pcSQUID™ User's Manual

PCS100 Control Software

PCS100DA Control Software with Data Acquisition

Programmable Feedback Loop
Model PFL-100

Personal Computer Interfaces
Models PCI-100 and PCI-1000

STAR Cryoelectronics

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Revision Record		
Date	**Revision**	**Description**
September 15, 1997	1.0.0	Initial Release Draft
December 1, 1999	2.0.0	STAR Cryoelectronics Release
September 25, 2001	2.1.0	Change of address; misc. corrections
January 27, 2003	2.2.0	Master mode, customizable initialization files, hot key assignments, 0.1 sec heater precision
November 15, 2003	2.3.0	Data Acquisition (for NI DAQ), Spectrum Analysis, Autotune/Calibration Modules
July 7, 2004	2.4.0	Remote Control Module

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The PCS100 and PCS100DA Control Software was developed using National Instruments' LabWindows/CVI. Copyright National Instruments Corporation. All rights reserved.

TECHNICAL SUPPORT

If you have any questions or comments about this product or other products from STAR Cryoelectronics, please contact:

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WARRANTY

STAR Cryoelectronics Limited Warranty

STAR Cryoelectronics warrants this product for a period of twelve (12) months from date of original shipment to the customer. Any part found to be defective in material or workmanship during the warranty period will be repaired or replaced without charge to the owner. Prior to returning the instrument for repair, authorization must be obtained from STAR Cryoelectronics or an authorized STAR Cryoelectronics service agent. All repairs will be warranted for only the remaining portion of the original warranty, plus the time between receipt of the instrument at STAR Cryoelectronics and its return to the owner.

This warranty is limited to STAR Cryoelectronics products that are purchased directly from STAR Cryoelectronics, its OEM suppliers, or its authorized sales representatives. It does not apply to damage caused by accident, misuse, fire, flood or acts of God, or from failure to properly install, operate, or maintain the product in accordance with the printed instructions provided.

This warranty is in lieu of any other warranties, expressed or implied, including merchantability or fitness for purpose, which are expressly excluded. The owner agrees that STAR Cryoelectronics' liability with respect to this product shall be as set forth in this warranty, and incidental or consequential damages are expressly excluded.

SAFETY PRECAUTIONS

Do remove product covers or panels except for modifications as specified in this manual.

Do not operate without all covers and panels in place.

Do not attempt to repair, adjust, or modify the instrument, except for modifications as specified in this manual. This could cause nullification of any warranty. For service, return the instrument to STAR Cryoelectronics or any authorized representative.

Do not operate this instrument in a volatile environment, such as in the presence of any flammable gases or fumes.

1 STAR Cryoelectronics' PC-Based DC SQUID Electronics: Overview

A Revolution in SQUID Instrumentation!

STAR Cryoelectronics' modular PC-based SQUID readout electronics, marketed under the trade name pcSQUID™, represent a breakthrough in dc SQUID instrumentation technology. This revolutionary architecture brings the power of your PC and the flexibility of virtual instrumentation to SQUID control and data acquisition. The easy-to-use user interface for Microsoft Windows™ puts the SQUID control on your computer right where you want it – fully integrated with your data acquisition and analysis tools.

Advanced Programmable Feedback Loop

The state-of-the-art Programmable Feedback Loop (PFL) Model PFL-100 provides unsurpassed performance and control functionality for applications requiring up to 255 channels. All SQUID signal levels are digitally controlled with 13-bit resolution via software running on a personal computer. The user may remotely select dc current bias or an ac bias-reversal technique to minimize low-frequency noise intrinsic to some types of 77K SQUIDs, all with wide bandwidth operation. Two sensor coupling ranges and three closed-loop feedback ranges, all remotely configurable, ensure optimum performance for a wide range of dc SQUID sensors. An external feedback input allows the implementation of sophisticated noise cancellation techniques. The compact and low-power design simplifies multichannel and portable operation.

PC Interface Unit

The PC Interface (PCI) unit is controlled by a personal computer via an RS-232 or parallel port. All digital control signals to the Programmable Feedback Loop are generated by a STAR Cryoelectronics Serial Control Code (SCC) transmitter in the PC Interface unit. The Model PCI-1000 can operate up to eight channels, while the low-cost Model PCI-100 is ideal for single-channel applications. Each model may be configured for master or slave mode for multichannel applications. The analog output signals from the Programmable Feedback Loops are available at the PC Interface unit via front-panel BNC connectors, either wideband or optional low-pass filtered with user-selected cutoff frequencies.

New PCS100 Control Software for Windows™

STAR Cryoelectronics' new PCS100 Control Software makes dc SQUID operation easy for the first-time user, yet allows experienced users complete control over the full power and features of the PFL-100 and PCI-1000 electronics. The graphical user interface for Microsoft Windows™ XP, 2k, 9*x* or NT displays multichannel information at a glance. The SQUID Control Module is used to individually configure and operate each PFL-100 feedback loop and to configure the PCI-1000 multichannel interface. A new Remote Control Module allows remote operation of the PCS100 software and system control via a local network or the Internet, and three new optional software modules are available for data acquisition and analysis functions. The Data Acquisition Module is used to control standard data acquisition devices and to configure the oscilloscope-like display for the digitized data. The Spectrum Analysis Module is used to perform a spectral analysis of the SQUID output signal, with the results displayed in a similar way as a stand-alone spectrum analyzer. The Autotune/Calibration Module is used to

automatically tune the SQUID, determine the flux-to-voltage calibration factor, and optimize the SQUID working point for lowest noise operation. The Data Acquisition and Autotune/Calibration Modules therefore enable each SQUID sensor to be optimally tuned and calibrated automatically in minutes without any additional equipment. The optional data acquisition and analysis modules are bundled with the basic PCS100 Control Software as an upgrade option, PCS100DA.

Multichannel Data Acquisition

The optional PCS100DA Control Software with Data Acquisition is now compatible with several types of 16-bit, 8-channel E-Series data acquisition (DAQ) boards and PCMCIA cards from National Instruments. Maximum sampling rates ranging from 100 kS/s to 333 kS/s are available. The E-Series DAQ boards may be ordered from STAR Cryoelectronics or purchased separately from National Instruments. This new data acquisition option significantly enhances system operation and performance, enabling autotuning, automatic calibration, spectrum analysis and noise optimization.

About this Manual

This manual describes the setup, operation, and technical specifications of the PFL-100 Programmable Feedback Loop, PCI-100 and PCI-1000 PC Interfaces, and the PCS100 and PCS100DA Control Software. Chapter 2 provides installation and setup instructions for your hardware and software, and addresses important configuration issues. Chapter 3 presents a brief tutorial on system operation, geared toward users having some familiarity with SQUIDs and SQUID electronics. It is designed to get you up-and-running quickly. Chapter 4 provides a detailed description of the PCS100 Control Software and PCS100DA Control Software with Data Acquisition, including its structure, operation, and functions of all controls. Chapter 5 focuses on the PFL-100 Programmable Feedback Loop, primarily on a technical description of its features and operation. It also includes a general discussion of the performance and characteristics of the PFL-100 when used with non-standard or custom SQUID sensors. Chapters 6 and 7 describe the PC Interface units, the PCI-100 for single-channel operation (Chapter 6) and the PCI-1000 for multichannel operation and use with the data acquisition system (Chapter 7). Finally, Chapter 8 presents a brief overview of the STAR Cryoelectronics Serial Control Code (SCC), a serial communications protocol developed especially for use with STAR Cryoelectronics' pcSQUID™ systems.

Thank you!

Thank you for purchasing pcSQUID™, STAR Cryoelectronics' family of advanced dc SQUID instrumentation electronics. We hope you will find your system to be extremely powerful and flexible, yet easy to use and integrate with your application. And remember, the experienced technical staff at STAR Cryoelectronics are always available to discuss your particular application or needs.

2 Installation and Setup

STAR Cryoelectronics' pcSQUID™ system based on the Model PFL-100 Programmable Feedback Loop is available in two pre-configured packages for either single-channel or multichannel applications. Each basic package includes all necessary cabling for a complete one-channel installation (not including sensor and cryocable). STAR Cryoelectronics also offers a complete line of LTS and HTS sensors and cryocables for a wide variety of applications. For multichannel applications, additional single-channel add-on packages may be ordered, as well as an optional data acquisition and analysis package. STAR Cryoelectronics' pcSQUID™ is a complete, modular system designed to fit your application needs.

2.1 Unpacking and Inspection

Prior to unpacking your pcSQUID™ system, inspect the shipping carton(s) for any signs of damage that may have occurred during shipment. If damage is observed, notify the carrier immediately to allow for a possible insurance claim.

The following sections list the items included with standard single-channel and multichannel pcSQUID™ systems based on the PFL-100 Programmable Feedback Loop. If any items are missing, notify your STAR Cryoelectronics representative immediately.

2.1.1 Model PC-100 Single-Channel dc SQUID Electronics

This package includes:

PFL-100	Single-channel Programmable Feedback Loop (PFL) for LTS and HTS dc SQUIDs.
PCI-100	Single-channel PC Interface with integral STAR Cryoelectronics Serial Control Code Transmitter.
LP-5	Low-Pass Filter, 5 kHz, 4-pole Butterworth (factory installed in the PCI-100)
PS-115	Power Source, 115 VAC, 60 Hz, wall plug-in (or international version).
CBL-9P10	PFL Cable, Double-Shielded, 9-pin M/F, 10 feet.
CBL-25P2	Interface Cable, 25-pin M/F, 2 meters.
PCS100	Control Software for Microsoft Windows™.
UM-PCS100	User's Manual.

2.1.2 Model PC-1000 Basic Multichannel dc SQUID Electronics

This package includes:

PFL-100	Single-Channel Programmable Feedback Loop (PFL) for LTS and HTS dc SQUIDs.
PCI-1000	Multichannel PC Interface with integral STAR Cryoelectronics Serial Control Code Transmitter; AC power cord and fuses installed in the Power Entry Module (user selectable for 110 or 220 VAC, 50/60 Hz; factory configured for 120 VAC operation unless specified otherwise).

CBL-9P10 PFL Cable, Double-Shielded, 9-pin M/F, 10 feet.

CBL-25P2 Interface Cable, 25-pin M/F, 2 meters.

PCS100 Control Software for Microsoft Windows™.

UM-PCS100 User's Manual

In addition to the above, the following options may be shipped along with the basic multichannel system.

Model LP-SET Low-Pass Filter Set for PCI-1000 (*Optional*)

Four low-pass 4-pole Butterworth filters for each channel. The filter cutoff frequencies depend on the data acquisition device to be used. The filters are factory installed in the PCI-1000 at time of shipment if ordered; user installed if purchased separately.

Model PC-1000A Additional Channel add-on package (*Optional*)

This package includes:

PFL-100 Single-Channel Programmable Feedback Loop (PFL) for LTS and HTS dc SQUIDs.

CBL-9P10 PFL Cable, Double-Shielded, 9-pin M/F, 10 feet.

CBL-1P1 Clock Cable for slave PFL, 1 foot.

Model PC-1000D Data Acquisition add-on package (*Optional*)

This package includes:

DAQ-*NNNN* National Instruments 16-bit E-Series DAQ board or PCMCIA card with maximum sampling rate of 100 kS/s, 200 kS/s, or 333 kS/s (NNNN specifies the NI-DAQ model number). Includes NI-DAQ™ software and user manual.

DAQ-CBL*X* Cable for use with the selected DAQ board.

DAQ-CB Connector box for use with the selected DAQ board.

CBL-25P2 Interface Cable, 25-pin M/F, 2 meters.

PCS100DA Control Software with Data Acquisition for MS Windows™, including the following modules:

- SW-SQ SQUID Control Module.
- SW-DA Data Acquisition Software Module.
- SW-SA Spectrum Analysis Software Module.
- SW-AT Autotune/Calibration Software Module.
- SW-RC Remote Control Software Module.

2.2 Additional Equipment Required

STAR Cryoelectronics' pcSQUID™ systems are designed to operate with an IBM-compatible personal computer running Microsoft Windows XP, 2k, 9*x* or NT.

If your system configuration does not include the Model PC-1000D Data Acquisition package, you will also need:

Oscilloscope and BNC cables.

If you are using a PC-100 system, you will also need:

Function generator and BNC cables.

If you are not using dc SQUIDs and cryocables provided by STAR Cryoelectronics, you will need an appropriate dc SQUID sensor and cryogenic cabling that mates with the 10-pin LEMO plug on the Model PFL-100 Programmable Feedback Loop (see Figure 5-6 in Section 5.15).

2.3 Hardware Installation and Configuration

1. Verify that the PFL-100 is properly configured for the sensor to be used. Unless specified otherwise by the customer on the customer's purchase order and on the packing slip shipped with the hardware, the PFL-100 is factory configured for one-transformer sensor coupling to the room-temperature preamplifier in the PFL-100. See Section 5.1 for a discussion of the available input transformer coupling schemes and instructions on how to change the coupling.
2. Configure the hardware addresses of the PFL-100 and PCI-1000 units you will be using in your system. The PCS100 and PCS100DA Control Software assume a very specific addressing scheme and your system must be set up accordingly. The PCI-100 is not addressable and needs no adjustment.

   The addressing scheme is as follows: available addresses range from 1 to 255. The hardware address of each PFL-100 must correspond to its channel number, starting with address 1 for Channel 1 and increasing sequentially. The first PCI unit (Channels 1 to 8) should be set to address 255, the second PCI unit (Channels 9 to 16) to address 254, etc. The PCI-1000 addresses decrease sequentially in this manner as units are added. This scheme, where PFL-100 addresses increase starting from 1, and PCI-1000 addresses decrease starting from 255, maximizes the use of the 255 available addresses. A summary is given in Table 2-1.

   Normally, PFL-100 units are factory configured with address 1, and PCI-1000 units are factory configured with address 255. For a single channel system, it is unlikely that you will need to change the address of either the PFL or the PCI units. If you purchased a multichannel system, the proper addresses will already have been configured at the factory and each PFL-100 will be labeled with the corresponding channel number. The address of each PFL-100 and PCI-1000 is set using a DIP switch located inside the unit. In each case, a cover panel must be removed to access this switch. For detailed instructions, please refer to Section 5.12 (for PFL-100) or Section 7.3 (for PCI-1000).

3. Verify that the power switch on the PCI is in the OFF position. If you are using a PCI-100, check that the plug-in Power Source is the proper type for the voltage in your area. Plug the DIN connector into the POWER socket on the back of the PCI-100, and connect the Power Source to a mains outlet. If you are using a PCI-1000 interface, inspect the voltage selector on the rear panel of the PCI-1000 and make sure it is set for the proper voltage in your area. Connect the ac power cord to the PCI-1000 and plug it into a grounded power outlet.
4. If you are using a PCI-100 interface, connect the female end of the 9-pin interface cable to the PFL unit and connect the male end of the 9-pin PFL cable to the FEEDBACK LOOP connector on the rear panel of the PCI-100. If you are using a PCI-1000 interface, for each channel connect the female end of the 9-pin interface cable to the PFL unit and connect the male end of the cable to the connector of the appropriate channel on the rear panel of the PCI-1000. The PFL-100 channels must be connected to the PCI-1000 in correspondence with the hardware address of each PFL unit. If you are installing the Data Acquisition option, note that the channel numbers will also match the corresponding Data Acquisition channel numbers.
5. Verify that the power to the PC is turned Off (if necessary, follow the manufacturer's instructions to power down the PC). Connect one end of the 25-pin interface cable to either the parallel port or RS-232C interface (an adapter may be necessary) on the PC. Connect the other end to the appropriate interface port on the rear panel of the PC Interface.
6. If you are using more than one PCI unit, connect these additional units to their corresponding PFL unit(s) and power sources as in Steps 3 and 4 above. Instead of following Step 5, however, you should first connect all PCI units together in a daisy-chain manner, so that the SCC may be transmitted throughout the system. To do this, use a single-pin LEMO cable (part number CBL-1P1) to connect "SCC Out" of the first PCI unit to "SCC In" of the second unit. These connectors are located on the back of the PCI unit. Continue in this manner until all PCI units are daisy-chained together. This operation may be performed on any combination of PCI unit styles.
7. If you are using more than one PFL unit, you may optionally synchronize the clock frequencies (and thus the modulation frequencies) of the PFL units by interconnecting them in a daisy-chain manner using the provided clock cables. See Section 5.13 for further information. Connect one end of a single-pin LEMO clock cable (part number CBL-1P1) to the connector labeled CLOCK OUT on the PFL, which you wish to be the master. Connect the other end of this cable to the CLOCK IN connector of the first slave PFL. The PFL will recognize the presence of a signal at the CLOCK IN input and will automatically configure itself as a slave unit. Connect a second clock cable between the CLOCK OUT of the first slave PFL and the CLOCK IN of the second slave PFL. Continue to connect the all of the slave PFL units in this manner.
8. In order to use the Data Acquisition, Spectrum Analysis, and Autotune/Calibration modules, a 16-bit E-Series DAQ board from National Instruments is required. The list of DAQ devices supported by the PCS100DA Control Software is given in Table 2-2. Before installing the DAQ board, install the NI-DAQ™ software provided with your board. Then, shut down and unplug the computer, and install the DAQ board according to the manufacturer's installation instructions. Observe all safety precautions specified in the manufacturers' documentation for both the computer and the DAQ board. After the board is

installed, restart the computer, and follow the instructions of the NI-DAQ™ software installer to complete the installation.

9. In order to use the Remote Control Module to operate the pcSQUID™ system via the Internet, a high-speed Internet connection is necessary. A dial-up connection may be used only to verify that a DataSocket connection can be established and to confirm that remote operation is possible.

Table 2-1. Required hardware address settings for the pcSQUID™ system.

Hardware	**Address**
PFL, Channel 1	1
PFL, Channel 2	2
:	
PFL, Channel 9	9
:	
PCI-1000, Channels 1-8	255
PCI-1000, Channels 9-16	254
:	

Table 2-2. Compatible 16-bit E-Series DAQ boards from National Instruments and their respective device codes.

Device type	**Device code**
PCI-6030E	204
PCI-6031E	220
PCI-6032E	221
PCI-6033E	222
PCI-6034E	314
PCI-6035E	316
PCI-6036E	348
DAQCard-6036E	348
PCI-6052E	273

2.4 Software Installation and Configuration

The PCS100 Control Software and PCS100DA Control Software with Data Acquisition are designed for IBM-PC compatible computers running Microsoft Windows™ XP, 2k, 9*x* or NT.

The basic PCS100 software includes the SQUID Control Module (SW-SQ), which provides all control functions for STAR Cryoelectronics' PFL-100 Programmable Feedback Loop and PCI-1000 PC Interface, and the Remote Control Module (SW-RC), which enables remote system control via a local network connection or the Internet.

The optional data acquisition and analysis software supports National Instruments 16-bit E-Series DAQ boards and PCMCIA cards. This software upgrade includes three additional modules that significantly enhance system operation and performance:

- Data Acquisition Module (SW-DA)
- Spectrum Analysis Module (SW-SA)
- Autotune/Calibration Module (SW-AT)

These modules can be used to configure and operate a compatible data acquisition device (National Instruments 16-bit E-Series DAQ board or PCMCIA card), perform a spectral analysis of the SQUID output signal, and automatically optimize and calibrate each SQUID channel for lowest noise operation. The data acquisition and analysis modules are bundled with the SQUID Control Module and Remote Control Module as a single installation package, PCS100DA.

The PCS100 Control Software and PCS100DA Control Software with Data Acquisition were developed using National Instruments' LabWindows/CVI. Running this software requires the CVI Run-Time Engine, which is included in your software package and installed automatically. If you plan to use data acquisition, you also need to install National Instruments' software for DAQ boards (NI-DAQ™) provided with your DAQ device. This should be installed before installing the DAQ board or card in the computer.

2.4.1 First-Time Installation Procedure

1. The installation is performed while running Microsoft Windows™. For best results, quit all other applications before installing the PCS100 software. If you are installing the optional PCS100DA software, replace "PCS100" with "PCS100DA" in the discussion below.
2. Insert the installation CD into a CD drive of your computer. Double-click on the "My Computer" icon, and then on the "Compact Disc" icon. The installation CD contains a folder named "PCS100_Kit". Open this folder.
3. Double-click on "Setup.exe". The installation software will launch and display the message "Welcome to the PCS100 Installation Wizard". Follow the instructions of the installation Wizard. The default installation directory for the PCS100 software is C:\Program Files\PCS100. A different directory may be selected during the installation process if desired.
4. After all installation steps have been completed, the message "PCS100 has been successfully installed" will be displayed. To run the program, go to the "Start" menu and select Programs>PCS100>PCS100. Alternatively, a shortcut may be created and placed on your desktop. Right-click on a free area on your desktop and select New>Shortcut. On the Create

Shortcut panel, click on "Browse…" and select C:\Program Files\PCS100\PCS100.exe. Click on Next> to continue, and enter a name for the shortcut (*e.g.*, PCS100). Click on "Finish" to create the shortcut.

5. If you plan to install a data acquisition device, National Instruments' DAQ software (NI-DAQ™) should be installed before installing the data acquisition device. Follow the instructions provided with the data acquisition device. After both the NI-DAQ™ software and the DAQ board have been installed, you can use the NI Measurement and Automation Explorer (NI-MAX™), which is installed automatically with the NI-DAQ™ software, to check if the DAQ board is properly installed and to determine the device number for this board. If you are not using data acquisition, the PCS100 Control Software will function without the NI-DAQ™ software.

2.4.2 Procedure to Replace an Existing Software Version

Run the utility program "Setup.exe" which is a part of the new installation package. The existing version of the software will be uninstalled automatically. Then follow the steps in Section 2.4.1. If you are installing the optional PCS100DA software, replace "PCS100" with "PCS100DA" in the discussion below.

2.4.3 Software Configuration Procedure

1. Turn the PC Interface ON, and launch the PCS100 Control Software by clicking on Start>Programs>PCS100>PCS100 (or by clicking on the desktop shortcut created as described above in Section 2.4.1).
2. The information panel (splash screen) will appear for a short time. This panel provides the version number of the software, and lists the installed software modules. Note this information when contacting STAR Cryoelectronics for support.
3. After the information panel disappears, the main panel of the SQUID Control Module with control, tuning, and configuration sections will be displayed. From the main menu, select SYST>Show System panel (or use the hot-key Y). The System Configuration panel will be displayed next to the main panel. The System Configuration panel is shown in Figure 2-1.
4. The HARDWARE section of the System Configuration panel includes controls to define the basic hardware configuration of the pcSQUID™ system. Use the "N of Channels" control to set the number of channels equal to the number of connected PFL-100 units. Set the "PCI Units" control to either 'PCI-100' or the appropriate number of PCI-1000 units. The default setting is 'One PCI-1000'.
5. The indicators in the SOFTWARE section specify which optional software modules are included in your PCS100 software package in addition to the SQUID Control Module (SW-SQ) and Remote Control Module (SW-RC). Note that the Data Acquisition (SW-DA), Spectrum Analysis (SW-SA), and Autotune/Calibration (SW-AT) Modules are always provided together. If these modules are not included, the DATA ACQUISITION section of the panel is not visible as in Figure 2-2.
6. Use the "Port" control in the PORT OPERATION section of the System Configuration panel to select the computer port to be used for communication with the PC Interface. One of three parallel (LPT) ports or one of three serial (COM) ports may be selected. The default port is

COM1. For applications requiring higher-speed communications, a parallel port (say, LPT1) should be used. The "Status" indicator shows the status of the selected port ('Enabled' or 'Disabled'). The "Transmission" indicator reports whether data have been successfully written to this port ('Success' or 'Failure'). Make sure that the port connected to the PC Interface is enabled. If the port is disabled, no data will be sent. If the port is enabled, but an error occurs during data transfer, a popup window with the message "Data transmission was unsuccessful" will appear. This may happen, for example, if the selected port is not connected to the PC Interface. Make sure that the connection is correct, and click the "Try again" button. If this does not help, click the "Change port" button and select a different port.

