “Next”:



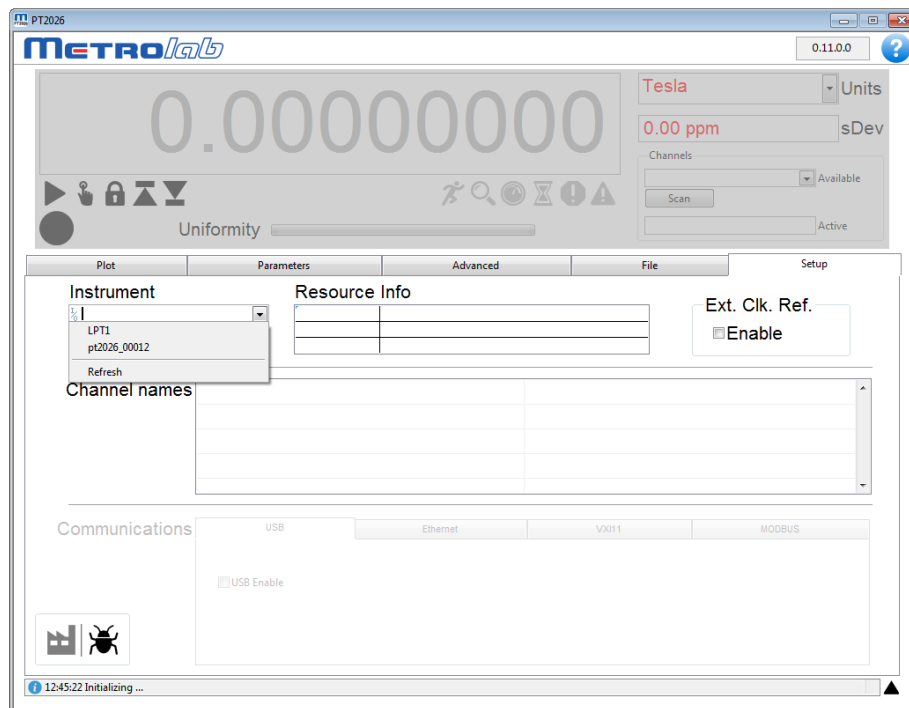
- In the last dialogue, select the entry that corresponds to your PT2026, and click “Finish”:



- In the main MAX window, if you expand the item “Devices and Interfaces”, then the subjacent item “Network Devices”, you will now see an entry for your PT2026. Click on the entry to reveal the Settings panel for your PT2026 network device:



- Now, in the Setup panel of the PT2026 software, if you click on the Instrument pull-down menu, you will see the entry for your PT2026 network device:



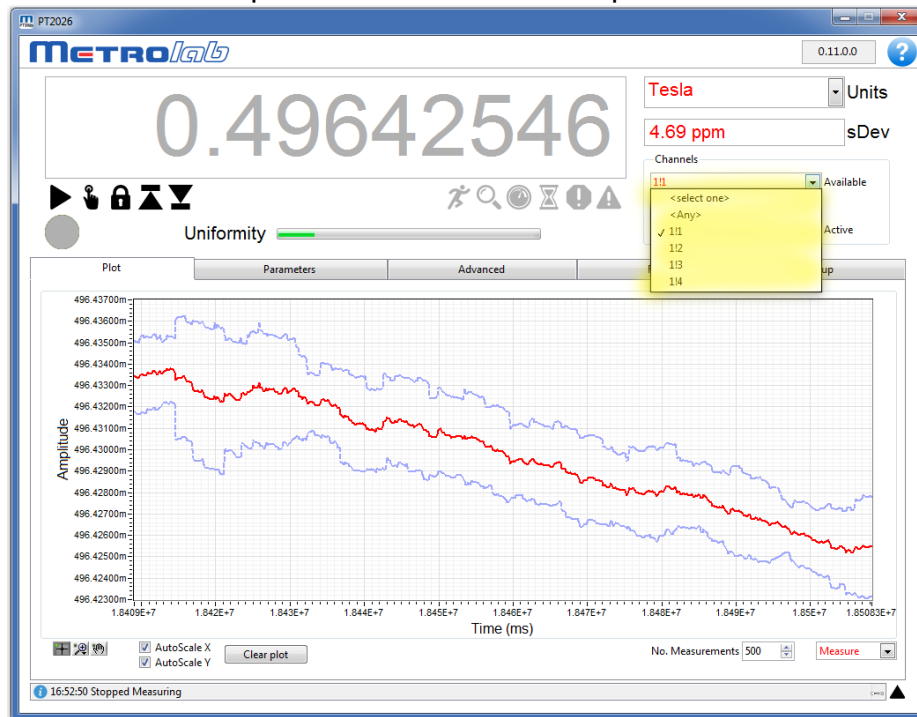
Select it and go!

## 2-6 USING MULTIPLEXERS

- Connect the MUX6026 multiplexer to the PT2026 using the Probe-Extension / MUX cable, and connect the probes to the multiplexer ports:



- Select the active probe from the Channels pull-down menu:



- Start measuring as described in Section 2-3.

## 2-7 RESET AND FORCED POWER-DOWN

If things go seriously awry, here are a few things to try. Start with the first – easier – steps, and continue until you run out of things to try. At that point, see Section 2-8.

- Stop and restart measuring.
- Reconnect the instrument via the Instruments pull-down in the Setup screen.
- Restart the PT2026 by powering down and back up.
- Restore the factory defaults using the Setup screen in the PT2026 software.
- Keep the power switch depressed while powering down the PT2026. After approximately five seconds, the instrument should restore the factory settings and then power down.
- The power-down reset described above will not work if the instrument firmware has crashed. In this case, continue to hold the power switch, and after approximately ten seconds, the PT2026 will be forced to power down.

- If the PT2026 firmware detects a serious fault during startup, the instrument will reboot in Device Firmware Upgrade (DFU) mode, ready to receive a firmware upgrade. See Section 2-8.

## 2-8 CALIBRATION, MAINTENANCE, REPAIR AND WARRANTY

- Calibration overview:

Recalibrating a PT2026 consists of adjusting its internal time base, a procedure only to be performed at the Metrolab factory. However, any properly equipped calibration laboratory can certify the calibration by measuring the internal 10 MHz reference clock output on the back panel. In addition, if you use an external 10 MHz reference clock, the PT2026 does not need to be calibrated at all.

- Recommended calibration interval:

All customers are of course free to fix the intervals at which they check the calibration of their instruments, within the context of their quality assurance policy. Metrolab's recommendation is to check the PT2026 calibration once every year.

- Upgrades:

Via its website, Metrolab will make available improvements and bug fixes for the PT2026 firmware, software and manual. The Download page of the Metrolab website ([www.metrolab.com](http://www.metrolab.com)) will always contain the latest versions.

- Firmware upgrades:

The PT2026 Main Unit is designed such that you can upgrade the firmware in the field. Firmware upgrades are a delicate procedure, as a failure may render the instrument unusable. Metrolab has made every effort to make the process foolproof, but please take your time and follow the instructions provided with the upgrade carefully.

The PT2026 peripherals (probes, multiplexers, etc.) also contain firmware. However, at this time, this firmware cannot be upgraded in the field; peripherals need to be sent back to the factory to be upgraded.

- Repairs:

Many problems can be diagnosed over the phone or via e-mail. Should you

have trouble with your PT2026, you should first contact your local representative. Please check the distributor list on our web site, [www.metrolab.com](http://www.metrolab.com), for the representative closest you.

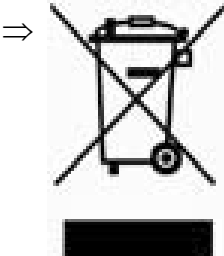
If your local representative cannot correct the problem, please contact Metrolab ([contacts@metrolab.com](mailto:contacts@metrolab.com)). Again, we will try to resolve the problem on the spot, but if that proves to be impossible, we will issue a Return Material Authorization (RMA) number and provide shipping instructions. If the instrument is out of warranty, we will diagnose the problem and send you an estimate before undertaking the repair.

- Warranty:

The standard warranty period is two years from the date of purchase.

During this period, Metrolab will replace a failing unit free of charge, unless it is clear that the unit has been abused (crushed probe or electronics, torn cable, etc.). We do not assume responsibility for consequential damage, for example to your PC.

## 2-9 DISPOSAL

NOTICE	
	<p>This product conforms to the WEEE Directive of the European Union (2002/96/EC) and belongs to Category 9 (Monitoring and Control Instruments). For proper environment friendly disposal, you can return the instrument free of charge to us or our local distributor.</p>

# **USING THE PT2026**

## **3-Overview**

This chapter provides a quick overview of what you can do with the PT2026. Additional details are provided in subsequent chapters. Note that the contextual help in the PT2026 software is very useful; in fact, it is exactly the same as Chapter 4- “Software User Interface”.

### **3-1 MEASUREMENT**

- You can measure magnetic flux density with a precision of parts per million ( $10^{-6}$ ) or even better – but beware of the limitations of NMR magnetometers (see Section 8-3).
- Before starting to measure the flux density, NMR magnetometers must find the NMR resonance. The software tells you what the PT2026 is doing with a status light, a series of status symbols, a search progress bar, and a message log (see Section 4-1).
- If for some reason the PT2026 cannot find the NMR resonance, you can limit the search range (see Section 4-3). If all else fails, you can manually force it to search at a given field strength (see Section 4-1).
- Once the NMR resonance has been found and the PT2026 is measuring, the search progress bar turns into a field-uniformity display, to help you position the probe in your magnet’s “sweet spot” (see Section 4-1).
- The software will display the measurements numerically and plot the results on a strip chart. You can freeze the numeric display and change its resolution (see Sections 4-1 and 4-6), and you can manipulate many features of the plot. Some of the plot options, such as the auto-scaling controls, are evident; others, such as the cursor controls, are accessed by right-clicking on the plot (see Section 4-2).
- You can select the appropriate measurement units, such as Tesla or kGauss. The choices also include some exotic but useful units, such as MHz, MHz-proton and parts per million (see Section 4-1).



- You can enable measurement averaging and display the standard deviation of the measurements. You can control the averaging method and the filter length (see Sections 4-1 and 4-3).
- If you are using a probe multiplexer, you use the PT2026 software to select which probe to use (see Section 4-1).
- With a multiplexer, you can also group a set of probes – for example those in a particular magnet – as a single logical channel. The PT2026 will search across the range of each probe in turn, and will start measuring with the one where it finds the NMR resonance. The PT2026 comes with one pre-configured logical channel, Any, which includes all probes that are plugged in. (See Section 4-13).
- To help you find the peak field in a volume, you can have the PT2026 software display only maximum or minimum field values (see Section 4-1).
- You can have the measurements triggered either continuously, at regular intervals, via the software interface, or via a TTL signal (see Section 4-4).
- You can also have the PT2026 generate an output trigger when a particular field value is attained (See Section 4-5). The PT2026 only has a single Trigger connector, configured either as input or output, so the output trigger cannot be used at the same time as the TTL measurement trigger.
- If need be, you can optimize the measurements by manipulating a host of internal parameters using the Advanced tab (see Sections 4-7 through 4-10). Unless you are very familiar with the instrument and the principles of NMR, you probably should not touch these. A possible exception is the Advanced > RF Pulse > Period, to increase the measurement rate (see Section 4-9).
- You can store and recall your favorite settings (see Section 4-3).
- You can record and play back measurements (see Section 4-12).
- Finally, the Setup tab embodies a host of useful utility features that deserve browsing.

## 3-2 INTERFACES

The interfaces are described in detail in Chapter 6- “Host Interfaces”. Generally, you don’t have to know anything about them, since the PT2026 software takes care of it all. If you want to know, the most important point is that the PT2026 adheres closely to industry standards:

- **USB interface:**  
Compliance with the USB 2.0 mechanical, electrical and protocol standard provides basic connectivity with any USB-capable computer. The instrument supports USB full-speed communication (12 Mbps).
- **Ethernet interface:**  
Automatically configures itself for 10 or 100 Mbps and Full or Half Duplex operation.
- **Standardized USB class driver:**  
Compliance with the USB Test & Measurement Class (USBTMC) allows the instrument to be connected without installing a custom USB driver. All that is required is a generic class driver for test and measurement equipment, as provided by suppliers of instrumentation software. The software supplied with this instrument includes the National Instruments USBTMC driver.
- **Standardized IEEE488.2 protocol:**  
Compliance with the USB488 protocol specification for USBTMC provides all the capabilities of an IEEE488 instrument on the USB bus. IEEE488, derived from HP-IB/GPIB, is the world’s most widely used instrumentation protocol. IEEE488 compliance allows any VISA library (Virtual Instrument Software Architecture) to control every aspect of the instrument. The software supplied with the instruments includes the National Instruments VISA Runtime library.
- **Standardized VXI-11 protocol:**  
For the Ethernet interface, IEEE488 compatibility is provided by the VXI-11 standard, providing the same advantages as USBTMC for USB.
- **Standardized instrument command protocol:**  
The SCPI standard (Standard Commands for Programmable Instruments)

is the standard developed and used by large instrumentation manufacturers such as Tektronix and HP/Agilent, and provides a programming interface familiar to many instrumentation system programmers.

### 3-3 PROBE MECHANICAL DESIGN

The dimensions and sample locations for the standard PT2026 probes are shown below.

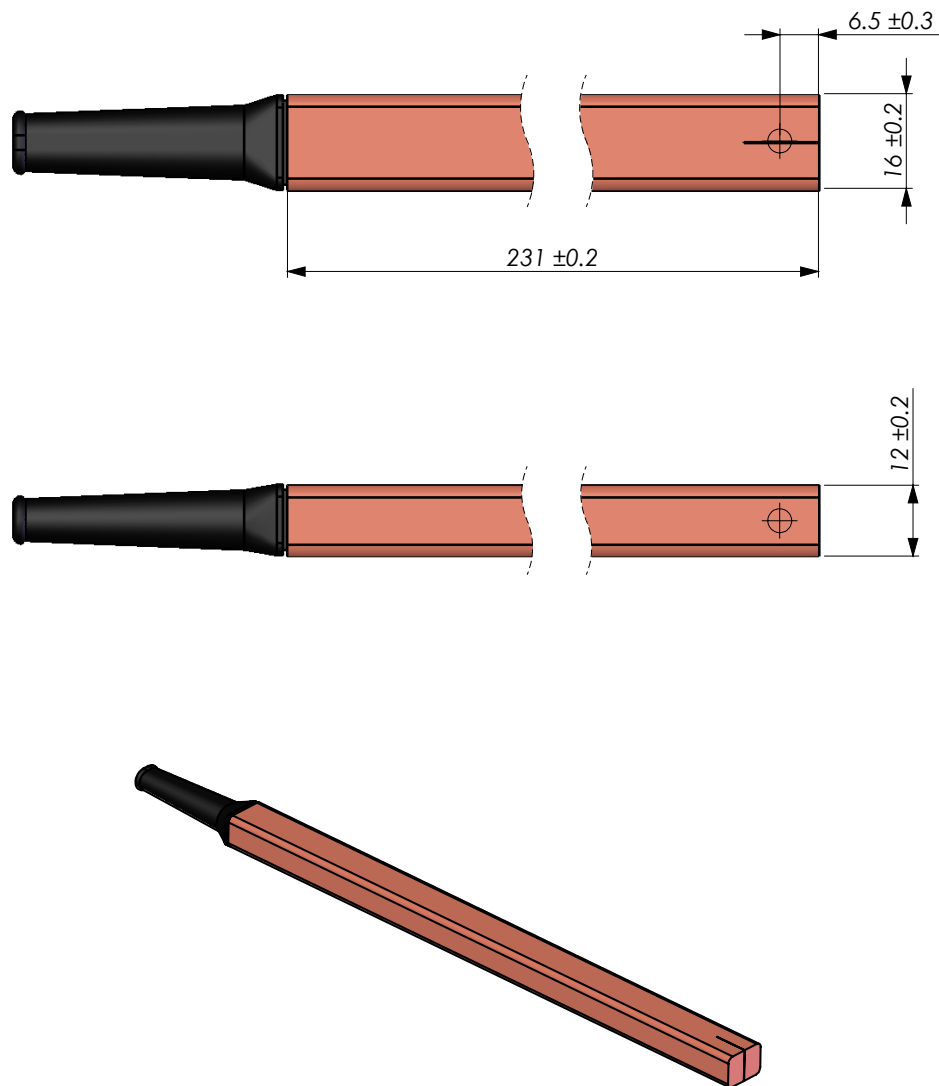


Figure 1. Dimensions and sample location for Model 1226 standard probe.

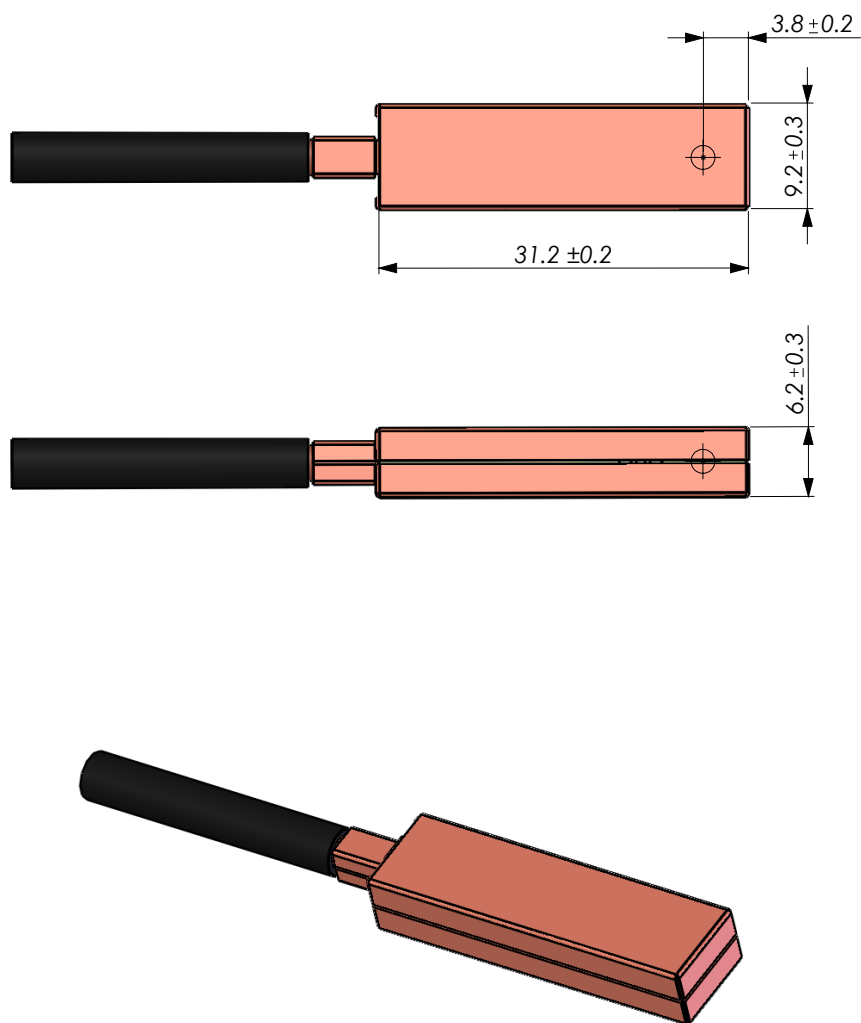


Figure 2. Dimensions and sample location for Model 1226 remote-head probe, rubber sample.

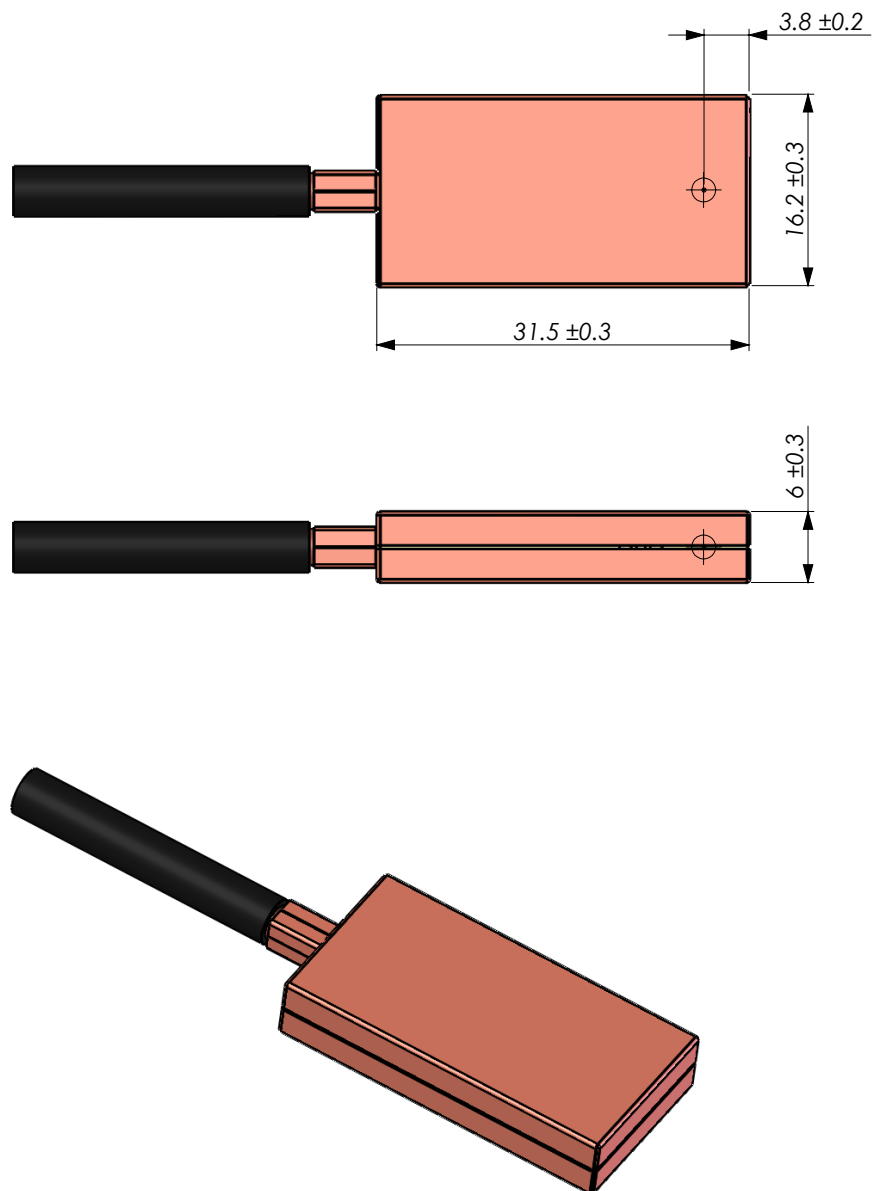


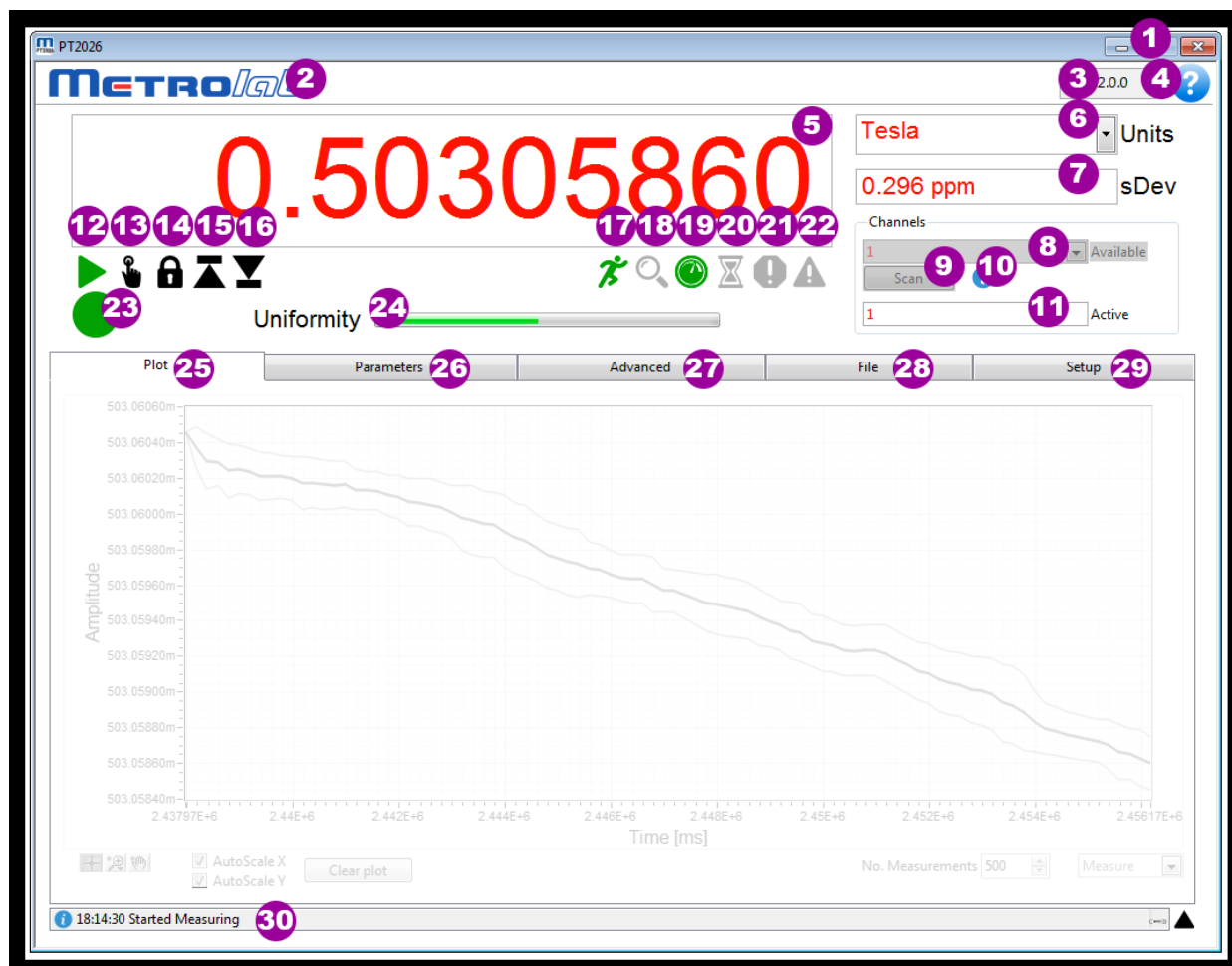
Figure 3. Dimensions and sample location for Model 1226 remote-head probe, deuterium sample.

# USING THE PT2026

## 4-Software User Interface

This chapter provides a detailed explanation of the operation of PT2026 software. The same information is available on-line, by clicking the Help button (see Section 4-1).

### 4-1 GENERAL



#### PURPOSE:

Basic instrument control and display.

#### CONTROLS AND INDICATORS:

1. Quit the application.
2. Go to Metrolab web site.
3. Displays the software version.
4. Show contextual help for the current page.
5. Displays the measured field strength, in the selected units. Becomes an input when Manual Search mode (see item 13) is selected; it then dictates the field strength where the instrument searches for the NMR resonance. Type the value, in the selected units, or use the arrow keys to increment or decrement the digit to the left of the cursor.

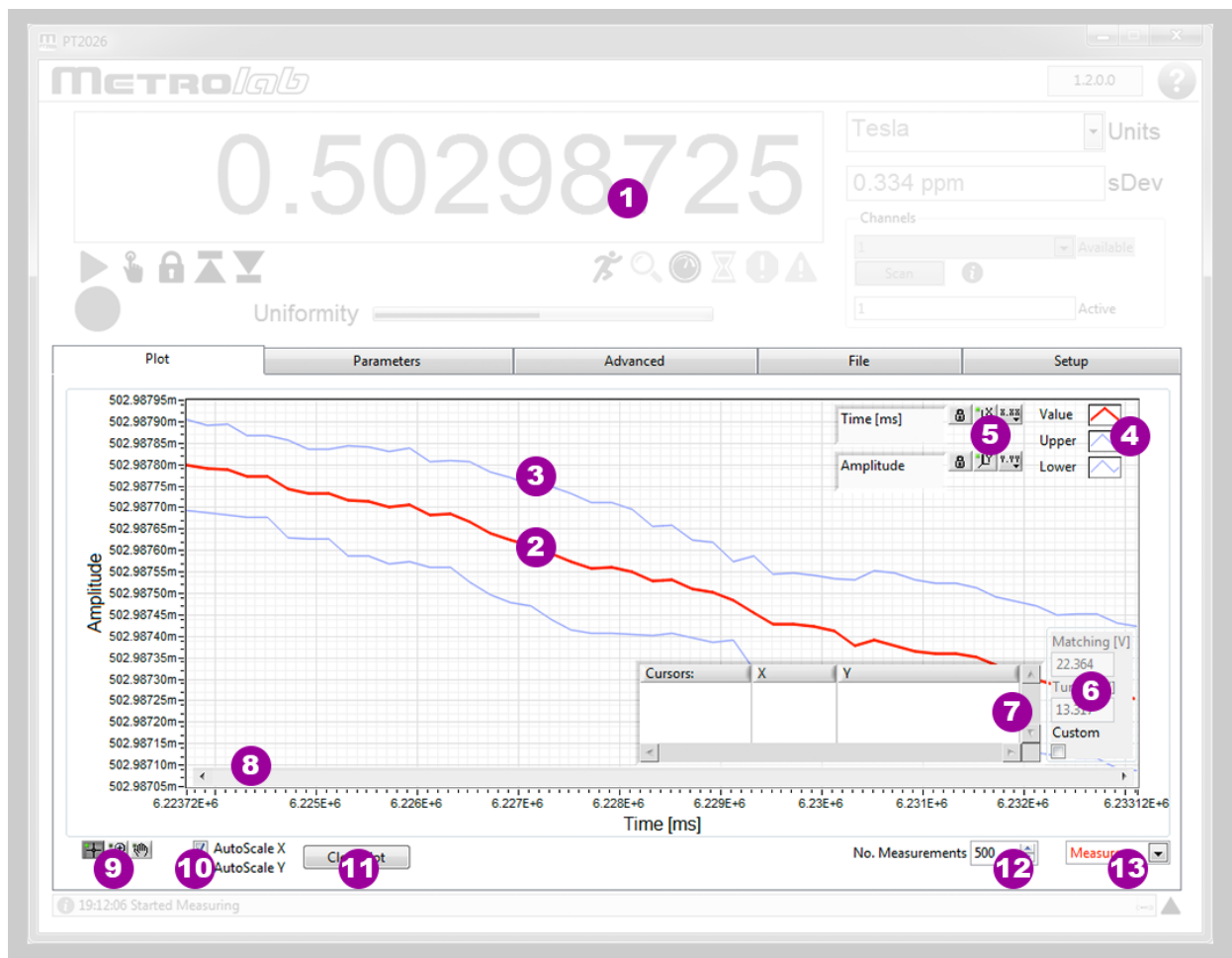
6. Select the units in which to display the measurement results:
  - T: Tesla
  - mT: mTesla ( $1\text{T}=10^3\text{ mT}$ )
  - G: Gauss ( $1\text{T}=10^4\text{ G}$ )
  - kG: kGauss ( $1\text{T}=10\text{ kG}$ )
  - ppm: parts per million (relative to value set in Parameters > Display)
  - MHz: NMR frequency (depends on gyromagnetic ratio of sample material)
  - MHz-p: proton equivalent NMR frequency ( $1\text{T} \approx 42.5775\text{ MHz-p}$ )
7. Standard deviation of the measurement. Shown on the plot as error bars. Displays "NaN", and no error bars, if Parameters > Search / Averaging > Measurement averaging is turned off.
8. The channel to be searched. A channel is either a physical probe, or a logical collection of probes, defined in Setup.
9. Force the PT2026 to scan for connected probes and update the channel list.
10. The currently active probe. For a physical channel, this is the same as the Channel selection, but for a logical collection of probes, this indicates which of those probes was used for the last measurement.
11. Probe information. Shows the currently active probe's serial number and designation.
12. Start measuring. Click again to stop measuring.
13. Manual Search. Modify the Numeric Result field to set the search value (see item 5). Click this button again to reenter standard search mode; if the NMR value was found, it will be retained and the instrument will start measuring.
14. Freeze the Numeric Result display. The instrument, the Plot display and the file recording continue to function.
15. Retain the maximum measurement. The instrument, the Plot display and the file recording continue to function.
16. Retain the minimum measurement. The instrument, the Plot display and the file recording continue to function.
17. Indicates the instrument is running.
18. Indicates the instrument is searching for the NMR resonance.
19. Indicates the instrument is measuring.
20. Indicates the instrument is waiting for a trigger.
21. Indicates that the instrument is unable to detect an NMR signal.
22. Indicates the measurement is not trustworthy. Lit in Manual Search mode because the NMR resonance might be above or below the set frequency.
23. Indicates the overall instrument status:
  - Green: Measuring; the displayed result is trustworthy.
  - Orange: Measuring in Manual Search mode; the displayed result is not the NMR resonance.
  - Red: Indicates that the instrument is unable to detect an NMR signal.
  - Yellow: Reviewing recorded data.
  - Off: Not measuring.