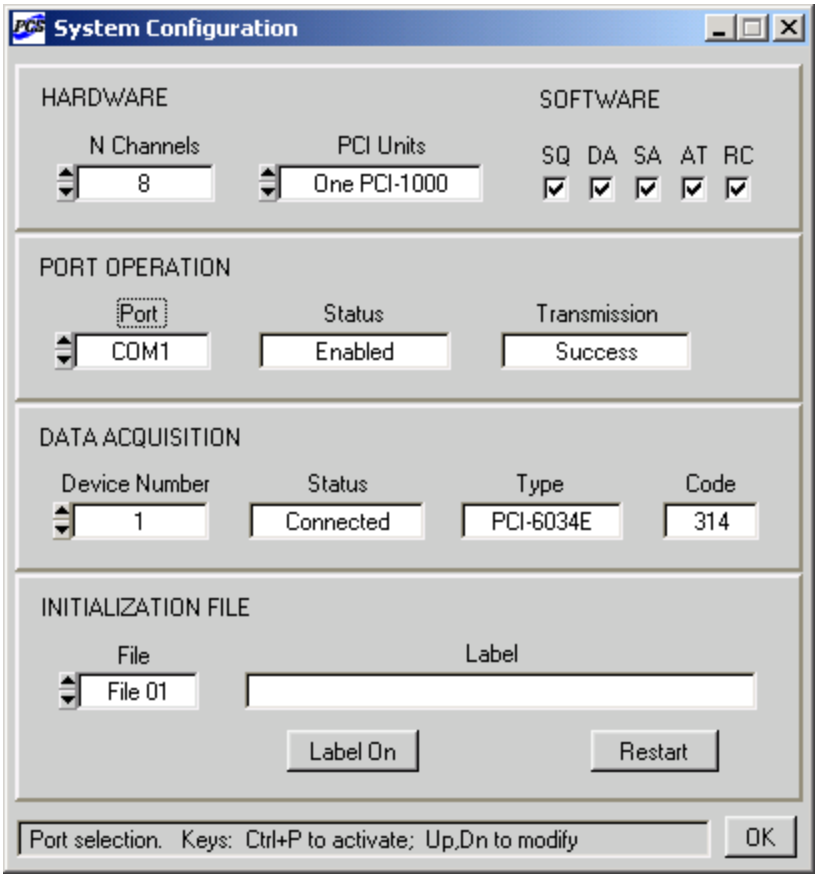


Figure 2-1. System Configuration panel of the PCS100 Control Software with all optional software modules included.

7. To confirm proper installation and successful data transmission, click on the REFRESH button in the control section of the PCS100 SQUID Control main panel to send all data to the installed PFL-100 feedback loops (see Section 2.3 for hardware installation and configuration). If data transmission is successful, the DATA indicator LED on the PFL-100 corresponding to the selected channel will turn green. If this does not happen, check that the hardware address switch settings inside the PFL-100 agree with the selected channel number

(see detailed instructions in Section 5.12) and, if a PCI-1000 is used, that the hardware address agrees with the channel number to which the PFL-100 is connected on the rear panel of the PCI-1000.

8. If the Data Acquisition Module (SW-DA) and related software Modules (SW-SA, SW-AT) are present, the DATA ACQUISITION section of the System Configuration panel is visible. Use the "Device Number" control to select a DAQ device number. If there is only one NI DAQ board or card installed in your computer, the device number is typically 1. You can use the NI Measurement and Automation Explorer (NI-MAX™) to view a list of installed devices and their device numbers. The "Status" indicator shows the present state of the DAQ board, which is either 'Connected' or 'Unconnected'. The 'Connected' state means that the DAQ board has been successfully configured, and is ready to acquire data. If the device associated with the selected device number is supported by the current version of the PCS100DA Control Software, the "Type" indicator will display the name of this device, for example, 'PCI-6034E'. If the device is not present, or is not compatible with the PCS100DA software, this indicator will show 'Unknown'. Each data acquisition device from National Instruments has a unique device code. The "Code" indicator displays the code of the device, associated with the selected device number. The device codes for several NI DAQ boards, supported by the PCS100DA Control Software, are listed above in Table 2-2. If the displayed code is –1, the device is not one of NI DAQ devices.

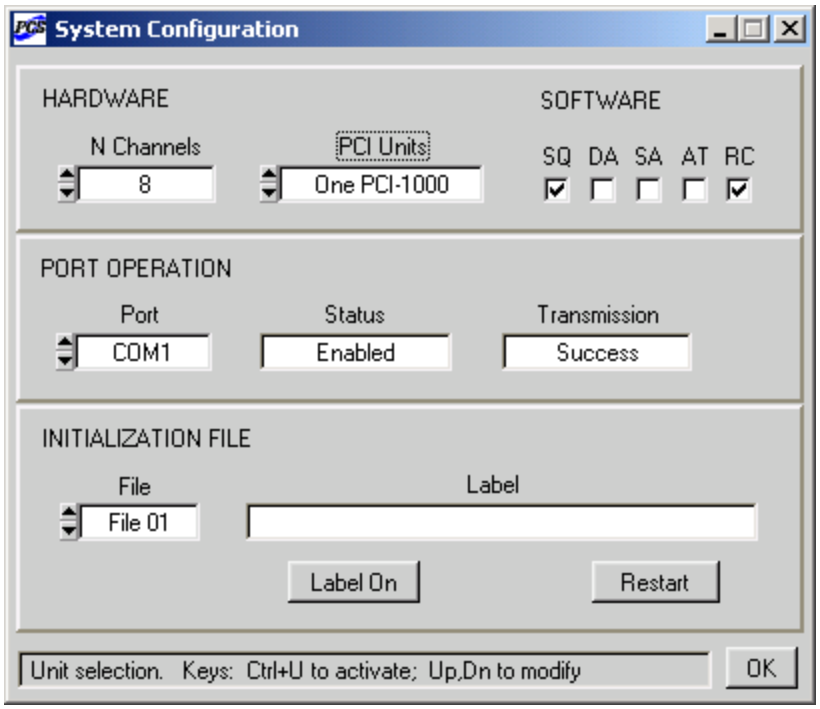


Figure 2-2. Appearance of the System Configuration panel for the PCS100 software package without the optional Data Acquisition, Spectrum Analysis, and Autotune/Calibration Modules.

9. Multiple initialization files can be used to store settings for different configurations. When the PCS100 Control Software is run for the first time, the initialization file is PCS100f01.ini. You can use the "File" control in the INITIALIZATION FILE section of the System Configuration panel to select a different file, and click "Restart" to restart the program with this file. If it does not exist, it will be created with default settings. The name of the currently used initialization file in the "File" control window is black, while the other file names are gray. Up to 99 different initialization files may be created. For greater reliability, all file names are predefined (*i.e.*, PCS100f01.ini, PCS100f02.ini,...PCS100f99.ini), but each file may be assigned a unique label. To define a new label for an initialization file, enter a desired text into the "Label" control window, and click the "Label On" button to assign it to the chosen file. The initialization file in use is updated whenever the program is shut down. When it is started next time, the same initialization file is used to restore the last configuration. Different users are recommended to store their settings in different files, and switch from one configuration to another using the "File" and "Restart" controls. If the same file will be used every time, there is no need to modify the "File" control.
10. You can right-click on any control to view its description and hot-key assignment on the information bar at the bottom of each panel. If any PFL or PCI unit was temporarily turned off or disconnected, use the REFRESH button to re-send all configuration data.

2.4.4 Initialization Files and Default Settings

Each initialization file for the PCS100 Control Software and PCS100DA Control Software with Data Acquisition has two main functions. First, it stores information about a particular SQUID system configuration, so that this configuration can be restored automatically when the program is started next time or re-started with this initialization file. Second, it enables a user to change the parameters associated with various controls of the PCS100 or PCS100DA Control Software without changing the software itself.

If updates or modifications are made to the PFL-100 or PCI-1000 units, the parameters associated with the controls displayed by the user interface of the PCS100 or PCS100DA Control Software must be changed to reflect the new hardware properties. This can be done by editing the appropriate hardware-related parameters in the initialization file. For example, if the maximum value of the DC bias current produced by the PFL-100 is changed, the `BIASDCMAX` entry in the `[HARDWARE]` section of the initialization file should be edited to agree with the new maximum DC bias. Or, if the standard filters inside the PCI-1000 interface unit are replaced with filters having non-standard frequencies, the `FILTERA`, `FILTERB`, `FILTERC`, and `FILTERD` entries in the `[HARDWARE]` section should be appropriately updated. The hardware-related parameters associated with various software controls are discussed in more detail in Section 4.2 (PFL-100 controls) and Section 4.3 (PCI-1000 controls).

Note that changes to the parameters in the `[HARDWARE]` section of an initialization file do not affect the hardware properties in any way. They are only used to change the appearance and properties of the user interface controls.

If hardware modifications are made to a specific PFL-100, a new initialization file for the modified PFL should be created and used whenever the modified PFL is operated; otherwise, the parameters displayed by the control software will not match the actual parameters of the PFL.

The initialization files are created and stored in the same directory as the program executable file (PCS100.exe or PCS100DA.exe). Each file can easily be modified using Notepad™. Only the [HARDWARE] section contains parameters that can be set by the user; all of the other parameters are set by the program itself and are not user-configurable. If an initialization file is corrupted, it is better to delete it altogether and launch the PCS100 or PCS100DA Control Software to create a new file with default settings. The [HARDWARE] section of the initialization file with default parameter settings is shown below.

Initialization file [HARDWARE] section with default settings

```
--------------------
[HARDWARE]
BIASDCMAX=200.000000
BIASACMAX=100.000000
MODLOWMAX=5.000000
MODHIGHMAX=50.000000
OFFLOWMAX=5.000000
OFFHIGHMAX=50.000000
SKEWMAX=100.000000
COMPMAX=100.000000
PHASEMAX=100.000000
PCIAMPMAX=5.000000
TIMESHIFT=0.000000
RESLOW=1 kOhm
RESMED=10 kOhm
RESHIGH=100 kOhm
RESMORE=1 MOhm
CAPLOW=1 nF
CAPMED=10 nF
CAPHIGH=100 nF
TESLOW=10 uA/V
TESMED=100 uA/V
TESHIGH=1000 uA/V
FRELOW=2 kHz
FREMED=64 kHz
FREHIGH=128 kHz
COILOW=+/- 5 uA
COIHIGH=+/- 50 uA
FILTERA=LP 6 kHz
FILTERB=LP 10 kHz
FILTERC=LP 20 kHz
FILTERD=LP 60 kHz
--------------------
```

3 Operation

3.1 Basic Operation and Tuning

This section describes the basic procedures to be followed when operating a single channel PC-100 or multichannel PC-1000 system in the manual mode. It is intended as a guide for a moderately experienced SQUID user to get up and running quickly. A detailed description of the operation of the PCS100 and PCS100DA Control Software is given in Section 4.

Before powering up the system, verify that all system interconnects are properly installed as described in Section 2. Power up the computer and electronics, and start the PCS100 or PCS100DA Control Software. Be sure to configure the software properly if you have not already done so. This procedure is described in Section 2.4.3.

Install and cool the dc SQUID sensor to be used. If you are using STAR Cryoelectronics dc SQUIDs and cryocables, follow the appropriate installation instructions for the specific components you are using.

In the PCS100 SQUID Control panel (Figure 4-1), select the channel number corresponding to the SQUID to be adjusted and select the TUNE mode. The green DATA indicator LED on the appropriate PFL should light. If it does not light, verify that the PFL interface cable is connected to the correct channel on the PC interface (PCI-1000 only), and verify that the hardware address switch settings inside the PFL matches the channel number. Also verify that the PC interface cable is correctly installed and the correct port is selected by the "Port" control on the System Configuration panel (see the Section 2.4.3).

Select the BIAS MODE, typically DC for LTS SQUIDs, AC for HTS SQUIDs. If the AC bias mode is selected, the bias reversal frequency is set by the BIAS FREQ control. Three bias reversal frequencies are available: 128 kHz, 64 kHz and 2 kHz.

Note the value of the modulation coupling for your sensor, in units of $\mu A/\Phi_0$. The measured value of this parameter is specified on the data sheet supplied with your STAR Cryoelectronics sensor. If this information is not readily available, an estimated value is sufficient. The settings of several controls depend on the sensor modulation coupling.

First, using the modulation coupling value, select the SQUID TYPE and TEST INPUT parameters from Table 3-1 below, and set the corresponding controls accordingly.

Table 3-1. Guide for selecting the SQUID TYPE and TEST INPUT settings based on the sensor modulation coupling.

Modulation Coupling ($\mu A/\Phi_0$)	**SQUID TYPE**	**TEST INPUT**
0 – 10	TYPE I	10 μA/V
10 – 100	TYPE II	100 μA/V

Next, calculate the modulation current required to produce roughly $\Phi_0/2$ peak-to-peak. To do this, multiply the modulation coupling value in units of $\mu A/\Phi_0$ by $\Phi_0/2$ to obtain the result in microamperes. Set the MOD control to this value.

Finally, determine the peak-to-peak amplitude (in volts) of the input test signal that will produce roughly 1 Φ_0 flux in the SQUID, according to the formula:

$$\text{Test Signal [V]} = (1\ [\Phi_0])(\text{Modulation Coupling } [\mu A/\Phi_0])/(\text{Test Input } [\mu A/V]).$$

Determination of these settings may be illustrated by the following example. If your SQUID sensor has 5 μA/ Φ_0 modulation coupling, set the SQUID TYPE control to 'Type I', and the TEST INPUT control to '10 μA/V'. The MOD control should be set to 5 $\mu A/\Phi_0 \times \Phi_0/2$ = 2.5 μA, and the test signal will have a peak-to-peak value of

$$(1\ \Phi_0)(5\ \mu A/\Phi_0)/(10\ \mu A/V) = 0.5\ V_{pp}.$$

Select the SENSITIVITY setting. Typically, this setting is 'High' for tuning purposes.

Set the TEST SIGNAL control to 'On' in order to supply the test signal to the SQUID modulation coil. If you are using a PCI-1000, make sure that the TEST SIGNAL OUTPUT ENABLE switch on the PCI panel (Figure 4-4), corresponding to the selected channel, is also 'On'. To bring up this panel, select PCI>Show PCI panel menu item on the Main panel of the SQUID Control Module, or use the hot-key I.

Set up an oscilloscope to monitor the wideband signal output of the PFL. This signal is always available at the WIDEBAND BNC terminal on the front panel of the PC interface (all PCI models). If you are using a PCI-1000, the output signal measured at the front panel FILTERED BNC connector is selected by the "Multiplexer" control on the PCI panel. To bring up this window, select PCI>Show PCI panel. In the FRONT PANEL OUTPUT section of the PCI panel, select the "Specify channel to track" radio button and then set the appropriate channel number using the "Channel" control. Alternatively, you may select the "Track selected channel" radio button, and the output of the channel selected on the PCS100 SQUID Control panel will be routed to the front panel BNC connectors of the PCI-1000.

If the dc voltage offset is excessive, make sure the mode is set to TUNE and that communication to the PFL is executing properly. If the dc voltage offset is still excessive, it may be necessary to adjust the integrator offset trimpot inside the PFL (see Section 5.2).

Next, set up a source to provide a flux sweep for the sensor. If you are using a PCI-100, you will need a signal generator to do this. If you are using a PCI-1000, you may use its internal test signal generator, which is controlled using the PCI panel, instead of an external signal generator.

To apply an external test signal, set up your signal generator to provide a 100 Hz triangle wave. Adjust the peak-to-peak voltage output of the external signal source to the value you calculated earlier, which corresponds to roughly 1 Φ_0. Use a BNC cable to connect the signal generator to the TEST INPUT BNC connector on the front panel of the PCI unit (all PCI models).

To apply an internally generated test signal using the PCI-1000, simply adjust the "Frequency" and "Amplitude" controls in the TEST SIGNAL GENERATOR section of the PCI panel, and make sure the generator is 'On'. Set the frequency to 100 Hz, and the amplitude to one half the value you calculated (which was a peak-to-peak value). Make sure that the TEST SIGNAL OUTPUT ENABLE switch for the selected channel is 'On' (*i.e.*, has a black dot in the center).

Adjust the BIAS control to maximize the peak-to-peak magnitude of the PFL output voltage. If the step size is too coarse, select the FINE mode.

Adjust the MOD control to further maximize the PFL output. Use the FINE mode if necessary.

If you are using an HTS SQUID, first set the SKEW and COMP (compensation) controls to zero. Then, adjust the SKEW value to maximize the output, and adjust the COMP setting to eliminate the switching spikes in the output signal. Using the 128 kHz or 64 kHz bias reversal frequencies, these spikes appear as high frequency "fuzz" riding on top of the output waveform.

Adjust the PHASE to maximize the PFL output signal.

Repeat the adjustments of the BIAS, MOD, SKEW, COMP and PHASE controls to further maximize the PFL output, if necessary.

You may now adjust the peak-to-peak magnitude of the applied test signal so that it corresponds to exactly 1 Φ_0. When properly adjusted, the sharp peaks and dips in the PFL output waveform, corresponding to the maximum and minimum peaks of the test signal, will be at the same horizontal level. You may change the OFFSET value, which adds a dc flux offset to the test signal, in order to view the sharp peaks and dips in the output waveform. This is illustrated in Figure 3-1.

If the SQUID has trapped flux (which is evidenced by a low output signal), it is possible to heat the SQUID above the T_c to release this flux. The heater for the selected channel is activated by clicking on the HEAT button. The heat and cool times (in seconds with either 0.1 sec or 1 sec resolution) are set individually using the HEATER Heat and HEATER Cool controls, respectively. When a heat cycle is activated, power is applied to a heater resistor in the SQUID package. After the heat time has elapsed, the heater power is switched off, and all PFL output signals to the SQUID are automatically set to zero while the SQUID cools. After the cool time has elapsed, the PFL output signals to the SQUID are restored. After heating the SQUID, repeat the adjustments of the BIAS, MOD, SKEW, COMP and PHASE controls as discussed above in order to maximize the PFL output signal.

Lock the feedback loop by clicking on the LOCK button. The PFL output will track the applied test signal. If necessary, click on the RESET button to bring the triangle signal in range. If you encounter unstable operation, you may need to reduce the SENSITIVITY setting in order to maintain lock. If you still encounter stability problems, try switching the SQUID TYPE setting to Custom. In this case, the FEEDBACK resistor and the INTEGRATOR capacitor may be selected independently. This is likely in the event the modulation coupling is in the range of roughly
10-25 $\mu A/\Phi_0$, or if a SQUID with separate feedback and modulation coils having significantly different coupling strengths is used.

Note the peak-to-peak magnitude of the output triangle signal in the LOCK mode. Because the test signal amplitude was adjusted to 1 Φ_0 in the TUNE mode, this voltage in the LOCK mode is now equal to the feedback loop calibration in units of V/Φ_0. The SQUID feedback coupling strength is simply this number divided by the feedback resistance R_{fb}. The value of R_{fb} is specified by the FEEDBACK control. If the same coil is used for both modulation and feedback, you will obtain the same value for the feedback coupling and the modulation coupling.

Turn off the test signal by setting the TEST SIGNAL control to 'Off' or 'Auto', and send a RESET command again if necessary. The SQUID is now ready for operation.

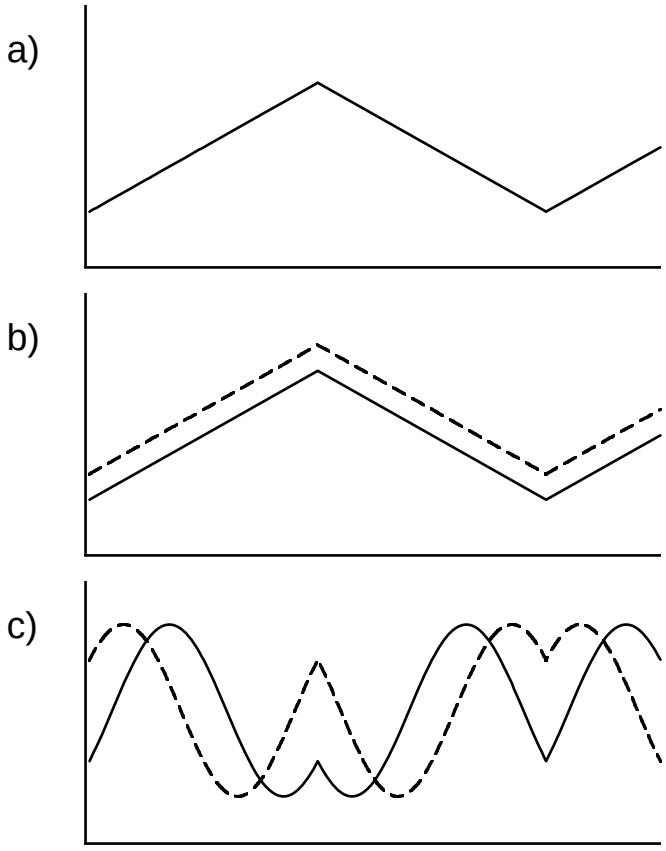


Figure 3-1. Effect of the OFFSET adjustment on the SQUID output in the TUNE mode. a) Test signal vs time. b) Flux applied to sensor vs time: the solid line corresponds to OFFSET = 0, the dashed line corresponds to OFFSET > 0. c) SQUID output vs time for this applied flux: the solid line is for OFFSET = 0, the dashed line is for OFFSET > 0. In these figures, the test signal peak-to-peak magnitude corresponds to 1 Φ_0.

3.2 Reset Operation and Flux Jumps

This section describes the basic principles of SQUID operation in the LOCK (feedback) mode, and explains the effect of the RESET command.

It is important to keep in mind that the PFL-100 does not measure the absolute value of the signal of interest (magnetic flux or magnetic field in the case of a magnetometer sensor), but rather a relative value. The output voltage of the PFL in the LOCK mode is shown in Figure 3-2. The horizontal axis in this graph is the offset flux, which is generated using the OFFSET control. However, the same behavior occurs as a result of any applied flux, including the external flux from the signal of interest. The slope of the voltage output curves is the calibration, or response, of the sensor in units of V/Φ_0. This output voltage is multi-valued, that is, any particular flux value could produce one of several possible voltages. These values are constrained only by the output voltage limit of the PFL-100. When the offset flux is changed, the value of the output voltage increases or decreases accordingly along one of the lines. When the RESET command is issued, the effect is to jump to the curve closest to zero volts. This curve is located in the shaded region in the figure, which we call the "stable region". From that point, you may again move up and down the curve by changing the applied offset flux.

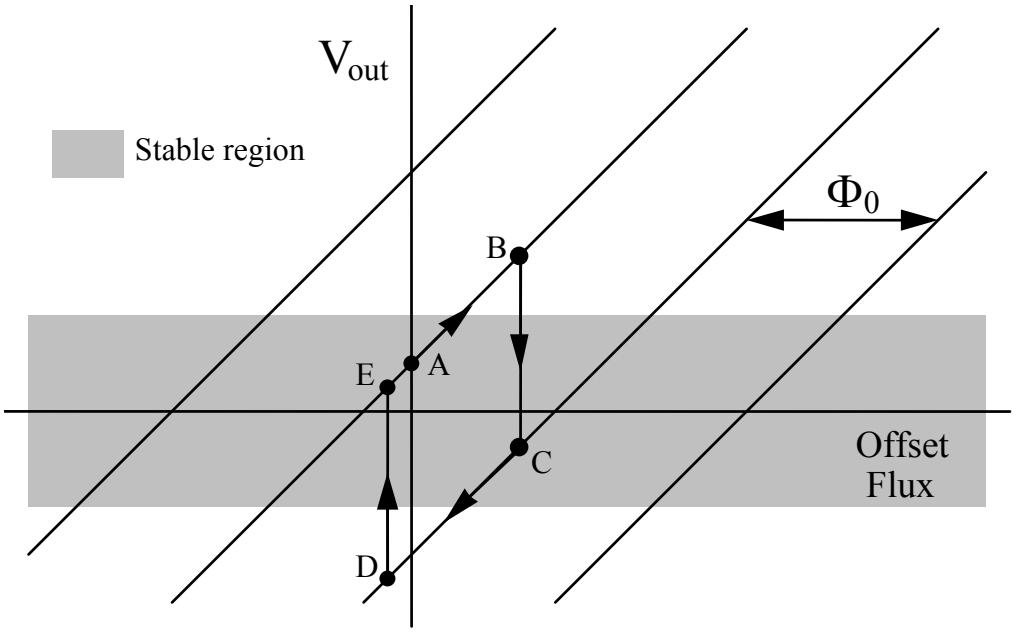


Figure 3-2. PFL-100 output voltage V_{out} in LOCK mode as a function of the applied offset flux. The output voltage is a multi-valued function shown by the family of diagonal lines. The slope of these lines is the SQUID calibration factor in units of V/Φ_0.

This effect is illustrated in Figure 3-2. Consider a SQUID sensor with zero offset signal applied. The voltage output V_{out} is represented by point A in the Figure. Note that the voltage is not necessarily zero for zero offset. This may arise as a result of several possible factors such as asymmetries in the SQUID sensor or residual flux. By increasing the OFFSET value, flux is

applied to the SQUID and the voltage output increases to point B, which lies outside of the stable region. In this case, if a RESET command is issued, the voltage output will jump from point B to point C which lies on the lower output voltage curve. By reducing the offset flux, the output may be moved to point D in the Figure. Again, this is outside of the stable region, and when the RESET button is clicked, the voltage will jump from D to E, which lies on the original curve.