24. The Search progress bar shows the status of the NMR signal search; to be precise, it shows the current frequency within the selected range. Once the NMR signal has been found, the name of the progress bar changes to Uniformity, and indicates an estimate of the field uniformity.
25. Displays the Plot page, for graphical data displays.
26. Displays the Parameter page, for basic instrument adjustments.
27. Displays the Advanced page, for advanced instrument adjustments.
28. Displays the File page, for saving and recalling measurement files.
29. Displays the Setup page, for instrument configuration settings.
30. Provides prompts and status information. Click on the black arrow to expand it and see a log of past messages.

### NOTES:

In Manual Search mode, the search value must be at least several kHz removed from the NMR resonant frequency for the mixer to produce an output. It is useful to display the NMR plot while adjusting the search value. When the NMR resonance is found manually, the Status Light turns orange.

## 4-2 PLOT DISPLAY



### PURPOSE:

Graphical data display.



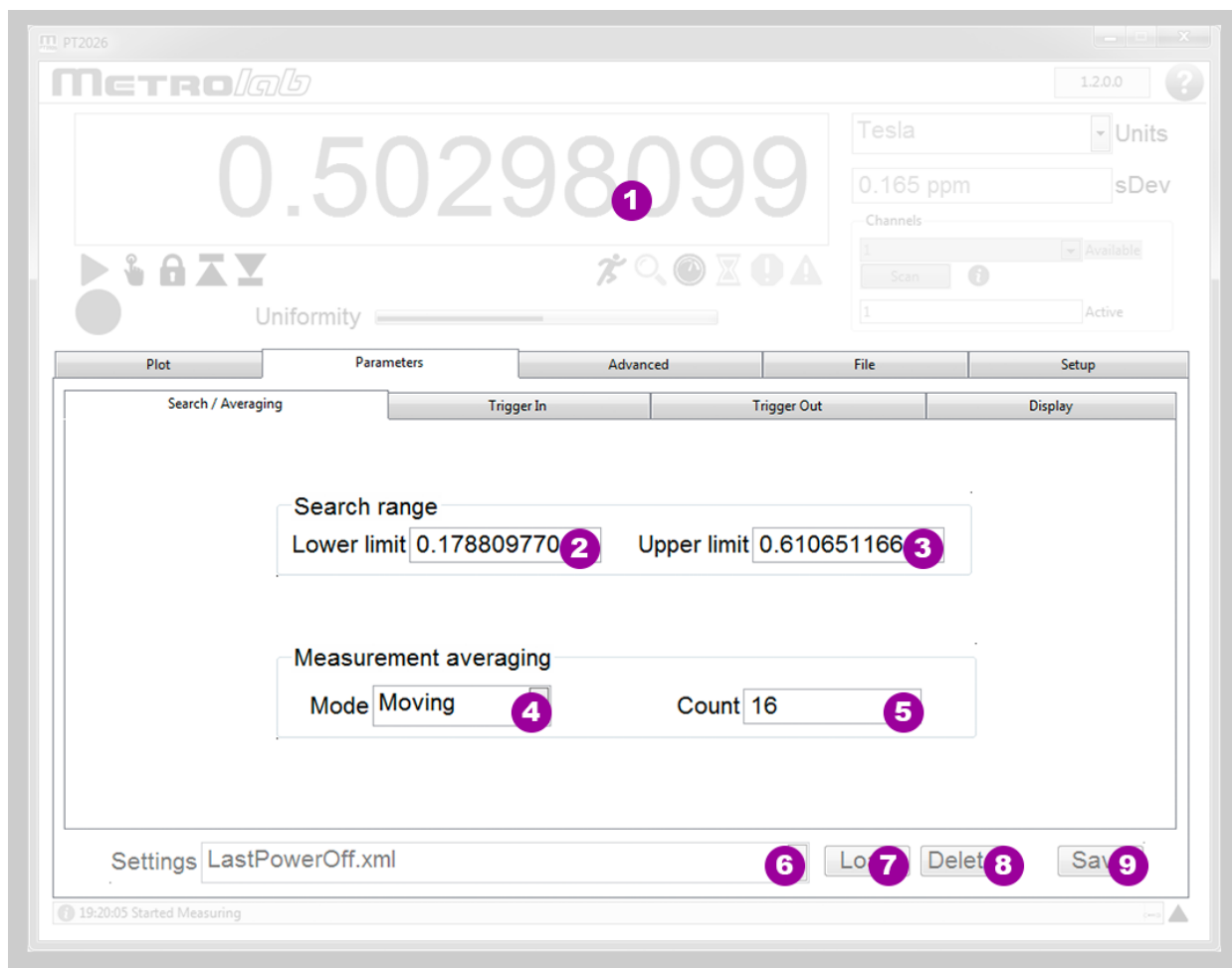
**CONTROLS AND INDICATORS:**

1. For general controls and indicators, see Section 4-1.
2. Data plot. Displays, depending on the chosen plot type (see item 13):
  - A strip-chart display of the measured field strength, in the selected units;
  - An oscilloscope display of the NMR signal; or
  - A spectral display of the NMR signal.Right-click on the plot to open a contextual menu:
  - Show or hide the data legend (see item 4), scale legend (see item 5), graph palette (see item 9), cursor palette (see item 6) or scroll bar (see item 8).
  - Turn auto-scaling off and on.
  - Export the data or the graph.
3. Error bars: show the standard deviation of the measurements. Only available for the Measurements strip chart display, if Measurement Averaging is enabled.
4. Data legend. Hidden by default; show and hide with plot contextual menu (see item 2). Right-click on a trace to open a contextual menu to:
  - Make the data trace visible or invisible.
  - Change the appearance of the data trace.
  - Export the data.
5. Scale legend. Hidden by default; show and hide with plot contextual menu (see item 2).
  - Change the axis labels.
  - Turn auto-scaling on or off.
  - Auto-scale once, if auto-scaling is off.
  - Change the format, precision and representation of the scale; show or hide the scale and axis labels; and change the grid color.
6. Match/Tune adjustment. Hidden by default; show and hide with the Advanced > Match / Tune screen.
7. Cursor palette. Hidden by default; show and hide with plot contextual menu (see item 2).
  - Create multiple cursors, either free or attached to a data trace.
  - Display the cursor values.
  - Change cursor attributes such as color.
8. Scroll horizontally if zoomed. Hidden by default, show with the plot contextual menu (see item 2).
9. Graph Palette. The graph palette tools manipulate the plot:
  - The Cursor tool moves the cursors created on the cursor palette (see item 6).
  - The Zoom tool zooms horizontally, vertically or both.

- The Hand tool pans the graph, once zoomed.
10. Turns horizontal and vertical auto-scaling on and off. When manual scaling is selected, the scale can be modified by double-clicking and editing the minimum and maximum values.
  11. Clear the plot and reset the scale.
  12. The maximum number of measurements on the strip chart display.
  13. Select the data to be plotted:
    - Measure: Plot the field measurements in strip-chart format.
    - NMR: Plot the NMR signal.
    - FFT: Plot the spectrum of the NMR signal.

#### NOTES:

### 4-3 PARAMETERS > SEARCH & AVERAGING



#### PURPOSE:

Set commonly used search and averaging parameters.

#### CONTROLS AND INDICATORS:

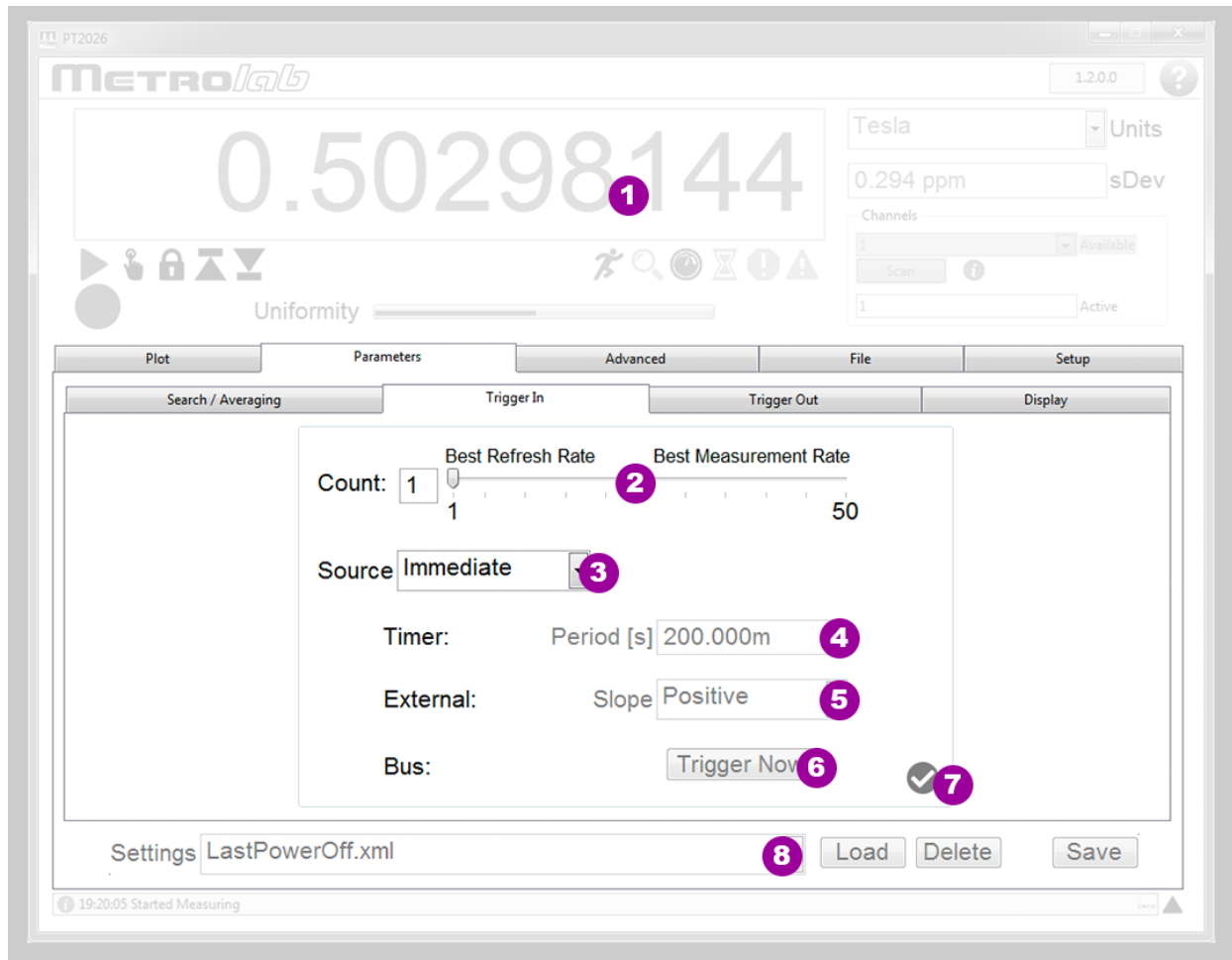
1. For general controls and indicators, see Section 4-1.

2. Lower limit of the range to be searched for an NMR resonance. Set to the current channel's lower limit by default.
3. Upper limit of the range to be searched for an NMR resonance. Set to the current channel's upper limit by default.
4. Measurement averaging averages a number  $N_m$  of field measurements, in order to know, and to reduce, the measurement variance. Available averaging modes:
  - Off (default)
  - Exponential: weighted average of each new measurement (weight =  $1/N_m$ ) and the previous value of the average (weight =  $(N_m - 1)/N_m$ ). Does not reduce the update rate.
  - Moving: the last  $N_m$  measurements are averaged. Does not reduce the update rate.
  - Block: successive blocks of  $N_m$  measurements are averaged. Reduces the update rate by a factor of  $N_m$ .
5. Measurement averaging count,  $N_m$ .
6. Pull-down list of settings saved in the instrument's nonvolatile memory. The following names are predefined:
  - LastPowerOff.xml: automatically saved when the instrument is powered off.
  - <Factory>: factory default settings.
7. Load the selected settings. Note that loading certain settings requires rebooting the PT2026, which will break the connection to the instrument.
8. Delete the selected settings. The factory default settings cannot be deleted.
9. Save the current instrument settings under a user-defined name. Either all settings, or only a certain category of settings, can be saved:
  - All: all instrument settings.
  - Communication: computer interface settings.
  - Measure: search and measurement settings.
  - Trigger: trigger in and trigger out settings.
  - Reference Clock: reference clock settings.
  - Units: selected units and ppm reference value.

**NOTES:**

Some settings (for example communications settings) will cause the instrument to reboot, causing the connection to be lost.

## 4-4 PARAMETERS > TRIGGER IN



### PURPOSE:

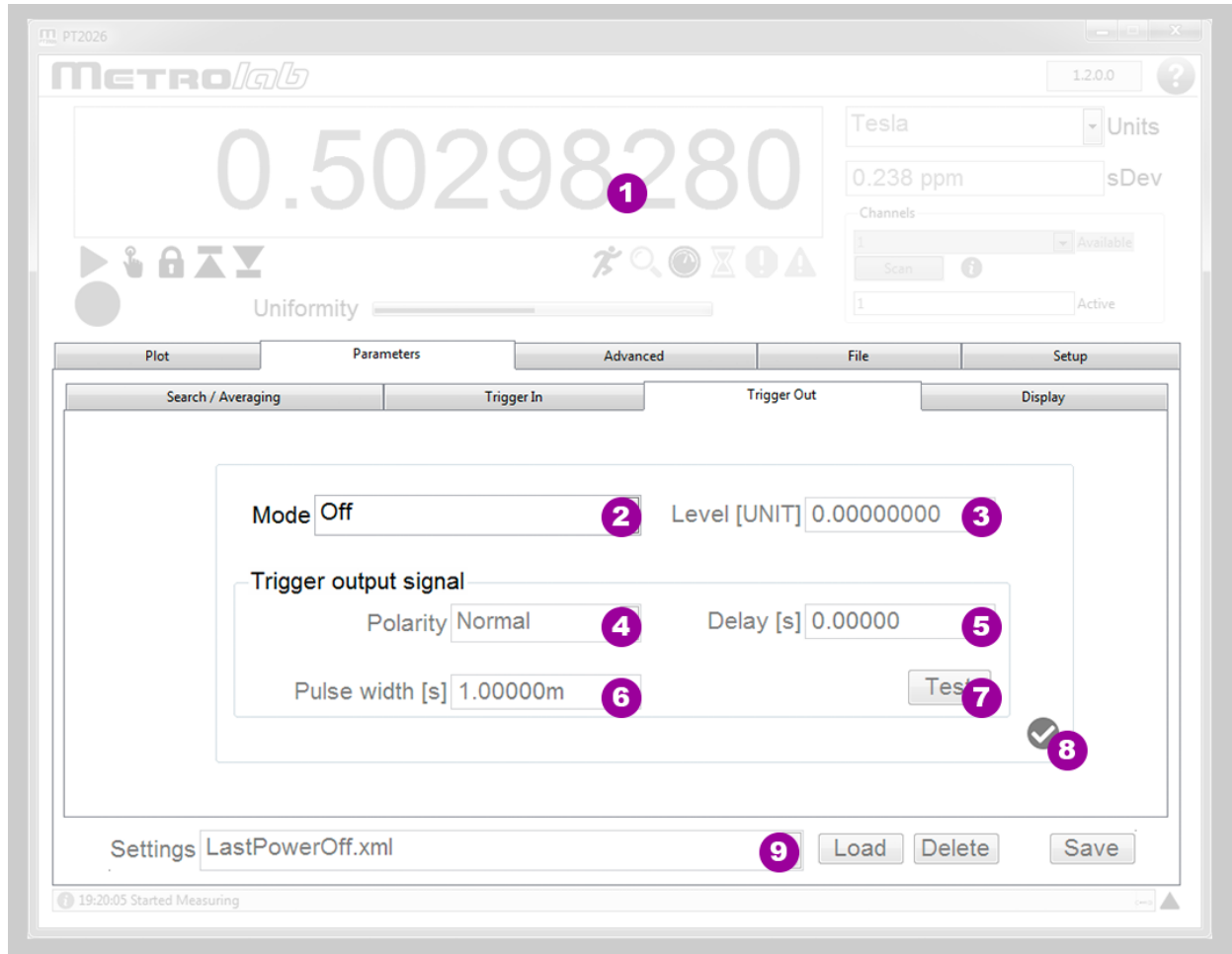
Set the trigger-in parameters, which determine when a field measurement is taken.

### CONTROLS AND INDICATORS:

1. For general controls and indicators, see Section 4-1.
2. Buffer count: to allow for rapid measurement rates, measurements can be buffered in the instrument before being transferred to the host computer.
3. Trigger source, determines when a new measurement is initiated:
  - Immediate (default): immediately after the previous measurement terminates.
  - Timer: at regular intervals.
  - Bus: via a \*TRG command or special USB / Ethernet trigger packet.
  - External: by an external TTL signal connected to the BNC connector marked "Trigger in/out" (see note below).
4. Trigger period, if the Trigger Source is "Timer".
5. Trigger slope, if the Trigger Source is "External".
6. Generate a trigger immediately, for test purposes, if the Trigger Source is "Bus".
7. Apply the settings changes.
8. The Settings controls are documented under "Parameters > Search / Averaging".

**NOTES:**

The “Trigger in/out” BNC connector is either a trigger-in or a trigger-out. Consequently, the Trigger In Source can be set to “External” only if the Trigger Out Mode is “Off”.

**4-5 PARAMETERS > TRIGGER OUT****PURPOSE:**

Set the trigger-out parameters, which determine the timing and shape of an output trigger signal on the “Trigger in/out” BNC connector.

**CONTROLS AND INDICATORS:**

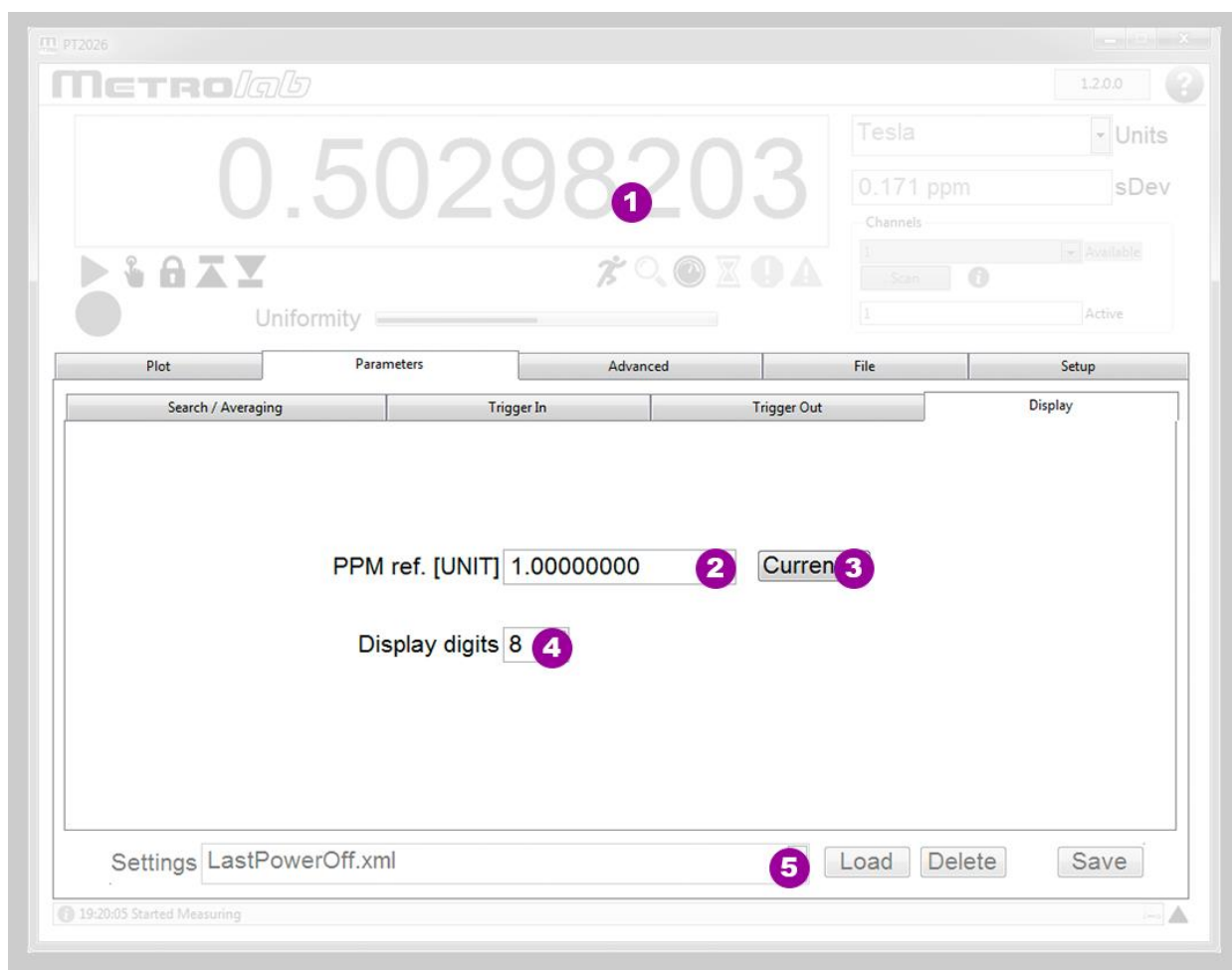
- For general controls and indicators, see Section 4-1.
- The Mode determines whether the trigger signal is a pulse or level, and the circumstances under which a trigger is generated:
  - Off (default).
  - Pulse – B rising
  - Pulse – B falling
  - Pulse – B rising or falling
  - Level – B greater than
  - Level – B less than

3. Field strength threshold, in the selected units.
4. With normal polarity, the trigger signal is a positive-going pulse or positive level. With inverted polarity, the trigger signal is a negative-going pulse or zero level.
5. Hold-off delay: time between the detection of the trigger condition and the generation of the trigger signal.
6. Pulse width, for a pulse trigger.
7. Generate a trigger signal in the selected configuration, for testing.
8. Apply the settings changes.
9. The Settings controls are documented under “Parameters > Search / Averaging”.

#### NOTES:

The “Trigger in/out” BNC connector is either a trigger-in or a trigger-out. Consequently, the Trigger Out Mode can only be “Off” if the Trigger In Source is set to “External.”

### 4-6 PARAMETERS > DISPLAY



#### PURPOSE:

Set display parameters.

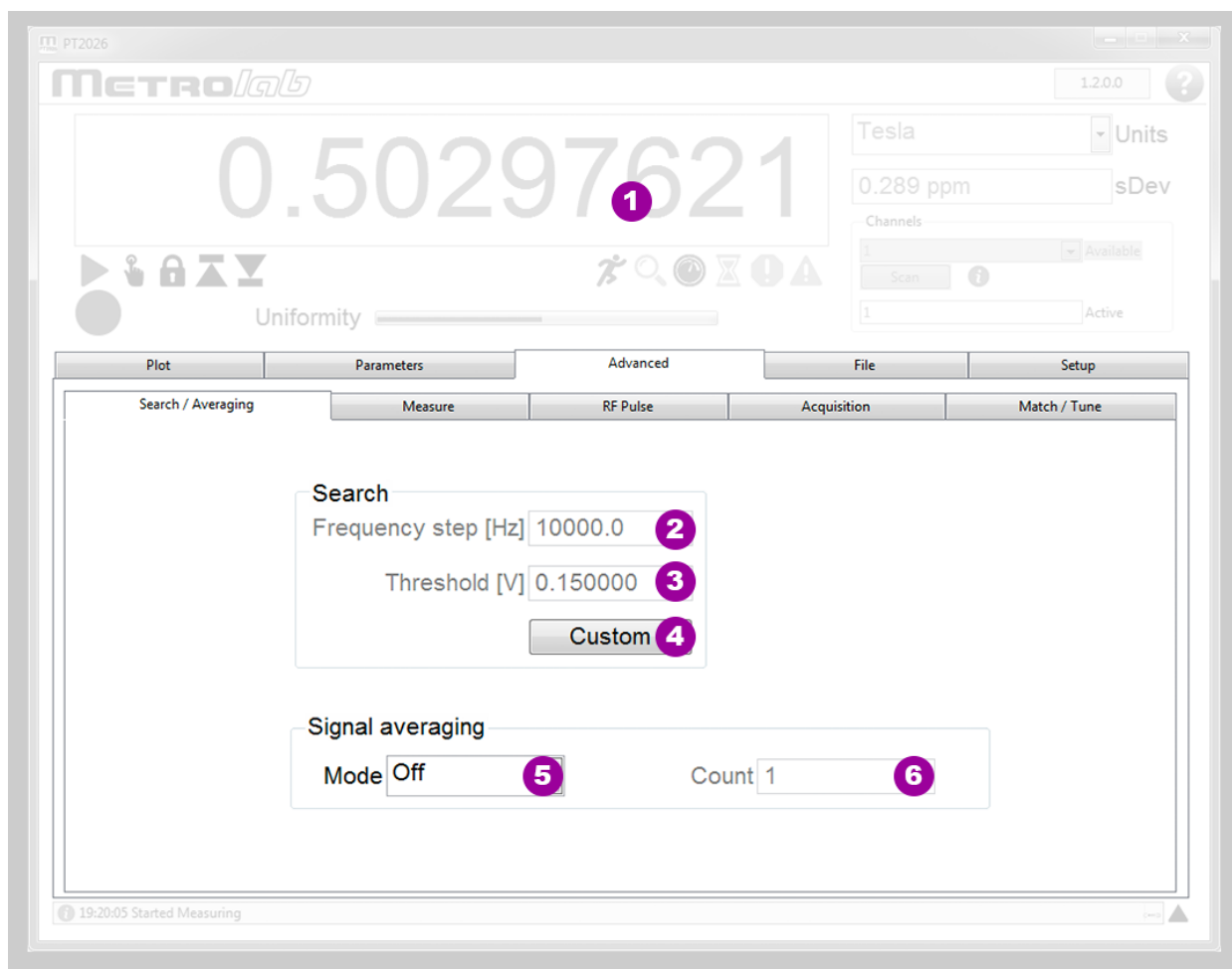
#### CONTROLS AND INDICATORS:

1. For general controls and indicators, see Section 4-1.
2. Reference field strength if the selected units are “ppm”.

3. Set the reference field strength to the currently measured value.
4. Set the number of digits of precision (i.e. number of digits behind the decimal point) for the numeric measurement display.
5. The Settings controls are documented under “Parameters > Search / Averaging”.

#### NOTES:

### 4-7 ADVANCED > SEARCH & AVERAGING



#### PURPOSE:

Set advanced search parameters.

#### CONTROLS AND INDICATORS:

1. For general controls and indicators, see Section 4-1.
2. Frequency step used in the sweep to find the NMR resonance frequency.
3. Threshold value used in the sweep to find the NMR resonance frequency.
4. Press to customize the parameters, press again to restore the default settings.
5. Signal averaging averages a number  $N_s$  of NMR signal acquisitions before proceeding with the spectral analysis, in order to reduce noise. Available averaging modes:
  - Off (default)

- Exponential: weighted average of each new NMR signal (weight =  $1/N_s$ ) and the previous value of the average (weight =  $(N_s-1)/N_s$ ). Does not reduce the update rate.
- Block: successive blocks of  $N_s$  NMR signals are averaged. Reduces the update rate by a factor of  $N_s$ .