The set of voltage output curves are separated by a value of Φ_0. This is a result of the intrinsic periodic response (of period Φ_0) of a SQUID to magnetic flux. Because the neighboring curves are separated by 1 Φ_0 and they represent a physical difference in SQUID flux of 1 Φ_0, the transition between adjacent curves is often referred to as a "flux jump". This transition can occur not only as a result of a reset, but also as a result of external events such as interference or high slew signals.

Because the voltage output curves are separated by a value of Φ_0, the procedure illustrated in Figure 3-2 also presents itself as an alternate method of obtaining the calibration of the sensor in units of V/Φ_0. Because the slope of the voltage output curves is the calibration in V/Φ_0, and the curves are separated by a flux of Φ_0, the difference in voltage between points Band C (or points D and E) is the calibration value. In practice, one could connect a voltmeter to the SQUID output and record the value of the voltage output at points B and C, and calculate the difference. It is helpful to have an idea of how large you expect the calibration value to be, in order to have an idea of how much the OFFSET control should be adjusted in order to make sure a transition of exactly 1 Φ_0 is made. If the offset is too small, the output voltage will return to its initial value, and you should increase the magnitude of the offset to get out of the "stable region". If the offset is too large, the output voltage may jump by more than 1 Φ_0, and in this case the wrong calibration factor would be determined. It is therefore recommended to try different offset values to make sure that the determined voltage change corresponds to exactly 1 Φ_0.

4 PCS100 and PCS100DA Control Software

This section describes the structure and operation of the PCS100 Control Software and PCS100DA Control Software with Data Acquisition for Microsoft Windows™ XP, 2k, 9*x* or NT.

The basic PCS100 Control Software includes the SQUID Control Module (SW-SQ) and the Remote Control Module (SW-RC) only. The optional PCS100DA software with Data Acquisition includes these two modules and three additional modules: the Data Acquisition Module (SW-DA), the Spectrum Analysis Module (SW-SA), and the Autotune/Calibration Module (SW-AT). We begin this section with an overview of the functionality and basic operation of each of these software modules. We then examine each module in detail.

The SQUID Control Module (SW-SQ) provides complete control over each installed PFL-100 Programmable Feedback Loop. The SQUID Control Module serves as the foundation for the PCS100 control software.

The SQUID Control Module includes the PCI Module, which is used to configure and operate the PCI-1000 interface. The multichannel PCI-1000 contains hardware such as the on-board signal generator that may be remotely configured. Each PCI-1000 is controlled using an individual PCI panel. The single-channel PCI-100 interface has no configurable hardware, and there is therefore no PCI panel for this interface.

The Remote Control Module (SW-RC) allows a user to access and operate the PCS100 Control Software running on a host or server computer remotely via a local network or the Internet. This module was developed using DataSocket technology from National Instruments. Remote operation of the PCS100 or PCS100DA Control Software is very similar to manual operation of a stand-alone, unconnected application. Almost all features of the SQUID Control Module, the optional Data Acquisition Module and Autotune/Calibration Module are remotely controllable.

The optional Data Acquisition Module (SW-DA) is used to acquire, display, and save digitized data from up to 8 channels. This software module can configure and control several types of 16-bit E-Series DAQ boards from National Instruments. The list of DAQ boards that may be used depends on the version of the PCS100DA Control Software. The user interface of the Data Acquisition Module is similar to that of an oscilloscope. Note that this module provides data for both the Spectrum Analysis and the Autotune/Calibration modules. These modules can be used only if a compatible DAQ board is installed and properly configured.

The optional Spectrum Analysis Module (SW-SA) enables the user to compute, display, save, and print a spectrum of the SQUID output signal. The spectrum is calculated by means of the fast Fourier transform (FFT), and displayed in real time. The Spectrum Analysis Module has many features found in general-purpose spectrum analyzers. A spectrum from only one data acquisition channel may be computed and displayed at a time, but a user can easily switch among different channels.

The optional Autotune/Calibration Module (SW-AT) enables the user to automatically tune and calibrate each SQUID channel for optimal noise performance. This module implements three different procedures. First, the SQUID is autotuned to maximize the SQUID output signal. Second, the SQUID is locked and the calibration factor is determined automatically. Third, the noise spectral density at a given frequency is minimized automatically by fine tuning the SQUID

bias and modulation parameters. Thus, all of the SQUID parameters and performance characteristics can be determined and optimized automatically.

The optional data acquisition and analysis modules are bundled with the SQUID Control Module and Remote Control Module as a single installation package, PCS100DA. Although the control functions discussed above are divided amongst several different modules, it is important to note that the PCS100DA Control Software is an integrated package and works as a whole. The autotune/calibration feature is a good example of the integrated control functionality. During autotuning, calibration, and noise minimization, the SQUID Control Module sets the SQUID parameters, which are sent to the PFL-100. The PCI Module specifies the properties of the test signal, which is generated by the PCI-1000 interface, and makes the appropriate filter selection. The Data Acquisition Module controls the DAQ board, which is used to measure the PFL output. The Spectrum Analysis Module calculates the spectrum of the SQUID output signal. The Autotune/Calibration Module analyzes the data, and determines the new SQUID tune parameters, which are transferred back to the SQUID Control Module. The Remote Control Module may be used to control the entire procedure from a remote computer. Thus, all of the hardware units and all of the software modules are involved in this process. For this reason, it is important that all system hardware and software are configured properly as described in Sections 2.3 and 2.4.

4.1 Operating the Software: A Brief Look

When the PCS100 or PCS100DA Control Software is launched for the first time, default initialization settings are used. Your first step will be to configure the software for the specific hardware you have installed. This is done using the System Configuration panel (Figure 2-1). Refer to Section 2.4.3 for detailed instructions on how to configure the software. Note that operation of the System Configuration panel is fully interactive, and all the settings take effect immediately. The only exception is the file selection: the "Restart" button should be used to restart the program with a different initialization file.

The main panel of the SQUID Control Module is shown in Figure 4-1. It includes three vertical sub-panels, the menu bar at the top, and the information bar at the bottom.

The left sub-panel is the Control section, which contains buttons used to select the operating mode. It also includes a display showing the state of every channel. When the number of channels is changed by means of the "N of Channels" control on the System Configuration panel, the display is updated automatically. The REFRESH button (see Section 4.2.7) is used to re-send all data to all PFL-100 and PCI-1000 units specified on the System Configuration panel. The MASTER toggle key is used to put the system into the Master mode (see Section 4.2.8). When this key is On (the letters are red), every command is copied to all channels.

The middle sub-panel is the Tune section. It includes numeric controls used to tune the SQUID. Normally, operation of these controls will affect the selected channel only. In the Master mode, however, any new control setting for the selected channel will be copied to all channels. The Tune section also contains the BIAS MODE control, which allows one to switch between the DC and AC bias modes. In Figure 4-1, the DC mode is selected, so the COMP (compensation), SKEW, and BIAS FREQ controls are not visible. These controls, however, are used in the AC bias mode. A typical appearance of the main panel when the AC mode is selected is shown in Figure 4-2.

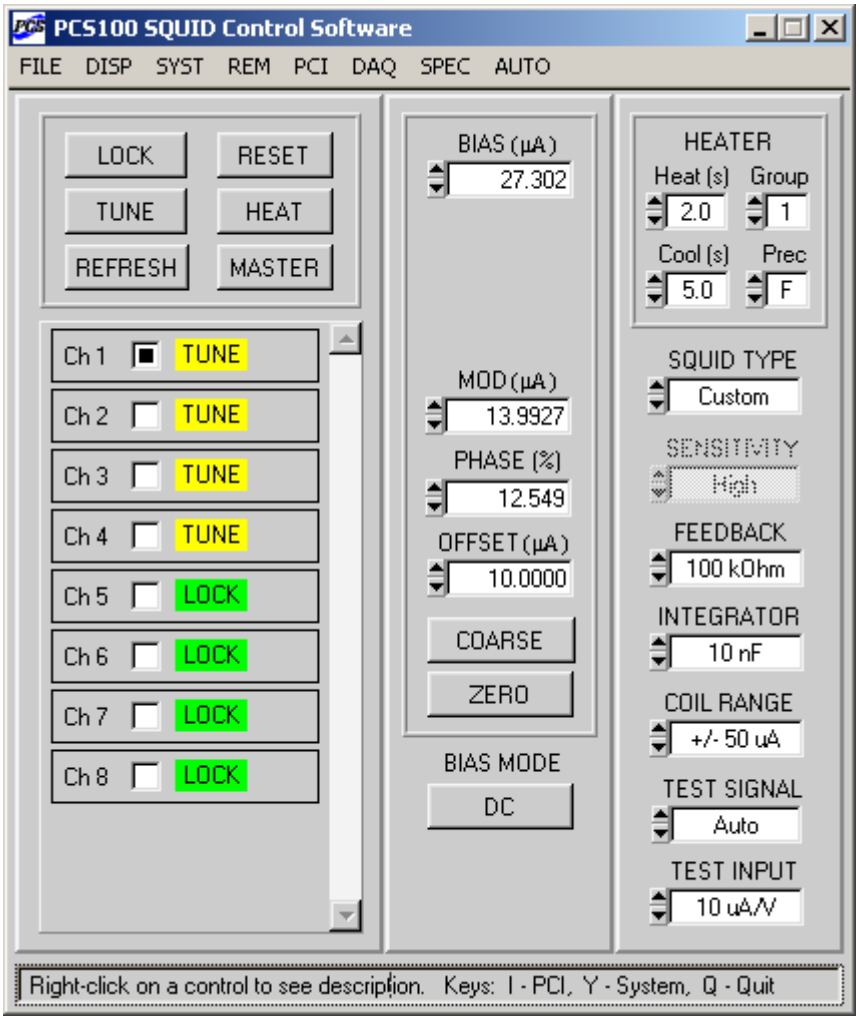


Figure 4-1. The main panel of the SQUID Control Module, configured for 8-channel operation. Channel 1 is the selected channel. It is operated here in the DC bias mode. All control settings on the middle and right sub-panels correspond to this channel. SQUID channels 1 – 4 are in the TUNE mode, while channels 5 – 8 are in the LOCK mode.

The right sub-panel of the main panel is the Configuration section. Controls in this section are used to configure the feedback loop parameters and test signal parameters for the selected channel. The heater parameters are the same for all channels. In the Master mode, any new setting entered for the selected channel will be translated to all the other channels. Note that the FEEDBACK, INTEGRATOR, and COIL RANGE settings may be adjusted independently only if the SQUID TYPE control is set to 'Custom'. Otherwise, these settings are selected automatically based on the setting of the SENSITIVITY control. One can use the HEATER Prec control to set precision of the Heat and Cool time controls to either 0.1 sec ('F'), or 1 sec ('C').

Each channel is represented in the Control section by its own small panel with three control indicators, which are used to display information about the channel, change its state, and select that channel for subsequent action.

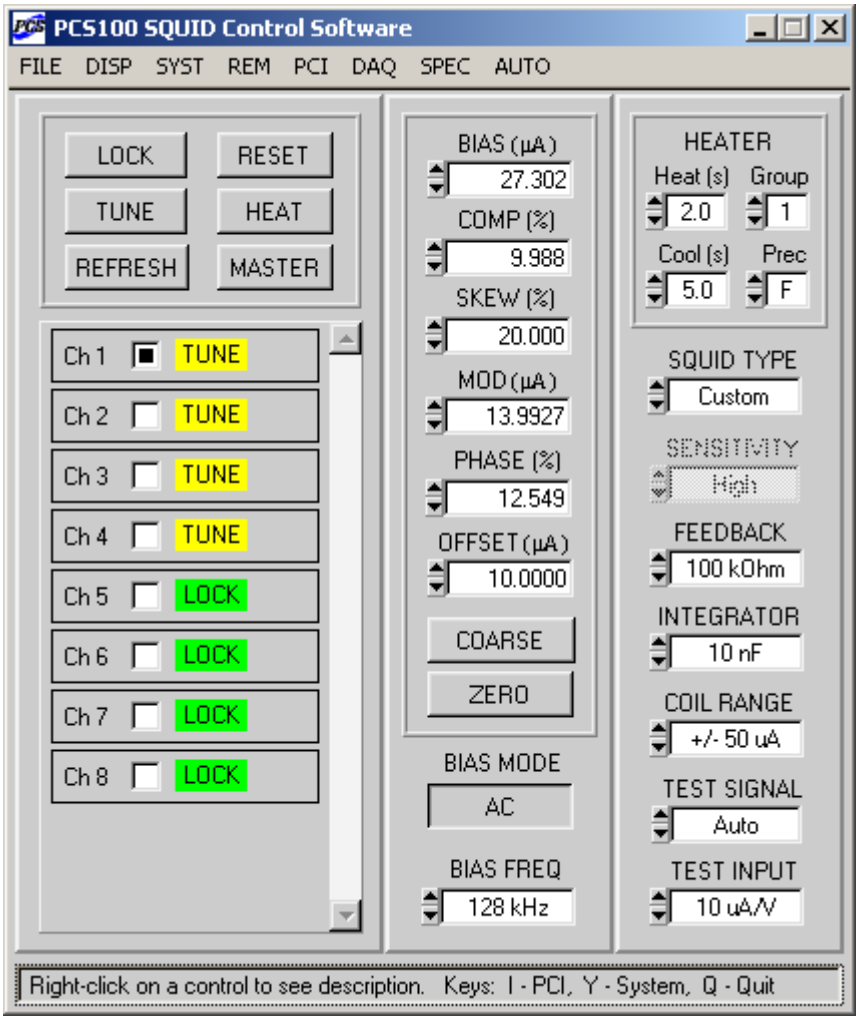


Figure 4-2. Appearance of the main panel of the SQUID Control Module if the selected channel is operated in the AC bias mode. The COMP, SKEW, and BIAS FREQ controls are now visible and functional.

To select a channel, simply use the mouse to click on the Select box located to the right of the channel number. Only one channel may be selected at a time. Detailed information about the selected channel is displayed in the Tune and Configuration sections of the main panel. When a different channel is selected, settings for that channel are then displayed. In this way, settings for each channel may be adjusted independently.

Next to the Select box, there is a colored State indicator. The State indicator is yellow in the TUNE mode, green in the LOCK mode. One can switch between the two modes simply by clicking on the State indicator. The corresponding channel then automatically becomes selected. The State indicators turn red during heating and blue during subsequent cooling. A typical appearance of the Main panel during a heat cycle is shown in Figure 4-3. Note that, during a heat cycle, all controls, except for the heater controls and State indicators, are disabled, and their settings cannot be changed. The same applies to all controls on the System Configuration panel.

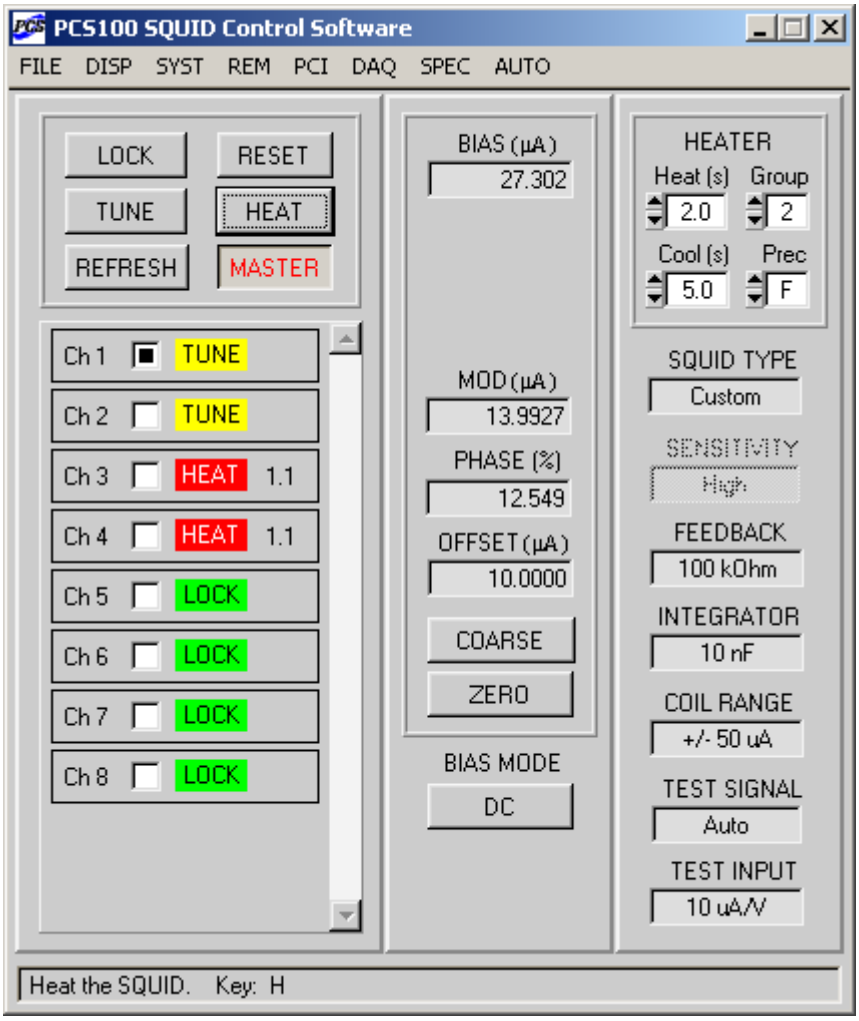


Figure 4-3. Appearance of the main panel of the SQUID Control Module during a heat cycle. Only the heater controls and the State indicators can be operated while heating or cooling is in progress. The Count indicators show the amount of time left for heating (1.5 sec). Here the system is in the Master mode (see Section 4.2.8), and channels are heated in groups of two.

If one clicks on any of the State indicators during heating, the heating process will be terminated, and cooling will begin. Clicking on any of them during cooling will end the cooling process and restore the normal state.

A Count indicator on the right of the State indicator is visible only during a heat cycle. It exhibits the amount of time, in seconds remaining (with either 0.1 sec or 1 sec resolution depending on the setting of the HEATER Prec control), for heating or cooling.

The main panel also features an information bar. Every time a control is operated, activated, or right-clicked, a description of this control, together with its hot-key assignment, appears at the bottom of the main panel. The same applies to all panels of the PCS100 and PCS100DA Control Software: information about any control can be viewed at the bottom of the corresponding panel.

The menu bar on the main panel of the SQUID Control Module has several items (PCI, DAQ, SPEC, AUTO, and REM), which are used to show or hide the other software modules.

If you are using a PCI-1000 unit, you may open a PCI panel by selecting PCI>Show PCI panel, or using the hot-key I. If you have more than one PCI-1000 unit, a submenu offering choices for each unit will appear. From the PCI panels, you may control all the settings pertaining to the PCI units, including the internal test signal generator and optional filters for each channel. To hide a PCI panel, select PCI>Hide PCI panel, or (as with all windows encountered in the PCS100 and PCS100DA Control Software) click on the standard Windows™ "close" button (×) in the upper right corner of the window. If the "PCI Units" control on the System Configuration panel is set to 'PCI-100', the PCI menu item is hidden, reflecting the fact that the PCI-100 interface is not programmable.

If you have installed the PCS100DA software upgrade which includes the Data Acquisition Module and related modules, use DAQ>Show DAQ panel menu item (or the hot-key D) to bring up the Data Acquisition panel. If this option is not available, but instead DAQ>Connect DAQ appears, select this item to connect to the DAQ board. The software will then try to initialize a DAQ device associated with the number set by the "Device Number" control on the System Configuration panel (Figure 2-1). You can hide the Data Acquisition panel by using the DAQ>Hide DAQ panel menu item.

If the DAQ board is successfully configured, the menu bar of the main panel displays two additional items: SPEC and AUTO. Use the SPEC>Show Spectrum panel menu item (or the hot-key E) to bring up the Spectrum Analysis panel. Select the AUTO>Show Autotune panel item (or use the hot-key A) to display the Autotune Procedure panel. If the DAQ board is not present, or is not configured properly, the SPEC and AUTO menu items will be hidden.

You may use the REM>Show Remote panel menu item to bring up the Remote Control panel. The Remote Control Module allows remote operation of the PCS100 and PCS100DA Control Software via the Internet.

To quit the PCS100 or PCS100DA Control Software, select FILE>Quit from the main menu, or use the hot-key Q. The current configuration settings will be saved, and recalled automatically the next time the PCS100 or PCS100DA Control Software is started.

4.2 SQUID Control Module

4.2.1 Main Panel Menu Items

FILE>About: Brings up the information panel which displays the version number of the software and lists the installed software modules. Please note this information when contacting STAR Cryoelectronics for support. Left-click on this panel to hide it.

FILE>Quit (hot-key Q): Quits the PCS100 or PCS100DA Control Software. Alternatively, the "close" button in the upper right corner of the Main panel may be used. All current settings are stored in the selected initialization file, and are restored when the PCS100 or PCS100DA software is launched the next time.

DISP>Show Tune, Config: Displays the Tune (middle) and Configuration (right) sub-panels.

DISP>Show Tune only: Displays the Tune sub-panel and hides the Configuration sub-panel.

DISP>Hide Tune, Config: Hides both the Tune and Configuration sub-panels of the Main panel.

SYST>Show System panel (hot-key Y): Brings up the System Configuration panel, which is used to configure the basic parameters of the system, such as the number of channels, type and number of PCI units, computer port, and DAQ device number.

SYST>Hide System panel (hot-key Alt + Y): Hides the System Configuration panel.

PCI>Show PCI panel (hot-key I; PCI-1000 only): Brings up PCI panel(s). If you have more than one PCI-1000 unit, a sub-menu appears which allows selection of a particular PCI panel to show. If several PCI panels are displayed, a particular PCI panel may be activated using the hot-key combination Ctrl + panel number.

PCI>Hide PCI panel (hot-key Alt + I; PCI-1000 only): Hides the PCI panel(s). If several PCI-1000 units are installed, a sub-menu appears, which offers a selection of PCI panels to hide. Alternatively, the OK button, or the "close" button in the right upper corner of each PCI panel may be used.

DAQ>Show DAQ panel (hot-key D; only if the DAQ Module is installed and the DAQ device is connected and configured): Brings up the Data Acquisition panel.

DAQ>Hide DAQ panel (hot-key Alt + D; only if the DAQ Module is installed and the DAQ device is connected and configured): Hides the Data Acquisition panel.

DAQ>Connect DAQ (only if the DAQ Module is installed): Attempts to connect to and configure a DAQ device. This menu item normally appears when communication with the DAQ board cannot be established. Note that the data acquisition software checks only the device number selected on the System Configuration panel. Use the "Device Number" control on that panel to select a different number. If communication is successfully established, the "Type" indicator on the System Configuration panel displays a valid device name, and the DAQ>Connect DAQ menu item is replaced by the DAQ>"Show DAQ panel".

SPEC>Show Spectrum panel (hot-key E; only if the DAQ Module is installed and the DAQ device is connected and configured): Brings up the Spectrum Analysis panel.

SPEC>Hide Spectrum panel (hot-key Alt + E; only if the DAQ Module is installed and the DAQ device is connected and configured): Hides the Spectrum Analysis panel.

AUTO>Show Autotune panel (hot-key A; only if the DAQ Module is installed and the DAQ device is connected and configured): Brings up the Autotune Procedure panel.

AUTO>Hide Autotune panel (hot-key Alt + A; only if the DAQ Module is installed and the DAQ device is connected and configured): Hides the Autotune Procedure panel.

REM>Show Remote panel: Brings up the Remote Control panel.

REM>Hide Remote panel: Hides the Remote Control panel.

4.2.2 Channel Controls

Select box (hot-key Alt + number to select a channel from 1 to 9, Alt + N to select the next one): Used to select a channel as a target for subsequent operations. Settings for this channel are then displayed in the Tune and Configuration sections of the main panel.

State indicator (hot-keys T to tune, L to lock): Displays the mode of the selected channel, taking on values TUNE (yellow), LOCK (green), HEAT (red), and COOL (blue). The TUNE state indicates that the feedback circuit is open, allowing examination of the PFL-100 output while the SQUID tune parameters are adjusted. The LOCK state indicates that the sensor is locked in the feedback mode, the standard operating mode for signal detection. The HEAT state is displayed while power is applied to the sensor heater in order to heat the SQUID above its critical temperature to remove trapped flux. Finally, the COOL state indicates the cool-down period following the HEAT state. Click on the State indicator to toggle between the TUNE and the LOCK modes. The channel automatically becomes selected. If any State indicator is clicked during heating, the heating will terminate and cooling will begin. If it is clicked during cooling, the cooling will end and the normal state will be restored. For detailed description of the heater operation, see Section 4.2.9.