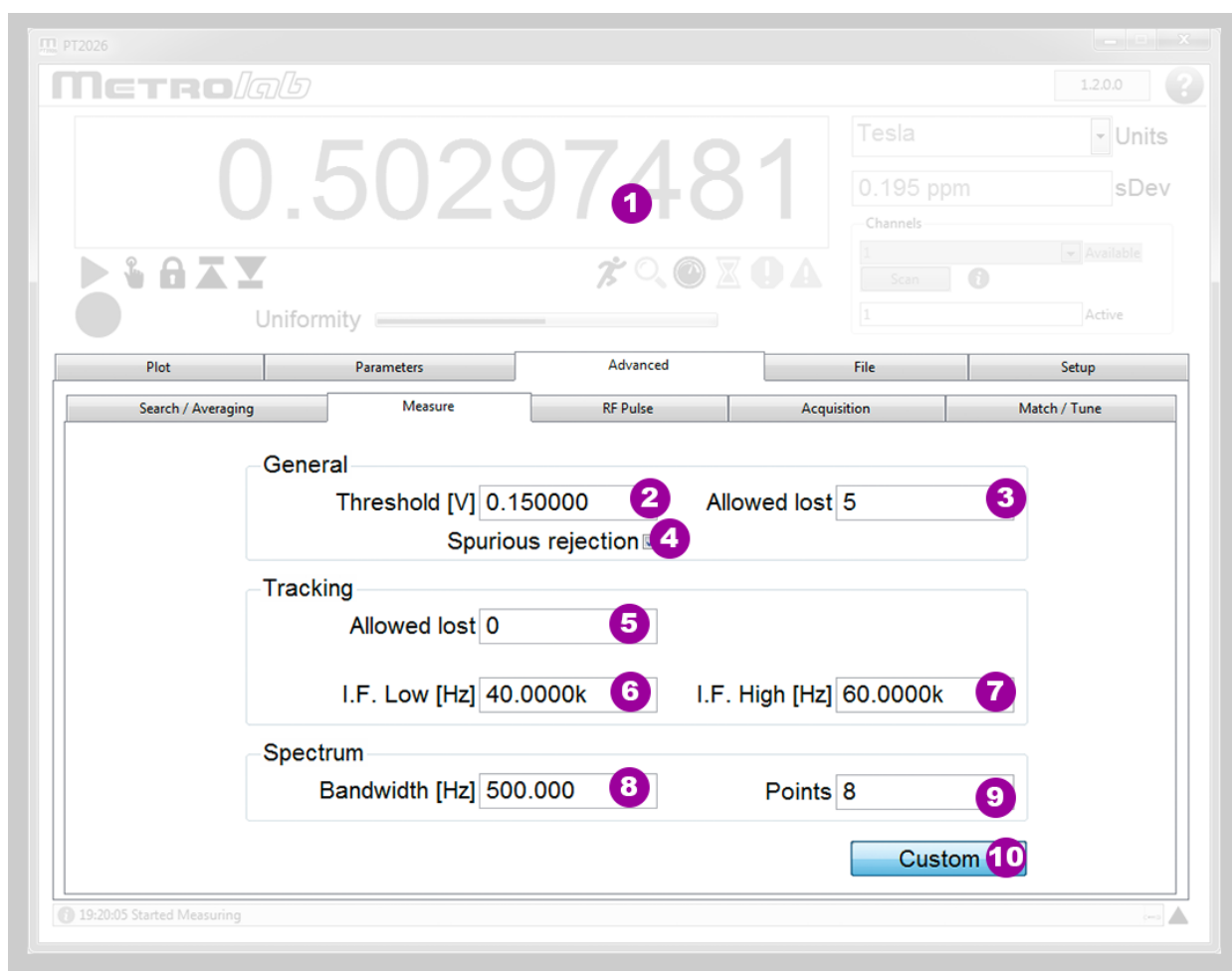
6. Signal averaging count,  $N_s$ .

#### NOTES:

The Advanced settings may cause the instrument to not measure. Restore the Factory defaults if necessary.

Averaging NMR signals can lead to strange behavior, especially if the magnetic field is not perfectly stable.

### 4-8 ADVANCED > MEASURE



#### PURPOSE:

Set advanced measurement parameters.

#### CONTROLS AND INDICATORS:

1. For general controls and indicators, see Section 4-1.
2. Threshold value used to determine whether a spectral peak is a candidate NMR signal.

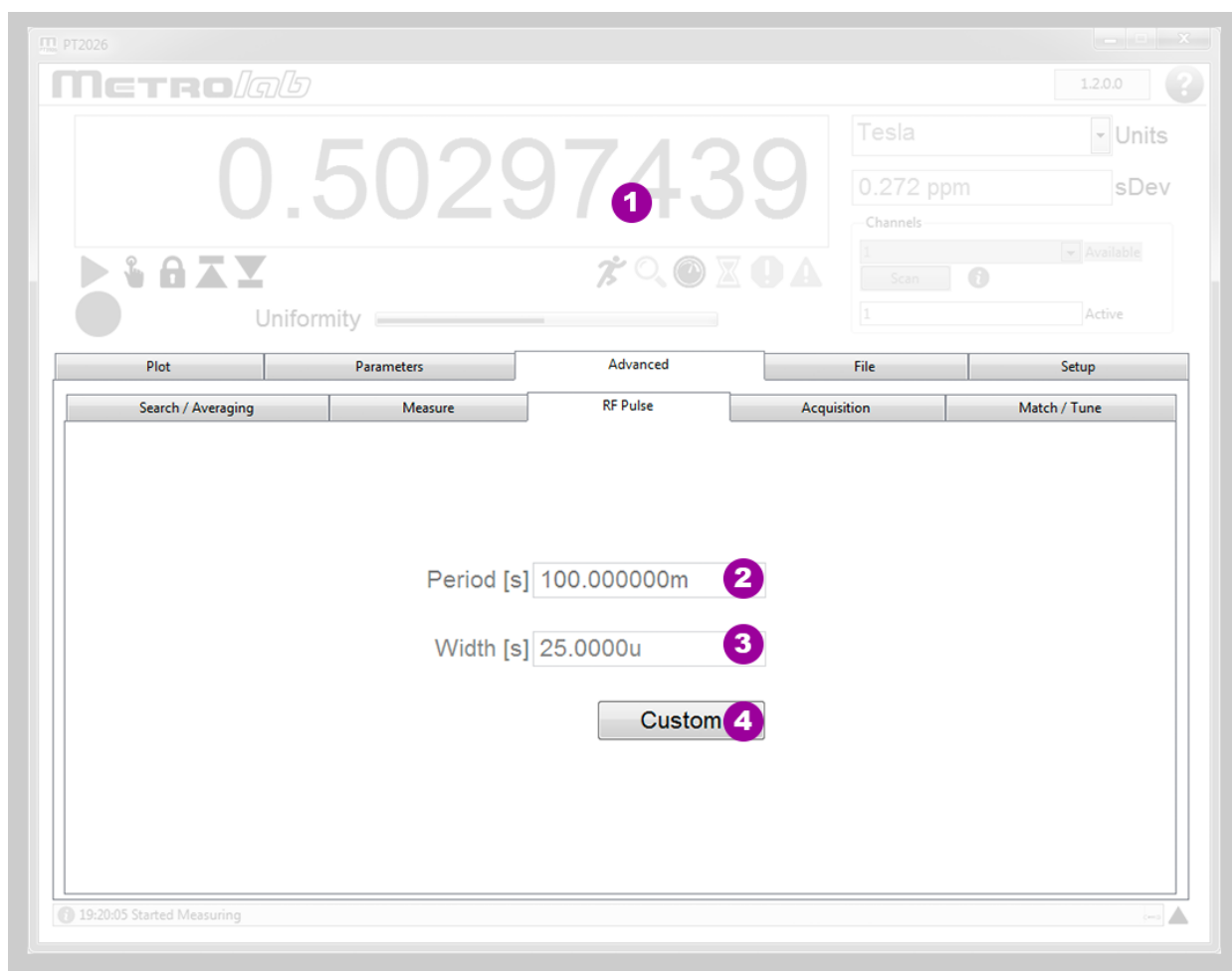


3. The number of failed measurements that are allowed before the instrument gives up and starts searching for the NMR resonance again.
4. Whether or not to test for, and reject, spurious signals that might be mistaken for an NMR resonance signal.
5. The number of measurements allowed outside the Intermediate Frequency tracking window before the RF frequency is adjusted.
6. The lower limit of the Intermediate Frequency tracking window.
7. The upper limit of the Intermediate Frequency tracking window.
8. The bandwidth over which the detailed spectral analysis is performed.
9. The number of points computed during the detailed spectral analysis.
10. Press to customize the parameters, press again to restore the default settings.

#### NOTES:

The Advanced settings may cause the instrument to not measure. Restore the Factory defaults if necessary.

#### 4-9 ADVANCED > RF PULSE



#### PURPOSE:

Set advanced parameters to control the RF pulse.

## CONTROLS AND INDICATORS:

1. For general controls and indicators, see Section 4-1.
2. The period of the Radio Frequency pulse.
3. The width of the Radio Frequency pulse.
4. Press to customize the parameters, press again to restore the default settings.

## NOTES:

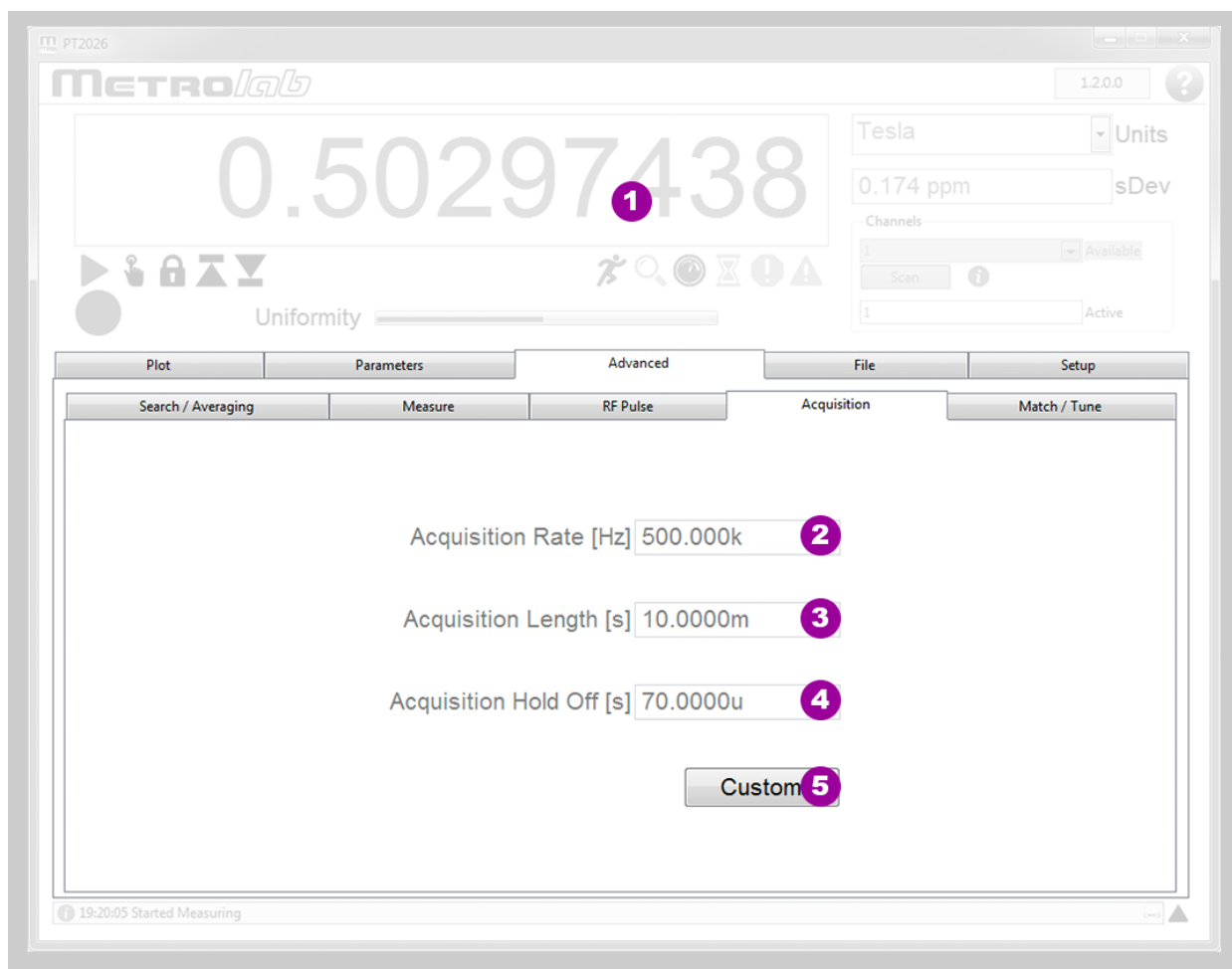
The Advanced settings may cause the instrument to not measure. Restore the Factory defaults if necessary.

The pulse period determines the measurement rate. Selecting too small a period relative to the NMR sample's relaxation time will reduce the NMR signal amplitude (c.f. Ernst angle).

The pulse width determines the bandwidth of the pulse: a wide pulse will have a narrow bandwidth, and may require a reduced search frequency step (see Search & Averaging parameters).

The pulse width also determines the angle through which the spins are rotated (the "nutation" angle); a pulse that is too narrow or too wide will reduce the NMR signal amplitude (c.f. Ernst angle).

## 4-10 ADVANCED > ACQUISITION



**PURPOSE:**

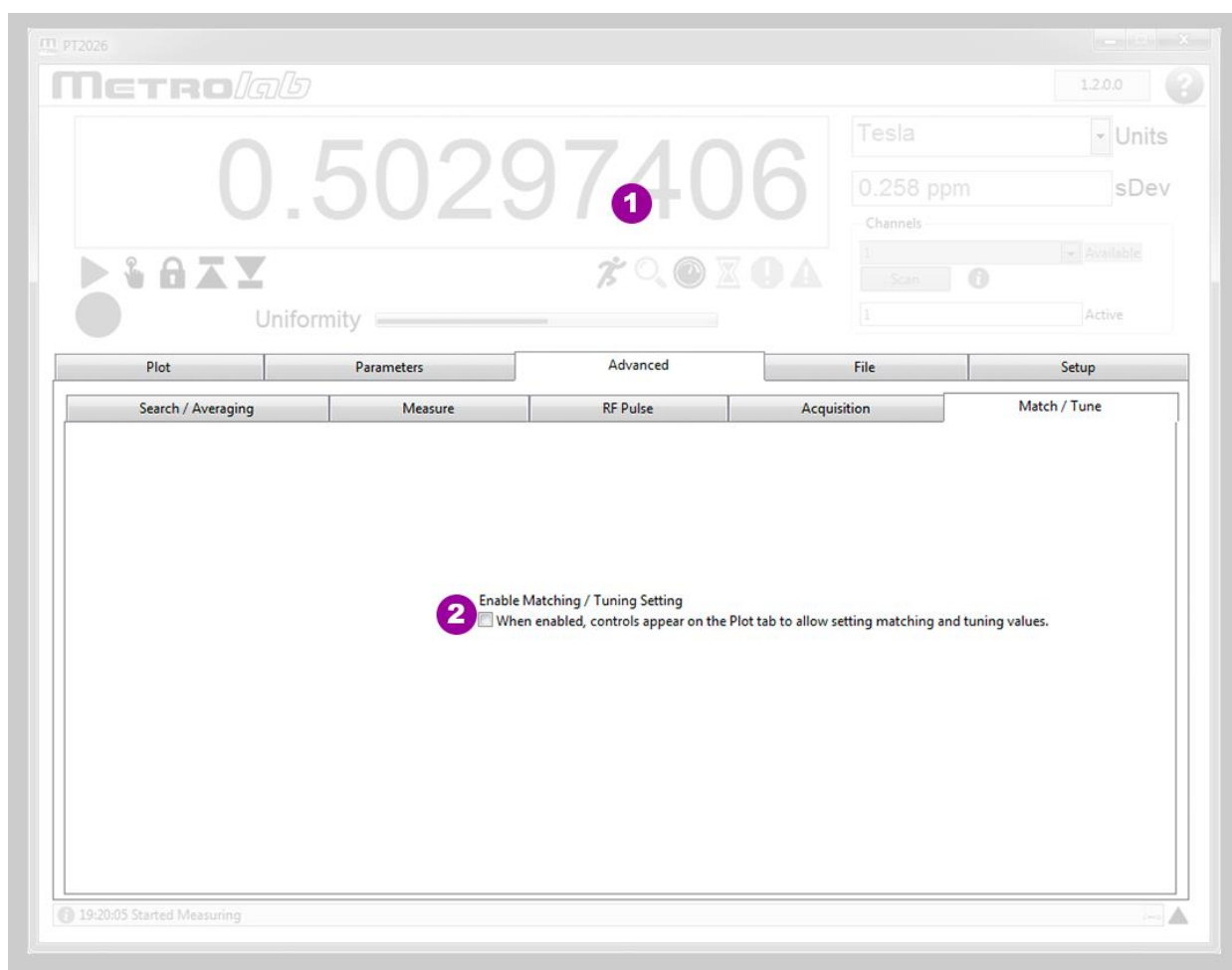
Set advanced digitization parameters.

**CONTROLS AND INDICATORS:**

1. For general controls and indicators, see Section 4-1.
2. The sample rate of the analog-to-digital conversion.
3. The length of the digitized NMR signal.
4. The dead time at the beginning of the acquisition, to avoid acquiring switching noise.
5. Press to customize the parameters, press again to restore the default settings.

**NOTES:**

The Advanced settings may cause the instrument to not measure. Restore the Factory defaults if necessary.

**4-11 ADVANCED > MATCH & TUNE****PURPOSE:**

Set advanced parameters for probe matching and tuning.

**CONTROLS AND INDICATORS:**

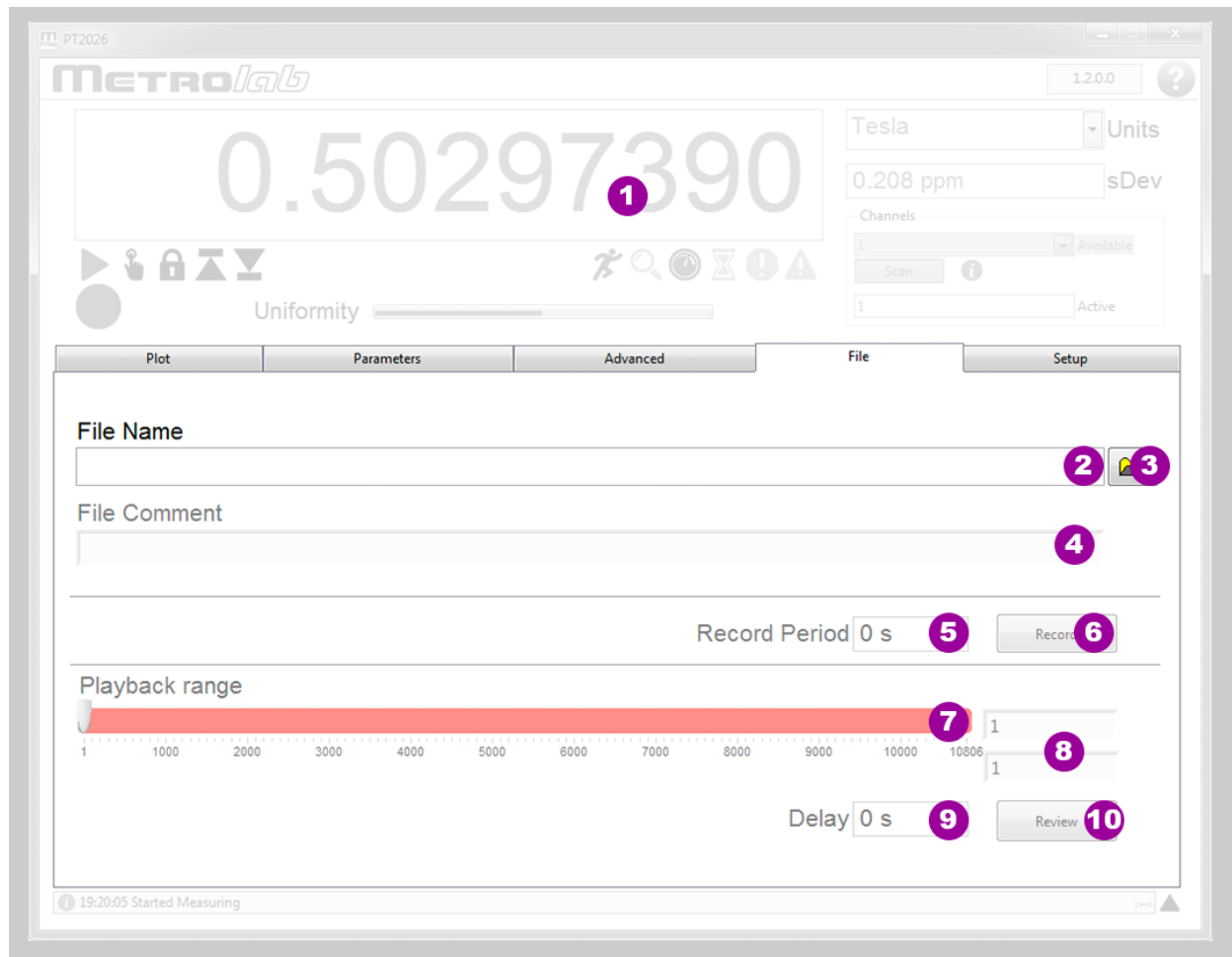
1. For general controls and indicators, see Section 4-1.

- When enabled, controls appear on the Plot screen to allow adjusting the matching and tuning voltages for the current probe.

### NOTES:

The Advanced settings may cause the instrument to not measure. Restore the Factory defaults if necessary.

## 4-12 FILE



### PURPOSE:

Save and replay a measurement file.

### CONTROLS AND INDICATORS:

- For general controls and indicators, see Section 4-1.
- Path of the measurement file.
- Click to select or create a new measurement file.
- Comment entered in the header of the measurement file.
- Period between recorded measurements. Enter zero to record all data.
- Click to start recording, click again to stop.
- Range of measurement numbers to review.
- Numeric display of selected measurements.

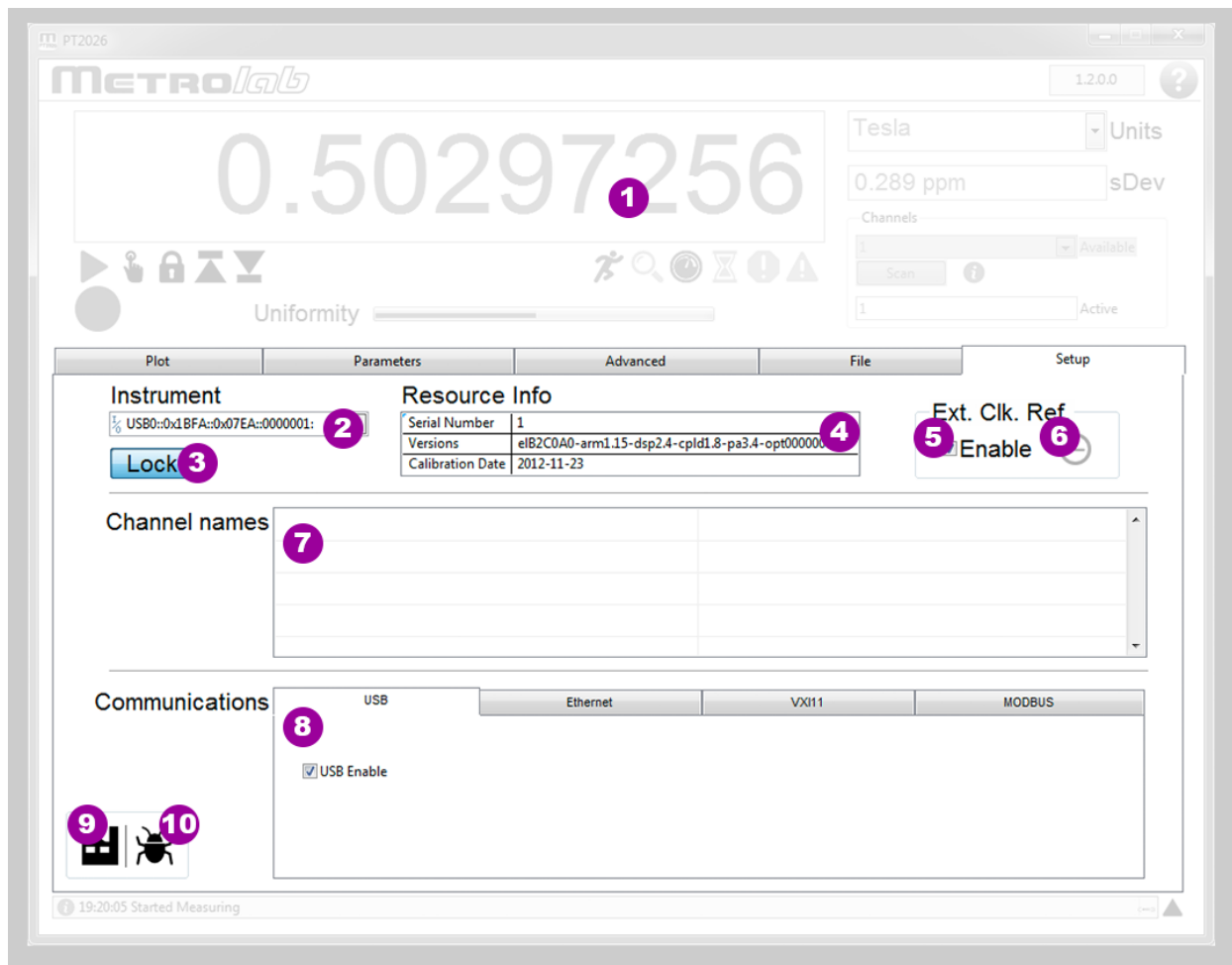
9. Update delay for reviewing measurements.

10. Click to start review, click again to stop.

### NOTES:

The measurement file is a self-documenting human-readable text file, using the XML (Extensible Markup Language) format. It consists of a header section and a body section; the body section, in turn, is decomposed into a series of datasets, each with a table of measurement data, column headings, and associated instrument settings.

## 4-13 SETUP



### PURPOSE:

Setup instrument configuration.

### CONTROLS AND INDICATORS:

1. For general controls and indicators, see Section 4-1.
2. Select the instrument and interface.
3. Lock an instrument to be able to change its parameters. Only one instance of the software can lock an instrument; unlocked instances can only monitor the measurements and any parameter changes.
4. Information concerning the instrument.
5. Enable the external reference clock.

6. Signals that an external reference clock is connected to the “10 MHz in/out” BNC connector.
7. Give a logical channel name to a list of one or more probes. Double-click on an empty line to add a definition, or double-click on an existing line to delete or modify it.
8. Enable or disable the different interfaces, and change parameters such as the IP addressing for Ethernet. Note that MODBUS is not yet supported.
9. Restore the factory defaults. This does the same thing as selecting the predefined “<Factory>” settings file. Note that loading factory settings require rebooting the PT2026, which will break the connection to the instrument.
10. Create a software debug log. The file is saved in the “Metrolab/PT2026/DebugLogs” subdirectory of the <User Application Data> directory. On Windows, the User Application Data path should be \Users\<User>\AppData\Local; on MacOS, /Users:<User>:Library:Application Support.

**NOTES:**

The syntax for defining channels is defined by the SCPI standard (Standard Commands for Programmable Instruments). Selecting a logical channel will search all its probes in order, and start measuring on the first one where an NMR resonance is found.

# PROGRAMMING THE PT2026

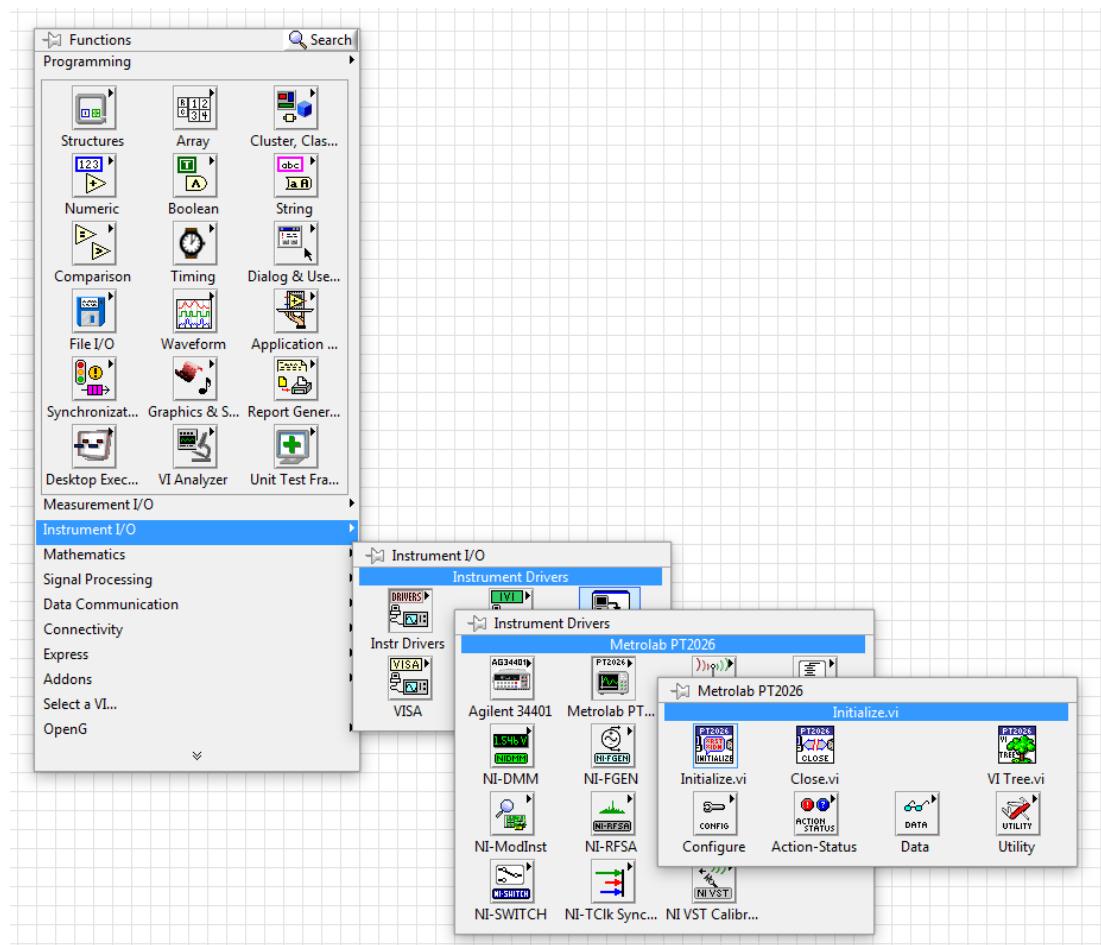
## 5-LabVIEW Instrument Driver

The LabVIEW Instrument Driver allows users to easily write instrument control programs for the PT2026, using the LabVIEW® graphical programming environment from National Instruments ([www.ni.com](http://www.ni.com)).