4.2.3 Mode Controls

LOCK (hot-key L): Used to put the selected channel into the LOCK mode, that is, close the feedback loop and switch the electronics into the locked-loop mode. The LOCK mode is marked by a green State indicator with the word LOCK.

TUNE (hot-key T): Used to put the selected channel into the TUNE mode. In the TUNE mode, the feedback loop is open. This mode is used to adjust the SQUID parameters for optimal performance. The TUNE mode is marked by a yellow State indicator with the word TUNE.

RESET (hot-key R): Sends a RESET command to the selected channel. This action, which has effect in the LOCK mode only, temporarily opens the feedback loop and discharges the integrator. After executing a reset, the PFL-100 will resume tracking the applied signal starting with a value as close to zero as possible.

HEAT (hot-key H): Initiates a heat cycle for the selected channel. It may also be used during an ongoing heat cycle to restart it. The State indicator displays the word ‘HEAT’ during heating, and the word ‘COOL’ during subsequent cooling. A detailed description of the heat cycle is given in Section 4.2.9.

REFRESH (hot-key X): Used to re-send all current data and configuration settings to all PFL-100 and PCI-1000 units, specified on the System Configuration panel. See Section 4.2.7.

MASTER (hot-key Ctrl + M): Used to put the system into the Master mode. When this control is engaged (the letters are red), any command from the selected channel is copied to all the other channels. This allows simultaneous operation of all connected PFL-100 and PCI-1000 units. The Master mode is discussed in detail in Section 4.2.8 and Section 4.3.5.

4.2.4 Tune Parameter Controls

The tune parameter controls are BIAS, COMP (compensation), SKEW, MOD, PHASE, and OFFSET. These controls are used to adjust various tune parameters in order to optimize performance of the SQUID sensor. Each control programs an associated digital-to-analog converter in the PFL-100. A hot-key is assigned to each control. When the control is active, one may use the scroll arrows in the control window or Up and Down arrow keys to change the displayed value. The COARSE / FINE control sets the step size, which is defined as a certain fraction of the maximum value for each control. The FINE setting corresponds to a single DAC bit, *i.e.*, the highest possible resolution. Additionally, one may simply type the desired value into the control window and then press Enter. If the entered value is out of range, the control will display the nearest valid value. Below are descriptions of the individual controls. Note that if you right-click on any control, information about that control will appear at the bottom of the main panel.

BIAS (hot-key B): Sets the value, in microamperes, of the SQUID bias current. The bias mode (dc or ac) is specified by the BIAS MODE toggle button. In the DC bias mode, the maximum bias current is 200 μA. In the AC bias mode, the maximum value of the amplitude of the ac bias current is 100 μA. If the BIAS setting is less than or equal to 100 μA, it does not change when one toggles between the DC and AC modes. If, in the DC bias mode, the bias current is greater than 100 μA, it will be forced to 100 μA when the AC bias mode is selected. Note that the full-scale labels of the BIAS control in the DC and AC modes can be changed by editing the `BIASDCMAX` and `BIASACMAX` entries in the corresponding initialization file.

COMP (hot-key C): Sets the value of the compensation signal in the AC bias mode. This control is not visible in the DC mode. The COMP signal is measured in percent of full scale; the valid range is from -100% to 100%. The compensation signal is used to cancel the switching spikes generated by the bias current reversal when using the AC bias mode. These spikes and their harmonics produce artifacts in the SQUID output. The full-scale label of the COMP control can be changed by editing the `COMPMAX` entry in the corresponding initialization file.

SKEW (hot-key S): Sets the value of the skew signal in the AC bias mode. This control, like the COMP control, is not visible in the DC mode. It is also specified in percent of full scale, ranging from -100% to 100%. The skew signal is an ac flux offset used to cancel the effects resulting from asymmetries in the SQUID when operated using bias reversal. The full-scale label of the SKEW control can be changed by editing the `SKEWMAX` entry in the corresponding initialization file.

MOD (hot-key M): Sets the peak-to-peak magnitude, in microamperes, of the modulation signal. For optimal performance, this parameter should correspond approximately to one-half the current required to produce a change of 1 Φ_0 in the SQUID. The modulation current is generated by the PFL-100 in one of two possible ranges. Depending on which range is used, the maximum value for the MOD control is either 5 μA or 50 μA. The range is configured using the COIL RANGE control. The proper selection of the range, as well as determination of the

approximate setting for the MOD control, are discussed in detail in Section 4.2.10. Note that the full-scale labels for the two ranges of the MOD control can be changed by editing the `MODLOWMAX` and `MODHIGHMAX` entries in the corresponding initialization file.

PHASE (hot-key P): Used to adjust the delay of the multiplier reference signal in order to compensate for delays in the SQUID output signal. The range of this control is from 0 to 100%. See Section 5.7 for a detailed discussion about phase delays. The full-scale label of the PHASE control can be changed by editing the `PHASEMAX` entry in the corresponding initialization file.

OFFSET (hot-key O): Used to set the value of the dc offset flux applied to the SQUID sensor, specified in units of current (microamperes). This control may be used to offset the output signal while in the LOCK mode, or to adjust the offset of the flux sweep in the TUNE mode. Similar to the MOD control, the OFFSET control is dual-range, 0-5 μA or 0-50 μA, as determined by the COIL RANGE control. However, if your sensor uses separate feedback and modulation coils, the offset current is applied to the feedback coil. See the discussion concerning SQUID type and range selection in Section 4.2.10. The full-scale labels for the two ranges of the OFFSET control can be changed by editing the `OFFLOWMAX` and `OFFHIGHMAX` entries in the corresponding initialization file.

COARSE / FINE (hot-key W): Sets the incremental step for the tune parameter controls located immediately above it. The FINE setting corresponds to the highest resolution. Click on this control to toggle its value.

ZERO / RESTORE (hot-key Z): Sets all tune parameters to 0, while keeping in memory their original values. This is useful when connecting or disconnecting the PFL from the sensor, or during an initial cooldown of the sensor. Click on this control to zero the outputs (if not in "zero" state), or to restore them to the original values (if in "zero" state). This control may be conveniently used in the Master mode (see Section 4.2.8). Turn the MASTER control On (the letters become red), and click on ZERO. This will zero the outputs of all connected PFL-100 units, so that any of them may be disconnected without harming the associated sensor. Click on RESTORE, and all PFL outputs will be restored independently to their original settings. Turn the MASTER control Off to operate each channel individually. If some PFL units are re-connected, use the REFRESH button to re-establish communication. Note that the ZERO/RESTORE control also affects the test signal mode. If you click on ZERO, the TEST SIGNAL control is automatically set to 'Off', and the test signal is disconnected. This prevents flux trapping while the sensor is idle, as during the initial cooldown. Clicking on RESTORE will restore the original test signal mode.

BIAS MODE (hot-key K): Sets the bias current mode to AC (bias reversal) mode or DC (standard or non-bias reversal) mode. In the AC bias mode, the bias current changes polarity at the frequency set by the BIAS FREQ control. Note that, in the DC bias mode, two of the tune parameter controls (COMP and SKEW), as well as the BIAS FREQ control, are not visible. These parameters are relevant only to the AC bias mode. The AC mode is typically used to reduce the low-frequency noise associated with HTS sensors, while the DC mode is simpler and usually adequate for most LTS sensors.

BIAS FREQ (hot-key F): Sets the bias current reversal frequency in the AC bias mode. This control is not visible in the DC mode. The available bias reversal frequencies are 128 kHz,

64 kHz and 2 kHz. The frequency labels of the BIAS FREQ control can be changed by editing the `FRELOW`, `FREMED`, and `FREHIGH` entries in the corresponding initialization file.

4.2.5 Heater Controls

The HEATER control section includes four controls: "Heat", "Cool", "Group", and "Prec". Their settings apply to all channels. These controls may be adjusted during a heat cycle, and the new settings take effect immediately.

HEATER Heat (hot-key Ctrl + H): Sets the amount of time, in seconds, during which power is applied to the sensor heater. The precision (0.1 sec or 1 sec) is set by the HEATER Prec control.

HEATER Cool (hot-key Ctrl + L): Sets the amount of time, in seconds, during which the sensor is allowed to cool down after heating. All outputs of the PFL-100 are set to zero during the cooling cycle to prevent flux re-trapping. The precision (0.1 sec or 1 sec) is determined by the HEATER Prec control.

HEATER Group (hot-key Ctrl + G): Sets the number of channels for simultaneous heating or cooling in the Master mode (see Section 4.2.8). If, for example, this number is equal to 2, the channels will be heated in pairs: first, a heat cycle will be completed for the first two channels (starting with the selected channel), then automatically for the next two channels, and so on. In Figure 4-3, the heat cycle has been completed for channels 1 and 2, and is in progress for channels 3 and 4. This control has effect only if the MASTER key is On (see Section 4.2.8). Because of power limitations, the maximum number of simultaneously operated heaters that may be set with the HEATER Group control is equal to 6.

HEATER Prec (hot-key Ctrl + P): Sets the precision for the Heat and Cool controls, as well as for the Count indicators. If this control is set to 'F' (Fine), both the heating and cooling times are displayed with one decimal place after the point, and can be modified with 0.1 sec resolution. If this control is set to 'C' (Coarse), the Heat and Cool controls display integer values, which can be modified in 1 sec steps only. When this control is switched from 'F' to 'C', both time values are truncated. The 'F' setting is useful, for example, to configure the precise amount of power necessary to just heat a SQUID above T_c when the sensor is installed in vacuum.

4.2.6 Configuration Controls

The configuration controls are SQUID TYPE, SENSITIVITY, FEEDBACK, INTEGRATOR, COIL RANGE, TEST SIGNAL, and TEST INPUT. The first five controls determine the modulation and feedback loop parameters. Their settings are not independent; if a value of one control is changed, the values of the other controls will change automatically, as described below. The last two controls define the test signal mode and test input sensitivity. All configuration controls are ring controls with a limited number of options.

SQUID TYPE (hot-key Ctrl + K): Used to specify the sensor type, based on the coupling strength of the sensor modulation coil. The coupling strength is quantified by the amount of current required to generate 1 Φ_0 change in the SQUID. This quantity is displayed by the COIL RANGE control. Sensors of Type I have a nominal coupling strength of 5 $\mu A/\Phi_0$, sensors of Type II have a nominal coupling strength of 50 $\mu A/\Phi_0$. If the SQUID TYPE control is set to 'Type I' or 'Type II', the COIL RANGE setting is predetermined and cannot be changed. Also, the FEEDBACK and INTEGRATOR controls are in the indicator mode, so the feedback loop

parameters are determined exclusively by the SENSITIVITY control. If the SQUID TYPE control is set to 'Custom', the COIL RANGE control is enabled and can be configured. Also in this case, the SENSITIVITY control is dimmed, and the feedback resistor and integrator capacitor can be selected independently using the FEEDBACK and INTEGRATOR controls. For more details, see the discussion in Section 4.2.10.

SENSITIVITY (hot-key Ctrl + S): When set to 'Low', 'Medium', or 'High', selects the gain of the feedback loop, while keeping the frequency response fixed. This is accomplished by changing the values of the feedback resistor and integrator capacitor together while keeping their product constant. Generally, the 'High' setting will give the best sensitivity at the expense of a reduction in dynamic range. Conversely, the 'Low' setting enables the largest dynamic range at the expense of some loss of sensitivity. Note that the SENSITIVITY control may be configured if the SQUID TYPE control is set to 'Type I' or 'Type II', and is dimmed if the SQUID TYPE is set to 'Custom'. See the discussion in Section 4.2.10 for more details.

FEEDBACK (hot-key Ctrl + F): Used to select the value of the feedback resistor if the SQUID TYPE control is set to 'Custom'. If the SQUID TYPE setting is 'Type I' or 'Type II', the feedback resistor value is predetermined by the SENSITIVITY setting and cannot be changed independently. The FEEDBACK control may be used to manually set the feedback resistor to 1 kΩ, 10 kΩ, 100 kΩ, or 1 MΩ. For more details see Section 4.2.10. The resistor labels of the FEEDBACK control can be changed by editing the `RESLOW`, `RESMED`, `RESHIGH`, and `RESMORE` entries in the corresponding initialization file.

INTEGRATOR (hot-key Ctrl + I): Used to select the value of the integrator capacitor if the SQUID TYPE control is set to 'Custom'. If the SQUID TYPE setting is 'Type I' or 'Type II', the integrator capacitor value is predetermined by the SENSITIVITY setting and cannot be changed independently. The INTEGRATOR control may be used to manually set the integrator capacitor to 1 nF, 10 nF, or 100 nF. See Section 4.2.10 for a detailed discussion. The capacitor labels of the INTEGRATOR control can be changed by editing the `CAPLOW`, `CAPMED`, and `CAPHIGH` entries in the corresponding initialization file.

COIL RANGE (hot-key Ctrl + J): Used to select the modulation coil coupling range when the SQUID TYPE control is set to 'Custom'. This selection governs the range of the MOD and OFFSET controls. If the COIL RANGE control is set to ±5 μA/Φ_0, the maximum value for the MOD and OFFSET controls is 5 μA. If the COIL RANGE setting is ±50 μA/Φ_0, the maximum value for these two controls is 50 μA. If the COIL RANGE control is toggled between its two values, the MOD and OFFSET settings change by a factor of 10, so that the output value of either control remains a constant fraction of its maximum value. When the SQUID TYPE control is set to 'Type I' or 'Type II', the COIL RANGE control acts as an indicator, and cannot be operated. See Section 4.2.10 for a detailed discussion. The coupling labels of the COIL RANGE control can be changed by editing the `COILOW` and `COIHIGH` entries in the corresponding initialization file.

TEST SIGNAL (hot-key Ctrl + T): Determines when the test signal (whether supplied by the PCI-1000 internal generator or an external source) is applied to the SQUID. The available options are 'Off', 'On', and 'Auto'. The operation is summarized in Table 4-1. If the TEST SIGNAL control is set to 'Off' or 'On', the test signal is definitely Off or definitely On, respectively. If this control is set to 'Auto', the test signal is On when the SQUID is in the

TUNE mode, and Off when it is in the LOCK mode. In this case, the applied signal is present only when necessary for tuning. If the selected channel is in the "zeroed" state, the test signal is 'Off', and the TEST SIGNAL control cannot be operated. When the heater is activated, the test signal mode remains unchanged during heating, but is always 'Off' during subsequent cooling.

The TEST SIGNAL control operates a switch inside the PFL-100. One should be aware, when using a PCI-1000, that the TEST SIGNAL OUTPUT ENABLE switches on the PCI panels also affect the connection between the test signal source and the SQUID sensor. See the description of the PCI Module in Section 4.3 for further information. One should also remember that, because the test signal switch (operated by the TEST SIGNAL control) is located within the PFL-100, even though the TEST SIGNAL is 'Off' (or equivalently, set to 'Auto' in the LOCK mode), the actual test signal voltage is carried along the cables to the PFL-100. It is possible for this test signal to capacitively couple to the output signal wires, and thus be seen in the SQUID output. Therefore, for sensitive measurements, the test signal should be turned off using the TEST SIGNAL OUTPUT ENABLE switch on the PCI panel.

Table 4-1. Operation of the TEST SIGNAL control.

	Mode	
TEST SIGNAL Setting	TUNE	LOCK
OFF	Off	Off
ON	On	On
AUTO	On	Off

TEST INPUT (hot-key Ctrl + V): Selects the current limiting resistor in the test signal input circuit, and thus determines the voltage-to-current conversion for the test signal input. This applies to test signals originating from the internal generator in the PCI-1000 as well as to signals supplied externally via the front panel TEST INPUT connector on either the PCI-100 or PCI-1000. The TEST INPUT can be configured for 10 μA/V, 100 μA/V, and 1000 μA/V. Note that these labels can be changed by editing the `TESLOW`, `TESMED`, and `TESHIGH` entries in the corresponding initialization file.

4.2.7 REFRESH Command

The REFRESH command is used to re-send all data and configuration settings to all the PFL-100 and PCI-1000 units, specified on the System Configuration panel (Figure 2-1). Communication to these units is uni-directional, with all configuration data originating from the computer. Thus, the PCS100 or PCS100DA Control Software cannot poll these devices in any way to read their current configuration. Instead, the software keeps a copy of the current configuration, which is updated as new commands are sent. This works well under normal conditions. If, however, these units cannot receive the commands sent, the software copy of the configuration will not match the hardware configuration. This may occur, for example, if the power to the units is turned off, if any of the units are disconnected, or if the computer port is disabled, or not configured properly. Under these conditions, when communication is restored, one should click the REFRESH button to re-synchronize the hardware and software configurations.

4.2.8 Master Mode

Sometimes it may be convenient to send a single command to all PFL-100 units. For example, one should zero all PFL units before connecting or disconnecting them from their sensors. Or, if all sensors have the same design, it may be convenient to set the same initial values of the tune parameters for all channels, and then fine-tune each channel individually. Also, because each heat cycle takes time, heating many channels one by one can be a tedious task. Heating groups of channels will in these cases save time.

To allow simultaneous control of all channels, a Master mode is implemented in the PCS100 or PCS100DA Control Software. Every PFL-100 unit can be programmed to respond to a different address in addition to the hardware address set by the internal DIP switch inside the PFL. The PCS100 and PCS100DA software takes advantage of this important design feature.

The MASTER control is located in the Control section of the main panel next to the REFRESH button (Figure 4-1). Its normal state is Off (the letters are black), and every channel in this case is controlled individually via its hardware address. When the MASTER control is toggled to the On state (the letters are red), all PFL-100 units are programmed to respond to address 0 as well. Thus, any command sent to address 0 is executed by all channels simultaneously, and the DATA indicator LEDs of all connected PFL-100 units turn green at the same time. Note that turning the MASTER control On does not change any settings by itself. Any subsequent command, however, will affect all installed channels.

Normally, changing one setting for all channels in the Master mode does not affect the other settings. For example, sending the RESET command to all PFL-100 units will not affect their individual tune or configuration parameters. However, some settings are not independent, and, therefore, should be adjusted simultaneously. The SQUID TYPE, SENSITIVITY, FEEDBACK, INTEGRATOR, and COIL RANGE configuration parameters are examples of this. If any of these parameters is changed for a given channel in the Master mode, all five parameters are adjusted and sent to all installed PFL units.

The REFRESH command sends data to each PFL-100 unit depending on its hardware address only. Thus, the settings for each channel are restored or refreshed individually, even in the Master mode. At the same time, if the MASTER control is On, the REFRESH command will enable address 0 for each channel. After sending this command, all PFL units can be operated in the Master mode, even if some of them were temporarily disconnected from the PC Interface.

The HEAT command can be sent to several PFL-100 units using address 0. In this case, the advantage of the programmable address option is very clear. Indeed, transmission of this command to all PFL units sequentially using their individual hardware addresses would take much time and disrupt the precise timing of the heat cycle. In the Master mode, the heat cycle is performed automatically for groups of channels as configured using the HEATER Group control. All channels, belonging to one group, are heated simultaneously. Due to power limitations, however, not more than 6 channels may be heated at the same time. Address 0 is enabled for the current group of channels only. After the heat cycle, the settings for each channel are restored individually. Thus, one can easily operate all the heaters without changing the individual configuration of each channel.

Finally, it should be noted that all commands in the Master mode “commute” with the ZERO / RESTORE command. If new settings are entered for a given channel in the Master mode while

another channel is in the "zero" state, that channel will remain in the "zero" state, but a subsequent RESTORE command will produce outputs corresponding to the new settings.

4.2.9 Heater Operation

The heater is used to remove trapped flux from the SQUID sensor. The sensor is warmed above its critical temperature T_c so that the superconducting films become normal, and any trapped flux is released. The heating procedure must be performed only when the SQUID is at cryogenic temperatures, *e.g*. the sensor is immersed in a liquid helium or nitrogen bath.

WARNING

Attempting to heat the sensor while at room temperature may potentially damage the sensor by heating the sensor package to extreme temperatures.

The heater follows a specific cycle according to the following principle of operation. The heat cycle is initiated by clicking on the HEAT button or by pressing the hot key H. The first segment of the cycle is the heat segment, marked by the red State indicator, displaying the word 'HEAT'. During this segment, power is supplied to a resistor mounted within the sensor package for a fixed amount of time, set by the HEATER Heat control. The applied power will heat the sensor up to a temperature above its critical temperature, when the trapped flux will be released. After the heating time elapses, the cool segment of the cycle is started, and the blue State indicator exhibits the word 'COOL'. During this segment, the sensor is allowed to cool down below the critical temperature, while all currents and signals normally applied to the SQUID are temporarily set to zero in order to minimize the risk of flux re-trapping in the device. This is evidenced by the tune controls, which all display zero during this segment. The cooling segment lasts for the amount of time set by the HEATER Cool control. When the cooling is completed, the settings are returned to their original values. At any time during the cycle, the entire cycle may be re-started by executing a new HEAT command.

Both the heating and the cooling times can be varied from 0.1 sec to 300 sec with either 0.1 sec or 1 sec resolution. This allows precise adjustment of the heat cycle parameters. Using the fine adjustment of the heat time, the power applied to the heater can be configured for the minimal value necessary to release trapped flux, thereby avoiding excessive heating. This is mostly advantageous for SQUIDs installed in vacuum.

It should be noted, however, that the actual heating time may depend on the speed at which data are transferred from the computer to the PFL-100 unit(s). For example, if a serial (COM) port is used for communication, the time needed for transmission of the command terminating the heat segment can be as long as 50 msec. Thus, if one sets the heating time to 0.1 seconds using the HEATER Heat control, the heater will remain On for 0.1+0.05=0.15 seconds. In order to eliminate this discrepancy, one has to adjust the `TIMESHIFT` parameter in the `[HARDWARE]` section of the initialization file. This parameter specifies the amount of time, in seconds, needed to transmit the heater command. Its default value is zero. If the transfer time for the heater command is 50 msec, this parameter should be set to 0.05. The command to terminate the

heating process will then be issued (heat time – time shift) seconds after the start of heating, so that the total heating time in the above example will be exactly 0.1 seconds.

In order to perform fine adjustment of the heating time, one should connect an oscilloscope to the heater output of the PFL-100 unit (disconnected from the sensor), and measure time profile of the heat pulse. The output connector pinout of the PFL-100 is described in Section 5.15. The measured heating time will normally be a little longer than the time, set by the HEATER Heat control. Adjust the `TIMESHIFT` parameter to make these two times equal.

Two additional aspects of the heater function should be noted. First, during the heat and cool segments, the time remaining in the segment is displayed by the Count indicator in real time. You may change the duration of each segment using the HEATER Heat or HEATER Cool controls while the segment is in progress. The total time is simply adjusted to reflect the new setting. If you wish to terminate one of these segments prematurely, simply click on any State indicator, and the next segment will be started immediately. For example, if you believe the heater has been on long enough, you may click on the red HEAT indicator, and this will immediately start the cool segment. Click again and the heat cycle will end.

Second, if the SQUID is initially in the LOCK mode, it will switch to the TUNE mode while the heat and cool segments are in progress. This enables one to observe the SQUID voltage-flux output if the TEST SIGNAL control is set to 'Auto' or 'On'. As the sensor temperature increases towards the critical temperature, the SQUID output signal will gradually decrease in amplitude until the sensor goes normal. Often this transition is accompanied by a short jump in the level of the output signal, which then becomes completely flat. Observation of this effect is a good method for determining the optimum heating time. During the cooling segment, the TEST SIGNAL control is automatically set to 'Off' to prevent any flux re-trapping, and returned to its initial state after the end of cooling. The initial LOCK mode is also restored after the cooling, and a RESET operation is automatically performed.

4.2.10 Selecting the SQUID Type and Sensitivity Parameters

The PFL-100 is designed to provide the greatest flexibility of use possible for a wide range of sensors, while still providing optimized, low-noise operation. For this reason, several parameters in the PFL-100 are available for configuration to best match your sensor and application. All of these parameters may be easily adjusted using the PCS100 or PCS100DA Control Software.

With regard to the coupling strength between the modulation coil and the SQUID, the sensors manufactured by STAR Cryoelectronics generally fall into two categories. These two categories are designated Type I and Type II and correspond to nominal values of 5 $\mu A/\Phi_0$ and 50 $\mu A/\Phi_0$, respectively. For optimal performance, the modulation current is generated by the PFL-100 in two ranges, 0-5 μA peak-to-peak for Type I sensors, and 0-50 μA peak-to-peak for Type II. In this way, the optimal setting will fall roughly mid-range, although coupling strengths taking values anywhere between 0 and 50 $\mu A/\Phi_0$ may be accommodated. Thus, depending on which range is used, the maximum value for the MOD control is either 5 μA or 50 μA. It is determined by the COIL RANGE control. The OFFSET control range is also set according to Types I and II, which correspond to ranges of ±5 μA and ±50 μA, respectively.