The Instrument Driver is included in source code format (LabVIEW 2015 SP1) on the CD that came with your PT2026. In the future, it will also be distributed on the National Instruments Instrument Driver Network ([www.ni.com/idnet](http://www.ni.com/idnet)). If upgrades become available, you will be able to download them from the Metrolab website, [download.metrolab.com](http://download.metrolab.com), or from the Instrument Driver Network.

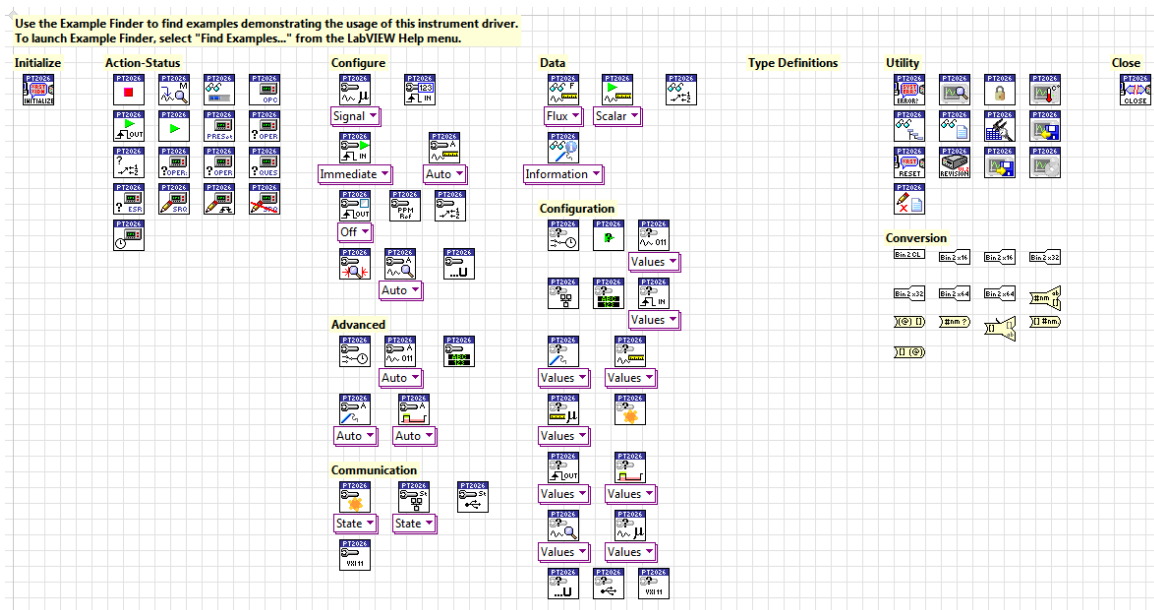
### 5-1 INSTALLATION

To manually install the Instrument Driver, copy the folder “Metrolab PT2026” into the “instr.lib” folder inside the LabVIEW program folder. If LabVIEW was running, restart it. You should now find “Metrolab PT2026” in the Instrument Drivers palette:



## 5-2 OVERVIEW OF DRIVER INTERFACE

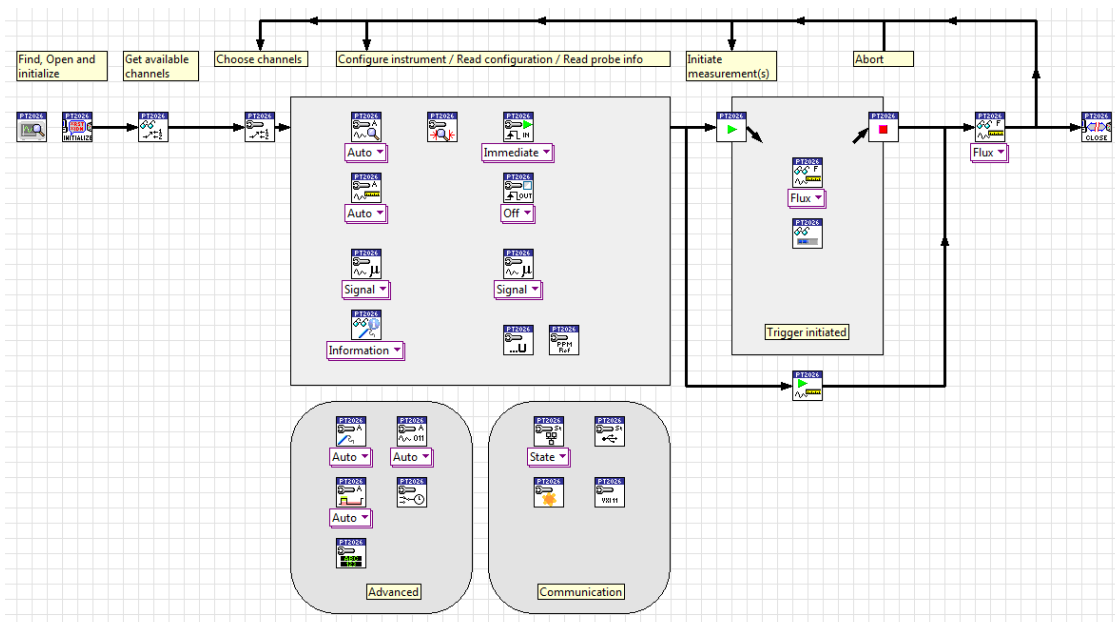
The Virtual Instrument (VI) “VI Tree.vi” on the PT2026 driver palette is a dummy VI that provides an overview of the entire public interface of the Instrument Driver:



To access this overview, you can use the Instrument palette to place “VI Tree.vi” on a blank VI, double-click to open “VI Tree.vi”, and select the menu item “Window > Show Block Diagram”. You can copy any of the driver VIs onto your VI block diagram.

## 5-3 APPLICATION TEMPLATE

“Metrolab PT2026/Public/VI Template.vi” is a second dummy VI that shows the order in which the key driver VIs should be called in a typical application:

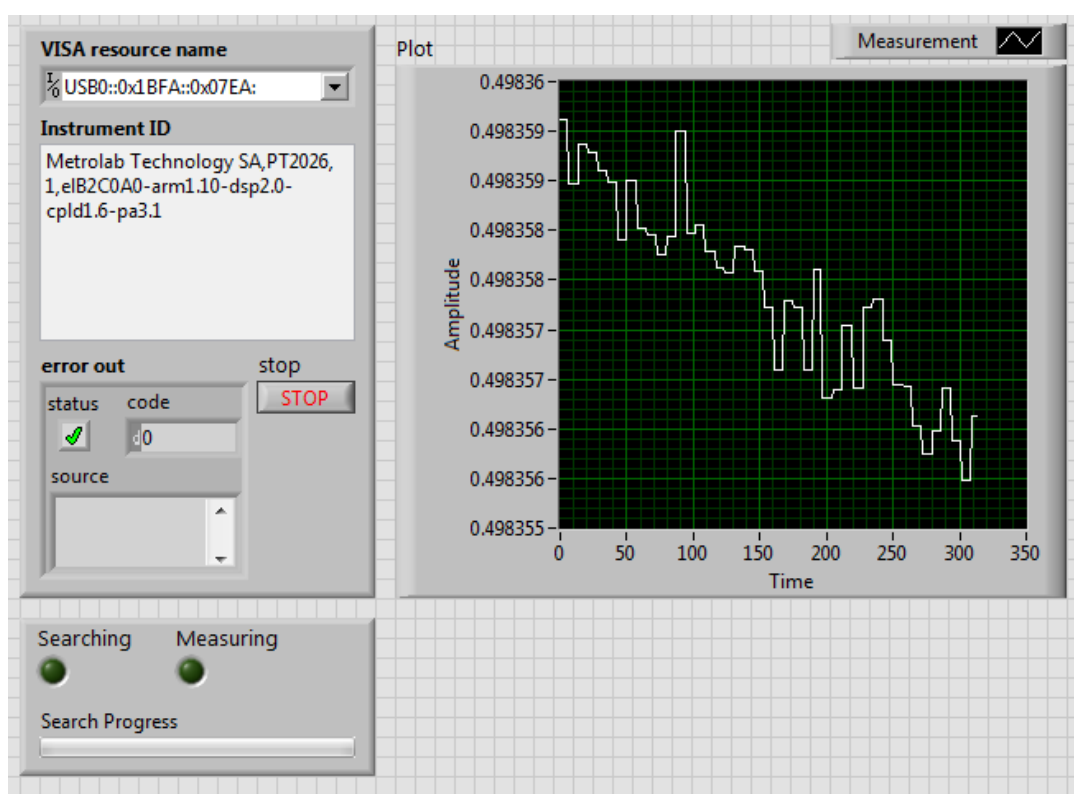




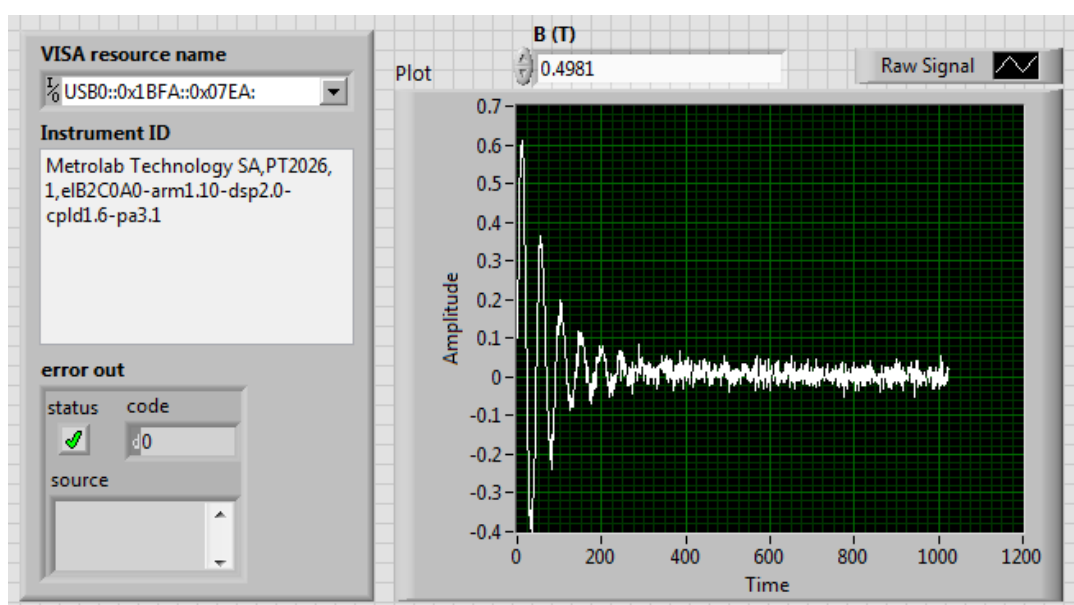
## 5-4 SAMPLE CODE

The folder “Metrolab PT2026/Examples” contains two sample applications:

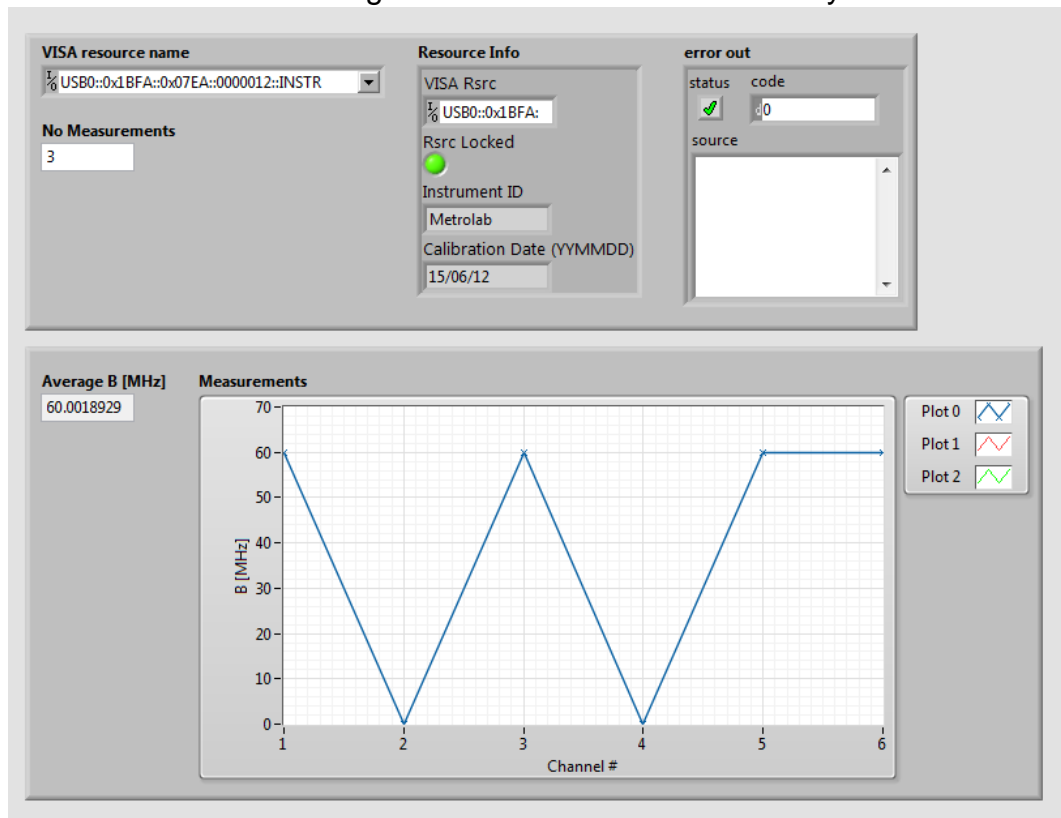
- Metrolab PT2026 Fetch Flux Continuously.vi: Launch a cycle of continuously repeating measurements, wait for the NMR signal search to complete, and fetch and plot the measurements, until the user presses “stop”.



- Metrolab PT2026 Fetch Raw Signal.vi: Launch a single measurement at a given field, wait for it to complete, and retrieve the NMR signal.



- Metrolab PT2026 MFC Measurements.vi: Perform a given number of measurements with a Magnetic Field Camera MFC2046 system.



## 5-5 STANDARD INPUTS AND OUTPUTS

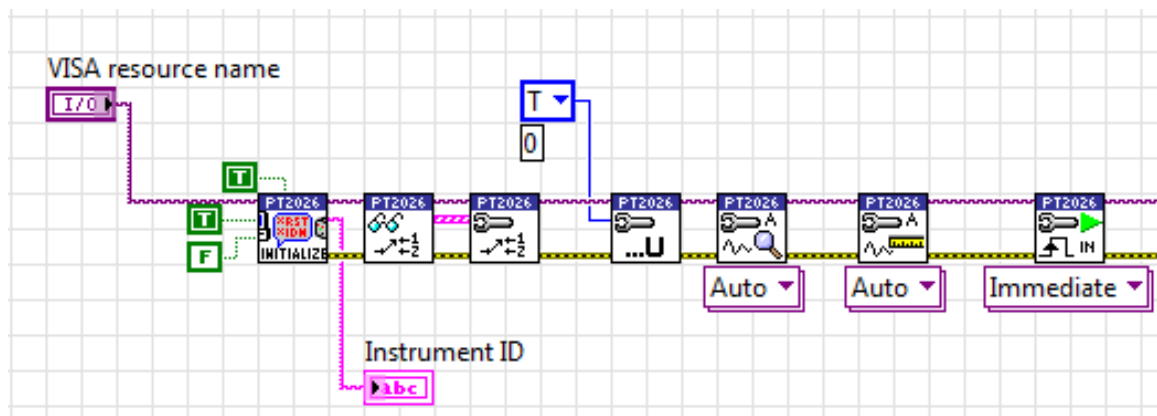
The VIs in the programming API have two standard inputs:

- VISA resource name: Specifies the instrument with which we want to communicate.
- error in (no error): Describes any errors that may have occurred in previous VIs. The value in parentheses is the default value.

and two standard outputs:

- VISA resource name out: Copy of the VISA resource name.
- error out: Describes errors that occurred in this VI or in previous ones.

It is common practice in LabVIEW to place the connectors for these standard inputs and outputs in the four corners of the VI's icon. In a sequence of VIs, the standard outputs of each VI are wired to the standard inputs of the succeeding VI, as shown in the example below:



This chaining serves two purposes: it forces the VIs to be executed in the given order, and it stops the execution of the chain if an error occurs. In fact, each VI checks whether its “error in” input indicates that an error has occurred in a previous VI; if so, instead of its normal function, it simply copies “error in” to “error out.” In this fashion, the “error out” at the end of the chain indicates the precise error that caused the rest of the chain not to execute.

The sections below describe each Virtual Instrument (VI), with its inputs and outputs. The standard inputs and outputs, described above, are not documented for each VI.

## 5-6 INITIALIZE AND CLOSE

### 5-6-1 *Initialize.vi*

Establishes communication with the instrument and optionally performs an instrument identification query and/or an instrument reset. It also places the instrument in a default state needed for other instrument driver operations. Therefore, call this VI before calling other instrument driver VIs for this instrument. Generally, you need to call the Initialize VI only once at the beginning of an application.

ID Query (True)	In	Boolean	Specify whether you want to perform an ID Query. See *IDN, Section 6-2-4.
Reset (True)	In	Boolean	Specify whether you want to reset the instrument during the initialization procedure.
Request Lock (True)	In	Boolean	Specify whether you want to request a lock, thus allowing you to modify parameters.
Instrument ID	Out	String	Instrument ID string returned by ID query. Only filled when ID Query was requested.

### 5-6-2 *Close.vi*

Performs an instrument error query before terminating the software connection to the instrument.

## 5-7 CONFIGURE

### 5-7-1 Configure Averaging.vi

Configure averaging. Polymorphic: Signal or Measurement.			
No. of points (1)	In	I32	Length of averaging filter. The interpretation of this parameter depends on the averaging Type.
Type (0: None)	In	I32 – enum	Averaging type (see :CALCulate, Section 6-2-5): <ul style="list-style-type: none"> <li>- None</li> <li>- Exponential</li> <li>- Moving (not supported for Signal averaging)</li> <li>- Repeat</li> </ul>

### 5-7-2 Configure Input Trigger Count.vi

Configure the input trigger count value.			
No. of Triggers (1)	In	U8	Number of triggers.

### 5-7-3 Configure Input Trigger.vi

Configure the input trigger. Polymorphic: Immediate, Timer, External, or Bus.			
No. of Triggers (1)	In	U8	Number of triggers.
Period (1 s)	In	F64	Timer period. (Timer)
Trigger Slope (0: Positive)	In	U16 – enum	Trigger slope. (External)

### 5-7-4 Configure Measure.vi

Configure the measurement parameters. Polymorphic: Auto or Manual.			
Parameters for Manual:			
Reject (F)	In	Boolean	Reject spurious signals.
Detection Level (1 V)	In	F64	Minimum level of NMR peak relative to average spectral noise [V].
Bandwidth (1600 Hz)	In	F64	Frequency range around peak value used to fit response [Hz].
No. of Fitting Points (16)	In	U32	Number of points used to fit the response.
Allowed Missing Measurements (5)	In	U32	How many missing measurements to allow before aborting measurement mode.
Tracking Parameters:			
Max IF (12000 Hz)	In	F64	Max intermediate frequency [Hz].
Min IF (8000 Hz)	In	F64	Min intermediate frequency [Hz].
Allowed Missing Measurements (0)	In	U32	How many measurements to allow outside the range before correcting the RF frequency.

### 5-7-5 Configure Output Trigger.vi

Enable/disable and configure the output trigger. Polymorphic: Off or On. Parameters for On:			
Trigger Level (UNIT)	In	F64	The measurement value at which Trigger Output is activated [in currently selected units].
Trigger Slope (0: Positive)	In	U16 – enum	Output Trigger slope: - Positive, - Negative, or - Both.
Output Shape (0: DC)	In	U16 – enum	Output Trigger signal shape: - DC: Logic level, depending on Output Polarity - Pulse: Pulse at transition, as defined by Pulse Width and Output Delay
Invert Output Polarity? (F)	In	Boolean	Invert the polarity of the trigger signal. For pulse output, the normal polarity is a positive-going pulse. For DC output, the normal polarity is low level when the field is below the threshold, high level when it is above.
Pulse Width (0.001 s)	In	F64	Trigger pulse width [s]. Valid only if Output Shape is Pulse.
Output Delay (0 s)	In	F64	Output signal hold-off [s].

### 5-7-6 Configure PPM Reference.vi

Set the reference value for PPM measurement units.			
PPM Reference (0 UNIT)	In	F64	Reference value for PPM measurement units. By default, the units of the reference value are the current units.

### 5-7-7 Configure Route.vi

Select one or several active channels.			
Channel List (empty)	In	Channel [ ]	Active channels. The PT2026 searches for an NMR signal on each of these channels, in order, and will start measuring on the first channel where it finds a signal. Each channel is an array of multiplexer port numbers.

### 5-7-8 Configure Search Limits.vi

Configure the search limits, i.e. the range over which the PT2026 searches for an NMR signal.			
High limit (0 UNIT)	In	F64	NMR search maximum, in currently active units.
Low limit (0 UNIT)	In	F64	NMR search minimum, in currently active units.

### 5-7-9 Configure Search.vi

Configure the parameters for searching for the NMR signal. Polymorphic: Auto, Custom, or Manual.

Custom allows you to modify the search parameters. Manual allows you to bypass the search altogether by specifying a field value.

Detection Level (0 V)	In	F64	Minimum level of NMR peak relative to average noise [V]. (Custom, Manual)
Frequency Step (0 Hz: Computed from probe)	In	F64	Frequency step. Zero indicates default step size, as computed from probe data. (Custom)
Value (0 UNIT)	In	F64	Field value. (Manual)

### 5-7-10 Configure Unit.vi

Set the unit of measurement.

Unit (0:T)	In	Enum – U16	<p>Selected measurement units:</p> <p>T: Tesla</p> <p>mT: mTesla (1T=10<sup>3</sup> mT)</p> <p>Gauss: Gauss (1T=10<sup>4</sup> G)</p> <p>kGauss: kGauss (1T=10 kG)</p> <p>ppm: parts per million (relative to value set in “Configure PPM Reference.vi”)</p> <p>MHz (p): proton equivalent NMR frequency (1T ≈ 42.5775 MHz-p)</p> <p>MHz: NMR frequency (depends on gyromagnetic ratio of sample material)</p>
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## 5-8 CONFIGURE – ADVANCED

### 5-8-1 Configure Clock Source.vi

Select the clock source.

Source (0:Internal)	In	Enum – U16	<p>Selected clock source:</p> <ul style="list-style-type: none"> <li>- Internal</li> <li>- External, connected to “10 MHz” back-panel connector</li> </ul>
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### 5-8-2 Configure Digitization.vi

Configure the NMR signal digitization. Polymorphic: Auto or Manual.

Parameters for Manual:

Offset Time (0 s)	In	F64	Offset used to mask the transient at the beginning of the NMR signal, caused by the transmit pulse [s].
Sweep Time (0.01 s)	In	F64	Length of digitized signal [s].
Digitization Rate (1E+6 Hz)	In	F64	Digitization rate [Hz].

### 5-8-3 Configure Format.vi

Set format for returned data.			
Format (0:Ascii)	In	Enum – U16	Selected format: - Ascii: results are returned as ASCII text. - Integer: results are returned as binary data.

### 5-8-4 Configure Matching-Tuning.vi

Set control voltages for probe's matching and tuning varicaps. Polymorphic: Auto or Manual.			
Parameters for Manual:			
Matching (0 V)	In	F64	Matching voltage [V].
Tuning (0 V)	In	F64	Tuning voltage [V].

### 5-8-5 Configure Pulse.vi

Set parameters of RF pulse. Polymorphic: Auto or Manual.			
Parameters for Manual:			
Period (30e-3 s)	In	F64	Pulse period [s].
Width (1e-6 s)	In	F64	Pulse width [s].

## 5-9 CONFIGURE – COMMUNICATION

### 5-9-1 Configure Ethernet.vi

Enable, disable, restart or configure the Ethernet interface. Polymorphic: State or Setting.			
Parameters for State:			
State (0:Enable)	In	enum – U16	Desired state: - Enable - Disable - Restart
Parameters for Setting:			
IP Address	In	String	IP network address. If AUTO, DHCP is used to obtain the IP address, network mask, broadcast address, gateway address, and DNS server address.
Mask	In	String	IP network mask.
Domain	In	String	Domain name.
Broadcast	In	String	IP broadcast address.
Gateway	In	String	IP gateway address.
DNS Server	In	String	IP address of DNS server.
NBNS enabled	In	Boolean	Enable NBNS (NetBIOS Name Service).
Identifier	In	String	System identifier, used for DNS and NBNS.

### 5-9-2 Configure Modbus.vi

Enable and configure the MODBUS interface. Polymorphic: State or Setting.			
Parameters for State:			
Enabled (T)	In	Boolean	Enable the MODBUS protocol on the Ethernet interface.
Parameters for Setting:			
Hosts (empty)	In	String [ ]	Legal host IP numbers. If empty, all IP addresses are accepted.
Legal No. of Connections (4)	In	U32	Legal number of connections.
Use 32bits floats (F)	In	Boolean	Whether 32-bit floating-point numbers are returned, rather than 64-bit floating-point numbers.

### NOTICE

⇒ The MODBUS interface protocol is not yet implemented.

### 5-9-3 Configure USB.vi

Enable or disable the USB interface.			
Enabled (T)	In	Boolean	Enable or disable the USBTMC-USB488 interface. This interface is always enabled at system startup.

### 5-9-4 Configure VXI11.vi

Enable or disable the VXI11 interface.			
Enabled (T)	In	Boolean	Enable or disable the “native” VXI-11 protocol on the Ethernet interface.

## 5-10 ACTION-STATUS

### 5-10-1 Abort.vi

Stop execution of a command.			
Cancel Continuous (True)	In	Boolean	Stop continuous measurements in progress before executing abort.

### 5-10-2 Change Manual Search Value.vi

Changes the current manual search value (the RF sent to the current probe).			
Value (0 UNIT)	In	F64	New RF value, in the selected units.

### 5-10-3 Fetch Search Progress.vi

Retrieve the current percentage of completion of the NMR signal search.			
Value (0 UNIT)	Out	U16	Search progress, as a percentage of the range to be searched.



**5-10-4 Force Operation Complete.vi**

Forces the device into the Operation Complete Command Active State.

**5-10-5 Force Output Trigger.vi**

Force the output trigger.

Usually used to test the output trigger settings. Cannot be performed when the trigger is initiated.

**5-10-6 Initiate.vi**

Initiate a measurement with the current parameters.

Continuous (F)	In	Boolean	Set continuous-trigger state, where the trigger is automatically re-enabled after each acquisition.
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**5-10-7 Preset Status.vi**

Reset Operation and Questionable status registers.

**5-10-8 Query Arbitrary Status.vi**

Read an arbitrary set of operation status registers. (See Section 6-2-2)

Arbitrary Register Set	In	Cluster[]	Each cluster specifies a register to be read:
Register Set (0:OPERation)		enum – U16	Selected register set: - Questionable - Operation - Operation:Bit11 - Operation:Bit12 - Questionable:Bit12
Register (0:Event)		enum – U16	Selected register: - Event - Condition - Enable
Arbitrary Status	Out	U16 []	Value of each of the requested registers.

**5-10-9 Query Current Route.vi**

Retrieve the currently selected channel list and active channel.

Current list	Out	Channel []	Currently selected channel list. Each channel is an array of multiplexer port numbers.
Active channel	Out	Channel	Currently active channel, as an array of multiplexer port numbers.

**5-10-10 Query Status Operation BITx.vi**

Read the device-specific OPERation:BITx fan-out status register. (See Section 6-2-2)			
Register Set (0: BIT11)	In	enum – U16	Selected register set: - Operation:Bit11 - Operation:Bit12
Register (0:Event)	In	enum – U16	Selected register: - Event - Condition - Enable
Status Operation BITx	Out	U16	Value of the requested register.

**5-10-11 Query Status Operation.vi**

Read an operation status register. (See Section 6-2-2)			
Register (0:Event)	In	enum – U16	Selected register: - Event - Condition - Enable
Status Operation	Out	U16	Value of the requested register.

**5-10-12 Query Status Questionable BITx.vi**

Read the device-specific QUEStionable:BITx fan-out status register. (See Section 6-2-2)			
Register Set (0: BIT12)	In	enum – U16	Selected register set: - Bit12
Register (0:Event)	In	enum – U16	Selected register: - Event - Condition - Enable
Status Operation BITx	Out	U16	Value of the requested register.

**5-10-13 Query Status Questionable.vi**

Read a questionable status register. (See Section 6-2-2)			
Register (0:Event)	In	enum – U16	Selected register: - Event - Condition - Enable
Status Questionable	Out	U16	Value of the requested register.

**5-10-14 Query Status Standard Event.vi**

Read the standard event status register. (See Section 6-2-2)			
Status Standard Event	Out	U16	Value of the requested register.

**5-10-15 Register To SRQ.vi**

Set enable bits for the selected register set. (See Section 6-2-2)			
Register Set (0: Questionable)	In	enum – U16	Selected register set: - Questionable - Operation - Operation:Bit11 - Operation:Bit12 - Questionable:Bit12
Enable (0x0000)	In	U16	Selected bits to set.

**5-10-16 Set Transition Filter.vi**

Set and/or clear transition filter bits for the selected register set. (See Section 6-2-2)			
Register Set (0: Questionable)	In	enum – U16	Selected register set: - Questionable - Operation - Operation:Bit11 - Operation:Bit12 - Questionable:Bit12
Transition (0:Positive)	In	enum – U16	Selected transition filter: - Positive - Negative
Set (0x0000)	In	U16	Selected bits to set.
Clear (0x0000)	In	U16	Selected bits to clear.

**5-10-17 Unregister From SRQ.vi**

Clear bits in enable register for the selected register set. (See Section 6-2-2)			
Register Set (0: Questionable)	In	enum – U16	Selected register set: - Questionable - Operation - Operation:Bit11 - Operation:Bit12 - Questionable:Bit12
Disable (0x0000)	In	U16	Selected bits to clear.

### 5-10-18 Wait For Operation To Complete.vi

Block the dispatcher until the operation completes.

If asked, the completion of the operation is notified into the SESR, and the VI closes whereas operation is active. Otherwise, the VI waits for this completion.

Notify (T)	In	Boolean	Request response.
timeout (-1 : unchanged)	In	U16	Timeout value, in ms. If < 0, use previously set timeout.