When the SQUID TYPE control is set to 'Type I' or 'Type II', the SENSITIVITY control is visible. These two controls determine the appropriate combination of the feedback resistor and

integrator capacitor values in such a manner as to keep the frequency response of the feedback loop fixed (the integrator *RC* product is kept constant). You may think of the SQUID TYPE and SENSITIVITY as independent parameters, and the FEEDBACK, INTEGRATOR, and COIL RANGE as dependent parameters. The last three controls act as indicators for SQUIDs of Type I or II. Possible combinations of these parameters are shown in Table 4-2.

Table 4-2. Dependence of the FEEDBACK, INTEGRATOR, and COIL RANGE parameters on the SQUID TYPE and SENSITIVITY settings.

	SENSITIVITY			**COIL RANGE**
	HIGH	**MED**	**LOW**	
TYPE I	1 MΩ	100 kΩ	10 kΩ	±5 μA
TYPE II	100 kΩ	10 kΩ	1 kΩ	±50 μA
INTEGRATOR	1 nF	10 nF	100 nF	

For maximum flexibility, the SQUID TYPE control may be set to 'Custom'. In this mode, the SENSITIVITY control is dimmed and cannot be configured. Instead, the FEEDBACK, INTEGRATOR, and COIL RANGE controls become configurable, and their settings can be changed independently. It may be necessary to experiment to determine the appropriate combination of parameters for stable operation in the 'Custom' mode. This is likely in the event that the modulation coupling is in the range of roughly 10-25 $\mu A/\Phi_0$, or if separate feedback and modulation coils significantly differing coupling strengths are used. Refer to Table 4-3 for recommended settings of the SQUID TYPE control for various ranges of feedback coupling.

Table 4-3. Recommended SQUID TYPE setting as a function of feedback coupling.

	Feedback Coupling ($\mu A/\Phi_0$)		
SQUID Type	<10	10 - 25	25 – 100
TYPE I	•		
TYPE II			•
CUSTOM	•	•	•

4.3 PCI Control Module

The PCI Module is a part of the SQUID Control Module, which is used to control the internal settings of the PCI-1000 Interface. The PCI panels are available if the "PCI Units" control on the System Configuration panel (Figure 2-1) is set to one or more PCI-1000 units. If the "PCI Units" control in the System Configuration is set to PCI-100, the PCI menu is not available.

When setting up a system that was not factory pre-configured, be careful to properly configure the internal hardware addresses of each PCI-1000 unit. Instructions are given in Section 2.3. The PCI-1000 uses the same address space and communications port as the PFL-100. Just as in the case of the PFL, it is necessary to send a REFRESH command following any event where the PCI-1000 has been powered down or the communication cable has been disconnected.

Each installed PCI-1000 unit has its own associated PCI panel labeled according to the channels it controls, such as "PC Interface: Channels 1 - 8" for the first unit. The PCI panel may be brought up by selecting the PCI>Show PCI panel menu on the main panel. If several PCI-1000 units are installed, a submenu listing all the panel choices appears. The PCI panel for the first PCI-1000 unit (Channels 1 through 8) is shown in Figure 4-4.

The PCI panel has four main sections, each pertaining to a major function group representing a component or switch setting within the PCI-1000. A block diagram illustrating these various components and their interconnections is shown in Figure 4-5. The four sections are: the TEST SIGNAL GENERATOR, the TEST SIGNAL OUTPUT ENABLE switches, the SIGNAL CONDITIONING controls, and the FRONT PANEL OUTPUT controls. These functional groups and their controls are described in detail below.

4.3.1 Test Signal Generator

The TEST SIGNAL GENERATOR section of the PCI panel provides control over the internal triangle waveform generator of the PCI-1000. This generator is used to supply the test signal necessary to tune the SQUID. The test signal is routed internally to the PFL units and ultimately to the sensor modulation coil. This is done to apply a flux sweep to the SQUID sensor for tuning purposes.

Note in Figure 4-5 that both the output of the internal test generator and the signal applied to the TEST INPUT front panel BNC are connected to a summing amplifier. Thus, one may use either method to supply a test signal to the sensor. However, this also means that the external signal and the signal of the internal test generator will add together if the generator is On. Make sure that only one of these test signal sources is used.

On / Off (hot-key G): Turns the internal signal generator "On" or "Off". Click on the corresponding box to toggle the value. If the generator is turned "Off", the "Frequency", "Amplitude", and COARSE / FINE controls, located in the same section of the PCI panel, are dimmed.

Frequency (hot-key F): Sets the frequency of the test signal. The frequency may be set to values between 1 Hz and 4096 Hz with 1 Hz resolution. To change the frequency in 1 Hz steps, set the COARSE / FINE control to FINE.

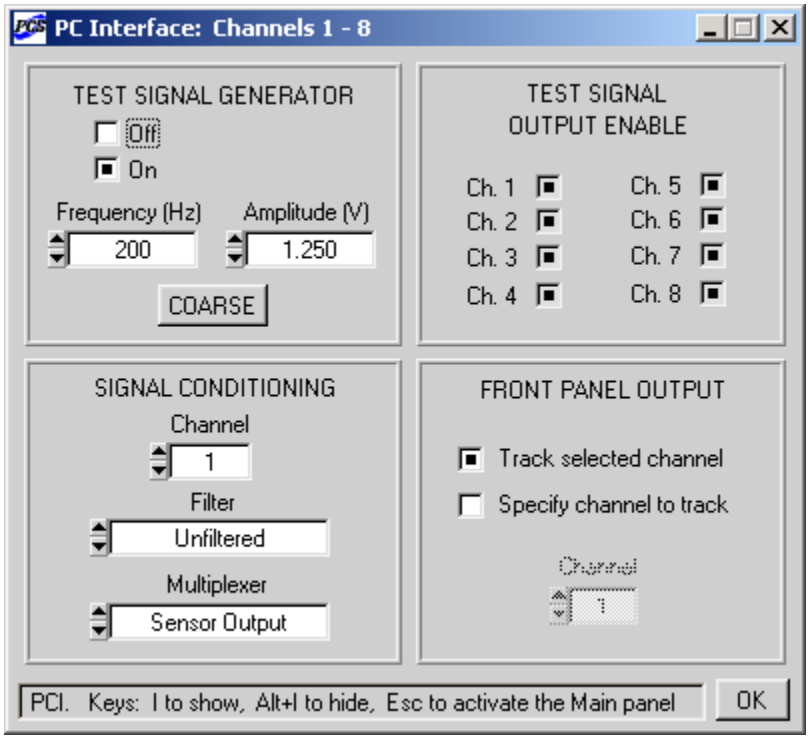


Figure 4-4. The PCI panel for channels 1 to 8.

Amplitude (hot-key A): Sets the amplitude of the test signal. The default maximum value for this control is 5.0 V. The full-scale label can be changed by editing the `PCIAMPMAX` entry in the corresponding initialization file.

COARSE / FINE (hot-key W): Sets the incremental step for the "Frequency" and "Amplitude" controls. The step is defined as a certain fraction of the maximum value for each control. The FINE setting gives the highest resolution.

4.3.2 Test Signal Output Enable

TEST SIGNAL OUTPUT ENABLE (hot-key Alt + channel number): This section consists of a set of eight independent switches, one for each channel controlled by the PCI-1000 unit. Each of these switches connects the test signal to the PFL-100 unit for that particular channel. Click on the switch to connect or disconnect the test signal. Note that, according to the block diagram in Figure 4-5, this works regardless of whether the signal is generated internally using the test signal generator, or supplied by an external source through the TEST INPUT front panel BNC connector.

These 8 switches are provided in order to isolate the test signal source on channel-by-channel basis from the 25-pin INPUT connector located on the PCI-1000 back panel. This feature may be used, for example, to implement a noise cancellation strategy by supplying signals directly to the SQUID modulation coil via the 25-pin INPUT connector.

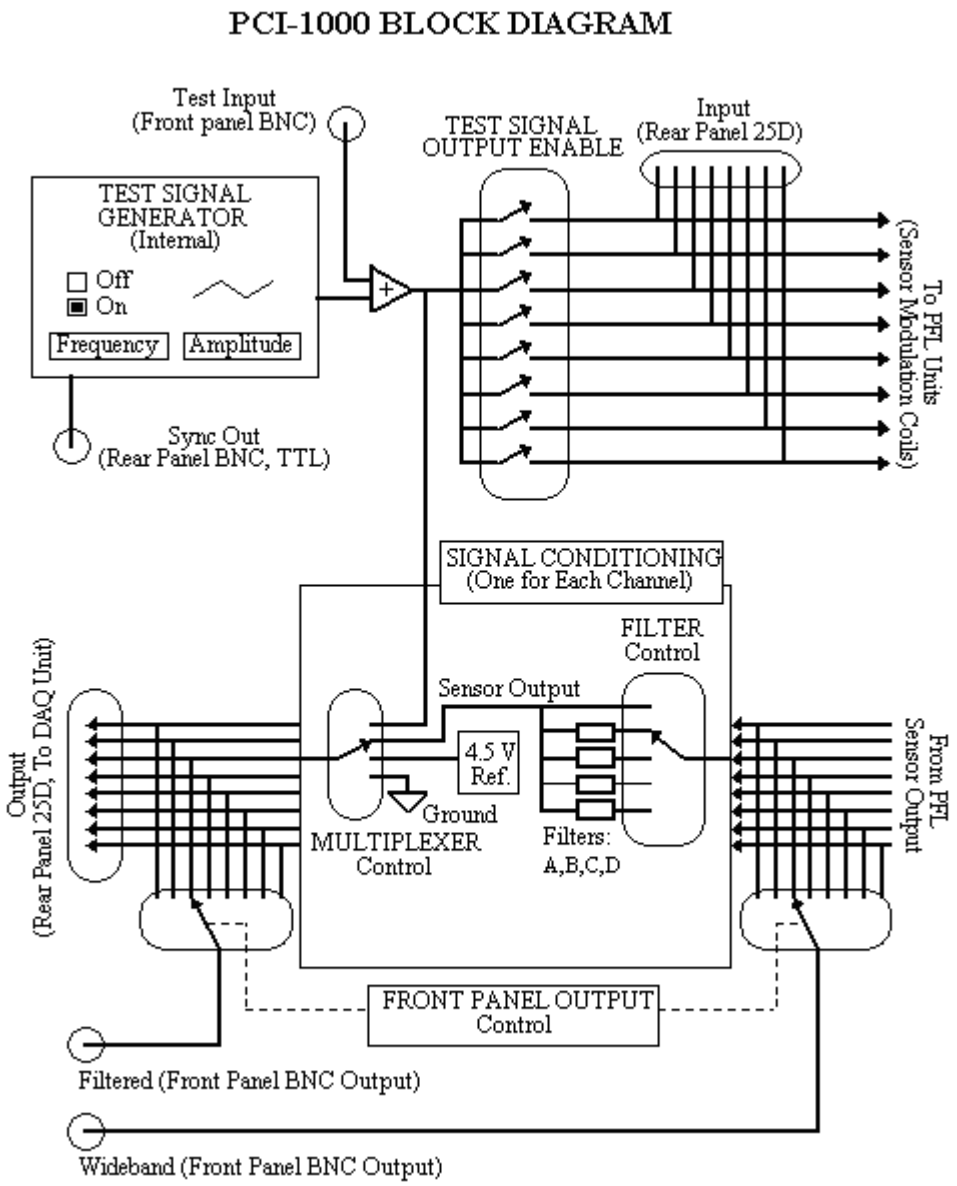


Figure 4-5. Block diagram of the PCI-1000 Interface, showing basic signal routes and their relationship to the PCI panel features. Note that this is a relational diagram only. Some features such as buffers, etc., have been omitted for clarity, and wired connections cannot always be interpreted literally.

4.3.3 Signal Conditioning

The SIGNAL CONDITIONING section provides control over a multiplexer and four optional low-pass filters for each channel controlled by the PCI-1000. This is illustrated in the above block diagram (Figure 4-5).

Channel (hot-key K): Selects the channel for which the filter and multiplexer settings are displayed.

Filter (hot-key L): Used to select the low-pass filter (optional). The raw PFL-100 signal passes through the filter subsystem before reaching the multiplexer as the Sensor Output. The Filter control can be set to one of four optional 4-pole low-pass Butterworth filters. If it is set to 'Unfiltered', the raw PFL signal is passed. The filter cutoff frequencies should be chosen to provide the appropriate anti-aliasing filtration, and depend on the sampling rates of the DAQ device. See Section 4.5.3 for details. For the PCI-6034E and similar boards with the maximum sampling rate of 200 kS/s, the recommended filter frequencies are 60 kHz, 20 kHz, 10 kHz, and 6 kHz. They corresponds to data acquisition from 1, 2, 4, and 8 channels, respectively. For the PCI-6030E and the other boards with 100 kS/s maximum sampling rate, these frequencies should be 30 kHz, 10 kHz, 6 kHz, and 3 kHz. Finally, for the PCI-6052E board with the maximum sampling rate of 333 kS/s, 100 kHz, 30 kHz, 20 kHz, and 10 kHz filters are recommended. Note also that the filters are normally installed at the factory only at the time of ordering your PCI-1000. If you have added more channels, you may first have to install additional filters within the PCI-1000. See Section 7.3 for instructions. If filters with cutoff frequencies different from the above mentioned frequencies are installed, the frequency labels of the "Filter" control should be changed by editing the `FILTERA`, `FILTERB`, `FILTERC`, and `FILTERD` entries in the initialization file. These entries correspond to increasing cutoff frequencies.

Multiplexer (hot-key M): Used to select among four signal sources for the PCI-1000 output: 'Sensor Output', 'Test Signal', 'Ground', and '4.5 V Reference'. If this control is set to 'Sensor Output', individual channel outputs may be routed to the FILTERED front panel BNC connector using the FRONT PANEL OUTPUT control section. Setting the multiplexer to 'Test Signal' allows one to view the test signal, whether it is internally or externally generated, at the FILTERED output of the PCI-1000. The '4.5V Reference' and 'Ground' settings allow calibration of the DAQ unit or whatever device you may choose to connect to the rear panel output. The multiplexer output can be sent to the DAQ device via the 25-pin D-type OUTPUT connector on the back panel of the PCI-1000.

4.3.4 Front Panel Output

The FRONT PANEL OUTPUT section is used to control which signal is routed to the WIDEBAND and FILTERED front panel BNC connectors of the PCI-1000 interface unit.

Track Selected Channel (hot-key O): When this option is chosen, the front panel output is the output of the channel selected on the main panel of the SQUID Control Module. This is a convenient setting if, for example, you wish to observe the output on an oscilloscope and switch frequently among various channels. Simply connect the oscilloscope to the FILTERED connector on the PCI-1000 front panel. When you select a channel, the output of that channel will be tracked automatically and displayed on the oscilloscope screen.

Specify Channel to Track (hot-key O): When this option is selected, the output of the channel specified by the "Channel" control is always available at the front panel output BNC connectors, regardless of the channel selection on the Main panel.

Channel (hot-key Alt + K): Sets the number of channel, output of which is available at the front panel BNC connectors on the PCI-1000 interface. This control is dimmed if the "Track Selected Channel" option is chosen.

4.3.5 Master Mode

In Section 4.2.8, the Master mode of operation was described, which may be used to send various commands simultaneously to all PFL-100 units. Similarly, this mode allows one to send certain PCI commands to all PCI-1000 units and all their channels. To initiate the Master mode, turn the MASTER control on the Main panel of the SQUID Control Module On (the letters become red).

Only the controls in the TEST SIGNAL GENERATOR and the SIGNAL CONDITIONING sections of the PCI panel have collective effect in the Master mode. If one uses the "On", "Off", "Frequency" or "Amplitude" controls in the TEST SIGNAL GENERATOR section of the selected PCI panel after the Master mode is enabled, the corresponding commands are sent to all PCI-1000 units, and the corresponding controls on all PCI panels are updated automatically. This way, test signal generators of all connected PCI-1000 units can be controlled simultaneously. If the "Filter" or "Multiplexer" controls in the SIGNAL CONDITIONING section of the selected PCI panel are operated for any channel selected by the "Channel" control, their new settings are copied to all channels of all PCI-1000 units. This is convenient, because individual adjustment of these three controls for each channel is a time-consuming process.

The controls in the TEST SIGNAL OUTPUT ENABLE and the FRONT PANEL OUTPUT sections of the PCI panel are adjusted individually, and their settings are independent of the Master mode.

4.4 List of Hot-Keys for the PCS100 and PCS100DA Control Software

General Control Hot-Keys	Function
Y	Show the System Configuration panel
Alt + Y	Hide the System Configuration panel
I	Show all PCI panels
Alt + I	Hide all PCI panels
D	Show the Data Acquisition panel
Alt + D	Hide the Data Acquisition panel
E	Show the Spectrum Analysis panel
Alt + E	Hide the Spectrum Analysis panel
A	Show the Autotune Procedure panel
Alt + A	Hide the Autotune Procedure panel
Esc	Activate the main SQUID Control panel
Ctrl + PCI number	Activate a PCI panel (number = 1 – 5)
X	Refresh all settings
Ctrl + M	Master mode On<>Off
Alt + chan number	Select a channel (number = 1 - 9)
Alt + N	Select the next channel
Tab	Activate the next control
Q	Quit the program

Mode Control Hot-Keys	Function
L	Lock the SQUID
T	Tune the SQUID
R	Reset the SQUID
H	Heat the SQUID

Tune Control Hot-Keys	Function
B	BIAS becomes active control
C	COMP becomes active control
S	SKEW becomes active control
M	MOD becomes active control
P	PHASE becomes active control
O	OFFSET becomes active control
W	Coarse<>Fine step for the SQUID controls
Z	Zero<>Restore the SQUID tune parameters

Bias Mode Control Hot-Keys	Function
K	BIAS MODE AC<>DC
F	BIAS FREQ becomes active control

Heater Control Hot-Keys	Function
Ctrl + H	HEATER Heat becomes active control
Ctrl + L	HEATER Cool becomes active control
Ctrl + G	HEATER Group becomes active control
Ctrl + P	HEATER Prec Coarse <> Fine

Configuration Control Hot-Keys	Function
Ctrl + K	SQUID TYPE becomes active control
Ctrl + S	SENSITIVITY becomes active control
Ctrl + F	FEEDBACK becomes active control
Ctrl + I	INTEGRATOR becomes active control
Ctrl + J	COIL RANGE 5 μA <> 50 μA
Ctrl + T	TEST SIGNAL becomes active control
Ctrl + V	TEST INPUT becomes active control

System Control Hot-Keys	Function
Ctrl + N	"N of Channels" becomes active control
Ctrl + U	"PCI Units" becomes active control
Ctrl + P	"Port" becomes active control
Ctrl + D	"Device Number" becomes active control
Ctrl + F	"File" becomes active control
Ctrl + L	"Label" becomes active control
Ctrl + O	Turn the label function ON
Ctrl + R	Restart the program with the selected file

PC Interface Control Hot-Keys:	Function
G	Test signal generator On<>Off
F	"Frequency" becomes active control
A	"Amplitude" becomes active control
W	Coarse<>Fine step for the generator
K	"Channel" becomes active control
L	"Filter" becomes active control
M	"Multiplexer" becomes active control
Alt + channel number	Enable<>Disable test output (num = 1 – 8)
O	Track selected<>Specify channel to track
Alt + K	"Channel" becomes active control

4.5 Data Acquisition Module

The Data Acquisition Module (SW-DA) is an integral part of the optional PCS100DA Control Software with Data Acquisition. This Data Acquisition Module can be used to measure and display the SQUID sensor output, together with other signals of interest, during the tuning process, normal operation, or heat cycle. All acquired data can be saved to a file. The user interface of the Data Acquisition Module is similar to that of an oscilloscope.

The PCS100DA Control Software is compatible with all National Instruments 16-bit E-Series DAQ boards and PCMCIA cards. The currently available E-Series data acquisition devices may be divided into three main groups:

- PCI-6034E, PCI-6035E, PCI-6036E, and DAQCard-6036E. These are low-cost 16-bit multifunction DAQ boards with a sampling rate of 200 kS/s. There are 4 input ranges. A digital trigger is available.
- PCI-6030E, PCI-6031E, PCI-6032E, and PCI-6033E. These are 16-bit multifunction DAQ boards with a sampling rate of 100 kS/s. There are 7 input ranges. Both digital and analog triggers are available.
- PCI-6052E. This is a 16-bit multifunction DAQ board with a sampling rate of 333 kS/s. There are 8 input ranges. Both digital and analog triggers are available.

All of these boards have at least 16 single-ended analog inputs, which are used to form eight differential inputs. The present version of the PCS100DA software can control only one DAQ device, and can support no more than 8 channels of data acquisition. All inputs should be configured as differential.

Because all of the above data acquisition devices belong to the same class (National Instruments 16-bit E-Series), the software functions used to operate these boards are essentially the same. However, certain physical parameters, such as the sampling rate, may be different. Therefore, parameters of several controls on the Data Acquisition panel will depend on the board type.

4.5.1 Launching the Data Acquisition Module

Before using data acquisition, make sure that the DA, SA, and AT indicators in the SOFTWARE section of the System Configuration panel (Figure 2-1) are On, meaning that the corresponding software modules are included in your software package. Also make sure that the NI-DAQ™ software, provided by National Instruments together with your DAQ device, has been properly installed and configured for the type of device you are using.

When the PCS100DA Control Software is launched, it automatically attempts to connect to and configure the DAQ board with the device number specified by the “Device Number” control on the System Configuration panel. If the board is configured successfully, the “Status” indicator displays ‘Connected’, while the “Type” and “Code” indicators exhibit the board information, as shown in Figure 2-1. You can then bring up the Data Acquisition panel by selecting the DAQ>Show DAQ panel menu item on the Main panel of the SQUID Control Module. The Data Acquisition panel is exhibited in Figure 4-6.

If the initial configuration attempt is unsuccessful, the “Status” indicator on the System Configuration panel shows ‘Unconnected’, and the “Type” indicator displays ‘Unknown’.

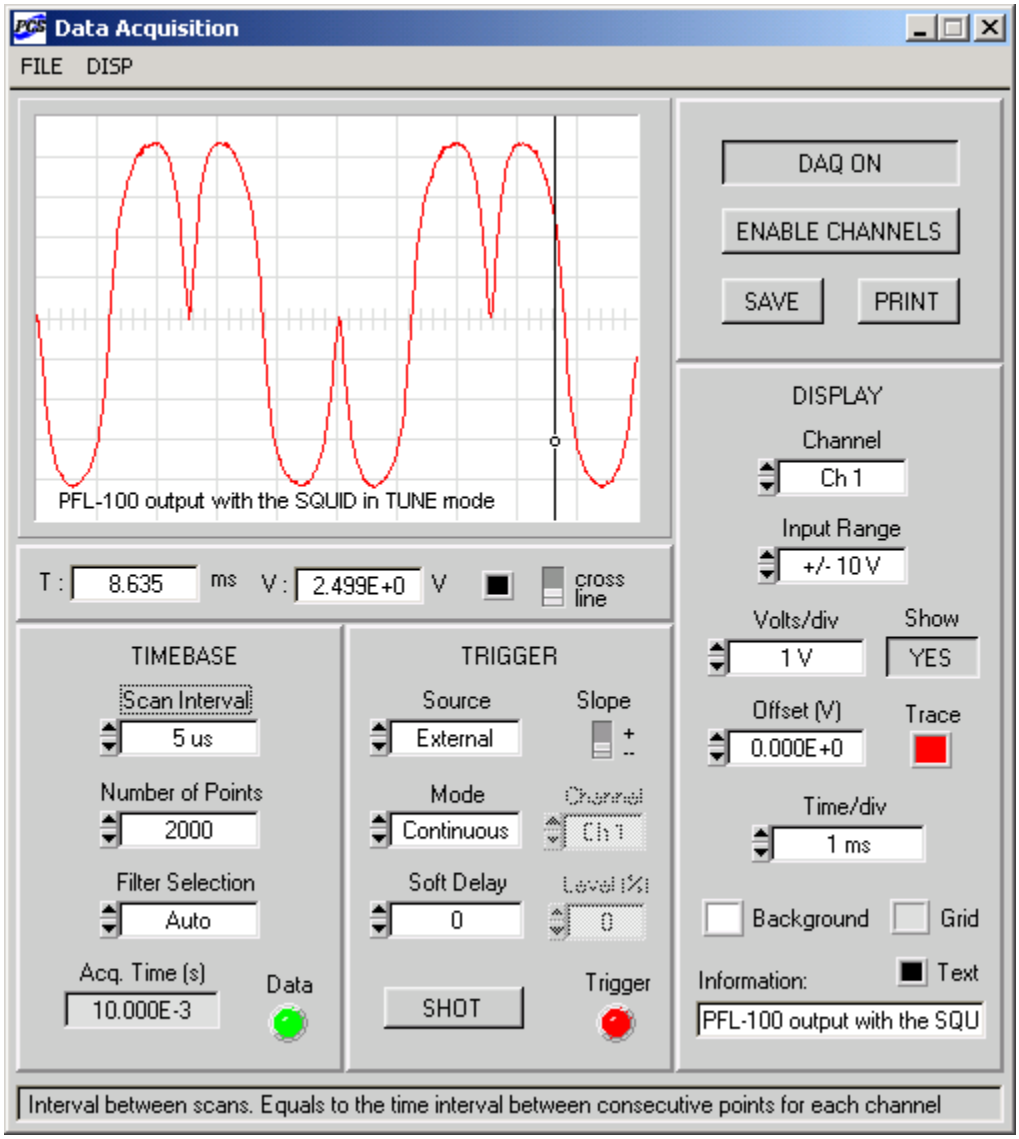


Figure 4-6. Appearance of the Data Acquisition panel using a PCI-6034E board. Only one channel is enabled. The minimum scan interval of 5 µs corresponds to 200 kS/s sampling rate.