## 5-11 DATA

### 5-11-1 Fetch.vi

Fetch the measurement results. Polymorphic: Flux, Basic, Advanced, All, or Arbitrary.			
Common parameters:			
No. Measurements (1)	In	U32	Number of measurements to fetch.
Digits (-1)	In	I32	Number of significant digits in result. -1 = default, 6 digits. Only used for ASCII output format – see Section 5-8-3.
Flux Unit	Out	Enum[ ] – U16	Units for each of the returned flux values (see Section 5-7-10).
Specific parameters for Flux:			
Flux (UNIT)	Out	F64[ ]	Measured flux density, in the units given in the corresponding entry of “Flux Unit”.
Specific parameters for Basic:			
Basic fetch results	Out	Cluster[]	Each cluster returns the following information for each measurement result:
Flux (UNIT)		F64	Measured flux density, in the units given in the corresponding entry of “Flux Unit”.
Deviation (ppm)		F32	Standard deviation of the measurement, in ppm (parts per million). Returns NaN (“Not a Number”) if measurement averaging is disabled (see Section 5-7-1).
Uniformity (%)		F32	Rough measure of field uniformity (0 to 100%).
Channel		Channel	Channel selected for measurement, as an array of multiplexer port numbers.
Timestamp		U64	Time stamp [ms].
Specific parameters for Advanced, in addition to those for Basic:			
Intermediate Frequency (Hz)	Out	F64	Measured intermediate frequency [Hz].
Relaxation Time (s)	Out	F32	Measured relaxation time [s].
Radio Frequency (Hz)	Out	F64	Radio frequency [Hz].

Specific parameters for All, in addition to those for Advanced:			
No. NMR Samples (1)	In	U32	Requested number of samples in NMR signal.
No. FFT Samples (1)	In	U32	Requested number of samples in FFT signal.
No. Spectrum Samples (1)	In	U32	Requested number of samples in spectrum.
Polynomial Degree (2)	In	U32	Requested highest degree of coefficients for polynomial fit.
NMR Signal Sample Period (s) Samples	Out	Cluster F32 F32[ ]	Last NMR IF signal acquired: Sample period [s]. NMR signal.
FFT Buffer Frequency Resolution (Hz) Samples	Out	Cluster F32 F32[ ]	Last FFT buffer: Frequency resolution [Hz]. FFT signal.
Spectrum Center Frequency (Hz) Frequency Resolution (Hz) Samples	Out	Cluster F32 F32 F32[ ]	Last peak spectrum: Center frequency [Hz]. Frequency resolution [Hz]. Spectrum values.
Fit Polynom	Out	F64[ ]	Polynomial coefficients, starting at degree 0. The first element is the residue.
Specific parameters for Arbitrary, in addition to those for All:			
Flux?	In	Boolean	Fetch flux density?
Deviation?	In	Boolean	Fetch standard deviation?
Uniformity?	In	Boolean	Fetch field uniformity?
Channel?	In	Boolean	Fetch selected channel?
Timestamp?	In	Boolean	Fetch time stamp?
Intermediate frequency?	In	Boolean	Fetch intermediate frequency?
Relaxation time?	In	Boolean	Fetch relaxation time?
Radio Frequency?	In	Boolean	Fetch radio frequency?

### 5-11-2 Measure Flux.vi

Abort any pending triggers and perform measurements, using either current or default search and measurement parameters. Polymorphic: Scalar, Array.			
Common parameters:			
Default Parm (F)	In	Boolean	If true, use default search and measurement parameters. Otherwise use the currently configured parameters.
No. of Digits (-1)	In	I32	Number of significant digits in result. -1 = default, 6 digits. Only used for ASCII output format – see Section 5-8-3.
Expected Field Value (-1)	In	F64	Constrains the NMR signal search. By default the full range of all active probes is searched.
Channel List ()	In	Channel [ ]	Channel list. Each channel is an array of multiplexer port numbers. The PT2026 searches for an NMR signal on each channel in the list, in order, and will start measuring on the first channel where it finds a signal. The default channel list is defined by "Configure Route.vi" (see Section 5-7-7), or else contains all connected probes.
Specific parameters for Scalar:			
Flux (UNIT)	Out	F64	Flux density measurement, in the currently configured units (see Section 5-7-10).
Specific parameters for Array:			
No. of Measurements (2)	In	U32	Number of measurements to perform.
Flux (UNIT)	Out	F64[ ]	Flux density measurements, in the currently configured units (see Section 5-7-10).

### 5-11-3 Read Channel List.vi

Read the current list of available channels.			
Channel List	Out	Channel [ ]	All channels which have a probe connected. Each channel is an array of multiplexer port numbers.

**5-11-4 Read Probe Data.vi**

Retrieve probe information. Polymorphic: Information, Limits, Hall.			
Parameters for Information:			
Channel List (empty)	In	Channel [ ]	Channels for which to retrieve the information. Each channel is an array of multiplexer port numbers.
Model Numbers	Out	U32[ ]	Model number for each of the specified probes.
Serial Numbers	Out	U32[ ]	Serial number for each of the specified probes.
Parameters for Limits:			
Channel List (empty)	In	Channel [ ]	Channels for which to retrieve the limits. Each channel is an array of multiplexer port numbers.
Maxima (UNIT)	Out	F64[ ]	Range maxima for each of the specified probes, in the currently configured units (see Section 5-7-10).
Minima(UNIT)	Out	F64[ ]	Range minima for each of the specified probes, in the currently configured units (see Section 5-7-10).
The “Hall” instance returns the Hall sensor reading of the currently selected probe. An error is returned if the probe has no Hall sensor.			
Parameters for Hall:			
B Hall	Out	F64	Returned Hall field magnitude.
Bx Hall	Out	F64	Returned Hall X component.
By Hall	Out	F64	Returned Hall Y component.
Bz Hall	Out	F64	Returned Hall Z component.

**5-12 DATA – CONFIGURATION****5-12-1 Query Clock Source.vi**

Query the source selection of the reference clock.			
Source	Out	Enum – U16	Source of the reference clock: - Internal - External

**5-12-2 Query Continuous State.vi**

Query the continuous-trigger state.			
Source	Out	Boolean	True if continuous-trigger state is enabled, where the trigger is automatically re-enabled after each acquisition.

### 5-12-3 Query Digitization Configuration.vi

Query digitization configuration. Polymorphic: Values, Limits.			
Common parameters:			
Automatic	Out	Boolean	Whether sweep time is computed automatically.
Parameters for Values:			
Offset Time (s)	Out	F64	Offset used to mask the transient at the beginning of the NMR signal, caused by the transmit pulse.
Sweep Time (s)	Out	F64	Current seep time.
Digitization Rate (Hz)	Out	F64	Digitization rate.
Parameters for Limits:			
Offset Time (s)	Out	Cluster:	Offset used to mask the transient at the beginning of the NMR signal, caused by the transmit pulse:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Sweep Time (s)	Out	Cluster:	Sweep time:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Digitization Rate (Hz)	Out	Cluster:	Digitization rate:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value

### 5-12-4 Query Ethernet Configuration.vi

Query the settings of the Ethernet interface.			
Enabled	Out	Boolean	Whether or not the Ethernet interface is enabled.
Ethernet settings	Out	Cluster:	Parameters of the Ethernet interface:
IP Address		String	IP network address.
Mask		String	IP network mask.
Domain		String	Domain name.
Broadcast		String	IP broadcast address.
Gateway		String	IP gateway address.
DNS Server		String	IP address of DNS server.
NBNS enabled		Boolean	Enable NBNS (NetBIOS Name Service).
Identifier		String	System identifier, used for DNS and NBNS.



**5-12-5 Query Format.vi**

Query data output format.			
Format	Out	Enum – U16	Data output format: - Ascii - Integer

**5-12-6 Query Input Trigger Configuration.vi**

Query input trigger configuration. Polymorphic: Values, Limits.			
Common parameters:			
Source	Out	Enum – U16	Trigger source: - Immediate - Timer - Bus - External
Trigger Slope (0: Positive)	Out	Enum – U16	Trigger slope for External trigger: - Positive - Negative - Either
Parameters for Values:			
Period (s)	Out	F64	Period for Timer trigger.
No. of Triggers	Out	I32	Number of triggers required to complete an acquisition.
Parameters for Limits:			
Period (s) Value Min Max Default	Out	Cluster: F64 F64 F64 F64	Period for Timer trigger: Current value Minimum value Maximum value Default value
No. of Triggers Value Min Max Default	Out	Cluster: I32 I32 I32 I32	Number of triggers required to complete an acquisition: Current value Minimum value Maximum value Default value

**5-12-7 Query Matching-Tuning Configuration.vi**

Query the matching / tuning configuration of the probe. Polymorphic: Values, Limits.			
Common parameters:			
Automatic?	Out	Boolean	If true, matching/tuning uses the probe's characteristic curves. If false, the matching/tuning voltages are set manually.
Parameters for Values:			
Matching (V)	Out	F64	Matching voltage.
Tuning (V)	Out	I32	Tuning voltage.
Parameters for Limits:			
Matching (V)	Out	Cluster:	Matching voltage:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Tuning (V)	Out	Cluster:	Tuning voltage:
Value		I32	Current value
Min		I32	Minimum value
Max		I32	Maximum value
Default		I32	Default value

### 5-12-8 Query Measure Configuration.vi

Query configuration of measurement parameters. Polymorphic: Values, Limits.			
Common parameters:			
Automatic?	Out	Boolean	Default measurement settings are used.
Reject?	Out	Boolean	Spurious signals are rejected.
Parameters for Values:			
Detection Level (V)	Out	F64	Minimum level of NMR peak relative to average spectral noise.
Bandwidth (Hz)	Out	F64	Frequency range around peak value used to fit response.
No. of Fitting Points	Out	U32	Number of points used to fit the response.
Allowed Missing Measurements	Out	U32	How many missing measurements to allow before aborting measurement mode.
Tracking Params:			
Max IF (Hz)	Out	F64	Max intermediate frequency.
Min IF (Hz)	Out	F64	Min intermediate frequency.
Allowed Missing Measurements	Out	U32	How many measurements to allow outside the range before correcting the RF.
Parameters for Limits:			
Detection Level (V)	Out	Cluster:	Minimum level of NMR peak relative to average spectral noise:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Bandwidth (Hz)	Out	Cluster:	Frequency range around peak value used to fit response:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value

No. of Fitting Points	Out	Cluster:	Number of points used to fit the response:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Allowed Missing Measurements	Out	Cluster:	How many missing measurements to allow before aborting measurement mode:
Value		U32	Current value
Min		U32	Minimum value
Max		U32	Maximum value
Default		U32	Default value
Tracking Params:	Out	Cluster:	
Max IF (Hz)		Cluster:	Max intermediate frequency:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Min IF (Hz)		Cluster:	Min intermediate frequency:
Value		I32	Current value
Min		I32	Minimum value
Max		I32	Maximum value
Default		I32	Default value
Allowed Missing Measurements		Cluster:	How many measurements to allow outside the range before correcting the RF:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value

**5-12-9 Query Measurement Averaging Configuration.vi**

Query the measurement-averaging configuration. Polymorphic: Values, Limits.			
Common parameters:			
Averaging Type	Out	Enum – U16	Selected measurement averaging type: - None: measurement averaging is disabled - Exponential - Moving - Repeat See documentation of :AVERage2 command in Section 6-2-6.
Parameters for Values:			
No. of Measurements	Out	U32	Number of signals in average.
Parameters for Limits:			
No. of Measurements	Out	Cluster:	Number of signals in average:
Value		U32	Current value
Min		U32	Minimum value
Max		U32	Maximum value
Default		U32	Default value

**5-12-10 Query Modbus Configuration.vi**

Query the settings of the Modbus interface.			
Enabled	Out	Boolean	Whether or not the Modbus interface is enabled.
Hosts	Out	String[ ]	Allowed host IP numbers.
No. of Connections	Out	U32	Allowed number of connections.
Use 32-bit floats	Out	Boolean	If set, 32-bit floating-point numbers are returned, else 64-bit.

**5-12-11 Query Output Trigger Configuration.vi**

Query the output trigger settings. Polymorphic: Values, Limits.			
Common parameters:			
Active?	Out	Boolean	Whether the Trigger Output signal is enabled.
Trigger Slope	Out	Enum – U16	Generate trigger signal for the following slope: - Positive: rising field - Negative: falling field - Either
Output Shape	Out	Enum – U16	Trigger Output signal shape: - DC: Logic level, depending on polarity - Pulse: Pulse at transition, with defined width and polarity
Inverted Output Polarity?	Out	Boolean	Polarity of the trigger signal. For pulse output, normal is a positive-going pulse. For DC output, normal is low level when the field is below the threshold, high level when it is above.
Parameters for Values:			
Trigger Level (UNIT)	Out	F64	The measurement value at which Trigger Output is activated, in the currently configured units (see Section 5-7-10).
Pulse Width (s)	Out	F64	Trigger pulse width, if Output Shape = Pulse.
Output Delay (s)	Out	F64	Trigger output signal hold-off.
Parameters for Limits:			
Trigger Level (UNIT)	Out	Cluster:	The measurement value at which Trigger Output is activated, in the currently configured units (see Section 5-7-10):
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Pulse Width (s)	Out	Cluster:	Trigger pulse width, if Output Shape = Pulse:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Output Delay (s)	Out	Cluster:	Trigger output signal hold-off:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value

**5-12-12 Query Pulse Configuration.vi**

Query the configuration of the RF pulse. Polymorphic: Values, Limits.			
Common parameters:			
Automatic?	Out	Boolean	Whether the pulse width and period are calculated automatically from the probe information, or set manually.
Parameters for Values:			
Period (s)	Out	F64	RF pulse period.
Width (s)	Out	F64	RF pulse width.
Parameters for Limits:			
Trigger Level (UNIT)	Out	Cluster:	RF pulse period:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Pulse Width (s)	Out	Cluster:	RF pulse width:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value

### 5-12-13 Query Search Configuration.vi

Query configuration of search parameters. Polymorphic: Values, Limits.			
Common parameters:			
Mode	Out	Enum – U16	Search mode: - Automatic: step through the specified search range with default search parameters. - Custom: as Automatic, but uses the custom detection level and frequency step. - Manual: set the RF frequency where a search is to be performed.
Parameters for Values:			
Detection Level (V)	Out	F64	Minimum level of NMR peak relative to average noise, used in Custom search mode.
Frequency Step (Hz)	Out	F64	Frequency step, used in Custom search mode.
High Limit (UNIT)	Out	F64	Maximum field value, in the currently configured units (see Section 5-7-10).
Low Limit (UNIT)	Out	F64	Minimum field value, in the currently configured units (see Section 5-7-10).
Manual Value (UNIT)	Out	F64	Field value used for Manual search mode, in the currently configured units (see Section 5-7-10).
Parameters for Limits:			
Detection Level (V)	Out	Cluster:	Minimum level of NMR peak relative to average noise, used in Custom search mode:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Frequency Step (Hz)	Out	Cluster:	Frequency step, used in Custom search mode:
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value



High Limit (UNIT)	Out	Cluster:	Maximum field value, in the currently configured units (see Section 5-7-10):
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value
Low Limit (UNIT)	Out	Cluster:	Minimum field value, in the currently configured units (see Section 5-7-10):
Value		U32	Current value
Min		U32	Minimum value
Max		U32	Maximum value
Default		U32	Default value
Manual Value (UNIT)	Out	Cluster:	Field value used for Manual search mode, in the currently configured units (see Section 5-7-10):
Value		F64	Current value
Min		F64	Minimum value
Max		F64	Maximum value
Default		F64	Default value

#### 5-12-14 Query Signal Averaging Configuration.vi

Query the signal-averaging configuration. Polymorphic: Values, Limits.			
Common parameters:			
Averaging Type	Out	Enum – U16	Selected measurement averaging type: - None: measurement averaging is disabled - Exponential - Repeat See documentation of :AVERage1 command in Section 6-2-6.
Parameters for Values:			
No. of Signals	Out	U32	Number of signals in average.
Parameters for Limits:			
No. of Signals	Out	Cluster:	Number of signals in average:
Value		U32	Current value
Min		U32	Minimum value
Max		U32	Maximum value
Default		U32	Default value

#### 5-12-15 Query Unit Configuration.vi

Query the units configuration.			
Unit	Out	Enum – U16	Currently selected units (see Section 5-7-10).
PPM Reference (UNIT)	Out	F64	Reference value for ppm, in the currently selected units.

**5-12-16 Query USB Configuration.vi**

Query the USB configuration.			
Enabled	Out	Boolean	Whether the USBTMC-USB488 interface is enabled. This interface is always enabled at system startup.

**5-12-17 Query VXI11 Configuration.vi**

Query the VXI-11 configuration.			
Enabled	Out	Boolean	Whether the VXI-11 interface is enabled.

**5-13 UTILITY****5-13-1 Error Query.vi**

<p>Queries the instrument for any errors in the instrument's error queue. It will continue to read errors until all errors have been read from the instrument. Any errors will be returned in the error out control.</p> <p>Note: This VI is called automatically by most driver VIs so it is not usually necessary to call this in an application.</p>			
Error Code	Out	I32[ ]	The instrument-specific error code(s) returned by the instrument.
Error Message	Out	String	Message returned by the instrument describing the instrument error(s).

**5-13-2 Find Instruments.vi**

Searches the VISA resource database for PT2026 instruments.			
Interfaces (0: All)	In	Enum – U16	What interfaces to search for: - All - USB - Ethernet
Visa Resources	Out	VISA[ ]	Returned VISA resource references.
Interfaces	Out	Enum[ ] – U16	Corresponding interface type: - USB - Ethernet
Serial Numbers	Out	I32[ ]	Corresponding serial numbers.

**5-13-3 Lock-Unlock.vi**

<p>Request the lock of the instrument.</p> <p>Multiple hosts may communicate with an instrument, but only the one that owns the lock is write-enabled.</p>			
Action (0: Request)	In	Enum[ ] – U16	Requested action: - Request: requests the lock - Release: releases the lock
Locked?	Out	Boolean	Returns true if a lock request was successful.

**5-13-4 Read Case Temperature.vi**

Read the temperature inside the instrument case.			
Case Temperature (°C)	Out	F64	Returned temperature.

**5-13-5 Read File Directory.vi**

Read the file directory of the flash memory.			
Used Bytes	Out	U32	Total bytes used.
Available Bytes	Out	U32	Total bytes available.
File List	Out	Cluster[]	File entries consisting of:
Name		String	- File name
Type		String	- File type
Size		U32	- File size in Bytes

**5-13-6 Read File.vi**

Read the specified file.			
File Path (/yaffs/)	In	String	Path of the file to be read.
File Content	Out	String	Content of file.

**5-13-7 Read Manufacturing and Calibration Dates.vi**

Read the instrument's manufacturing and calibration dates.			
Manufacturing Date (YY/MM/DD)	Out	String	Date of manufacture.
Manufacturing Timestamp	Out	Time	Date of manufacture, as timestamp.
Calibration Date (YY/MM/DD)	Out	String	Date of calibration.
Calibration Timestamp	Out	Time	Date of calibration, as timestamp.

**5-13-8 Recall Instrument Settings.vi**

Recall instrument settings from a settings file.			
Setting Name (/yaffs/settings/)	In	String	Path of settings file.

**5-13-9 Reset.vi**

Resets the instrument and restores the default setup.			
---	--	--	--

**5-13-10 Revision Query.vi**

Retrieve the revision numbers of the instrument's firmware and driver.			
Instrument Driver Revision	Out	String	Returns the instrument driver software revision in the form of a string.
Instrument Firmware Revision	Out	String	Returns the instrument firmware revision numbers in the form of a string. This version and its capabilities are set by the instrument manufacturer.

**5-13-11 Save Instrument Settings.vi**

Save the instrument settings to its internal Flash memory. Beware of VISA timeouts when saving settings. This operation can take several seconds.			
Setting Type (0:All)	In	Enum[ ] – U16	Subset of settings to be saved: - All - Communication - Measure - Triggers - Reference clock - Units
Setting Name ( )	In	String	Name of settings file.

**5-13-12 Upgrade.vi**

Initiate a firmware upgrade.			
------------------------------	--	--	--

**5-13-13 Write-Delete File.vi**

Write or Delete the specified file.			
Operation (0:Write)	In	Enum – U16	Requested action: - Write - Delete
File Path (/yaffs/user/)	In	String	Path of file to be written or deleted.
File Contents ( )	In	String	Contents of file to be written.

**5-14 UTILITY – CONVERSION****5-14-1 BinaryToChannelList.vi**

Convert binary input to a channel list.			
U8 Array	In	U8[ ]	Binary input.
Channel List	Out	Channel [ ]	Converted output: channel list. Each channel is an array of multiplexer port numbers.

**5-14-2 BinaryToX16.vi**

Convert binary input to a 16-bit integer.			
U8 Array (Big Endian)	In	U8 [ ]	Binary input.
U16	Out	U16	Converted output, as U16.
I16	Out	I16	Converted output, as I16.

**5-14-3 BinaryToX16Arr.vi**

Convert binary input to a 16-bit integer array.			
U8 Array (Big Endian)	In	U8 [ ]	Binary input.
U16 Arr	Out	U16 [ ]	Converted output, as U16 array.
I16 Arr	Out	I16 [ ]	Converted output, as I16 array.

**5-14-4 BinaryToX32.vi**

Convert binary input to a 32-bit number.			
U8 Array (Big Endian)	In	U8 [ ]	Binary input.
U32	Out	U32	Converted output, as U32.
I32	Out	I32	Converted output, as I32.
F32	Out	F32	Converted output, as F32.

**5-14-5 BinaryToX32Arr.vi**

Convert binary input to a array of 32-bit numbers.			
U8 Array (Big Endian)	In	U8 [ ]	Binary input.
U32 Arr	Out	U32 [ ]	Converted output, as U32 array.
I32 Arr	Out	I32 [ ]	Converted output, as I32 array.
F32 Arr	Out	F32 [ ]	Converted output, as F32 array.

**5-14-6 BinaryToX64.vi**

Convert binary input to a 64-bit number.			
U8 Array (Big Endian)	In	U8 [ ]	Binary input.
U64	Out	U64	Converted output, as U64.
F64	Out	F64	Converted output, as F64.

**5-14-7 BinaryToX64Arr.vi**

Convert binary input to a array of 64-bit numbers.			
U8 Array (Big Endian)	In	U8 [ ]	Binary input.
U64 Arr	Out	U64 [ ]	Converted output, as U64 array.
F64 Arr	Out	F64 [ ]	Converted output, as F64 array.

**5-14-8 FromArbitraryBlock.vi**

Decode “arbitrary block program data” (see Section 7.7.6 of IEEE 488.2 standard).			
Arbitrary block ()	In	String	Input: “arbitrary block program data” (see Section 7.7.6 of IEEE 488.2 standard).
String	Out	String	Decoded output, as string.
IsArbitraryBlock?	Out	Boolean	Whether the input is valid “arbitrary block program data.”
Data (Hex)	Out	U8 [ ]	Decoded output, as binary (U8 array).
Remaining String	Out	String	Data following the “arbitrary block program data,” as string.

**5-14-9 FromRawChannelList.vi**

Convert SCPI channel list (see Section 6-2-5) to a channel list.			
Raw Channel List (@)	In	String	Input: SCPI channel list (see Section 6-2-5).
Channel List	Out	Channel [ ]	Converted output: channel list. Each channel is an array of multiplexer port numbers.

**5-14-10 IsArbitraryBlock.vi**

Detect whether input is “arbitrary block program data” (see Section 7.7.6 of IEEE 488.2 standard).			
Arbitrary block ()	In	String	Input: “arbitrary block program data” (see Section 7.7.6 of IEEE 488.2 standard).
IsArbitraryBlock?	Out	Boolean	Whether the input is valid “arbitrary block program data.”

**5-14-11 PickChannelFromList.vi**

Select a channel in a channel list.			
Index (0)	In	U32	Channel number.
Channel List (empty)	In	Channel [ ]	Channel list. Each channel is an array of multiplexer port numbers.
Channel	Out	U16[ ]	Selected channel, as an array of multiplexer port numbers.
Channel String	Out	String	Selected channel, as a SCPI channel list (see Section 6-2-5).

**5-14-12 ToArbitraryBlock.vi**

Build “arbitrary block program data” (see Section 7.7.6 of IEEE 488.2 standard). Polymorphic: Array, String.			
Common parameters:			
Arbitrary block	Out	String	Output, as “arbitrary block program data” (see Section 7.7.6 of IEEE 488.2 standard).
Parameters for Array:			
Data In (empty)	In	U32	Data to be transmitted, as binary data.
Parameters for String:			
String ()	In	String	Data to be transmitted, as string.

**5-14-13 ToRawChannelList.vi**

Convert a channel list to a SCPI channel list (see Section 6-2-5).			
Channel List	In	Channel [ ]	Input: channel list. Each channel is an array of multiplexer port numbers.
Raw Channel List (@)	Out	String	Converted output: SCPI channel list (see Section 6-2-5).

# **PROGRAMMING THE PT2026**

## **6-Host Interfaces**

### **6-1 GENERAL**

The PT2026 supports two physical host interfaces, USB 2.0 and Ethernet, and two host interface protocols: “native” and “MODBUS.” The native protocol is based on the following standards, very widespread in the instrumentation industry:

- IEEE 488.2: device control,
- VXI-11: Ethernet device control,
- USBTMC-USB488: USB device control, and
- SCPI: command structure.

The native commands provide access to all the features of the PT2026. The same command set is supported on the USB and Ethernet interfaces.

The MODBUS protocol is commonly used in industrial automation applications. The PT2026 supports the MODBUS protocol only on the Ethernet interface, and it only provides access to a subset of the instrument's functionality.

#### **NOTICE**

⇒ The MODBUS interface protocol is not yet implemented.

If you use the turnkey software or the LabVIEW instrument driver, it is generally not necessary to refer to the information in this chapter. You may, however, want to write a program optimized for your application, without using the LabVIEW instrument driver provided by Metrolab. This chapter will provide you with the information necessary to do so.

The PT2026 was designed to plug-and-play with a Virtual Instrument Software Architecture (VISA) compliant software library – in particular, the NI-VISA library from National Instruments (see <http://www.ni.com/>). If you are not using NI-VISA, you will probably need information that is not provided in this chapter:

- USB 2.0

See “Universal Serial Bus Specification, Revision 2.0, April 27, 2000,” available from [http://www.usb.org/developers/docs/usb20\\_docs/](http://www.usb.org/developers/docs/usb20_docs/).

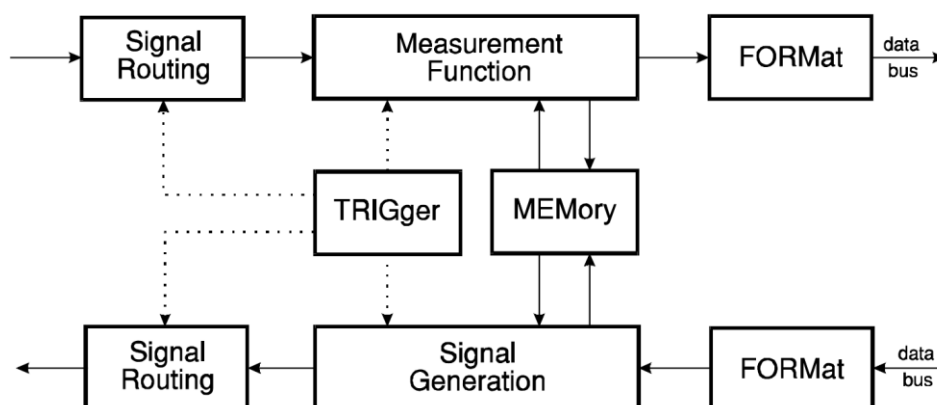


- USBTMC and USBTMC-USB488  
See “Universal Serial Bus Test and Measurement Class Specification (USBTMC), Revision 1.0, April 14, 2003” and “Universal Serial Bus Test and Measurement Class, Subclass USB488 Specification (USBTMC-USB488), Revision 1.0, April 14, 2003,” available from [http://www.usb.org/developers/docs/devclass\\_docs/](http://www.usb.org/developers/docs/devclass_docs/).
- SCPI  
See “Standard Commands for Programmable Instruments (SCPI), VERSION 1999.0, May, 1999,” available from <http://www.ivifoundation.org/specifications/default.aspx>.
- IEEE 488.2  
See “IEEE Standard Codes, Formats, Protocols, and Common Commands for Use With IEEE Std 488.1-1987, IEEE Standard Digital Interface for Programmable Instrumentation, IEEE Std 488.2-1992,” available from [http://standards.ieee.org/reading/ieee/std\\_public/description/im/488.2-1992\\_desc.html](http://standards.ieee.org/reading/ieee/std_public/description/im/488.2-1992_desc.html).
- VISA  
See “VPP-4.3: The VISA Library,” “VPP-4.3.2: VISA Implementation Specification for Textual Languages,” “VPP-4.3.3: VISA Implementation Specification for the G Language,” VPP-4.3.4: VISA Implementation Specification for COM,” all Revision 2.2 (March 17, 2000) by the VXI plug & play Systems Alliance, available from <http://www.ivifoundation.org/specifications/default.aspx>.

## 6-2 NATIVE INTERFACES

### 6-2-1 SCPI instrument model

The PT2026 complies with the Standard Commands for Programmable instruments (SCPI) standard. SCPI uses a standard instrument model to organize the command structure. The diagram below shows the subsystems concerning the signal flow.



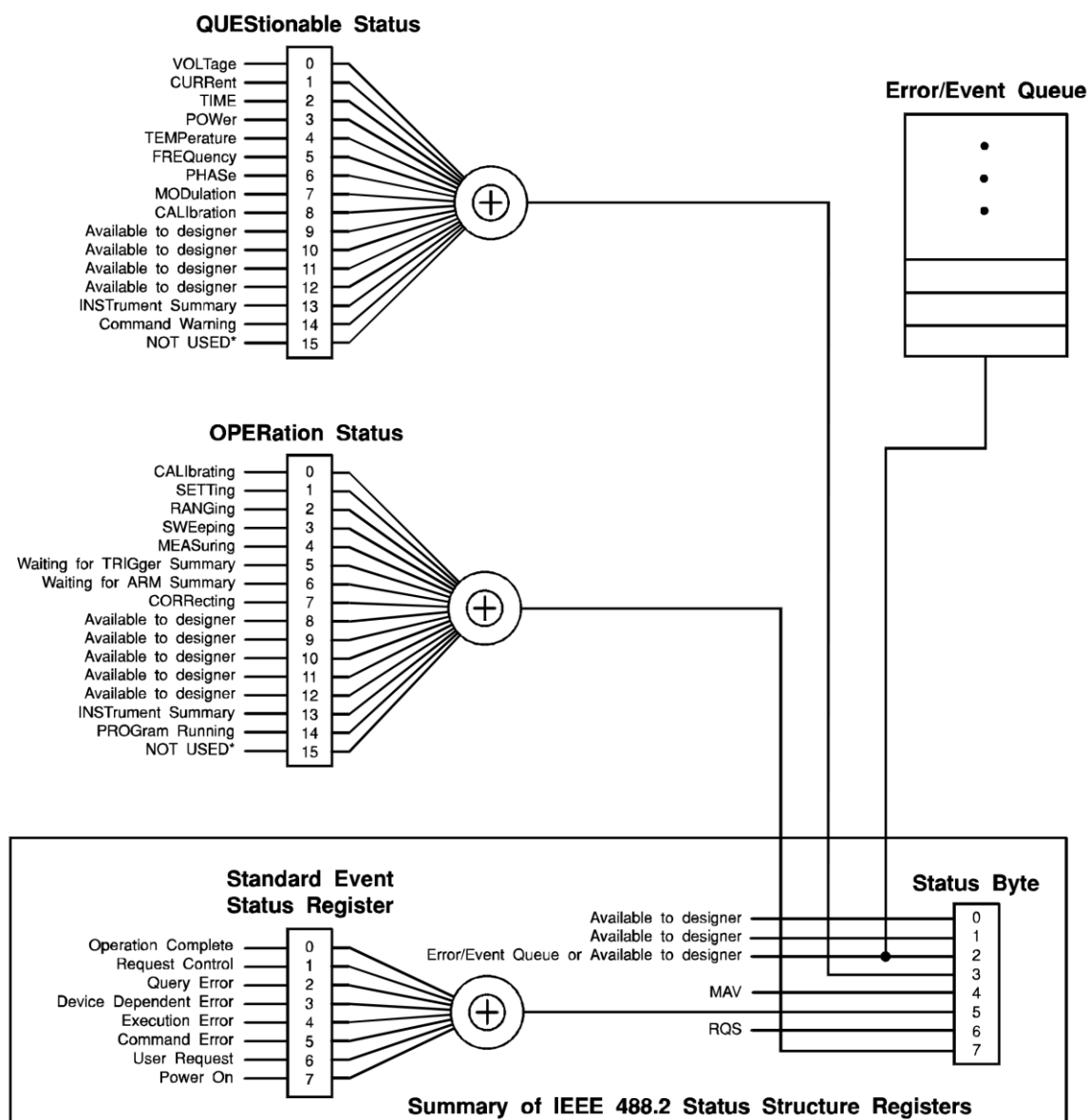
The following table provides a summary of the PT2026 capabilities, organized according to the SCPI instrument model. The supported commands include IEEE 488.2 “Common Commands” (start with “\*”) as well as SCPI commands – see Sections 6-2-4 through 6-2-6 for details. In addition to ASCII commands, the PT2026 also supports certain VXI-11 and USBTMC-USB488 low-level controls, also noted in this table.

Functional Block	Command(s)	Function
Measurement Function	:MEASure ...	Measure with standard settings. Equivalent to *RST;:READ ...
	:READ ...	Measure with custom settings. Equivalent to :ABORT;:INITiate ...;:FETCh ...
	:FETCh ...	Fetch measurement results previously acquired with MEASure, READ or INITiate
	:CONFigure ...	Configure probe matching/tuning, NMR signal search, measurement and tracking
Signal Routing in	... [, <channel_list>]	Parameter for MEASure and READ
	ROUTe	Explicit ROUTe command
INPut	INPut ...	Configure reference clock
SENSe	:SENSe ...	Configure digitization parameters
CALCulate in	:CALCulate:AVERage1	NMR signal averaging
	:CALCulate:AVERage2	NMR measurement averaging
FORMat	:FORMat ...	Set output format
	:UNIT ...	Set output units
TRIGger	*TRG	Generate a trigger
	VXI-11 / USBTMC	
	:ARM ...	Arm Trigger Out signal
	:INITiate ...	Enable triggers

Functional Block	Command(s)	Function
	:ABORt	Abort triggers
	:TRIGger:SEQuence1 ...	Initiate measurement
	:TRIGger:SEQuence2 ...	Generate Trigger Output signal
MEMory	–	Not used in PT2026
Signal Routing out	–	Not used in PT2026
OUTPut	:OUTPut:TRIGger ...	Configure Trigger Output signal
SOURce	:SOURce:PULSe ...	RF pulse characteristics
CALCulate out	*CLS	Clear status
STATus	*STB?, *SRE VXI-11 / USBTMC	Read / enable bits in Status Byte
	VXI-11 / USBTMC	Request service from host
	*ESR?, *ESE	Read / enable bits in Standard Event Status Register
	*OPC, *WAI	Detect and wait for operation complete
	:STATus ...	Read / enable bits in OPERation and QUEStionable registers
	:SYSTem:ERRor	Query error queue
	VXI-11 / USBTMC	Clear input and output buffers
SYSTem	VXI-11 / USBTMC	Remote/local control – ineffective since PT2026 has no local controls
	*RST	Perform reset
	*TST?	Perform self-test (not supported by PT2026)
	*IDN?	Return Instrument ID
	:SYSTem:VERSion	Return SCPI version
	:SYSTem:HELP ...	Provide command help
	:SYSTem:COMMunicate	Set up Ethernet parameters
	:SYSTem:LOCK ...	Lock out other host interfaces
MMEMory	:MMEMory ...	Manipulate parameter files
DIAGnostic	:DIAGnostic: ...	Initiate firmware upgrade

### 6-2-2 IEEE 488.2 / SCPI status registers

IEEE 488.2 compliant instruments have at least two registers: the Status Byte and the Standard Event Status Register. SCPI adds the Operation Status Register, Questionable Status Register and Error/Event Queue. The diagram below, taken from the SCPI standard, provides a good summary. This section describes how the PT2026 uses these status registers.



\* The use of Bit 15 is not allowed since some controllers may have difficulty reading a 16 bit unsigned integer. The value of this bit shall always be 0.

- **Status Byte**

Contains a 1-byte status summary. The PT2026 uses the following bits:

Bit	Name	Description
2	EAV	Error AVailable (in Error/Event Queue)
3	QSB	Questionable Summary Bit
4	MAV	Message AVailable: response ready to be read
5	ESB	Event Summary Bit
6	RQS	ReQuest for Service
7	OSB	Operation Summary Bit

- **Standard Event Status Register**

Latches certain standardized events. The PT2026 uses the following bits:

Bit	Name	Description
0	Operation Complete	*OPC has flagged operation complete
2	Query Error	Error in preceding query
3	Device Dependent Error	Errors specific to the PT2026, including internal errors
4	Execution Error	Error detected during command execution
5	Command Error	Error in preceding command
6	User Request	A parameter has been changed
7	Power On	PT2026 has been powered up

- **QUESTionable Status**

Indicates conditions that may reduce the quality of the measurement. The PT2026 sets the following bits:

Bit	Name	Description
9	Unable to measure	Unable to acquire and measure an NMR signal
10	Ignored setting	A setting was set, but is not taken into account because of other settings
11	Measurement	The quality of the measurement is questionable (e.g. Due to unknown IF in manual search mode)
12	BIT12	Summary Bit: DSP Status

- **QUESTionable:BIT12**

This is a fan-out for bit 12 of the QUESTionable register, a device-specific summary bit.

Bit	Name	Description
0	External Ref Detected	External reference clock is detected
1	External Ref Locked	Locked onto external reference clock
2	Beating Detected	Measurement was rejected as spurious signal (cf. :CONFigure:MEASure:REject command)

- **OPERation Status**

Captures conditions which are part of the instrument's normal operation.

The PT2026 uses the following bits:

Bit	Name	Description
2	RANGing	Scanning for available probes
3	SWEeping	Searching for NMR signal
4	MEASuring	Measuring magnetic field strength
5	Waiting for TRIGger	Waiting for trigger
8	New Acq Avail	New Acquisition Data is Available
9	New Meas Avail	New Measurement Available
11	BIT11	Summary Bit: A parameter has changed
12	BIT12	Summary Bit: Acquisition status

- **OPERation:BIT11**

This is a fan-out for bit 11 of the OPERation register, a device-specific summary bit. It indicates subsystems whose configuration has changed.

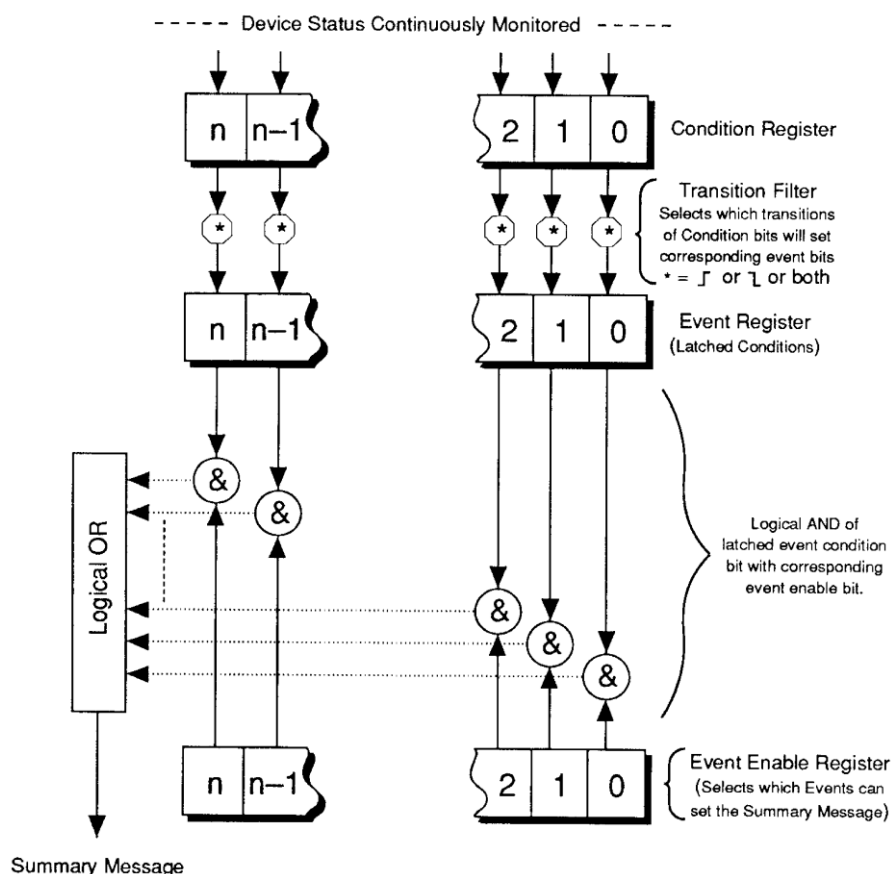
Bit	Name	Description
0	SYSTem	System: system ID, communications, lock
1	STATus	Status: enable bits
2	MEMory	Memory: parameter file loaded
3	MMEMory	Mass memory: parameters saved, created, deleted
4	CONFigure	Measurement: matching/tuning, search, tracking
5	ROUTE	Route: channel selection
6	INPut	Input: reference clock
7	OUTput	Output: trigger output signal
8	SENse	Sense: digitization
9	SOURce	Source: pulse
10	TRIGger	Trigger: measurement trigger, output trigger
11	CALCulate	Calculate: signal & measurement averaging
12	FORMat	Format: output format
13	UNIT	Units: output units

- OPERation:BIT12

This is a fan-out for bit 12 of the OPERation register, a device-specific summary bit.

Bit	Name	Description
0	DSP CPLD Fatal Error	Unable to use DSP and/or CPLD
3	Acquisition overrun	DSP's acquisition buffer is full
4	Trigger overrun	Trigger arrived before previous acquisition complete
5	NMR Path Broken	Active probe was unplugged
6	Peripheral Plugged	A peripheral was plugged into the PT2026

As shown in the figure below, taken from the IEEE 488.2 standard, each of the registers above is actually a set of three registers:



- Condition Register

Read-only register that is constantly updated to reflect the current state of the instrument.

- Event Register

Transitions in a Condition Register are latched in the corresponding Event Register. Event Registers are cleared when read.

- **Event Enable Register**

A mask indicating what bits in the Event Register are included in the Summary bit. The enable mask of the Status Byte is called the Status Enable register, and it determines which bits cause an RQS (ReQuest for Service).

In addition, transition filters are supported for the following register sets: QUESTIONable, QUESTIONable:BIT12, OPERATION, OPERATION:BIT11, and OPERATION:BIT12. Transition filters are used to detect events with positive transitions (false to true) and/or negative transitions (true to false). By default, only positive transitions are detected.

Note that some Condition Register bits signal permanent conditions – for example Power On – and others signal transient events – for example, Command Error. Reading a Condition Register will provide no indication of transient events; only the corresponding Event Register will catch such events.

Also note that for efficiency reasons, status register updates are deferred to the extent possible, and are normally performed only at end of each sequence of commands separated by semicolons. This also means that a ReQuest for Service (RQS) is normally generated only at the end of such a sequence. There are exceptions to this deferral rule, for example if the command sequence includes a status-query command.

Finally, remark that the PT2026 supports multiple IEEE 488.2 connections, and that each connection uses its own set of status registers. Thus status bits that only affect one interface – for example Command Error – are not seen by the other interfaces. However, status bits that indicate general instrument status – in particular the QUESTIONable and OPERATION registers – are propagated to all interfaces. Using this feature, the OPERATION:BIT11 registers can serve to broadcast parameter changes caused by any one interface.

### **6-2-3 IEEE 488.2 controls**

The following low-level functions are defined by the VXI-11 and USBTMC-USB488 protocols. Excluded are the functions that are fundamental to the operation – e.g. in VXI-11: `create_link`, `destroy_link`, `device_write`, `device_read`,



create\_intr\_chan, destroy\_intr\_chan, device\_enable\_srq, device\_intr\_srq, and device\_abort.

Historically, the functions listed below correspond to dedicated hardware signals in IEEE 488.1 (HP-IB or GPIB). Not all functions are supported in both VXI-11 and USBTMC-USB488. In addition, some of these functions are not supported on the PT2026; the Description column will note whether the function has no effect or whether it returns an error.

VXI-11	USBTMC-USB488	Description
device_clear	INITIATE CLEAR	Clears the device input and output buffers
device_trigger	TRIGGER	Assert bus trigger
	SRQ	Requests service from host
device_readstb	READ STATUS BYTE	Read status byte
device_remote	REN CONTROL	Remote Enable – no effect
device_local	GO TO LOCAL	Enable local controls – no effect
-	LOCAL LOCKOUT	Disable local controls – no effect
device_lock device_unlock	-	Acquire or release the device's lock
device_docmd	-	Do special command – unsupported, returns error

#### 6-2-4 IEEE 488.2 common commands

As any IEEE 488.2 compliant instrument, the PT2026 supports the following commands.

Command	Name	Description
*CLS	Clear status	Clear all event registers and queues (not enable registers) and error buffer
*ESE <value>	Program event enable	Program standard event enable register
*ESE?	Event enable query	Read standard event enable register
*ESR?	Event status query	Read standard event register and clear it
*IDN?	Identification query	Returns the following information: manufacturer; model; serial number; versions of hardware and firmware; and purchased options.  Note: This query returns "Arbitrary ASCII Response Data" (see IEEE488.2 standard) and cannot be followed by another query in the same command sequence.
*OPC	Set operation complete	Set the operation complete bit in the standard event register after all commands have been executed
*OPC?	Operation complete query	Returns an ASCII "1" after all commands have been executed
*RST	Reset	Reset device to power-on configuration
*SRE <value>	Program status enable	Program status enable register Important: you must also enable service requests on the host. See Section 6-2-7 for details.
*SRE?	Status enable query	Read status enable register
*STB?	Status byte query	Read status byte register
*TRG	Trigger	Generate bus trigger
*TST?	Self-test Query	Perform complete self-test, return 0 if successful, 1 if not
*WAI	Wait-to-Continue	Wait until previous commands have completed

### 6-2-5 SCPI command syntax

In the command definitions below, the following conventions are used:

[] optional keywords or parameters

<> value

The abbreviated form of each command is written in capital letters. For example, the "MEASure" command can be written as "MEASURE" or "MEAS", or, since capitalization doesn't matter, "measure" or "meas".

Each command is presented with its subcommand(s) indented below it. For example:

:FETCh		
[ :SCALar]		Fetch values acquired during last MEASure, READ or INITiate
[ :FLUX] ?	[<digits>]	Measured flux density
:SIGMa?	[<digits>]	Measurement deviation

According to this table, the following commands are legal:

:FETC:SCAL:FLUX?

:FETC? (same as above, omitting optional keywords)

:FETC:SIGM? (fetches measurement deviation)

The following special parameters are recognized:

MINimum

MAXimum

DEFault

The command syntax

<command>? MAXimum/MINimum[,...]

can be used to query the maximum or minimum values for all parameters of a command.

Some commands take a channel list parameter, to specify the probes to be used. The syntax of a channel list is specified in Section 8.3.2 of Volume 1 of the SCPI standard. In brief:

- Each channel is specified as a list of multiplexer ports separated by exclamation marks. For example “1!2” refers to the probe plugged into channel 2 of a second-level multiplexer plugged into channel 1 of the top-level multiplexer.
- A range of channels can be specified by separating the starting and ending channels with a colon. For example, “1!4:1!6” specifies channels 4 through 6 on the second-level multiplexer.
- An arbitrary list of channels and channel ranges can be specified by separating them with commas. For example, “1!2,1!4:1!6” specifies channels 2, 4, 5 and 6 on the second-level multiplexer.

- The channel list is opened by “(“ and closed by “)”. For example:  
“(1,2,3,4,5,6)”.  
“(1,2,3,4,5,6)”.

Command parameters may be set to their default values by omitting them. To use a parameter after an omitted parameter, keep the commas as placeholders. For example, to measure channels 1 and 2 with the default search range:

MEASURE? ,,(1,2)

Numeric parameters usually require units. Analogously, the values returned by queries contain units, as specified by the UNIT command. In addition, some units can have prefixes:

N = nano ( $10^{-9}$ )

U = micro ( $10^{-6}$ )

M = milli ( $10^{-3}$ )

K = kilo ( $10^3$ )

MA = mega ( $10^6$ )

G = giga ( $10^9$ )

The PT2026 recognizes the following units:

Base unit	Multiplier	Description
T	N, U, M	Tesla (default for magnetic field strength)
GAUSSs	U, M, K	Gauss
PPM		Parts Per Million deviation: magnetic field strength, relative to a reference value set with the :UNIT:PPMReference command
HZP	K, MA, G	Magnetic field strength measurements: equivalent proton NMR resonant frequency
HZ	K, MA, G	Frequency. For magnetic field strength measurements: NMR resonant frequency for the probe being used.
S	M, U, N	Seconds
V	M	Volts

Any parameters whose units indicate magnetic field strength (T, GAUSSs, PPM, HZP, HZ) use the units currently selected by the UNIT command.

#### 6-2-6 SCPI command summary

The following tables list the legal commands for the PT2026, in alphabetical order:

Command	Parameters	Description
:ABORT		Stop execution of a command

Command	Parameters	Description
[ :CALCulate]		Averaging control.
:AVERage1		NMR signal averaging. This is intended to reduce noise in the NMR signal. Measurements are performed on the averaged NMR signal. All subcommands are as for :CALCulate:AVERage2.  Note: This command should only be used with very stable fields. Averaging signals with different frequencies can lead to very confusing behavior.
:AVERage2		NMR measurement averaging. This permits an estimate of the measurement stability. Without measurement averaging, :FETCh:SIGMa? returns NaN ("Not a Number"). A measurement is returned only after averaging.
:COUNT?	[MINimum MAXimum DEFault]	Query averaging count.
:COUNT	<value>  MINimum MAXimum DEFault	Set number of signals in average. The measurement is performed after this number of acquisitions.  min = 1; max = 1000; default = 1.
[ :STATe]?	[DEFault]	Query averaging enabled/disabled.
[ :STATe]	<boolean> DEFault	Enable/disable averaging. The default state is OFF.
:TCONtrol?		Query the termination control setting.

:TCONtrol	EXPonential MOVing REPeat	<p>Specify action after &lt;avg_count&gt; signals:</p> <ul style="list-style-type: none"> <li>- EXPonential:</li> </ul> $AVG_n = \frac{1}{k} X_n + \frac{k-1}{k} AVG_{n-1}$ <p>where k = &lt;avg_count&gt;</p> <ul style="list-style-type: none"> <li>- MOVing:</li> </ul> <p>Moving window: oldest measurement is subtracted from average, and newest measurement is added. This action is not supported for :AVERage1.</p> <ul style="list-style-type: none"> <li>- REPeat:</li> </ul> <p>Clear the average and repeat. This is the default action.</p>
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Command	Parameters	Description
:CONFigure?		Returns string “<function><parameters>” with configuration set by the last CONF command or MEAS? query.
:CONFigure		Configure measurement and search parameters
[ :MEASure]		
:MODE?		Query measure mode.
:MODE	AUTO MANual	<ul style="list-style-type: none"> <li>- Automatic measure mode uses the default measurement settings.</li> <li>- Manual mode uses the values set with the :CONFigure[:MEASure] commands.</li> </ul>
:REJect?	[DEFault]	Query reject setting
:REJect	<boolean> DEFault	Enable or disable spurious signal rejection. The default state is ON.
:LEVel?	[MINimum MAXimum DEFault]	Query detection level [V].
:LEVel	<value>  MINimum MAXimum DEFault	Minimum level of NMR peak relative to average spectral noise [V]. min = 0, default = probe dependent, max = 32V.
:BANDwidth?	[MINimum MAXimum DEFault]	Query frequency range [Hz].
:BANDwidth	<value>  MINimum MAXimum DEFault	Frequency range around peak value used to fit response [Hz].
:POINts?	[MINimum MAXimum DEFault]	Query number of fit points
:POINts	<value>  MINimum MAXimum DEFault	Number of points used to fit the response. min = 3, default = 16, max = 32.
:HYSTeresis?	[MINimum MAXimum DEFault]	Query measurement hysteresis
:HYSTeresis	<value>  MINimum MAXimum DEFault	How many missing measurements to allow before aborting measurement mode
:PROBe		
:MODE?		Query matching/tuning mode.

:MODE	AUTO   MANual	<ul style="list-style-type: none"> <li>- Automatic matching/tuning uses the probe's characteristic curves.</li> <li>- Manual matching/tuning sets the voltages manually</li> </ul>
:MATChing?	[MINimum   MAXimum   DEFault]	Query matching voltage [V].
:MATChing	<value>   MINimum   MAXimum   DEFault	Set matching voltage [V]. min = 0, max = 30, default = 15.
:TUNing?	[MINimum   MAXimum   DEFault]	Query tuning voltage [V].
:TUNing	<value>   MINimum   MAXimum   DEFault	Set tuning voltage [V]. min = 0, max = 30, default = 15.
:SEARch		Configure search parameters.
:LEVel?	[MINimum   MAXimum   DEFault]	Query NMR level for search mode [V].
:LEVel	<value>   MINimum   MAXimum   DEFault	Minimum level of NMR peak relative to average noise [V]. min = 0, default = probe dependent, max = 32V.
:MODE?		Query search mode.
:MODE	AUTO   CUSTom   MANual	<ul style="list-style-type: none"> <li>- Auto search mode steps through the specified search range with default search parameters.</li> <li>- Custom search mode is as the Auto mode but uses the custom user search level and frequency step parameters.</li> <li>- Manual search mode sets the RF frequency where a search is to be performed.</li> </ul>
:FSTep?	[MINimum   MAXimum   DEFault]	Query frequency step [Hz].
:FSTep	<value>   MINimum   MAXimum   DEFault	Frequency step, used in CUSTom search mode [Hz]. Zero indicates default step size, as computed from probe data.



[ :LiMit]		min, max, default: those for the active probe.
:HIGH?	[MINimum MAXimum DEFault]	Query maximum field value [UNIT?].
:HIGH	<value>  MINimum MAXimum DEFault	Maximum field value [UNIT?].
:LOW?	[MINimum MAXimum DEFault]	Query minimum field value [UNIT?].
:LOW	<value>  MINimum MAXimum DEFault	Minimum field value [UNIT?].
:VALue?	[MINimum MAXimum DEFault]	Query manual field value [UNIT?].
:VALue	<value>  MINimum MAXimum DEFault	Field value, for manual mode [UNIT?].
:TRACking		Field-tracking parameters.
[ :LiMit]		min, max, default: those for the active probe.
:HIGH?	[MINimum MAXimum DEFault]	Query maximum IF [Hz].
:HIGH	<value>  MINimum MAXimum DEFault	Max intermediate frequency [Hz].
:LOW?	[MINimum MAXimum DEFault]	Query minimum IF [Hz].
:LOW	<value>  MINimum MAXimum DEFault	Min intermediate frequency [Hz].
:HYSTeresis?	[MINimum MAXimum DEFault]	Query tracking hysteresis.
:HYSTeresis	<value>  MINimum MAXimum DEFault	How many measurements to allow outside the range before correcting the RF frequency.  min = 0, max = 1000, default = 0.

Command	Parameters	Description
<code>:DIAGnostic</code> <code>:UPGRade</code> <code>[:INITiate]</code>		Initiate a firmware upgrade. The PT2026 will disconnect from the USB bus and reconnect as a DFU (Device Firmware Upgrade) device, <sup>2</sup> with the following alternate settings: CODE, DATA, CPLD and HWINFO.

### NOTICE

The `:DIAGnostic:UPGRade:INITiate` command is intended for use by the manufacturer only. It can cause your PT2026 to become nonoperational.

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<sup>2</sup> See "Universal Serial Bus Device Class Specification for Device Firmware Upgrade," Version 1.1, Aug 5, 2004, available from [http://www.usb.org/developers/devclass\\_docs/DFU\\_1.1.pdf](http://www.usb.org/developers/devclass_docs/DFU_1.1.pdf).

Command	Parameters	Description	Binary Format
:FETCh			
[ :SCALar]		<p>Fetch data values acquired during last MEASure, READ or INITiate.</p> <p>The following actions invalidate previously acquired data:</p> <ul style="list-style-type: none"> <li>- Reset;</li> <li>- Continuous trigger initiation; and</li> <li>- Changing trigger parameters.</li> </ul> <p>&lt;digits&gt;: return at least the requested number of significant digits.</p> <p>min = 1, max = 16, default = 3</p>	
[ :FLUX] ?	[<digits>]	Measured flux density [UNIT?].	f64
:SIGMa?	[<digits>]	<p>Standard deviation of measurement [ppm].</p> <p>Standard deviation of measurement. [ppm].</p> <p>Note: Returns NaN ("Not a Number") if :CALCulate:AVERage2 is not enabled.</p>	f64
:UNIFormity?	[<digits>]	Rough measure of field uniformity (0 to 1).	f64
:CHANnel?		Channel selected for measurement [FORMat?].	u8, 0 separated
:TIMEstamp?		Time stamp [ms].	u64
:IFRequency?	[<digits>]	Measured intermediate frequency [Hz]	f64
:RELaxation?	[<digits>]	Measured relaxation time [s]	f64
:RFFRequency?	[<digits>]	Radio frequency [Hz]	f64
:SPRogress?		Search progress, only useful when a search is initiated [%].	u16

:ARRay		Fetch values acquired during the last MEASure:ARRay or READ:ARRay. <size> must be no greater than the acquisition size. If FORMat is ASCii, returns a comma-separated list of values. The other parameters are as for :FETCh:SCALar.	
[ :FLUX ] ?	<size>[,<digits>]	Measured flux density [UNIT?].	f64
:SIGMa?	<size>[,<digits>]	Standard deviation of measurement. [ppm]. Note: Returns NaN ("Not a Number") if :CALCulate:AVERage2 is not enabled.	f64
:UNIFormity?	<size>[,<digits>]	Rough measure of field uniformity (0 to 1).	f64
:CHANnel?	<size>	Channel selected for measurement [FORMat?].	u8, 0 separated
:TIMestamp?	<size>	Time stamp [ms].	u64
:NMRSignal?	<size>	Return <size> samples of the last NMR IF signal acquired. The first datum returned is the sample period in seconds.	Period: f64 Sample: f32
:FFTBuffer?	<size>	Return <size> samples of the last FFT buffer. The first datum returned is the frequency resolution in Hz.	Resolution: f64 Sample: f32
:SPECTrum?	<size>	Return <size> samples of the peak spectrum. The first two data returned are the center frequency and the frequency resolution in Hz.	Center: f64 Resolution: f64 Sample: f32
:FIT?	<size>	Return <size> polynomial coefficients, starting at degree 0. The first datum returned is the residue.	Residue: f64 Coeffs: f32

Command	Parameters	Description
:FORMat		
[ :DATA] ?		Query data output format
[ :DATA]	ASCIi   INTeger	<p>Set format for returned data.</p> <p>ASCIi by default.</p> <p>INTeger returns an IEEE488.2 definite-length block, consisting of an 8-byte header of the form “#6nnnnnn” and followed by nnnnnn bytes of binary data.</p> <p>For the flux density and standard deviation, binary data consists of 64-bit little-endian floating-point values.</p> <p>The binary representation of a channel is a 16-bit little-endian unsigned integer, with channel numbers as defined in Section 6-3-2. The relevant commands are flagged with “[FORMat?]”.</p> <p>The binary representation of a timestamp is a 64-bit unsigned integer [ms].</p>

Command	Parameters	Description
:INITiate		Start measurements.  Note: This command is overlapped; in other words, other commands can be processed while initiated. Moreover, it does not affect the No Operation Pending Flag; in other words, it does not force *OPC, *OPC? and *WAI to wait for the INITiate to complete.
[:IMMediate]		
[:ALL]		Enable trigger with trigger source, trigger count and trigger period set by TRIGger commands
:CONTinuous?	[DEFault]	Query continuous-trigger state
:CONTinuous	<boolean> DEFault	Set continuous-trigger state, where the trigger is automatically re-enabled after each acquisition.  OFF by default.

Command	Parameters	Description
:INPut		
:CLOCK[:SOURce]?		Queries the clock source.
:CLOCK[:SOURce]	INTernal EXTernal	Selects the source of the reference clock. If configured as INTernal, the output from the OCXO, divided by 2, is presented at the Clock connector. For EXTernal, the Clock connector is configured as input. The default is EXTernal; thus if an external clock is connected, it is used; otherwise the OCXO is used.