Note that the "Code" indicator shows a real device code, returned by the configuration function. See Table 2-2 for codes for several DAQ boards. If the returned code is –1, the device with the selected device number is not one of National Instruments E-Series DAQ devices.

Use the "Device Number" control to check other possible device numbers. This process is fully interactive, and results are displayed immediately. If this does not help, launch the Measurement and Automation Explorer (NI-MAX™), and select "Devices and Interfaces" from the main configuration tree. If your DAQ board is detected and recognized, its name will be on the list, together with the associated device number.

If the DAQ board is not connected or configured properly, the DAQ menu on the main panel of the SQUID Control Module contains only one item: DAQ>Connect DAQ. You may select this

item to try to connect to the DAQ board. The difference from the initial configuration attempt is that now all errors are reported explicitly (using the DAQ Error Report panel) together with the corresponding error codes. This allows quick troubleshooting. You should also use this menu item to re-connect to the DAQ board, if the connection is lost due to some error during data acquisition.

4.5.2 Number of Channels and Scan Interval

The Data Acquisition Module of the optional PCS100DA Control Software with Data Acquisition allows simultaneous data acquisition for up to 8 channels. The eight channels of this module correspond to the first eight differential-input channels of the DAQ board. Refer to the user manual for your DAQ device for information about the correct way of connecting the inputs. Typically, the single-ended analog inputs ACH0 and ACH8 will form the first differential input, ACH1 and ACH9 the second differential input, and so on.

If only one channel is enabled for data acquisition, the minimum time interval between two consecutive readings is equal to the inverse of the maximum sampling rate. Thus, the minimum interval is 5 μs for the PCI-6034E, 10 μs for the PCI-6030E, and 3 μs for the PCI-6052E. The smallest 10 values of the "Scan Interval" ring control on the TIMEBASE sub-panel of the Data Acquisition panel (Figure 4-6) are always selected to be integer multiples of this minimum interval. For example, using PCI-6034E board, the lowest 10 settings of this control are 5 μs, 10 μs, 15 μs, …, 45 μs, 50 μs.

If several acquisition channels are enabled, a group of consecutive readings (with the minimum time interval), which includes one reading from each of the enabled channels, is called a *scan*. The scan interval is equal to the interval of time between two consecutive readings from the same channel. The scan interval cannot be shorter than the scan time, *i.e.*, the amount of time needed to sample all enabled channels once. Moreover, for most NI DAQ devices, the minimum scan interval is 2 μs longer than the scan time. This is because a small time gap is required between the end of one scan, and the start of the next one. In the case of the PCI-6034E, the minimum scan interval for two channels is $2 \cdot 5 + 2 = 12$ μs, for 3 channels it is $3 \cdot 5 + 2 = 17$ μs, and so on. Because the lowest settings of the "Scan Interval" control are chosen to be multiples of 5 μs for this board, the minimum allowed setting for two channels is 15 μs, 20 μsec for 3 channels, and so on. The results of using this rule are summarized in Table 4-4. Note that the "Scan Interval" control is updated in such a way that no values below the minimum allowed values are available.

Data acquisition from three channels is illustrated in Figure 4-7. The figure shows the outputs of two PFL-100 units with the SQUIDs operated in the TUNE mode, as well as the triangular test signal. The PCI-6034E board is used for data acquisition. The minimum allowed scan interval is 20 μs, according to Table 4-4.

Table 4-4. The minimum allowed settings of the "Scan Interval" control depending on the number of enabled channels (*N*) for three types of 16-bit E-Series DAQ boards.

N	PCI-6034E	PCI-6030E	PCI-6052E	Filter
1	5 µs	10 µs	3 µs	D
	10 µs	20 µs	6 µs	C
2	15 µs	30 µs	9 µs	C
3	20 µs	40 µs	12 µs	B
4	25 µs	50 µs	15 µs	B
5	30 µs	60 µs	18 µs	B
6	35 µs	70 µs	21 µs	A
7	40 µs	80 µs	24 µs	A
8	45 µs	90 µs	27 µs	A

4.5.3 Filter Selection

When data are acquired by means of a DAQ board, a continuous input waveform is discretely sampled. The sampling interval Δt is the reciprocal of the sampling rate, which is the number of samples per second. For any sampling interval there is a special frequency f_c, called the Nyquist critical frequency, given by

$$f_c = \frac{1}{2 \cdot \Delta t}.$$

According to the Nyquist sampling theorem, a continuous function with a bandwidth limited by the Nyquist critical frequency is completely determined by its samples. Consider, for example, a DAQ board with a sampling rate of 200 kS/s. The sampling interval is 5 µs, and the Nyquist frequency is 100 kHz. The acquired set of data will contain all information about the measured waveform, provided that this waveform has a bandwidth less than 100 kHz.

If the input waveform has a bandwidth greater than the Nyquist critical frequency, a phenomenon called *aliasing* occurs: any spectrum component that lies outside of the frequency range ($-f_c$, f_c) is spuriously moved into this range by the very act of discrete sampling. In order to prevent aliasing, the bandwidth of the measured signal should be limited by means of a low-pass filter.

An ideal anti-aliasing filter with a step-like transfer function would have a cutoff frequency equal to the Nyquist critical frequency, *i.e.*, one-half the sampling rate. For real low-pass filters with a smooth transfer function, the nominal cutoff frequency should be reduced to ensure that spectral components above the Nyquist frequency are sufficiently attenuated.

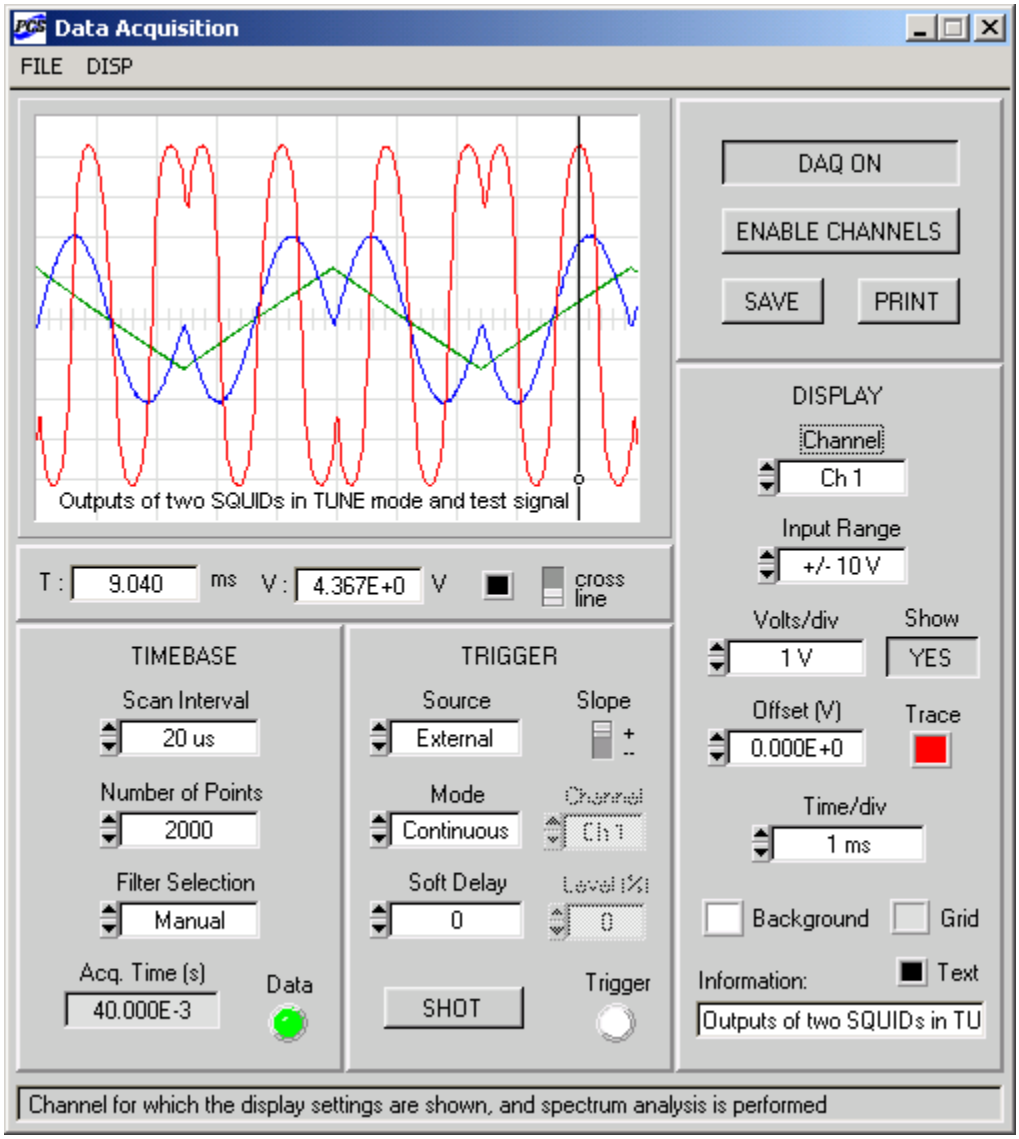


Figure 4-7. Data acquisition from three channels using a PCI-6034E board. The input range and certain display settings are exhibited for the selected DAQ channel by the "Channel" control.

In order to account for the roll-off of a non-ideal low-pass filter, the cutoff frequency should not exceed 2/3 of the Nyquist critical frequency, *i.e.*, 1/3 the sampling rate. In the above example of a 200 kS/s board, the low-pass filter should have the nominal cutoff frequency of about 60 kHz.

The PCI-1000 interface may be equipped with four optional low-pass filters (4-pole Butterworth) for each channel, as described in Section 7.3. These four filters are normally chosen to serve as anti-aliasing filters for data acquisition (at the maximum speed) for 1, 2, 4, and 8 channels, respectively.

For the PCI-6034E and similar boards with the maximum sampling rate of 200 kS/s, the recommended filter frequencies are 60 kHz, 20 kHz, 10 kHz, and 6 kHz. For the PCI-6030E and the other boards with 100 kS/s maximum sampling rate, these frequencies should be 30 kHz,

10 kHz, 6 kHz, and 3 kHz. Finally, for the PCI-6052E board with maximum sampling rate of 333 kS/s, 100 kHz, 30 kHz, 20 kHz, and 10 kHz filters are recommended. These four filters are labeled as A, B, C, and D, where A has the lowest and D the highest cutoff frequency. The recommended filter assignments for each available sampling rate are summarized in Table 4-5.

Table 4-5. Recommended filter assignments for available sampling rates.

	Sampling Rate		
Filter	100 kS/s	200 kS/s	333 kS/s
Filter_A	3 kHz	6 kHz	10 kHz
Filter_B	6	10	20
Filter_C	10	20	30
Filter_D	30	60	100

The "Filter Selection" control on the TIMEBASE sub-panel defines the way in which the anti-aliasing filters are selected during the system operation. If the "Filter Selection" control is set to 'Auto', the filter frequency (A, B, C, or D) is determined automatically according to Table 4-4 every time the "Scan Interval" value is changed. The corresponding filter is then selected for each of the eight channels of the first PCI-1000 unit, and the first PCI panel is updated accordingly. This is convenient, because the user may change the "Scan Interval" value without having to re-adjust the PCI panel controls every time.

If the "Filter Selection" is 'Manual', the user has to select appropriate filters using the "Channel" and "Filter" controls in the SIGNAL CONDITIONING section of the first PCI panel. The same filter should be selected for all channels, enabled for data acquisition. For example, in situation of Figure 4-7, one has to select filter B (10 kHz) for each of the first 3 channels. The 'Unfiltered' setting of the "Filter" control may be used only if the bandwidth of the input signal is lower than the Nyquist critical frequency.

4.5.4 Input Range

The input range is another important characteristic of a DAQ device. Available options depend on the board type. The input range can be selected individually for each channel, and should match the expected range of the input signal as closely as possible. Note that all ranges used by the Data Acquisition Module are bipolar.

The PCI-6034E and similar boards have 4 input ranges: ±50 mV, ±500 mV, ±5 V, and ±10 V. The PCI-6030E and the other boards in that group feature 7 input ranges: ±100 mV, ±200 mV, ±500 mV, ±1 V, ±2 V, ±5 V, and ±10 V. The PCI-6052E board has 8 available ranges: ±50 mV, ±100 mV, ±250 mV, ±500 mV, ±1 V, ±2.5 V, ±5 V, and ±10 V.

The range is selected using the "Input Range" control on the DISPLAY sub-panel of the Data Acquisition panel (Figure 4-7). The displayed setting applies to the channel specified by the "Channel" control. Note that, unlike the other controls on the DISPLAY sub-panel, which only determine display properties, the "Input Range" is related to an actual hardware configuration.

4.5.5 Triggering

The Data Acquisition Module of the PCS100DA Control Software supports several triggering sources and modes. The trigger controls are located on the TRIGGER sub-panel of the Data Acquisition panel (Figure 4-6).

The triggering source, *i.e.*, the signal or condition that initiates data acquisition, is specified by the "Source" control. This control may be set to 'External', 'Software', or 'Analog'. The last option is unavailable for the PCI-6034E and similar boards without the analog triggering.

The 'External' trigger is a TTL signal, which should be applied to the PFI0/TRIG1 digital input of the DAQ board with respect to the digital ground (DGND). If the PCI-1000 internal signal generator is used to provide the test signal, the triggering signal is available at the SYNC OUT connector on the back panel of the PCI-1000 unit. Data acquisition may be initiated on either rising or falling edge of the external TTL signal, depending on the setting of the "Slope" switch on the TRIGGER sub-panel.

The 'Software' trigger is a command to start data acquisition, issued by the software. It should be used when the external synchronization signal is unavailable, for example, during noise measurements. It may also be conveniently used to quickly check performance of the Data Acquisition Module, because neither external nor analog triggering is needed in this case.

When the triggering source is set to 'Analog', the channel specified by the "Channel" control on the TRIGGER sub-panel is monitored until its input voltage crosses a certain threshold level. This event is used as a signal to begin data acquisition. The threshold level is set by the "Level (%)" control as a percentage of the full-scale voltage for that channel. The direction of the threshold crossing (from below or from above) is set by the "Slope" control. If the DAQ board does not have the analog triggering feature, the 'Analog' setting of the "Source" control is unavailable, and both the "Channel" and the "Level (%)" controls are dimmed, as in Figure 4-6.

The triggering mode is set by the "Mode" control on the TRIGGER sub-panel. There are two possible modes: 'Continuous' and 'One-shot'. Both modes are available for every type of triggering source.

In the 'Continuous' mode, the external or analog trigger is re-armed automatically after the current set of data is acquired, so that data acquisition can be started again when the next trigger event occurs. This produces a continuously updated waveform, which does not move within the display graph. If the software trigger is used, a command to start new data acquisition is issued automatically a certain time after the end of the current acquisition. This delay time is set by the "Soft Delay (s)" control on the TRIGGER sub-panel. The displayed waveform is thus updated with periodicity roughly equal to the delay time, and can jump within the graph due to the lack of synchronization.

In the 'One-shot' mode, one should use the SHOT button on the TRIGGER sub-panel to obtain a single set of data. If the trigger source is 'Software', the acquisition begins immediately. If the 'External' or 'Analog' source is used, clicking on the SHOT button merely arms the external or analog trigger, and the acquisition begins only when the selected trigger condition is met. The 'One-shot' mode is convenient if you wish to save one set of data to a file or print the graph. Click on the SHOT button again to acquire another set of data.

4.5.6 Menu Items

FILE>Save: Brings up the Save Data panel, which is used to specify channels for saving data, select a file, and write data to this file. A complete data set should be available before it may be saved.

FILE>Print: Brings up the standard printer panel, which can be used to print the graph with the currently displayed waveforms. This may be done even if data acquisition is in progress.

DISP>Show plot only: Used to hide the control sub-panels from the Data Acquisition panel and display the graph only. The graph becomes scalable in this display mode, meaning that you may "grab" the lower right corner of the graph window to resize the window.

DISP>Show controls: Used to restore the Data Acquisition panel to its default display state, showing the graph and all the controls.

4.5.7 Function Controls

DAQ ON / DAQ OFF: This toggle key turns the data acquisition On and Off. The label indicates the present state: for example, DAQ ON means that the acquisition is currently on. Closing the Data Acquisition panel does not turn the data acquisition off; it will continue in the background as long as the control setting is DAQ ON. Note that if autotuning, calibration, or noise optimization procedures are started from the Autotune Procedure panel, the normal data acquisition is stopped, and this control is automatically switched to DAQ OFF state.

ENABLE CHANNELS: Brings up the Enable Channels panel, which is used to enable or disable channels and set other parameters. The Enable Channels panel is described in detail in Section 4.5.12. Note that the minimum allowed setting of the "Scan Interval" control depends on the number of enabled channels, as explained in Section 4.5.2.

SAVE: Brings up the Save Data panel, which is used to specify channels for saving data, select a file, and write data into this file. The Save Data panel is described in detail in Section 4.5.13. Note that a complete data set should be available before it may be saved. Therefore, the best way is to select the one-shot triggering mode, and use the SHOT button to acquire a single set of data. The SAVE control performs the same function as the FILE>Save menu item.

PRINT: Brings up the standard printer panel, which can be used to print the graph with the currently displayed waveforms. This may be done even if data acquisition is in progress. On the printer panel, you may select either a regular printer, or the Acrobat PDFWriter (if available), which will produce a PDF file containing the graph. In both cases, the "Print to file" check box on the printer panel should be unchecked. The PRINT control is analogous to the FILE>Print menu item.

4.5.8 Timebase Controls

Scan Interval: Sets the time interval between scans, which is equal to the time interval between consecutive data points taken for the same channel. The minimum allowed setting of this control depends on the number of enabled channels, as discussed in Section 4.5.2.

Number of Points: Sets the number of data points per channel, which is equal to the number of scans in one data set. For E-Series DAQ boards, this number may vary between 2 and 2^{24}-1. In practice, however, the maximum number of points that may be acquired per channel depends on

the size of the RAM buffer, allocated for data acquisition. This size is set by the "Buffer Size" control on the Enable Channels panel. If the requested amount of data cannot be accommodated within the available buffer, the maximum number of points per channel is automatically reduced, and the "Number of Points" control is updated accordingly.

Filter Selection: Specifies the way in which anti-aliasing filters are selected. In 'Auto' mode, the filters are chosen automatically as explained in Section 4.5.3. In 'Manual' mode, the filters should be selected using the "Channel" and "Filter" controls on the first PCI panel.

Acq. Time (s): This indicator displays the acquisition time, in seconds, for one data set. It is a product of the scan interval and the number of points per channel.

Data: This indicator shows the data status by displaying a particular color. If the color is gray, the indicator is Off. Click on it to turn it On. If the color is white, there is no valid data in the buffer. Red color means that the acquisition is in progress, and the buffer is being filled with new data. Green color indicates that the acquisition has completed, and the buffer contains a valid set of data. In the 'Continuous' trigger mode, the color of the "Data" indicator will repeatedly change between red and green. In the 'One-shot' mode, the indicator will flash red, and then turn green, showing that a valid data set is available and ready to be saved.

4.5.9 Trigger Controls

Source: Used to select the triggering source, as described in Section 4.5.5. It may be set to 'External', 'Software', or 'Analog'. The last option is unavailable if the DAQ board does not have the analog trigger feature.

Slope: If the source is 'External', sets the slope of the external TTL synchronization signal, which triggers the acquisition. The slope may be either positive (rising edge) or negative (falling edge). If the trigger source is 'Analog', the "Slope" control specifies the direction in which the threshold level should be crossed to initiate the acquisition. This direction may be either upward (+) or downward (-). See Section 4.5.5 for details.

Mode: Used to select the triggering mode, as described in Section 4.5.5. It may be set to 'Continuous' or 'One-shot'. If the mode is 'One-shot', the SHOT button should be used to start the acquisition or arm the external or analog trigger.

Soft Delay (s): Sets the interval of time between the end of one acquisition and the start of the next acquisition, if the source is 'Software' and the mode is 'Continuous'. See Section 4.5.5.

SHOT: This button is used only in the 'One-shot' triggering mode, as explained in Section 4.5.5. If the triggering source is 'Software', the acquisition begins immediately. If the source is set to 'External' or 'Analog', the trigger is armed, and the acquisition begins when the corresponding trigger condition is met. In each case, only one set of data is acquired, and the display graph is updated once. Click on the SHOT button again to acquire another set of data.

Channel (on the TRIGGER sub-panel): Used to select one of the enabled channels as the triggering channel, if the trigger source is 'Analog'. See Section 4.5.5 for details. If the installed DAQ board does not support analog triggering, both the "Channel" and the "Level (%)" controls are dimmed.

Level (%): Determines the threshold voltage level for the triggering channel, if the trigger source is 'Analog'. The triggering channel is selected with the "Channel" control on the

TRIGGER sub-panel. The level is specified in percents of the full-scale voltage for the triggering channel, and may take values from –99% to +99%. The input signal from the triggering channel is monitored until the threshold level is crossed (from below or from above, depending on the setting of the "Slope" control), and this initiates data acquisition. See Section 4.5.5 for more information.

Trigger: This indicator shows the current trigger status by displaying a certain color. If the color is gray, the indicator is Off. Click on it to turn it On. If the color is white, the trigger is idle. Red means that the system is waiting for the external or analog trigger. Yellow indicates that the system is waiting for the software trigger. In the 'Continuous' trigger mode, the "Trigger" indicator will flash repeatedly. In the 'One-shot' mode, it will flash once, and then turn either white (for 'External' or 'Analog' trigger), or yellow (for 'Software' trigger). If this indicator stays red, it means that either the external synchronization signal is not connected, or the analog triggering condition cannot be satisfied.

4.5.10 Display Controls

Channel (on the DISPLAY sub-panel): This control allows one to select a target channel among the enabled channels. This selection is important for the following reasons. First, the "Input Range", "Volts/div", "Show", "Offset", and "Trace" controls on the DISPLAY sub-panel exhibit settings for the target channel. Second, the cross cursor of the Data Acquisition graph uses the "Volts/div" setting for the target channel, and the vertical line cursor tracks the signal voltage for the target channel. Third, the target channel is the channel for which the spectrum analysis is performed and the spectrum is displayed in the Spectrum Analysis graph.

Input Range: Sets the input range for the channel selected by the "Channel" control. Each setting of this control corresponds to a certain input range of the DAQ board. The availability of different settings depends on the board type, as described in Section 4.5.4. The input range should match the expected signal range as closely as possible.

Show: Determines whether the waveform for the channel selected by the "Channel" control is displayed (YES or NO) on the plot. Note that "enabled" is not equivalent to the YES setting of the "Show" control: a channel may be enabled and acquire data without displaying the data.

Volts/div: Sets the vertical display scale for the channel selected by the "Channel" control. Note that this scale may be different for different channels, even if their waveforms are displayed on the same plot.