Command	Parameters	Description
:MEASure		Abort any pending triggers and perform measurements using the default search and measurement parameters.
[:SCALar]		
[:FLUX]?	[<expected_value>] [, <digits>] [, <channel_list>]	<p>Perform a single measurement. &lt;expected_value&gt; serves to constrain the NMR signal search; by default the full range of all active probes is searched [UNIT?].</p> <p>&lt;digits&gt; defines the number of significant digits to return for ASCII FORMat; the default is 6.</p> <p>The PT2026 searches for an NMR signal on each channel in &lt;channel_list&gt;, in order, and will start measuring on the first channel where it finds a signal. The default channel list is defined by the ROUTe command, or else contains all connected probes.</p>
:ARRay		
[:FLUX]?	<size> [, <expected_value>] [, <digits>] [, <channel_list>]	Perform a series of <size> measurements. The other parameters are as for the :MEASure:SCALar command.

Command	Parameters	Description
:MMEMory		Manipulate parameter files.
[ :CATalog]?		Read the file directory. Returns: - Total bytes used - Total bytes available - File entries consisting of: - File name - File type - File size
:DATA?	<filename>	Read the contents of the given file.
:DATA	<filename>,<data>	Write the contents of the given file. Note: <filename> must be a path starting with "/yaffs/user/".
:DELeTe	<filename>	Delete the given file.
:LOAD		
[ :STATe]	<value>,<filename>	Load the given parameter file. Since the PT2026 does not support the *SAV/*RCL commands, <value> must be 0.
:STORe		
[ :STATe]	<value>,<filename>, ALL COMMunication MEASure  TRIGger REFClk UNITs	Store the specified subset of the current parameters. <value> must be 0.



Command	Parameters	Description
:OUTPut[:TRIGger]		Configure Trigger Output signal. The output is initiated by TRIGger:SEquence2.
[:STATe]?	[DEFault]	Query the Trigger Output state.
[:STATe]	<boolean> DEFault	Enable or disable the Trigger Output signal.
:IMMediate		Force Trigger Output signal, as if the field had gone above the threshold.
:SHApe?	[DEFault]	Query Trigger Output shape
:SHApe	DC PULSe DEFault	Set Trigger Output signal shape: - DC: Logic level, depending on POLarity - PULSe: Pulse at transition, as defined by WIDTH and POLarity
:POLarity?	[DEFault]	Query trigger polarity
:POLarity	NORMal INVerted	Set the polarity of the trigger signal. For pulse output, NORMal is a positive-going pulse. For DC output, NORMal is low level when the field is below the threshold, high level when it is above.
:WIDTH?	[MINimum MAXimum DEFault]	Query trigger pulse width [s]. Valid only if SHApe = PULSe.
:WIDTH	<value>  MINimum MAXimum DEFault	Pulse width [s]. min = default = 1 ms, max = $2^{32} - 1$ ms
:DELay?	[MINimum MAXimum DEFault]	Query trigger output signal hold-off [s]
:DELay	<value>  MINimum MAXimum DEFault	Output signal hold-off [s]. min = default = 0 ms, max = $2^{32} - 1$ ms

Command	Parameters	Description
:READ		Abort any pending triggers and perform measurements using the current search, measurement and routing parameters.
[:SCALar]		
[:FLUX]?	[<expected_value>] [,<digits>] [,<channel_list>]	<p>Perform a single measurement. &lt;expected_value&gt; serves to constrain the NMR signal search; by default the full range of all active probes is searched [UNIT?].</p> <p>&lt;digits&gt; defines the number of significant digits to return for ASCII FORMat; the default is 6.</p> <p>The PT2026 searches for an NMR signal on each channel in &lt;channel_list&gt;, in order, and will start measuring on the first channel where it finds a signal. The default channel list is defined by the ROUTe command, or else contains all connected probes.</p>
:ARRay		
[:FLUX]?	<size> [,<expected_value>] [,<digits>] [,<channel_list>]	Perform a series of <size> measurements. The other parameters are as for the :READ:SCALar command.

Command	Parameters	Description
:ROUTe		Multiplexer control
:CLOSe	<channel_list>	Select active channels. The PT2026 will search for an NMR signal on each of these channels, in order, and will start measuring on the first channel where it finds a signal.
:STATe?		Returns list of selected channels [FORMat?].
:ACTive?		Returns the current active probe [FORMat?].
:PROBe		Returns information for the probe connected to the given channel(s)
:MODel?	<channel_list>	Model
:SERialno?	<channel_list>	Serial number
:MINimum?	<channel_list>	Minimum field [UNIT?].
:MAXimum?	<channel_list>	Maximum field [UNIT?].
:SCAN?		Returns an array of all channels which have a probe connected [FORMat?].
:HALL		Return the Hall sensor reading. If the probe has no Hall sensor, this command returns an error.
[ :TOTal ]?		Return the field magnitude
:X?		Return the X component [UNIT?].
:Y?		Return the Y component [UNIT?].
:Z?		Return the Z component [UNIT?].
:LOWLevel?	<message>	Send the given message to the probe/multiplexer system, and return the response. The message is encoded as "arbitrary block program data" (see Section 7.7.6 of IEEE 488.2 standard).

### NOTICE

The :ROUTe:PROBe:LOWLevel? command is intended for use by the manufacturer only. It can cause your PT2026 to become nonoperational.

Command	Parameters	Description
[ :SENSe]		
:SWEep		Set/query digitization parameters
[ :MODE] ?		Query sweep mode
[ :MODE]	AUTO MANual	Compute the sweep time automatically, or set it manually.
:OFFSet		Set/query offset used to mask the transient at the beginning of the NMR signal, caused by the transmit pulse.
:TIME?	[MINimum MAXimum DEFault]	Query offset [s].
:TIME	<value>  MINimum MAXimum DEFault	Set offset [s]. min = 0, max = 100 ms, default = 0
:TIME?	[MINimum MAXimum DEFault]	Query sweep time [s].
:TIME	<value>  MINimum MAXimum DEFault	Set sweep time [s]. min = 1 $\mu$ s, max = 100 ms, default = 10 ms
:FREQuency?	[MINimum MAXimum DEFault]	Query digitization rate [Hz].
:FREQuency	<value>  MINimum MAXimum DEFault	Set digitization rate [Hz]. min = 1 kHz, max = 1 MHz, default = 1 MHz

Command	Parameters	Description
[ :SOURce]		
:PULSe		Set/query the RF pulse parameters
[ :MODE] ?		Query pulse mode.
[ :MODE]	AUTO MANual	Determines whether the pulse width and period are calculated automatically from the probe information, or set manually.
:PERiod?	[MINimum MAXimum DEFault]	Query RF pulse period [s].
:PERiod	<value>  MINimum MAXimum DEFault	Set RF pulse period [s]. min = 30 ms, max = 1000 ms, default = 100 ms
:WIDTh?	[MINimum MAXimum DEFault]	Query RF pulse width [s].
:WIDTh	<value>  MINimum MAXimum DEFault	Set RF pulse width [s]. min = 1 $\mu$ s, max = 200 $\mu$ s, default = 25 $\mu$ s

Command	Parameters	Description
:STATus		
:OPERation   :OPERation:BIT<n>   :QUESTionable   :QUESTionable:BIT<n>		Register set to query/set
[:EVENTt]?		Read and clear event register
:CONDition?		Read condition register
:ENABle?		Query enable register
:ENABle	<numeric_value>	Set enable register
:NTRansition?		Query negative transition filter
:NTRansition	<numeric_value>	Set negative transition filter
:PTRansition?		Query positive transition filter
:PTRansition	<numeric_value>	Set positive transition filter
:PRESet		Reset OPERation and QUESTionable enable registers

Command	Parameters	Description
:SYSTem		
:CDATe?		Return calibration date
:COMMunicate		Definitions for communication
:ETHernet		Ethernet parameters
[ :ENABle]?	[DEFault]	Query whether Ethernet is enabled
[ :ENABle]	<boolean> DEFault	Enable or disable Ethernet default = enabled
:IDENTifier?		Query system identifier
:IDENTifier	<string>	Set system identifier, used for DNS and NBNS
:ADDRess?		Query IP network address
:ADDRess	AUTO <IP_address>	Set IP network address If AUTO, use DHCP to obtain the IP address, network mask, broadcast address, gateway address, and DNS server address.
:MASK?		Query IP network mask
:MASK	<network_mask>	Set IP network mask
:BROadcast?		Query IP broadcast address
:BROadcast	<broadcast_address>	Set IP broadcast address
:GATeway?		Query IP gateway address
:GATeway	<gateway_address>	Set IP gateway address
:DNSServer?		Query DNS server IP address
:DNSServer	<DNS_server_address>	Set DNS server IP address
:DOMain?		Query domain name
:DOMain	<domain_name>	Set domain name
:NBNS?	[DEFault]	Query whether NBNS is enabled
:NBNS	<boolean> DEFault	Enable or disable NBNS default = enabled
:REStart		Restart with new parameters
:MODBus		
[ :ENABle]?	[DEFault]	Query whether the MODBUS interface is enabled.

[ :ENABle]	<boolean> DEFault	Enable or disable the MODBUS interface. default = disabled
:HOSTs?		Query allowed host IP numbers
:HOSTs	<string>	Set allowed host IP numbers. List separated by spaces.
:NCONnections?	[MINimum MAXimum DEFault]	Query allowed number of connections
:NCONnections	<value>  MINimum MAXimum DEFault	Set allowed number of connections default = 1
:F32?	[DEFault]	Query whether 32-bit floating-point numbers are returned.
:F32	<bool> DEFault	Select whether 32-bit floating-point numbers are returned. default = false
:USBTmc		
[ :ENABle]?	[DEFault]	Query whether the USBTMC-USB488 interface is enabled.
[ :ENABle]	<boolean> DEFault	Enable or disable the USBTMC-USB488 interface. This interface is always enabled at system startup. default = enabled.
:VXI11		
[ :ENABle]?	[DEFault]	Query whether the VXI-11 interface is enabled.
[ :ENABle]	<boolean> DEFault	Enable or disable the VXI-11 protocol on the Ethernet interface. default = enabled
:ERRor		
[ :NEXT]?		Query error queue
:HELP		Instrument's help utilities for programmer
:HEADers?		Lists all available commands
:SYNTax?	<command header>	Lists syntax for a command

:LOCK		Lock out other host interfaces
:REQuest?		Attempts lock and returns 1 if successful, 0 if it fails
:RELease		Release lock
:MDATe?		Return manufacturing date
:TEMPerature?		Query the temperature inside the instrument case
:VERSion?		Query SCPI version (e.g. 1999.0)

Command	Parameters	Description
:TRIGger		
[ :SEQuence1]		TRIGger:SEQuence1 initiates a measurement.
:COUNT?	[MINimum MAXimum DEFault]	Query trigger count
:COUNT	<value>  MINimum MAXimum DEFault	Set the number of triggers required to complete an acquisition.  min = 1, max = 2048, default = 1  Note: Resets the trigger system.
:SLOPe?		Query the trigger slope for External trigger.
:SLOPe	POSitive NEGative	The trigger slope for External Trigger.
:SOURce?	[DEFault]	Query trigger source
:SOURce	IMMediate TIMer BUS  EXTernal DEFault	Trigger source: - IMMediate = no wait - TIMer = periodic trigger - BUS = VXI-11 or USB488 - EXTernal = trigger input default = IMMediate Note: Resets the trigger system.
:TIMer?	[MINimum MAXimum DEFault]	Query trigger timer [s].
:TIMer	<value>  MINimum MAXimum DEFault	Set period for Timer trigger [s].  min = default = pulse repetition period x signal averaging count; max = $2^{32}$ -1 ms; resolution = 1 ms  Note: Resets the trigger system.



Command	Parameters	Description
:TRIGger		
:SEQuence2		<p>TRIGger:SEQuence2 generates a Trigger Output signal.</p> <p>Note: TRIGger:SEQuence2 (Trigger Out) is mutually exclusive with TRIGger:SEQuence1:SOURce = EXTernal (Trigger In).</p>
:LEVel?	[MINimum MAXimum DEFault]	Query the trigger level [UNIT?].
:LEVel	<value>  MINimum MAXimum DEFault	<p>The measurement value at which Trigger Output is activated [UNIT?].</p> <p>min = 0, max = 100, default = 0</p>
:SLOPe?		Query the trigger slope.
:SLOPe	POSitive NEGative EITHer	Select Trigger Output on a rising measurement, a falling measurement, or either.

Command	Parameters	Description
:UNIT?	[DEFAult]	Query units
:UNIT	T   MT   GAUSS   KGAUSS   PPM   MAHZP   MAHZ   DEFAult	<p>Set units for the measurement results, or any flux-density parameter (marked as “[UNIT?]”).</p> <p>Supported units:</p> <p>T: Tesla</p> <p>mT: mTesla (1T=10<sup>3</sup> mT)</p> <p>G: Gauss (1T=10<sup>4</sup> G)</p> <p>kG: kGauss (1T=10 kG)</p> <p>ppm: parts per million (relative to value set in “Configure PPM Reference.vi”)</p> <p>MHz: NMR frequency (depends on gyromagnetic ratio of sample material)</p> <p>MHz-p: proton equivalent NMR frequency (1T ≈ 42.5775 MHz-p)</p> <p>default = T</p>
:ALL?		Return a list of all the units supported by this instrument, followed by the divisor for each set of units. The divisor converts T to the associated units.
:PPMReference?	[MINimum   MAXimum   DEFAult]	Query reference value for ppm [UNIT?].
:PPMReference	<value>   MINimum   MAXimum   DEFAult	<p>Set reference value for ppm [UNIT?].</p> <p>min = 0, max = 100, default = 1</p>

### 6-2-7 Programming hints

Here are a few notes on how the native command set is intended to be used:

- For simple measurements with the standard settings, use the MEASure? command. MEASure:ARRay? is the same, except it returns a time series.
- The “expected value” parameter can be used to minimize the search.
- When given a channel list, MEASure? tries to measure on each of the specified channels. This is useful for groups of probes with different field ranges used to measure a single magnet. Preference is given to channels with previous successful measurements, and the result from the first

channel with a successful measurement is returned. Use :FETCh:CHANnel? to know which channel was measured.

- Use the UNIT command to set the units in which the results are returned, and the “digits” parameter to control the number of significant figures returned (assuming FORMat is ASCii).
- For measurements with non-standard parameters, do a CONFigure, INPut, ROUTe, SWEep, SOURce and/or PULSe, followed by a READ. As with MEASure, READ:ARRay? returns a time series. The optional parameters act as for MEASure.
- Use the TRIGger:SEQuence1 commands to control the measurement timing. As trigger source, you can select “IMMediate”, an internal timer, a trigger command sent from the host, or an external Trigger In signal. After setting up the trigger source, you initiate a measurement using the INITiate command. The CONTinuous option immediately re-initiates an acquisition when the previous one has completed.
- Use the :CALCulate:AVERage commands to control averaging. The PT2026 supports averaging of the NMR signal, or averaging of the resulting measurement. Any combination of signal- and measurement averaging is supported. Averaging is only effective for a stable field.
- The measurement integration time depends on the trigger and the measurement averaging options:
  - If CALCulate:AVERage2:TCONtrol = REPeat, the measurement average is computed from a block of new measurements initiated by the trigger.
  - Otherwise, for EXPonential and MOVing mode averaging, the average is computed from one new measurement, initiated by the trigger, plus older measurements that have been acquired in the course of signal tracking (and may never have been returned to the user).
- Use the :OUTPut[:TRIGger] commands to configure an output trigger signal when the measured field value crosses a certain threshold. Use the TRIGger:SEQuence2 commands to initiate the output trigger. Note that the

Trigger In function (TRIGger:SEQuence1:SOURce = EXTeRnal) is mutually exclusive with the Trigger Out function.

- Use the FETCh command to retrieve all data corresponding to a preceding MEASure?, READ? or INITiate command, or FETCh:ARRay for the data corresponding to a MEASure:ARRay?, READ:ARRay? or INITiate with TRIGger:COUNt > 1. The NMR signal and intermediate signal analysis results corresponding to the last measurement can be retrieved with the FETCh:ARRay:NMRSignal? / FFTBuffer? / SPECTrum? / FIT? commands.
- The ROUTe:CLOSe command does the same thing as the channel list in the MEASure and READ commands. The syntax of the channel list is specified by Volume 1 of the SCPI standard, Section 8.3.2. For example, ROUTe:CLOSe (@1) selects channel 1, and ROUTe:CLOSe (@2!3) selects channel 3 on a secondary mux attached to channel 2 of the primary mux. Colons are used for ranges of channels; for example, ROUTe:CLOSe (@3:5) sets up to measure channel 3, 4 or 5. Commas are used to enumerate several channels or channel ranges; for example, ROUTe:CLOSe (@1,2) sets up to measure channel 1 or channel 2.
- Use ROUTe:SCAN? to find all channels with a probe attached. Use ROUTe:PROBe to retrieve information about a probe.
- To determine whether an NMR signal has been found, check the OPERation status register. By setting the appropriate Operation Status Enable bit, plus the OSB (Operation Summary Bit) in the Status Enable register, you can generate a ReQuest for Service (RQS) when the PT2026 enters a given state.
- Using the \*OPC command, you can also generate a ReQuest for Service (RQS) when a measurement (or any other action) is complete. Set bit 0 of the Standard Event Enable register and the ESB (Event Summary Bit) in the Status Enable register. Now, the execution of an \*OPC command will generate an RQS.
- Be sure to check the status after every command. The Standard Event Status register provides a general idea of what went wrong, and the message on the Error/Event Queue (retrieved by SYSTem:ERRor?)

provides a detailed diagnostic. See Section 6-2-8 for the exact interpretation of these error messages. It may be convenient to set up the Enable bits to generate a ReQuest for Service (RQS) when an error is encountered.

- On the USBTMC host interface, if you program the instrument to generate an RQS, it is very important to Enable Service Requests on the host. This posts a read on the appropriate USB endpoint, the Interrupt endpoint. In the USB protocol, the host initiates all transfers; so if the host has not posted a read, the instrument cannot complete its RQS transfer. This will block the Interrupt endpoint, and any other commands using this endpoint – notably the USBTMC-USB488 Read Status Byte function – will fail.
- The MMEMory commands are used to manipulate XML-format parameter files. The user can store custom parameters – e.g. user-friendly channel names – that they would like to store with the instrument.
- Two host interfaces can be synchronized using the STATus:OPERation:BIT11 register. Enable the bits of interest in STATus:OPERation:BIT11, bit 11 in STATus:OPERation, and the OSB in the Status Byte; now, a Service Request (SRQ) will be generated whenever the configuration of one of the corresponding subsystems changes. The application must then read STATus:OPERation:BIT11 to identify which subsystem is affected. Finally, the updated value of these parameters can be read back using the appropriate query. Note that since reading the STATus:OPERation:BIT11 register also resets it, this technique does not work for more than two host interfaces.

### 6-2-8 Error codes

Error codes returned by the native host interfaces are numbered according to the SCPI standard. Sections 21.8.9 through 21.8.16 of Volume 2 of the SCPI manual, “Command Reference”, provide a generic description of all possible error codes. In general, the codes are between -800 and 300. This chapter describes only the error codes produced by the PT2026, and the circumstances that might produce each error.

0	<b>NO ERROR</b>	Zero indicates no error.
-100	<b>COMMAND ERRORS</b>	
-102	Syntax error	The command header did not match any of the known commands.
-104	Data type error	A parameter within the command was of a type invalid for the command.
-115	Unexpected number of parameters	The wrong number of parameters was given in the command.
-120	Numeric data error	<value> parameter to :MMEMory:LOAD or STORE is non-zero.
-123	Exponent too large	The command contains a numeric parameter that was too large to be stored internally. This occurs if the value has an exponent greater than $\pm 43$ .
-151	Invalid string data	The parameters in the command contain an unmatched single or double quote, or invalid setting type in :MMEMory:STORE.
-171	Invalid expression	The parameters in the command contain an unmatched bracket.
-200	<b>EXECUTION ERRORS</b>	
-200	Execution error	*CLR or :ABORT has failed, for an unknown reason.
-210	Trigger error	Input trigger failed, for an unknown reason.
-221	Settings conflict	Indicates that a legal program data element was parsed but could not be executed due to the current device state: <ul style="list-style-type: none"> <li>• Conflicting parameters – see Figure 4.</li> <li>• Received bus trigger, but not in bus trigger mode.</li> <li>• Changing Trigger Out parameters while measuring.</li> <li>• Changing clock source while measuring.</li> <li>• Starting a measurement while already measuring.</li> <li>• Changing measurement parameters while measuring.</li> <li>• Loading new parameters while measuring.</li> <li>• Scanning probes or changing channels while measuring.</li> <li>• Disabling the active interface.</li> <li>• Setting ppm reference in ppm units.</li> </ul>
-222	Data out of range	Indicates that a legal program data element was parsed but could not be executed because the interpreted value was outside the legal range as defined by the device.
-225	Out of memory	The device has insufficient memory to perform the requested operation.
-240	Hardware error	DSP firmware failed to boot.

-257	File name error	<ul style="list-style-type: none"> <li>Filename parameter of :MMEMory:DATA? query is empty.</li> <li>Filename parameter of :MMEMory:DATA command does not start with "/yaffs/user/".</li> <li>Filename parameter of :MMEMory:DELeTe command does not start with "/yaffs/".</li> <li>Filename parameter of :MMEMory:LOAD command does not start with "/yaffs/settings/".</li> <li>Filename parameter of :MMEMory:STORe command is a path.</li> </ul>
-300	<b>DEVICE-DEPENDENT ERRORS</b>	
-350	Queue overflow	A specific code entered into the queue in lieu of the code that caused the error. This code indicates that there is no room in the queue and an error occurred but was not recorded.
-365	Time out error	DSP is not responding.
-400	<b>QUERY ERRORS</b>	
-400	Query error	Generic query error: reset in progress?
-410	Query INTERRUPTED	The host has sent a new command before finishing reading the response to a preceding query.
-420	Query UNTERMINATED	The host is trying to read a response without having sent a complete query.
-440	Query UNTERMINATED after indefinite response	Indicates that a query was received in the same program message after a query requesting an indefinite response was executed. On the PT2026, the only command returning an indefinite response ("Arbitrary ASCII Response Data") is *IDN.
100	<b>INSTRUMENT-DEPENDENT COMMAND ERRORS</b>	
101	Invalid value in list	One or more values in a numeric list parameter are invalid, e.g. floating point when not allowed.
102	Wrong units for parameter	A parameter within the command has the wrong type of units for the command.
103	Invalid number of dimensions in channel	The channel list provided refers to more layers of multiplexers than allowed.
104	Error in channel list	The channel list provided is not valid.
105	Numeric suffix invalid	Too many numeric suffixes, or one or more numeric suffix in the command is invalid, e.g. out of range.
200	<b>INSTRUMENT-DEPENDENT EXECUTION ERRORS</b>	
200	Software Error	The firmware has encountered an unexpected error.
201	No probe	No probe is plugged in.
202	No selected channel	No channel has been specified.
203	Invalid channel list	Channel specification is invalid.
204	Data not all available	The user is trying to fetch more data than was acquired.

205	Topology changed	The channel topology has changed: probes and/or multiplexers have been plugged or unplugged.
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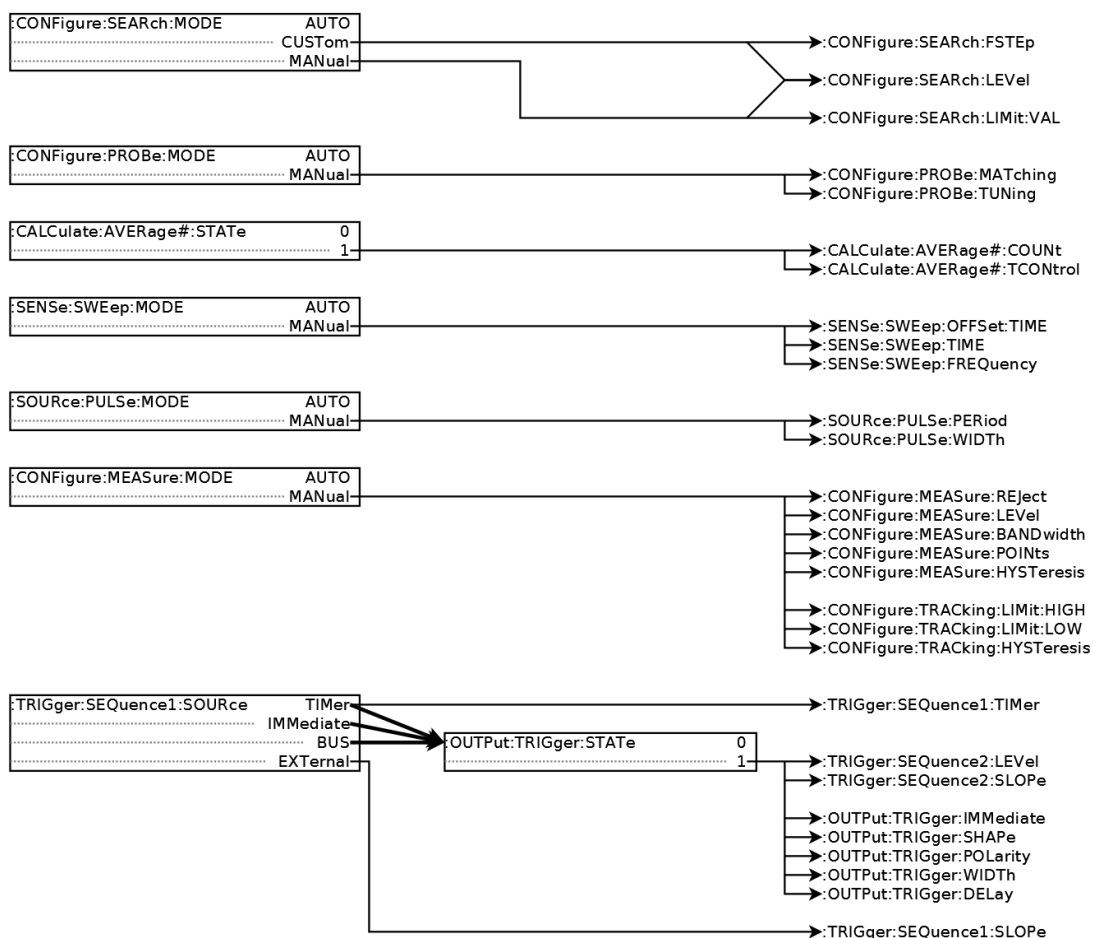


Figure 4. Parameter compatibility matrix.

## 6-3 MODBUS INTERFACE

### NOTICE

⇒ The MODBUS interface protocol is not yet implemented.

#### 6-3-1 Operational overview

- The PT2026 acts as a MODBUS TCP/IP server.
- For each channel to be measured, a set of Holding Registers contains the corresponding parameters for INPut, SOURce:PULSe, SENSe:SWEep, CONFigure, CONFigure, CALCulate:AVErAge1 and CALCulate:AVErAge2. Each channel is mapped to a known Holding Register address according to a well-defined channel map (see Section 6-3-2).



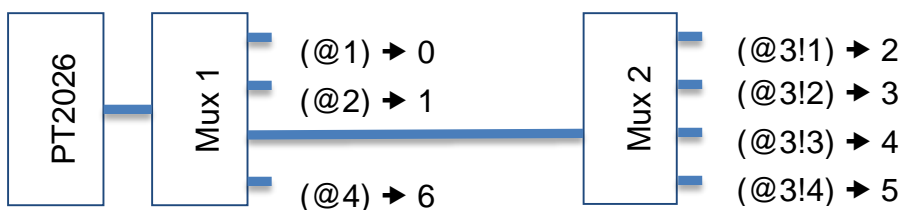
- The MODBUS module in the PT2026 will continuously scan the specified channels. The results of these measurements consist of:
  - the field value
  - the standard deviation
  - the time stamp.
- These results are stored in a set of Input Registers, available at any time for read-out. The Input Registers are mapped to channels in the same order as the Holding Registers. Initially, the Input Registers will return a time stamp of zero, allowing the host to determine whether a valid measurement is available yet.
- The Input Registers also contain the model and serial number of the attached probe. By reading these, the host can determine which channels can be activated.
- Bit-access, via "Discrete Inputs" and "Coils," is not used.
- Floating-point numbers are by default IEEE 64 bit format, and are mapped onto four 16-bit MODBUS registers using the big-endian convention. Optionally, they can be returned in IEEE 32 bit format; in this case, each floating-point number is mapped into the 32 MSBs of the allotted 64-bit slot. No assumption should be made concerning the contents of the unused 32 bits.
- Integers are mapped onto a single 16-bit register.
- The time stamp, indicating the end of the measurement, is an unsigned 32-bit tick count, where each tick is a ms. It is mapped onto two 16-bit registers, using the big-endian convention.
- Strings – for example the probe model – are written into successive 16-bit registers, using the big-endian convention, and are terminated by a null character.
- The MODBUS interface provides the following security features:

- Other interfaces (VXI-11 and USBTMC) can be disabled. The USBTMC interface will be automatically re-enabled upon power-up, to avoid locking up an instrument completely.
- The PT2026 can be constrained to accept MODBUS commands only from a limited set of IP addresses. This configuration option must be set through the native interface.
- The number of simultaneous connections is limited, by default to one. This parameter can be changed through the native interface. Attempted connections that exceed this limit will be refused. Each connection is maintained until terminated by the client.
- A saved instrument configuration can be read out and written back via one of the native interfaces. The output is an XML file that the PT2026 writes to flash memory to save its state. Using this file, a clever programmer could also automatically generate a SCADA configuration corresponding to the PT2026 configuration. Note, however, that the XML file is an undocumented internal interface whose format may change in future releases of the firmware.
- The following PT2026 features are not supported by the MODBUS interface:
  - Control over the time of measurement – be it programmatically, via a timer, via a bus trigger, or via the Trigger Input signal.
  - Detailed status of each measurement
  - Service requests (interrupts)
  - Results in units other than Tesla
  - Results in a format other than binary
  - Reading the NMR signal
  - Generating a Trigger Output signal
  - Changing the Ethernet communications parameters
  - Firmware upgrades

- Note that all these features continue to be available via the native VXI-11 or USBTMC interfaces.

### 6-3-2 Channel mapping

If one considers the multiplexers and their channels as a tree rooted at the PT2026, the channels are mapped to MODBUS registers in the order of a depth-first traversal of this tree. A simple example with two levels of multiplexers illustrates the relation of the SCPI “channel list” notation to the MODBUS channel map:



The same channel map is used for the Holding and Input Registers. The PT2026 MODBUS module supports up to 511 channels.