Offset: Used to adjust the vertical position of the trace for the channel selected by the "Channel" control. The offset is given in volts. This is a display parameter, which does not have physical meaning, and does not affect the actual waveform data. In contrast, the OFFSET control on the main panel of the SQUID Control Module actually changes the dc flux through the SQUID, which leads to a change in the dc voltage level of the PFL output signal in the LOCK mode.

Trace: Sets the color and thickness of the waveform trace for the channel selected by the "Channel" control. Left-click on this control to display a pop-up menu of available colors and select a color. Right-click to toggle between the thin and thick lines. Colors and linewidths of plot traces may also be changed from the Enable Channels panel (see Section 4.5.12). Note that the "Trace" control determines trace properties not only for the waveform plot on the Data Acquisition panel, but also for the corresponding spectrum plot on the Spectrum Analysis panel.

In this way, both the waveform and the spectrum for the same channel always have the same color and linewidth.

Time/div: Sets the horizontal display scale, which is the same for all channels. Note that, for high settings of this control, the displayed waveform may occupy only a part of the graph along the horizontal axis. This happens when the acquisition time, exhibited by the "Acq. Time" indicator, is shorter than the display time, equal to 10·Time/div. To improve the plot appearance, reduce the "Time/div" setting, or increase the number of points.

Background: Used to select the plot background color. Left-click on this control to display a pop-up menu of available colors and select a color. Right-click to toggle between black and white. This control sets the plot background color not only for the Data Acquisition graph, but also for the Spectrum Analysis graph.

Grid: Used to select the grid color for the plot. Like the "Background" control, the "Grid" control sets the color for both Data Acquisition and Spectrum Analysis graphs.

Text: Used to select the color of the information string, displayed on the plot. This setting applies to both Data Acquisition and Spectrum Analysis graphs.

Information: This is a text string control, which allows one to display information on the plot. Type in the desired text, and it will be displayed at the bottom of the plot when the acquisition is started. You can modify the displayed text as long as the acquisition continues and the plot is updated. The color of this text may be changed using the "Text" color control. The same text is displayed on the Spectrum Analysis plot.

4.5.11 Cursor Operation

The graph on the Data Acquisition panel allows the user to simultaneously display waveforms of up to 8 channels, despite the fact that their magnitudes may be very different. This is possible because there is no common vertical axis scale for all the channels, but, instead, every channel has its own vertical scale. This scale is set by the "Volts/div" control on the DISPLAY sub-panel for the channel currently selected by the "Channel" control. The horizontal axis scale is the same for all the channels, and is specified by the "Time/div" control.

The cursor of the Data Acquisition graph may be used to determine coordinates of any data point. The coordinates are displayed by the "T" (time in ms) and "V" (voltage in volts) indicators, located underneath the graph.

The cursor may have two different forms: short cross and vertical line. Use the "cross/line" switch below the graph to toggle between these two forms. Use the color control next to it to change the cursor color.

The cross cursor snaps to the nearest plot point when operated. The default position of this cursor is in the right upper corner of the graph, and both "T" and "V" indicators display zero in this case. To operate the cross cursor, click on it, drag it to a selected point, and release. Alternatively, you may click somewhere within the plot area, and the cursor will automatically snap to the nearest data point. The "T" and "V" indicators will exhibit coordinates of this point with respect to the current reference frame. This frame is defined as follows. The left border of the plot corresponds to zero time, and the time scale is set by the "Time/div" control. The horizontal line through the center of the plot corresponds to zero voltage. The voltage scale is

determined by the current setting of the "Volts/div" control, which depends on the setting of the "Channel" control. If the plot contains several traces, and you wish to measure properties of a trace for a particular channel, make sure that this channel number is displayed by the "Channel" control. Otherwise, if you measure a trace for one channel using the "Volts/div" value for another channel, the "V" readings will be incorrect. Note that the "T" and "V" values are only meaningful immediately after the cursor is released. If the measured waveform changes, the cross cursor has to be re-positioned to produce valid indicator readings. The cross cursor is convenient, for example, if a static waveform obtained in 'One-shot' trigger mode is to be studied in detail.

The vertical line cursor is used to continuously monitor the signal voltage at a specific time after the acquisition is started. If this cursor is used, the "V" indicator exhibits the current signal level at the point where the vertical line crosses the trace for the channel, selected by the "Channel" control. For example, the vertical line position in Figure 4-7 corresponds to 9.04 ms from the start of data acquisition. The "Channel" control is set to "Ch 1", meaning that the "V" indicator will show voltage measured for the first channel. The current reading of this indicator, 4.367 V, corresponds to the time of 9.04 ms, where the red trace and the vertical line cross each other. To move the vertical line cursor, click on the line at any point, drag it to a desired position, and release. Alternatively, you may click on a desired point, and the vertical line will automatically shift to go through that point. If the plot includes several traces, make sure that the "Channel" control shows the number of the channel you wish to monitor. Note that the "V" indicator is updated at each trigger event, and shows a correct reading as long as the acquisition continues. The vertical line cursor is convenient, for example, if you wish to measure constant levels of the PFL output voltage in the LOCK mode before and after the RESET command.

4.5.12 Enable Channels Panel

The Enable Channels panel is shown in Figure 4-8. It is brought up by clicking on the ENABLE CHANNELS button on the Data Acquisition panel. The Enable Channels panel is used to define a new set of enabled channels and/or a new buffer size. Note that changes made to the "Enable DAQ Channels", "Track Selected Channel", and "Buffer Size" controls do not take effect until the CONFIGURE button is used.

Enable DAQ Channels: These eight switches are used to enable a particular set of channels for data acquisition. They may be operated only if the "Track Selected Channel" control is Off. Click on the box corresponding to a channel to select (or un-select) that channel. If the requested number of channels to be enabled is incompatible with the "Scan Interval" setting, an error is reported.

Track Selected Channel: When this control is On (black dot appears), the data acquisition is configured for a single enabled channel, which is the channel currently selected on the Main panel of the SQUID Control Module. When the selected SQUID channel changes, the channel enabled for data acquisition changes accordingly. This is useful if you wish to switch frequently among different SQUID channels, keeping track of the signal from the currently selected channel. If the selected SQUID channel number is greater than 8, the "Track Selected Channel" is set to Off.

Color controls: Used to change color and linewidth of the traces displayed in the graph. The operation of these controls is identical to that described in Section 4.5.10 for the "Trace" control.

The advantage of accessing the color controls here is that colors for all eight channels may be modified including those channels that are not currently enabled. The new settings take effect immediately without use of the CONFIGURE button, and are not affected by the CANCEL command.

Buffer Size (Kbytes): Sets the size of the computer RAM buffer allocated for storing acquired data. Because each data point takes 2 bytes of memory (short integer), the maximum number of points that may be stored in the buffer is equal to 1000(buffer size in Kbytes)2. The maximum allowed number of points per channel is 1000(buffer size in Kbytes)/(number of enabled channels)/2. The last number is used as the maximum value for the "Number of Points" control on the TIMEBASE sub-panel of the Data Acquisition panel. If the requested number of points is greater than the maximum number, it is automatically reduced. The minimum possible setting of the "Buffer Size" is 10 Kbytes. It corresponds to a static array allocated when the program is launched. Any buffer greater than 10 Kbytes is allocated dynamically, and the maximum possible buffer size depends on the available computer RAM.

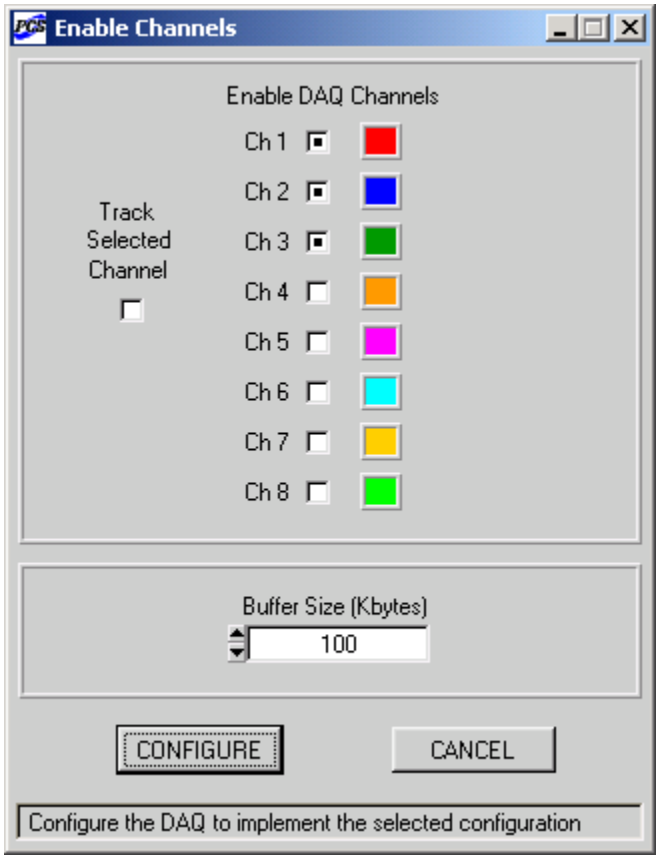


Figure 4-8. The Enable Channels panel of the Data Acquisition Module. Channels 1, 2, and 3 are enabled here. The default buffer size for acquired data is 100 Kbytes.

CONFIGURE: Used to implement the requested configuration. If the new configuration is not allowed, an error is reported, and the previous configuration is automatically restored if possible.

If the error is unrecoverable, the program disconnects the DAQ board, and the Data Acquisition panel is automatically hidden. Use the DAQ>Connect DAQ menu item on the main panel to reconnect and reconfigure the DAQ board.

CANCEL: Used to cancel any changes to "Enable DAQ Channels", "Track Selected Channel", and "Buffer Size" controls and restore settings corresponding to the existing configuration. This button has no effect after the requested configuration is successfully implemented by means of the CONFIGURE command.

To close the Enable Channels panel, use the Windows™ "close" button in the right upper corner of the panel. This operation is equivalent to using the CANCEL control: any configuration changes, which have not been implemented with the CONFIGURE command, are lost.

4.5.13 Save Data Panel

The Save Data panel is shown in Figure 4-9. It can be brought up by selecting the FILE>Save menu item, or by clicking on the SAVE button on the Data Acquisition panel. The controls and indicators featured on the panel are described in this section. A detailed description of how to save data is given in Section 4.5.14.

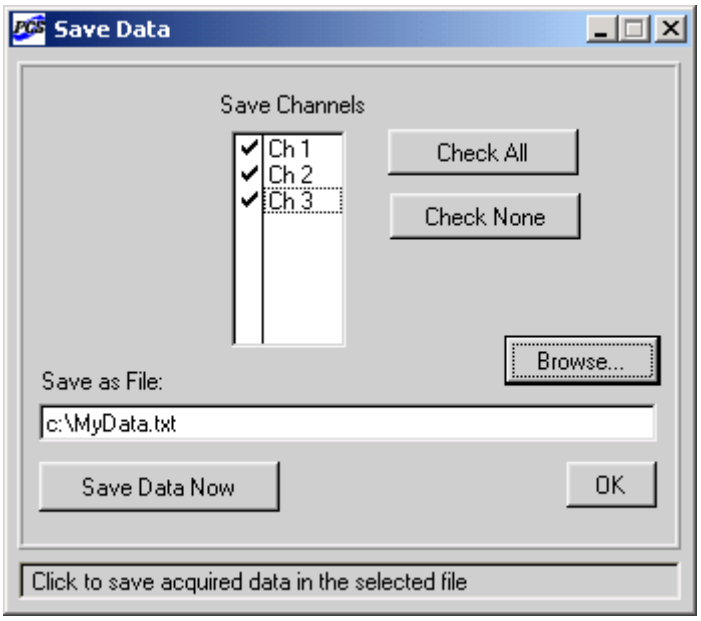


Figure 4-9. The Save Data panel of the Data Acquisition Module. Channels 1, 2, and 3 are selected for saving to the file MyData.txt.

Save Channels: Lists all enabled channels. To check or uncheck a channel on the list, click on the space to the left of the channel name. The data of the channels that are checked will be included in the data file. If no channels are checked, the "Save Data Now" control is dimmed.

Check All: Clicking this control automatically checks all channels in the "Save Channels" list.

Check None: Clicking on this control will automatically uncheck all channels in the "Save Channels" list control. Note that you must have at least one channel checked to save data.

Browse: Brings up a standard Windows™ dialog to select the directory and filename for the output file. The filename extension is always .txt.

Save as File: Displays the output filename and directory path. Note that it is an indicator only. To change the output file name or directory, use the "Browse…" control.

Save Data Now: Click on this button to write the data to the specified file. This button is dimmed if the configuration is invalid for any reason, for example, if no channels are selected (checked) or if no file is specified. Once data have been written to the file, this control also becomes dimmed to indicate that the task has been completed, and to prevent writing to the same file. If any of the save parameters are changed, the control becomes active again, so that the same data may be saved to a different file.

OK: Used to close the Save Data panel. Note that this action does not save data, so you should use the "Save Data Now" control before using the OK button.

4.5.14 Saving Data

The first step in saving data is to capture a complete and valid data set. If data acquisition has not been completed, or if one of the hardware configuration parameters has been changed since the data were acquired, saving data will not be allowed. Make sure that the acquisition has completed and that you do not change any of the hardware configuration parameters such as the trigger settings or range settings before the data are saved.

The recommended method is to use the 'One-shot' trigger mode. This method produces a single complete data set. Look at the "Data" indicator on the TIMEBASE sub-panel. This indicator is green if it has been turned on, and the buffer contains valid data. If you try to save data in the 'Continuous' trigger mode, the saving is performed only if the corresponding command happens to fall in the interval between two consecutive acquisitions. Otherwise, an error is reported.

Once a single data set for a particular group of enabled channels has been acquired, the data from any subset of those channels may be saved to an ASCII file. The filename extension is always .txt. Click on the "Save Data Now" button to save the data, provided that this button is active (not dimmed). After the data have been saved, the "Save Data Now" button becomes dimmed (de-activated) again. Changing the filename or the selection of channels will re-activate this button, thereby allowing a write to a different file. This button is also dimmed if no output file is specified or no channels are selected for saving.

An example of the data file format is given below. Data acquisition was carried out for three channels, Channel 1, Channel 2, and Channel 3, with the scan interval of 20 μs. The number of points was 2000 for each channel (the example below shows only a small portion of the data).

The data file includes a header and a table of data. The identifier `PCS100` always appears on the first line of the header. Next, there are `DATE` and `TIME`, which refer to the moment when the data were saved (not when they were acquired). The next two entries are the number of channels and the number of points per channel. Note that the number of channels here is the number of channels selected to be saved, not the number of channels enabled during data acquisition. The `SCANINTVAL` entry gives the scan interval (in seconds). The `TEXT` line contains the text string

from the “Information” control on the DISPLAY sub-panel of the Data Acquisition panel, which is displayed in the Data Acquisition and Spectrum Analysis graphs.

Below the header, there is the table of data. Each number in the first column, `POINT`, is the scan number, which is also the number of a corresponding data point for each channel. To determine the approximate time after the start of the data acquisition when the scan was acquired, multiply the scan number by the scan interval, given above by the `SCANINTVAL` value. The next several columns in the table contain voltages (in volts) measured for each channel. The word `CHAN` in the header of each column is followed by the actual channel number.

Sample data file:

```
PCS100
DATE=06-04-2004
TIME=10:10:44
CHANNELS=3
DATAPOINTS=2000
SCANINTVAL=2.00e-05

TEXT:  Outputs of two SQUIDs in TUNE mode and test signal

   POINT      CHAN1(V)    CHAN2(V)    CHAN3(V)
       1     -3.119907    0.226447    0.248421
       2     -2.814112    0.345775    0.242927
       3     -2.538224    0.457778    0.238655
       4     -2.537919    0.572222    0.233161
       5     -2.851955    0.727256    0.227668
       6     -3.272195    0.834376    0.223090
       7     -3.590808    0.932951    0.220038
       8     -3.769952    1.069063    0.215461
       9     -3.881954    1.123692    0.210883
      10     -3.984191    1.195410    0.207221
      11     -4.075137    1.268960    0.202643
      12     -4.151738    1.399579    0.198065
      13     -4.196295    1.420637    0.193182
      14     -4.206061    1.510361    0.189215
      15     -4.217658    1.566820    0.184637
      16     -4.233222    1.663869    0.180364
      17     -4.205756    1.708731    0.176702
      18     -4.146245    1.801813    0.172735
      19     -4.076357    1.860408    0.168462
      20     -3.986938    1.894894    0.164190
      21     -3.878902    1.918699    0.159917
      22     -3.745537    1.965697    0.155644
      23     -3.568224    1.992553    0.151067
      24     -3.334452    2.025208    0.147099
      25     -3.035066    2.062136    0.142216
      26     -2.646565    2.092349    0.139164
      27     -2.134770    2.062441    0.135197
      28     -1.502731    2.094485    0.130619
      29     -0.755943    2.092044    0.127567
      30      0.089419    2.066103    0.123905
```

4.6 Spectrum Analysis Module

The Spectrum Analysis Module of the optional PCS100DA Control Software with Data Acquisition allows the user to compute, view, save, and print a spectrum of the SQUID output signal. This module implements many features found in general-purpose spectrum analyzers. Several routines from the LabWindows/CVI Advanced Analysis Library are used to process the input signal, perform the Fast Fourier Transform (FFT), and convert the spectrum units.

The FFT procedure is based on the Split-Radix algorithm. It transforms a discretely sampled time-domain signal into a spectrum with discrete components. Like many other FFT algorithms, it may be employed only if the number of data points in the original waveform is a power of 2. The maximum number of data points that may be used is $2^{12} = 4096$. The computed spectrum includes components with both positive and negative frequencies. However, because the time-domain signal is defined for positive times, the positive harmonics contain all information about the spectrum.

To display the Spectrum Analysis panel, select the SPEC>Show Spectrum panel menu item on the main panel of the SQUID Control Module. In order to start the spectrum analysis process, switch both the DAQ ON/OFF toggle key on the Data Acquisition panel and the SPEC ON/OFF key on the Spectrum Analysis panel to the ON position. The Spectrum analysis panel is shown in Figure 4-10.

The Spectrum Analysis Module can perform spectrum analysis for only one channel at a time. The target channel is selected by the "Channel" control on the DISPLAY sub-panel of the Data Acquisition panel. If several channels of data acquisition are enabled, switch the "Channel" control to view a spectrum for any other enabled channel. The displayed spectrum has the same color and linewidth as the corresponding waveform trace in the Data Acquisition graph.

4.6.1 Frequency Resolution

The above-mentioned FFT algorithm computes spectrum values for frequencies ranging from zero to some maximum frequency, which is equal to the Nyquist critical frequency, given by

$$f_c = \frac{1}{2 \cdot \Delta t}.$$

Here Δt is the sampling time interval, which is equal to the scan interval. For example, if the scan interval is 5 μs, the maximum frequency that may be probed is 100 kHz. The frequency interval between two adjacent components of the computed spectrum is given by the formula:

$$\Delta f = \frac{1}{N \cdot \Delta t},$$

where N is the number of data points from the measured waveform, selected for spectrum analysis. Thus, the frequency interval is equal to the maximum frequency divided by $N/2$.

It is important to keep in mind that properties of the computed spectrum depend on the frequency resolution Δf, and the spectrum appearance may change visibly if the resolution is insufficient. According to the last formula, Δf is inversely proportional to both the scan interval and the

number of points. The scan interval is selected by the "Scan Interval" control on the Data Acquisition panel, and the number of data points to be used for spectrum analysis is set by the "Data Points" control on the SPECTRUM sub-panel of the Spectrum Analysis panel.

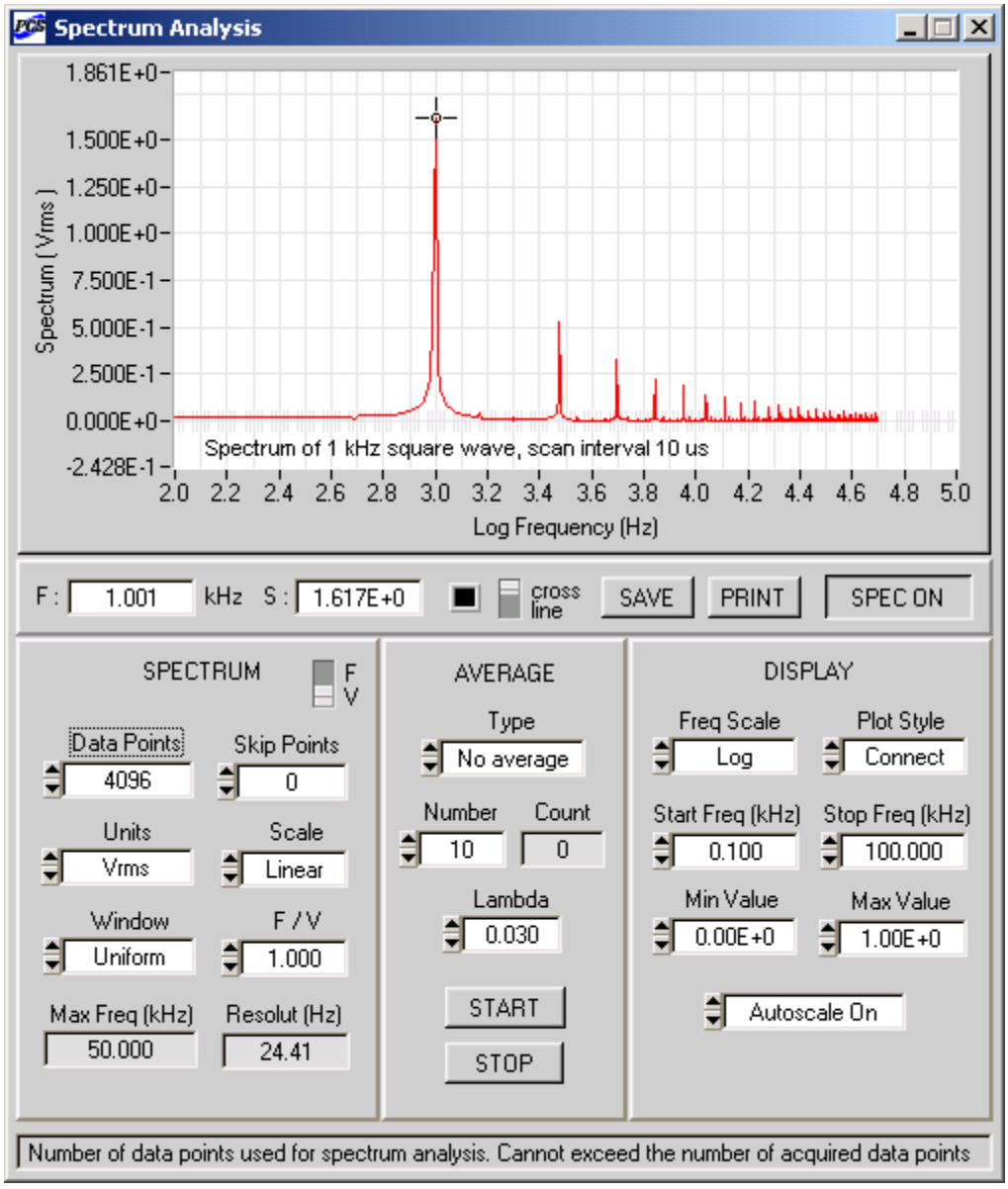


Figure 4-10. Typical appearance of the Spectrum Analysis panel. The "Max Freq" indicator displays the maximum frequency which may be probed for the selected scan interval. The "Resolut" indicator shows the corresponding frequency resolution.

The dependence on the scan interval is illustrated in Figure 4-11. Both graphs in this figure exhibit spectra of the same square wave with 1 kHz frequency and 2 V amplitude. The number of data points is also the same in both cases. However, the scan interval used to obtain data for the upper graph is 25 µs, while the scan interval for the lower graph is 5 µs.

Thus, the maximum frequencies are 20 kHz and 100 kHz, respectively, and the frequency resolution is 5 times better in the first case. One can see that spectrum peaks in the upper graph are sharper, and their positions are more precise. This comparison suggests that the scan interval should be increased if the low-frequency part of the spectrum is to be studied in detail. This, however, may require an anti-aliasing filter with a cutoff frequency lower than that of the standard low-pass filters provided with the PCI-1000 interface.