### 6-3-3 Holding register map

The Holding Registers are read/write registers that control the overall system operation and the operation of each channel. Each register is 16 bits. MODBUS supports up to 64K Holding Registers; this address space is divided into 512 blocks of 128 registers.

The first block controls overall system parameters:

Address	Content
0 – 9	System Identifier (:SYSTem:IDENtifier?)
100	Operation mode: 0 = Standby, 1 = Measure, 2 = Reset, 3 = Reset to factory defaults
110	Security options (may be cumulated): 0x0001 = Disable USBTMC interface 0x0002 = Disable VXI-11 interface
120	Other options (may be cumulated): 0x0001 = Return 32-bit floats instead of 64 0x0002 = Enable external reference clock input

Blocks 1 through 511 control the search and measurement parameters for each possible channel:

Relative address	Content
0-3	Probe matching voltage [V] (:INPut:MATChing?) Zero means automatic mode.
4-7	Probe tuning voltage [V] (:INPut:TUNing?) Zero means automatic mode.
8-11	Pulse frequency [Hz] (:SOURce:PULSe:FREQuency?) Zero means automatic mode.
12-15	Pulse width [s] (:SOURce:PULSe:WIDTh?) Zero means automatic mode.
16-19	Acquisition sweep time [s] (:SENSe:SWEep:TIME?) Zero means automatic mode.
20-23	Acquisition rate [Hz] (:SENSe:SWEep:FREQuency?)
24-27	Acquisition offset [s] (:SENSe:SWEep:OFFSet:TIME?)
28-31	Search threshold (CONFigure:SEARCh:LEVel?)
32-35	Search frequency step (CONFigure:SEARCh:FSTep?) Zero means default value.
36-39	Search lower limit [UNIT?] (CONFigure:SEARCh:LIMit:LOW?) Zero means default value.
40-43	Search upper limit [UNIT?] (CONFigure:SEARCh:LIMit:HIGH?) Zero means default value.
44-47	Search manual value [UNIT?] (CONFigure:SEARCh:LIMit:VALue?)
48-51	Measurement threshold (CONFigure:MEASure:LEVel?)
52-55	Analysis bandwidth (CONFigure:MEASure:BANDwidth?)
56-59	Minimum IF for tracking [Hz] (CONFigure:TRACking:LOW?)
60-63	Maximum IF for tracking [Hz] (CONFigure:TRACking:HIGH?)
100	Search mode (CONFigure:SEARCh:MODE?) 0 = Auto, 1 = Custom, 2 = Manual
101	Frame size (CONFigure:MEASure:FRAMe?)
102	Number of analysis points (CONFigure:MEASure:POINts?)
103	Signal averaging enable (:CALCulate:AVERage1:STATe?): 0 = Disable; 1 = Enable
104	Signal averaging termination control (:CALCulate:AVERage1:TCONtrol?): 1 = EXPonential, 2 = REPeat
105	Signal averaging count (:CALCulate:AVERage1:COUNT?)
106	Measurement averaging enable (:CALCulate:AVERage1:STATe?): 0 = Disable; 1 = Enable
107	Measurement averaging termination control (:CALCulate:AVERage2:TCONtrol?): 1 = EXPonential, 2 = REPeat, 3 = MOVing
108	Measurement averaging count (:CALCulate:AVERage2:COUNT?)
109	Hysteresis for tracking (CONFigure:TRACking:HYSTeresis?)
127	Channel state: 0 = Not present, 1 = Disabled, 2 = Enabled

### 6-3-4 Input Register Map

The Input Registers are read-only registers that provide information about the system as a whole and about each channel, including the measurement results. Each register is 16 bits. MODBUS supports up to 64K Input Registers; this address space is divided into 512 blocks of 128 registers.

The first block returns information about the system as a whole:

Address	Content
0 – 99	System model, version information (*IDN?)
100	System options: 0x0001 External reference clock is enabled

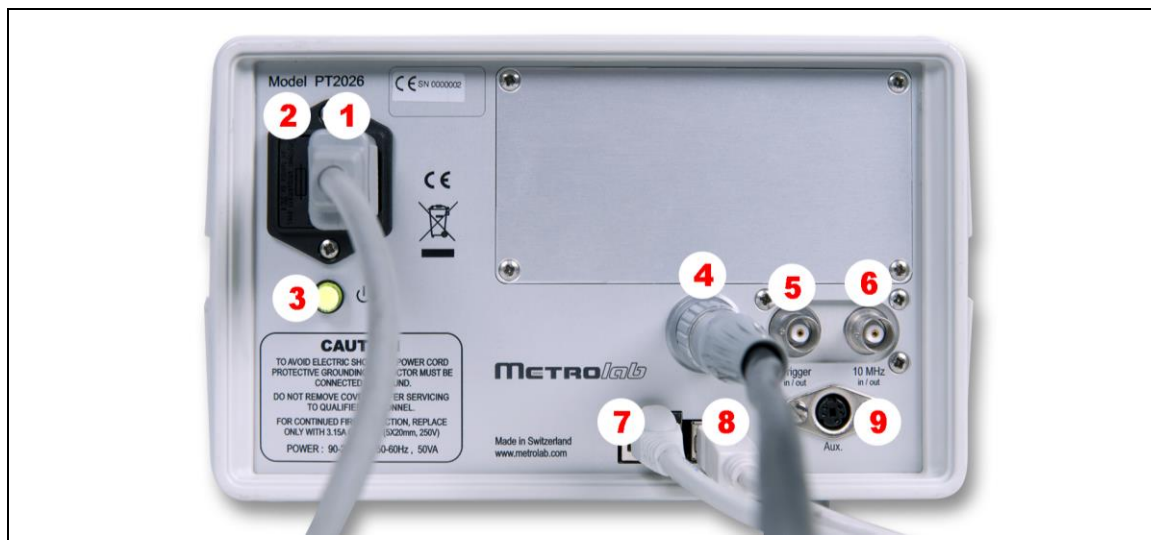
Blocks 1 to 511 return information from each channel, including the measurement results:

Relative address	Content
0-9	Probe Model (:ROUTe:PROBe:MODe1?)
10-19	Probe Serial Number (:ROUTe:PROBe:SERIalno?)
20-23	Measured flux density [UNIT?] (:FETCh:SCALar:FLUX?)
24-27	Standard deviation [UNIT?] (:FETCh:SCALar:SIGMa?)
28-31	Field uniformity [0 to 1] (:FETCh:SCALar:UNIFormity?)
32-33	Time stamp [1 ms ticks] (:FETCh:SCALar:TIMeStamp?) 0 = measurement not yet valid

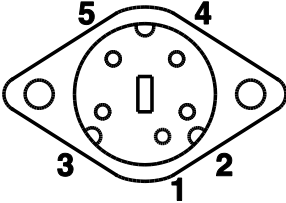
# REFERENCE

## 7-Key Specifications

### 7-1 BACK PANEL



1	Power	50 W, 90 – 260 VAC, 50/60 Hz
2	Fuse	3.15 A (T), 5x20 mm, 250 V
3	Power switch	<p>The front- and back-panel switches have the same functions:</p> <ul style="list-style-type: none"> <li>• Power on: with power off, hold ~1 sec</li> <li>• Power off: with power on, press momentarily</li> <li>• Factory reset: with power on, hold until power-off (~5 sec)</li> <li>• Forced shutdown: when system is hung, hold until power-off (~10 sec)</li> </ul>
4	Probe	The same connector is used for multiplexers and other PT2026 accessories; proprietary pin-out.
5	Trigger	<p>TTL Level; trigger output or input:</p> <ul style="list-style-type: none"> <li>• Trigger output: flags when field attains a given value; B rising, falling or either; pulse or level output; can drive 50Ω.</li> <li>• Trigger input: determines when measurement is taken; rising or falling edge; high impedance input.</li> </ul>
6	Reference clock	<ul style="list-style-type: none"> <li>• Internal reference output: 10 MHz <math>\pm</math> 1 Hz, can drive 50Ω.</li> <li>• External reference input: 10 MHz <math>\pm</math> 30 Hz, 50Ω input.</li> </ul>
7	Ethernet	RJ45

8	USB	USB 2.0, Standard B connector
9	Auxiliary 	Mini DIN 5: <ol style="list-style-type: none"> <li>1. On/Off: short to ground is like pressing power switch;</li> <li>2. NMR signal output;</li> <li>3. Modulation output (continuous-wave only);</li> <li>4. Sync output (pulsed-wave only);</li> <li>5. Ground.</li> </ol>

## 7-2 MEASUREMENT

Frequency range	1 MHz – 1 GHz
Resolution	$\pm 0.1$ Hz (stable field, low gradient, no averaging)
Accuracy	$\pm 5$ ppm, independent of temperature
Max gradient	$> 1000$ ppm/cm
Measurement rate	Up to 33 Hz
Trigger modes	Immediate, Timed, Bus, External

## 7-3 PROBES

Ranges	0.19 – 0.52 T (4 mm Ø p sample) 0.42 – 1.29 T (3 mm Ø p sample) 1.13 – 3.52 T (3 mm Ø p sample) 3.29 – 10.57 T (3 mm Ø p sample) 8.00 – 22.8 T (3 mm Ø D sample) Custom ranges upon request
Size	Standard probe / electronics: 16 x 12 x 231 mm Remote measurement head: 11. Head (p sample): 9.2 x 6.2 x 31.5 mm 12. Head (D sample): 16.2 x 6.2 x 31.5 mm
Cable length	10 m; custom upon request 100 m max total length (incl. multiplexers) Remote measurement head: 13. Electronics – head: 3 m (Ø 4.3 mm)
Search time	Full range typ. $< 10$ s
Multiplexer (optional)	Self-powered; 4 or 8 channels; up to 3 levels (512 probes max)

## 7-4 SYSTEM

Operating temperature	10 – 40 °C; no air inlet
Magnetic environment	< 0.2 T (main unit)
Size	210 x 125 x 324 mm (main unit) 250 x 80 x 180 mm (multiplexer)
Computer interface	USB / USBTMC and Ethernet / VXI-11; IEEE 488.2; SCPI

## 7-5 SOFTWARE

Supported platforms	Microsoft Windows XP SP3 or higher
API	Access to all system features; LabVIEW® 2015 SP1
Licenses	Metrolab (including source code for API) National Instruments (LabVIEW® and NI-VISA run-times)



## REFERENCE

### 8-NMR Magnetometers

*(This section is adapted from an article published in Magnetism Technology International 2011, pp. 78-71.)*

*Amongst a dozen physical phenomena exploited to measure magnetic field strength, NMR (Nuclear Magnetic Resonance) is by far the most accurate. In addition, NMR magnetometers are immune to temperature- or age-related drift. For these reasons, they are widely used as a reference for calibrating other magnetometers, such as the common Hall “gaussmeter.” However, due to technological constraints, their use beyond calibration has been limited to research and a few industrial applications. This may start to change. We review the principles of operation of NMR magnetometers, their benefits and constraints, and recent developments that aim to bring these fantastic instruments into more common use.*

#### 8-1 NMR: A DISCOVERY DESTINED FOR GREATNESS

Building on fifty years of physics research, Nuclear Magnetic Resonance (NMR) was experimentally demonstrated in late 1945 by two independent teams, led by Felix Bloch at Stanford and Edward Purcell at Harvard. Bloch and Purcell received the Nobel Prize in 1952, but industrialization of NMR had already started in 1948, when Russel Varian, a colleague of Bloch's, founded his company to use NMR for chemical analyses. NMR spectrometers are now an essential tool in chemistry. Similarly, Magnetic Resonance Imaging (MRI), first commercialized in 1978, has quickly developed into one of medicine's most important imaging modalities.

Commercial NMR magnetometers became available about the same time as MRI. The principle is straightforward: if a nucleus has spin, it will act like a little compass needle and align itself in a magnetic field. Quantum-mechanically speaking, the nucleus has two energy states: the lower-energy state where the nuclear magnetic moment is aligned with the external field, and the higher-energy state where it is opposed. The gap between these two energy states depends only on the magnitude of the magnetic moment and that of the magnetic field. Since the nuclear magnetic moment is a constant, this energy gap is a perfect measure of magnetic field strength.

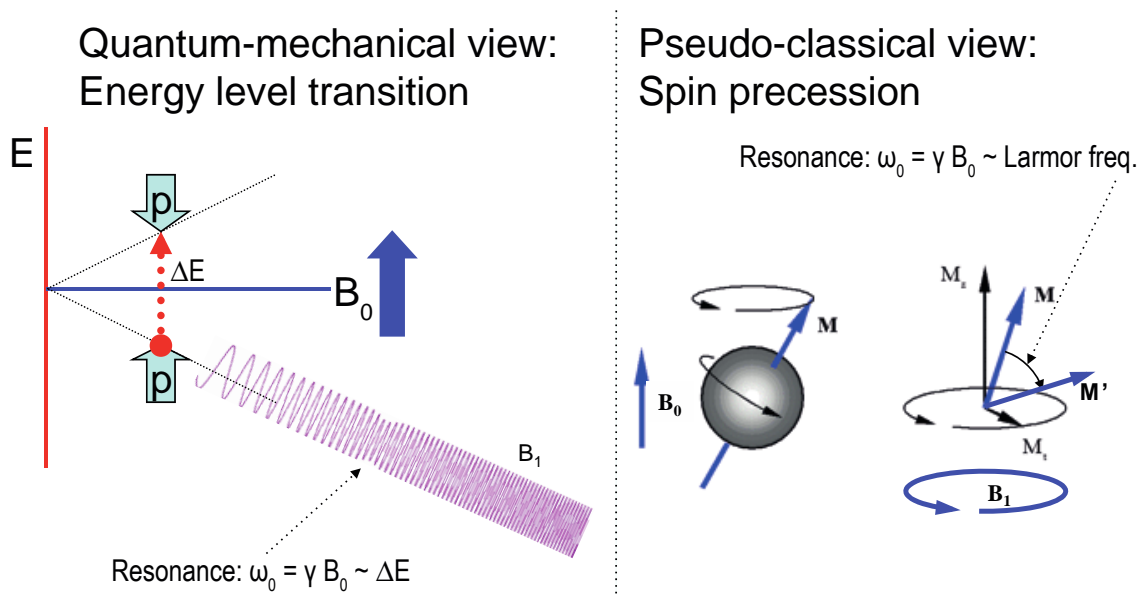


Figure 5. Principles of NMR.

As in spectroscopy, injecting just the right amount of energy will cause the nucleus to transition from the lower to higher energy level. The injected energy is proportional to its frequency, so a magnetic measurement via NMR consists of searching for the frequency – the resonant frequency – that cause the nuclear spins to flip.

The energy is injected by an AC magnetic field (usually called  $B_1$ ), perpendicular to the field being measured ( $B_0$ ). Just like the angular momentum vector of a spinning top precesses around the direction of gravity, the nuclear magnetic moment precesses around  $B_0$ ; resonance occurs when the frequency of  $B_1$  exactly matches the precession, or Larmor, frequency. At resonance,  $B_1$  rotates the spin away from  $B_0$  – even though  $B_1$  is generally orders of magnitude smaller than  $B_0$ .

## 8-2 THE INGREDIENTS FOR AN NMR MAGNETOMETER

Practically speaking, an NMR magnetometer has five main elements:

- **NMR sample:** The sample material must have a nuclear spin; many common isotopes, such as  $^{12}\text{C}$  or  $^{16}\text{O}$ , have zero spin and are transparent to NMR. The material must also exhibit a sharp resonance; in a molecule, the NMR resonance is broadened by interactions with the other nuclei and electrons. Finally, the nuclei must “relax” to their initial, spin-aligned state in a “reasonable” amount of time: too short a relaxation time prevents us from detecting the resonance, but too long renders repeated measurements more

difficult. The most readily available sample material is water (NMR resonance of  $^1\text{H}$ , or proton).

- **B<sub>1</sub> excitation coil:** The B<sub>1</sub> coil must be perpendicular to the field being measured – more or less. Unlike Hall magnetometers, imperfect alignment does not change the measurement result; it simply reduces the effective B<sub>1</sub>, causing some loss of sensitivity.
- **RF generator:** The key parameters are bandwidth ( $\approx 1\text{ MHz}$  to  $1\text{ GHz}$  for  $^1\text{H}$ ), stability ( $\approx \text{ppb/day}$ ), and suppression of spurious frequencies ( $< \approx -80\text{ dB}$ ). Producing such a generator economically is one of the major challenges in designing an NMR magnetometer.
- **Detector:** Various techniques exist to detect the NMR resonance:
  - Marginal oscillator: the B<sub>1</sub> coil is part of a marginally stable oscillator. At resonance, the NMR sample absorbs energy, acting like a resistance, thus lowering the Q and killing the oscillation.
  - Continuous wave (CW): because of the same resistance-like effect, the driving voltage on the B<sub>1</sub> coil dips slightly at resonance. An alternate CW technique is the inductive bridge, where a pick-up coil perpendicular to the B<sub>1</sub> coil detects when, at resonance, spins are rotated by  $90^\circ$ .
  - Pulsed-wave (PW): the sample is excited with a short, wide-band pulse applied to the B<sub>1</sub> coil; then, in a second step, the B<sub>1</sub> coil is used to detect the Larmor precession during the relaxation time.
- **Modulator:** All but the PW technique require some sort of modulation, to detect a change when crossing the resonance. The most obvious solution is to modulate the frequency, but it is often more practical to add a small coil to modulate B<sub>0</sub>, taking care to synchronize the measurement with the modulation zero-crossing.



Figure 6. The Metrolab Precision Teslameter PT2025.

Figure 7 shows the architecture of an actual instrument, Metrolab's Precision Teslameter PT2025. A detailed functional description can be found in the manual; here we just want to point out the five key elements: the Sample,  $B_1$  Coil and Detector are all physically located in the probe; the RF Generator consists of a Voltage Controlled Oscillator (VCO) and frequency dividers, located in the main unit; and the Modulator consists of a current generator in the main unit connected to a field modulation coil in the probe. Other important features of this architecture are the tracking loop that automatically adjusts the VCO to stay centered on the resonance, and the auto-tuned variable capacitance, forming a resonant tank circuit with the  $B_1$  coil and thus greatly improving the SNR. The basic design dates from 1985, and these instruments now represent the overwhelming majority of the world's installed base of NMR magnetometers.

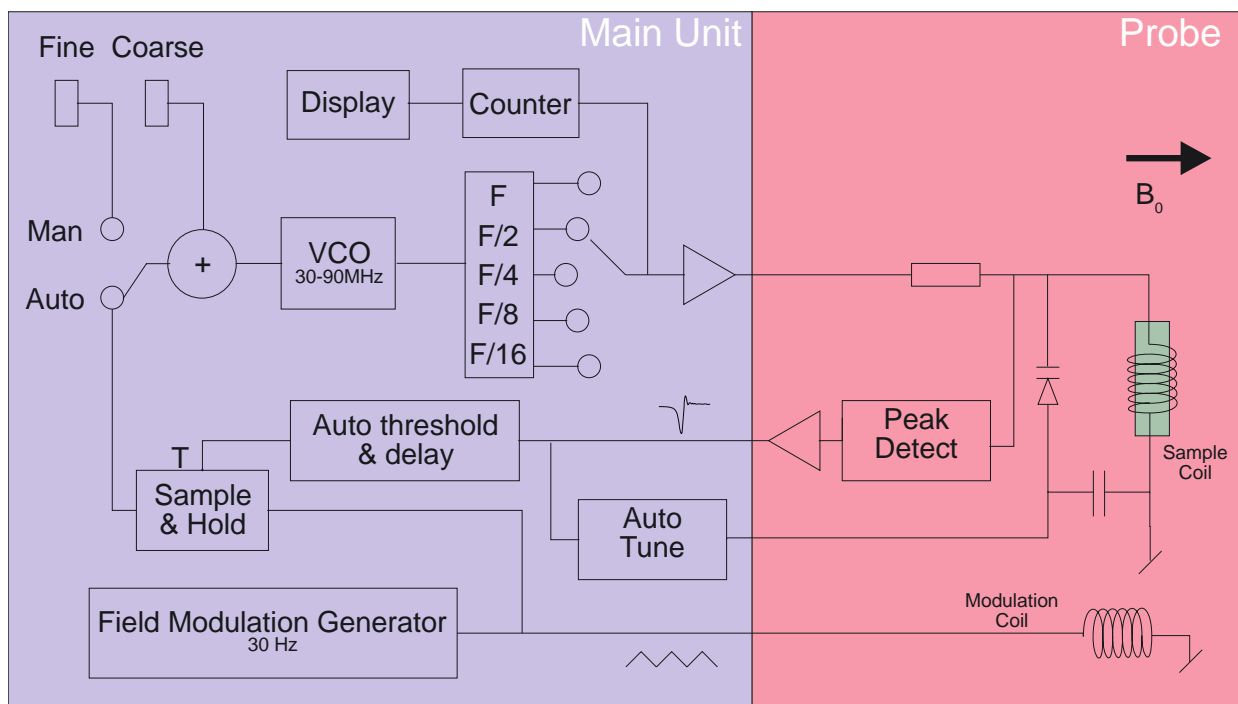


Figure 7. PT2025 functional block diagram.

### 8-3 PROS AND CONS

Compared to other magnetometer technologies, NMR has obvious benefits. First and foremost is the astounding precision and accuracy. The resolution is essentially limited by the stability of the RF generator and the sample's resonance width; for existing instruments such as the PT2025, this is around 0.1 parts per million (ppm). The absolute accuracy is limited by low-level field distortion caused, for example, by the susceptibility of materials surrounding the NMR sample; for the PT2025, this is around 5 ppm, which is more than enough to calibrate other magnetometers. It also allows researchers to measure minute magnetic effects such as the “training” of superconducting filaments. Last but not least, NMR is the only way to create a field map with enough resolution to guarantee the uniformity needed for MRI or NMR spectroscopy – NMR magnetometry serving its NMR sister technologies.

NMR is also essentially drift-free. Drift of the RF generator reference clock is important, but can be readily maintained at extremely low levels – parts per billion (ppb) or better. Finally, unlike Hall- or coil/integrator based magnetometers, NMR measures the total field  $B$ , regardless of the exact probe orientation.

Obviously, NMR magnetometers also have limitations. The most important is that it only works in a uniform magnetic field. The reason is simple: the sample has a

finite size ( $\approx 4$  mm diameter); a magnetic field gradient causes one end of the sample to resonate at a different frequency than the other, and the higher the gradient, the harder it becomes to determine “the” resonant frequency. Today’s limit is a field gradient on the order of 100 to 1000 ppm/cm. Most magnets are very far from this level of field uniformity.

Since NMR is a relatively slow technology – on the order of 10 to 100 ms per measurement – it is of limited use for rapidly varying fields. Finally, the field needs to be relatively strong for the spin-flip energy gap to rise significantly above the room temperature thermal noise. For example, the range of PT2025 probes starts at 40 mT, or roughly 1000x the earth’s field. Sadly, many interesting and useful applications fall into that three-order-of-magnitude “NMR no-fly zone.”

NMR magnetometers have continued to evolve since 1985. Many changes simply follow industry trends in terms of electronic components, microprocessors, displays, controls and computer interfaces. However, some improvements allow us to push back key limitations, opening the way for a more widespread use of NMR magnetometers. Let us take a look at some of these.

#### **8-4 MORE IS BETTER**

The first major step came in 1992, with the introduction of multi-probe systems for mapping MRI magnets – what eventually became Metrolab’s Magnetic Field Camera MFC3045. Up to 32 NMR probes functioning in parallel addressed the need for faster field maps. Other key improvements include the use of a Direct Digital Synthesizer (DDS) as RF Generator, which allows using frequency modulation and eliminating the field modulation coils. Also, the auto-tuning circuit with a varactor diode was replaced with a simple trim cap, reducing the measurement range from 300% per probe for the PT2025 to around  $\pm 2\%$  – a perfectly acceptable simplification for MRI magnets, where the target field is exactly known. Finally, the mechanical aspects of the instrument were optimized for MRI production, with robust housing and connectors, remote control, etc.



Figure 8. The Magnetic Field Camera probe array:  
(a) cut-away showing the probe positions; (b) as installed in a horizontal MRI magnet.

With this instrument, the time to map a magnet was reduced from many hours to around five minutes. Productivity gains add to technical benefits: less magnet drift and fewer human errors, combined with improved positioning precision, meant more self-consistent maps and better convergence of the entire magnet-tuning process. It is fair to say that without the development of multi-probe NMR systems, MRI would not be what it is today.

## 8-5 BETTER IS BETTER

For almost a decade, Metrolab has been working on a new-generation, “all digital” NMR magnetometer, the PT2026. As we can see from Figure 9, the term “all digital” is to be taken with a grain of salt: “all digital control” is more accurate. Other important technical improvements include:

- **RF Generator:** up to around 1 GHz, instead of 90 MHz for the PT2025. Absolute frequency control simplifies the architecture and improves stability.
- **Detection:** support for either continuous-wave (CW, like PT2025) or pulsed-wave (PW, as shown in Figure 9). Improved performance in poor-SNR environments due to sophisticated Digital Signal Processing (DSP).
- **Modulation:** field modulation for CW probes, or none for PW probes.
- **Multi-probe capability:** up to 512 PW channels, or 16x the MFC3045.
- **Probe tuning:** variable, like PT2025, or fixed, like MFC3045. For PW probes, dynamic matching improves power transfer.
- **Search of NMR resonance:** assisted by 3-axis Hall probe.



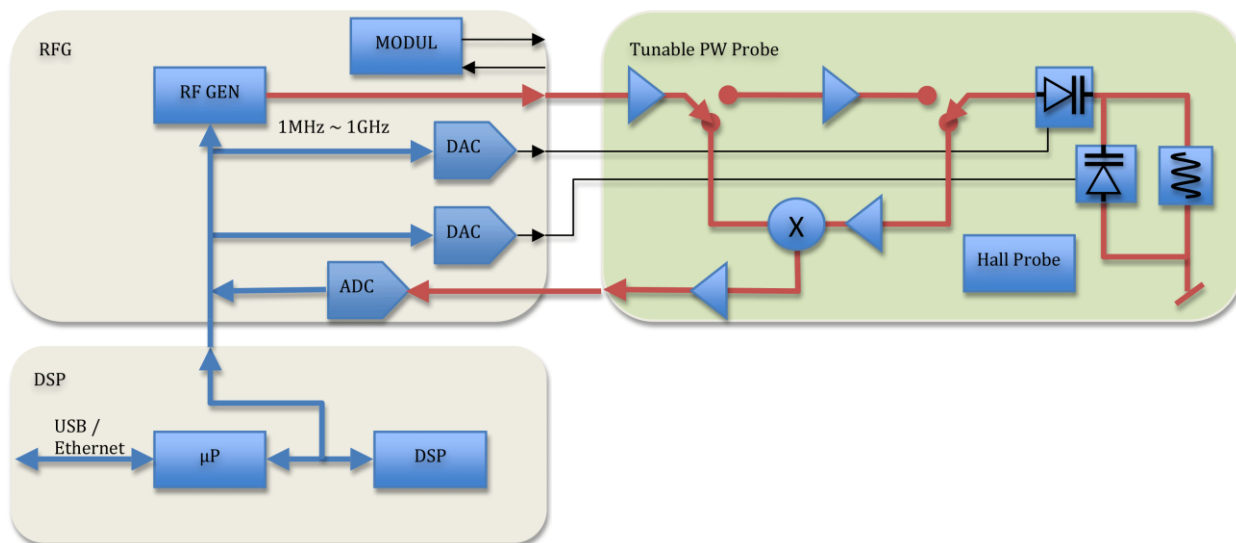


Figure 9. PT2026 functional block diagram.

What will change from a user's standpoint? For measurements above 2 T, delicate heavy water ( $^2\text{H}$ , or deuterium) based probes will be replaced with robust rubber ( $^1\text{H}$ ) based probes. The maximum field will go from not quite 14 T to over 20 T – or practically unlimited if one accepts deuterium probes. The measurement resolution remains around 1 Hz, but the measurement rate will be an order of magnitude faster. With optional signal averaging, measurement speed can be traded off against resolution; for typical NMR spectroscopy magnets, the resulting resolution starts to approach the parts per billion.

Massively parallel multi-probe systems allow us to conceive fixed, 3D probe arrays rather than rotating 2D probe arrays – resulting in even faster mapping and better positioning accuracy. In addition, the new PW probe arrays will share one set of electronics for all probes, making the actual array simpler and smaller. We have already demonstrated probe arrays that fit into the 40 mm bore of a conventional NMR spectrometry magnet – almost an order of magnitude smaller than currently possible.

In addition to maximum field, resolution, speed and multiple probes, the PT2026 promises another key improvement: tolerance of non-uniform fields, where we expect the combination of higher SNR and a DSP to provide close to an order of magnitude improvement. This, combined with usability improvements like fast search assisted by a 3-axis Hall probe, will significantly push back the limitations of NMR magnetometers.



## 8-6 EVEN LESS CAN BE BETTER

The PT2026 leaves one major barrier untouched: that for fields below 40 mT.

There are four basic approaches to address this problem:

- Larger sample: provides more nuclei and thus a better SNR. However, the large probe size is a great practical hindrance.
- Electron-Spin Resonance (ESR): very similar to NMR, except based on electron spin instead of nuclear spin, with a gyromagnetic ratio in the GHz/T instead of the MHz/T. Currently known ESR probe materials are chemically unstable and/or have wide resonance widths, making them unsuitable for an industrial instrument.
- Pre-polarization: improve the SNR by aligning the spins in a strong magnet before measuring the resonance in the weak field. Requires physically transporting the sample material – for example water – from the polarization magnet to the B<sub>1</sub> coil.
- Higher pick-up sensitivity: replace the coil with a more sensitive pick-up, such as a superconducting coil or Superconducting Quantum Interference Device (SQUID).

In the past, Metrolab has shipped PT2025 probes with large samples and with ESR samples; neither proved to be entirely satisfactory. Metrolab is now pursuing the third option, a flowing water system, specifically for calibrating Hall probes over a wide range of fields ( $\pm 2$  T) with a single probe. We also continue to search for innovative ESR sample materials. High-sensitivity pickups may be a promising long-term solution, but the technological complexity is currently daunting.

Metrolab earned their dominant position in NMR magnetometry by making a delicate piece of laboratory equipment work in the rough-and-tumble manufacturing environment. Our equipment goes from the arctic cold of an airplane hold to the sauna-like Singapore summer, gets dropped by the baggage handlers, yanked into place by a burly technician pulling on the probe cable – and is then expected to deliver parts-per-million accuracy. More than twenty years later, such systems are still returned for calibration (and occasionally, repair). We are committed to continuing to push back the limitations as far as physics and good engineering allow.