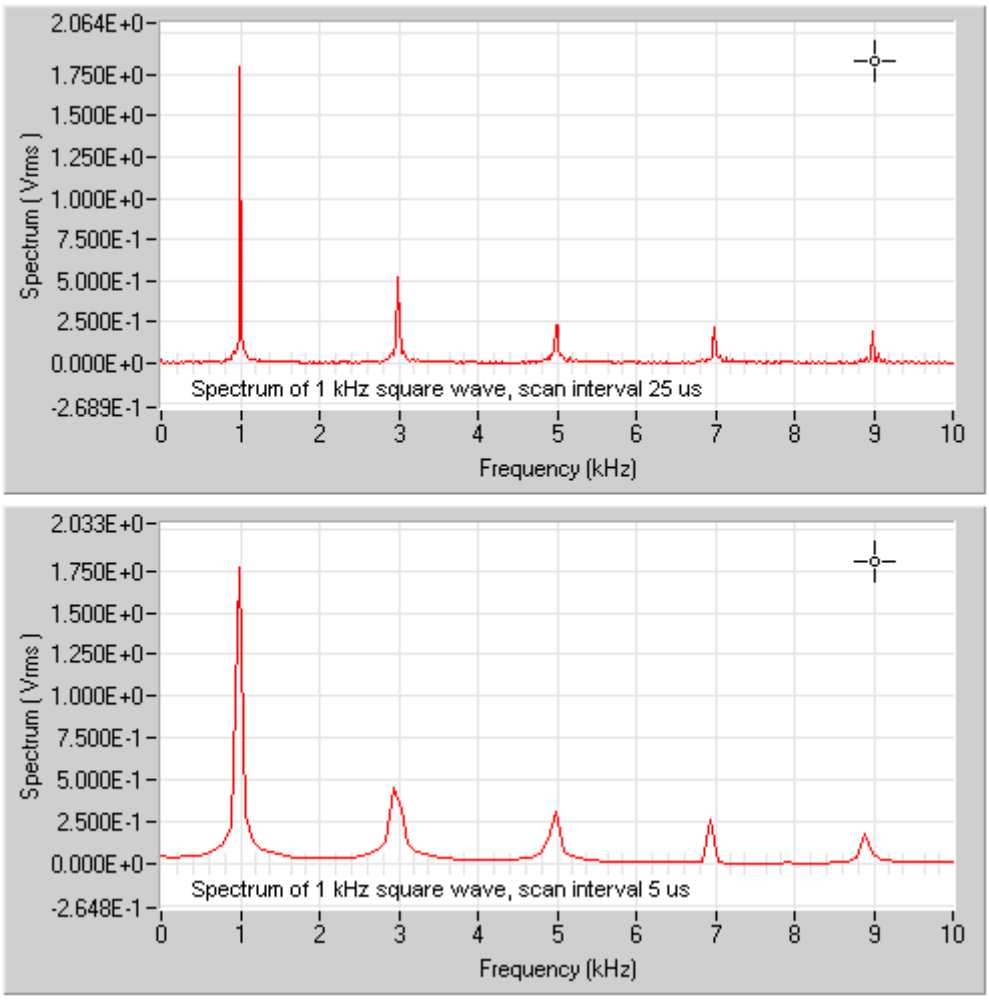


Figure 4-11. Dependence of the computed spectrum on the scan interval. The interval is 25 µs for the upper graph, and 5 µs for the lower graph. The number of data points is 2048 in both cases.

Figure 4-12 shows how appearance of the computed spectrum depends on the number of data points selected for spectrum analysis. This number is 4096 for the upper graph, and 512 for the lower one. The scan interval is the same. The frequency resolution is 8 times better in the first case, and the corresponding spectrum is clearly more precise.

The Nyquist critical frequency, corresponding to the selected scan interval, is displayed by the "Max Freq" indicator on the SPECTRUM sub-panel of the Spectrum Analysis panel. The frequency resolution is exhibited by the "Resolut" indicator on the same panel.

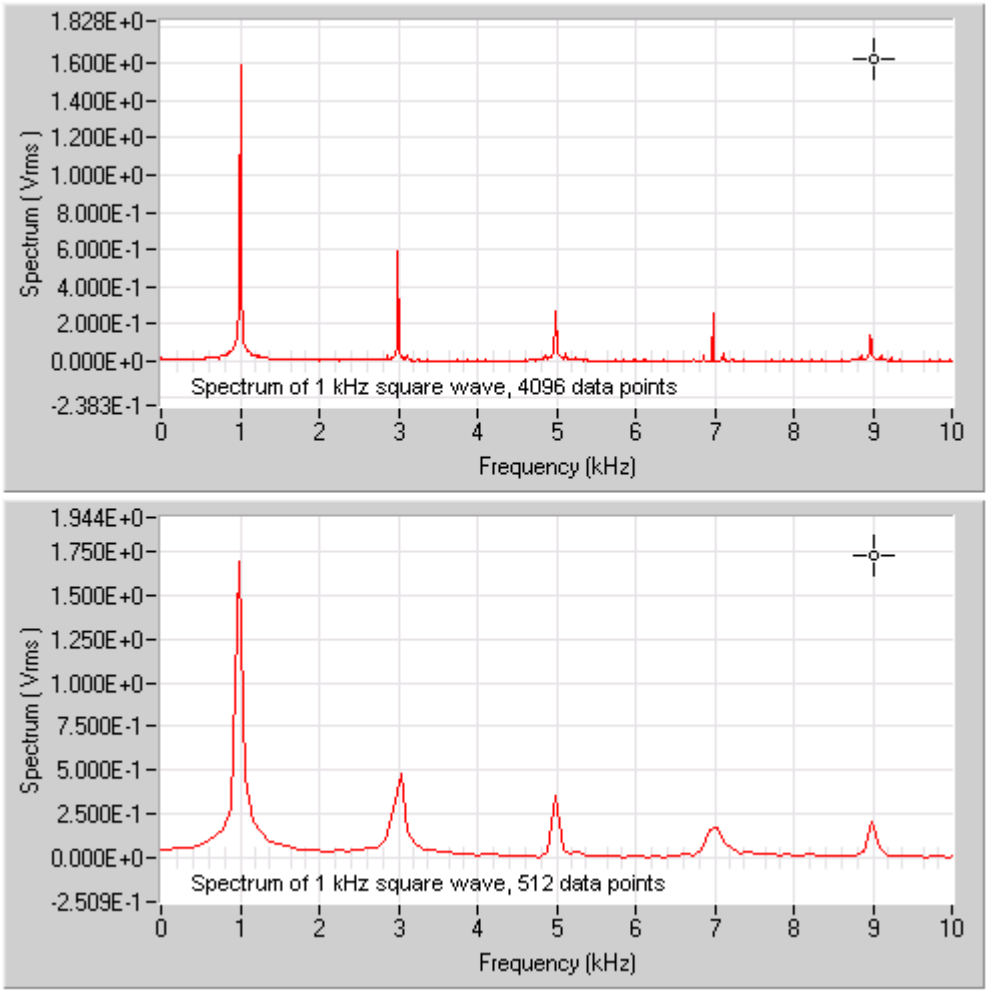


Figure 4-12. Dependence of the computed spectrum on the number of data points. This number is 4096 for the upper graph, and 512 for the lower graph. The scan interval is 20 μs in both cases.

4.6.2 Spectrum Units and Scales

Once a spectrum is computed, it may be expressed in different units. The amplitude spectrum has units of V_{rms} or V_{pk}, depending on whether this is a root-mean-square or peak amplitude. The power spectrum is expressed in either V_{rms}^2 or V_{pk}^2. If a measured signal has a large bandwidth (noise, for example), the magnitude of the power spectrum will change with the frequency span. In order to make it possible to compare measurements with different spans, the power spectral density is considered. It is equal to the magnitude of the power spectrum normalized to a 1 Hz bandwidth, and shows "how much power" corresponds to a 1 Hz interval at a given frequency. The power spectral density has units of V_{rms}^2/Hz or V_{pk}^2/Hz. The amplitude spectral density, accordingly, is measured in units of $V_{rms}/Hz^{½}$ or $V_{pk}/Hz^{½}$.

The spectrum may be displayed using either a linear or logarithmic scale. The logarithmic (dB) scale is defined as follows. The ratio, in decibels, of two signals with amplitudes A and A_0 is equal to $20\log_{10}(A/A_0)$. In order to use decibels as an absolute measure of amplitude, some reference amplitude level A_0 should be specified. The most common reference is 1 V_{rms}. The logarithmic unit thus defined is called dBV, and 0 dBV is equivalent to 1 V_{rms}. Because all spectrum units can be related to V_{rms}, the corresponding functions may be expressed in terms of dBV and displayed on the logarithmic scale. For example, $dBV_{pk}/Hz^{½}$ is the logarithmic unit for the peak amplitude spectral density.

The ratio of two signals in decibels may also be expressed in terms of their powers as $10\log_{10}(P/P_0)$. This definition is more general because it allows comparison of unlike signals, such as a sine wave and noise. Just as in the case of amplitudes, one can measure power in decibels, if some reference power P_0 is chosen. This reference is usually defined as 1 mW of RF signal dissipated in a certain resistive load. The resistances of 50 or 600 Ohm are typically used. The LabWindows/CVI Advanced Analysis Library assumes the 600 Ohm value. The logarithmic unit defined in this way is called dBm, and 0 dBm is equivalent to 1 mW, which corresponds to 0.78 V_{rms} for the 600 ohm load.

The units of the computed spectrum may be selected by the "Units" control on the SPECTRUM sub-panel of the Spectrum Analysis panel. The spectrum scale is set by the "Scale" control on the same panel. Note that the vertical axis label of the Spectrum Analysis graph includes a unit name for the currently displayed spectrum. This unit name is provided by the unit conversion routine.

It was assumed in the above discussion that the signal unit is volts. However, sometimes it may be more convenient to use some engineering unit, proportional to volts. In order to do this, set the "F or V" vertical toggle switch on the SPECTRUM panel to the 'F' position, and input a desired ratio into the "F / V" control. The unit F defined in this way will then be used instead of volts as the input signal unit, and all unit names displayed by both the "Units" control and the Spectrum Analysis graph will include F instead of V.

4.6.3 Spectrum Averaging

If the signal-to-noise ratio of the input signal is not very high, the overall spectrum quality may be improved by averaging many spectra. The spectra are averaged after being converted to their display units. The Spectrum Analysis Module allows the user to choose between two types of

average: linear and exponential. The average type is selected by the "Type" control on the AVERAGE sub-panel of the Spectrum Analysis panel.

The *linear* average is either RMS or arithmetic average. The RMS average, *i.e.*, the square root of the mean square, is used if the spectrum scale is linear. If the scale is logarithmic (dB or dBm), the arithmetic average is employed. The number of spectra to average is set by the "Number" control. Click on the START button to begin the averaging process. In order to save time, the spectrum is displayed only when the averaging is over. The STOP button may be used to stop the averaging process. In this case, the displayed average spectrum corresponds to the number of readings shown by the "Count" indicator.

Figure 4-13 shows a linear average of 1000 noise amplitude spectral density curves for a SQUID operated in the LOCK mode with no external flux applied. The spectrum scale in Figure 4-13 is linear, while the frequency scale is logarithmic. The engineering unit F, used instead of V, is the flux quantum Φ_0, and the ratio F/V = 0.364 Φ_0/V is the actual calibration factor. The 4096 data points used for spectrum analysis were acquired with 5 μs interval. The input signal was filtered using an anti-aliasing 60 kHz low-pass filter, and its effect is clearly visible in the figure.

The vertical line cursor is set at 1 kHz. The "S" indicator displays the spectrum level at the spectrum point closest to the vertical line. The average noise value at that point (1.025 kHz due to the finite frequency resolution) is 1.634 $\mu\Phi_0/Hz^{1/2}$.

The *exponential* average in its arithmetic form is defined as follows:

$$\text{New average} = \lambda(\text{New reading}) + (1 - \lambda)(\text{Previous average}).$$

Here λ is a real parameter between 0 and 1. One can see that this average is equivalent to the above mentioned linear average if $\lambda=1/(n+1)$, where n is the number or readings used in the previous average, and the new reading is reading number $(n+1)$. In this case, λ approaches 0 as n increases, meaning that the contribution of any new reading becomes almost negligible for large n. Therefore, the linear average cannot efficiently track systematic changes in the input data.

When the exponential average is used, λ is constant. This way, any new reading is included with the constant weight λ, while the very first reading has the weight $(1-\lambda)^n$. Therefore, the average can follow significant changes in the input signal even if n is high, but the result depends on λ.

If this parameter is close to 1, the tracking ability is high, but the averaging efficiency is low. If λ is very close to 0, the situation is opposite: small signal fluctuations are averaged out well, but signal drift is harder to follow. The optimum choice of λ depends on the signal properties. The exponential average in its RMS form is simply the square root of the squares averaged according to the above formula.

Unlike the linear average, the exponential average is computed continuously, *i.e.*, every new reading is used to update the average value. Note that this average grows as a function of n until it reaches saturation. After that, it follows changes in the input signal if they last sufficiently long.

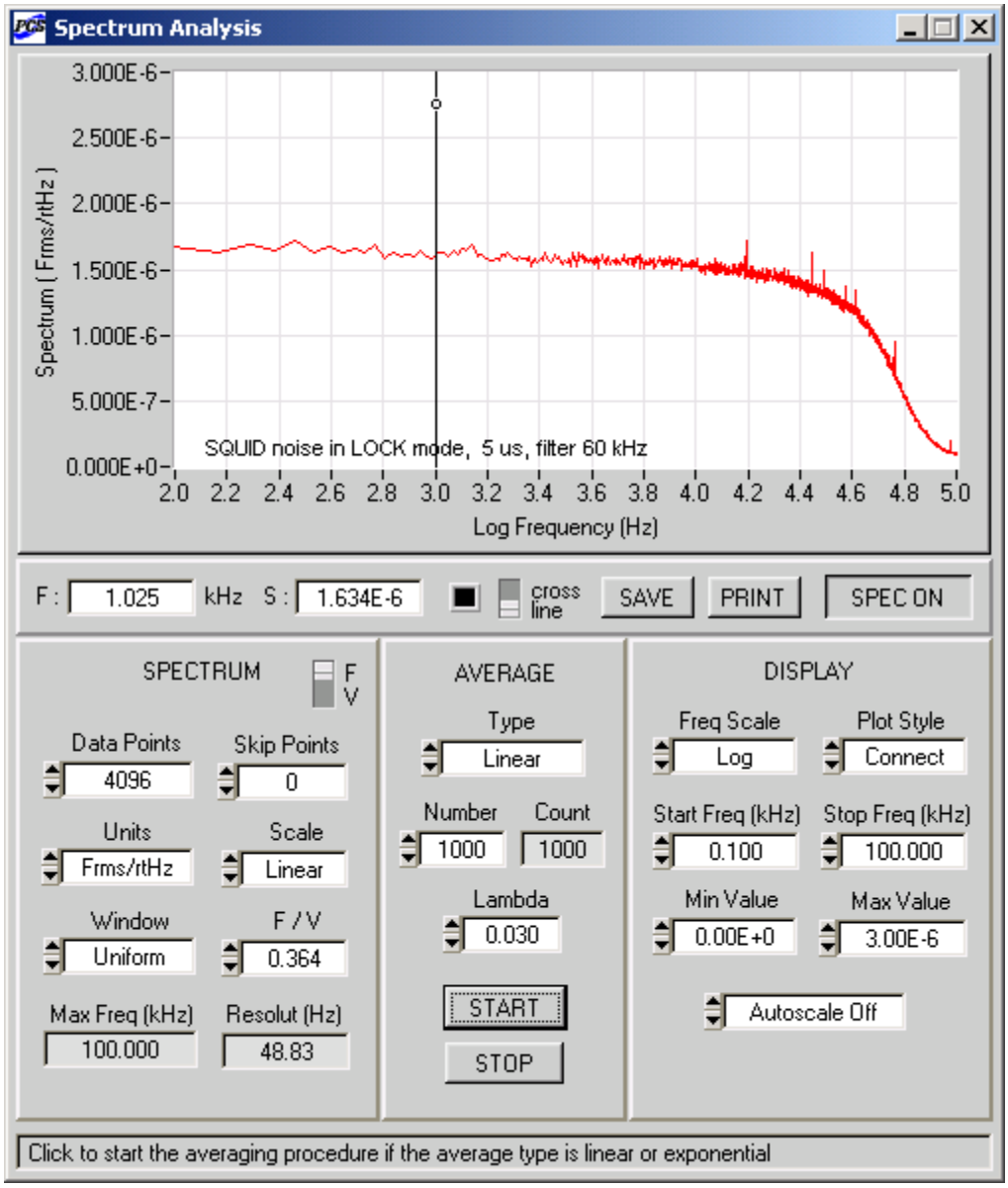


Figure 4-13. Spectral density of a SQUID operated in the LOCK mode. The engineering unit F is the flux quantum, and the ratio 0.364 Φ_0/V is the calibration factor. The displayed curve corresponds to the linear (RMS) average of 1000 individual spectra.

The exponential average is a convenient choice when tuning the SQUID in order to find a working point with the minimum noise level. The parameter λ is specified by the "Lambda" control on the AVERAGE panel. The averaging process is started by clicking on the START button. The exponential average is updated and plotted at every trigger event. This allows the user to monitor variations of the spectrum while adjusting the tune parameters. Note that the "Number" and "Count" controls are not used in the exponential average mode. Click on the STOP button to terminate the averaging process.

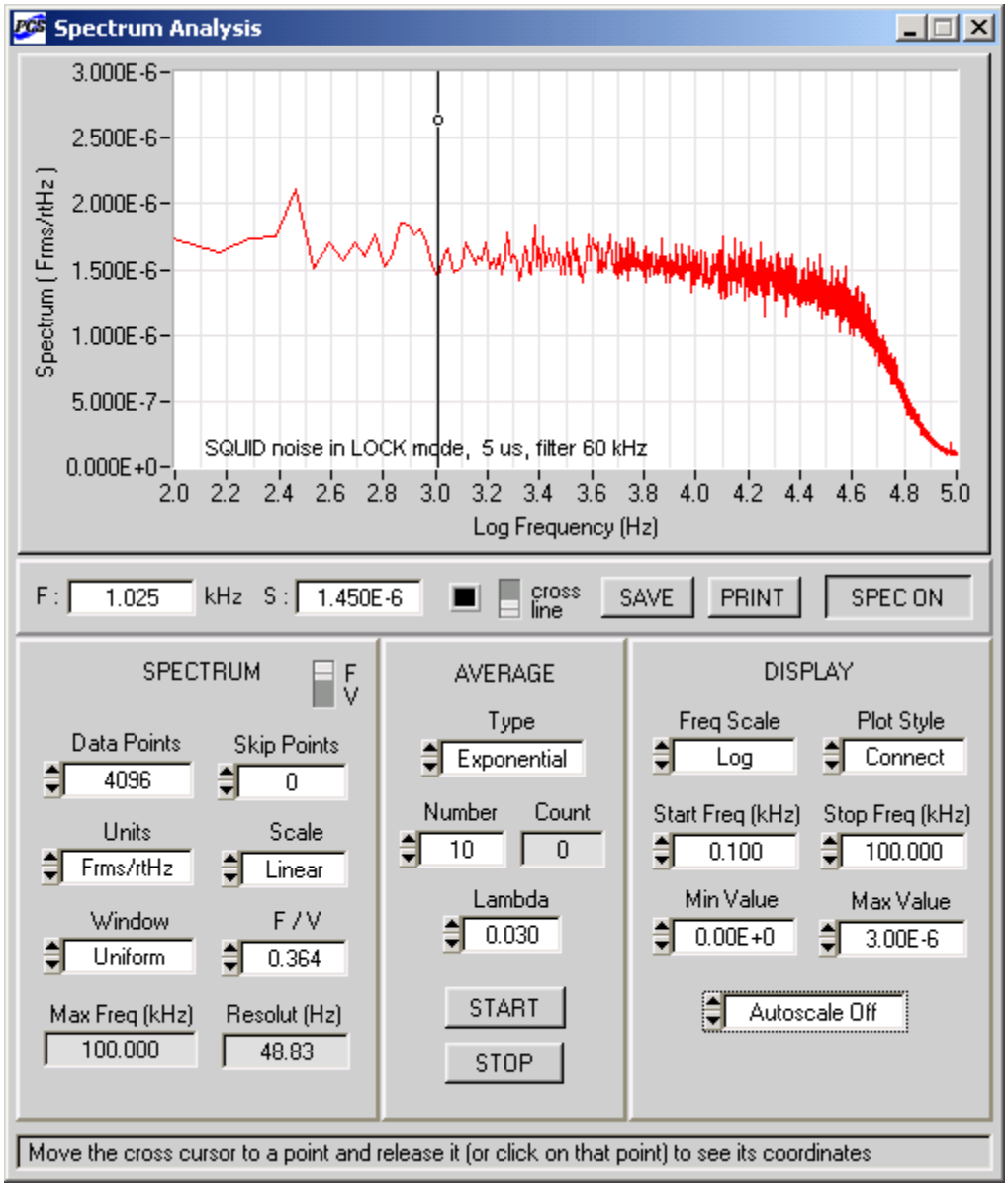


Figure 4-14. The same spectrum as in Figure 4-13, but averaged continuously using the exponential average with λ=0.03. The "S" indicator shows the current value of the exponential average at the spectrum point closest to the vertical line cursor.

This procedure is illustrated in Figure 4-14, which exhibits the continuously updated exponential average with λ=0.03. The "S" indicator shows the current value of the exponential average for the spectrum point closest to the vertical line cursor.

4.6.4 Spectrum Controls

Data Points: The number of data points from the measured waveform used for spectrum analysis. Values of this control are powers of 2, ranging from 2 to 4096. High settings (1024, 2048, or 4096) are recommended for best results. If the selected number of data points is greater than the setting of the "Number of Points" control on the Data Acquisition panel, it is automatically reduced to the largest power of 2 which does not exceed the "Number of Points" value.

Skip Points: The number of data points at the beginning of each data set, which are skipped and not included in the analysis. If the number of (data points + skip points) is greater than the setting of the "Number of Points" control on the Data Acquisition panel, first the number of skipped points is reduced (down to zero if necessary), and then the number of data points is corrected if required.

F or V: This vertical toggle switch is used to specify the units of the input signal. Set it to the 'F' position to select engineering units instead of volts. The value of the "F / V" control is used as a conversion factor. All spectrum units are then expressed in terms of F and not in terms of V.

Units: Sets physical units for the computed spectrum as discussed in Section 4.6.2. Depending on the setting of the "F or V" toggle switch, the base unit of the analyzed signal can be either volts or engineering units F.

Scale: Sets the scale for the computed spectrum as described in Section 4.6.2. If the scale is 'Linear', the spectrum unit is simply the setting of the "Units" control. If the scale is dB or dBm, the spectrum is measured in decibels with respect to the chosen 0 dB or 0 dBm level.

Window: Specifies the type of the scaled window applied to the time-domain signal before the spectrum is computed. The window type affects such spectrum properties as frequency resolution and frequency leakage. The Uniform window provides the highest resolution, but it is also characterized by significant leakage. This means that a spectrum line is very narrow, but its base is very broad. The Flattop window minimizes the leakage, but its resolution is not very good. Hanning, Hamming, and Blackman-Harris windows are the most commonly used window types.

F / V: Sets the conversion factor for the engineering unit F. This value is used only if the toggle switch, which selects between volts and engineering units, is set to the 'F' position.

Max Freq (kHz): This indicator exhibits the Nyquist critical frequency, *i.e.*, the maximum frequency which may probed for a given scan interval. See Section 4.6.1 for details.

Resolut (Hz): This indicator specifies the frequency resolution, *i.e.*, the frequency interval between two nearby components of the computed spectrum. See Section 4.6.1.

4.6.5 Average Controls

Type: Used to select the average type. Two average types are discussed in Section 4.6.3. If this control is set to 'Linear' or 'Exponential', use the START button to begin the averaging process. If the setting is 'No average', a new spectrum is computed at every trigger event and displayed immediately without any averaging.

Number (linear average only): Specifies the number of spectra to be averaged.

Count (linear average only): Shows how many spectra have been averaged so far.

Lambda (exponential average only): Sets a value of the parameter λ, which is used to define the exponential average as discussed in Section 4.6.3. The optimum value depends on the signal properties such as noise and drift.

START: Click on this button to begin the averaging process. The linear average is calculated once, and the average spectrum is displayed when this process is either completed or stopped. The exponential average is computed and displayed continuously.

STOP: Click on this button to stop the averaging process. If the average type is 'Linear', the displayed spectrum is an average of as many spectra as shown by the "Count" indicator.

4.6.6 Display Controls

Freq Scale: Used to select the frequency scale, which may be either linear or logarithmic. If the scale is linear, the Spectrum Analysis graph displays frequency values in kHz. If the scale is logarithmic, all frequencies are expressed in Hz before the base 10 logarithm is computed.

Plot Style: Specifies whether the nearby spectrum points should be connected by straight lines or left scattered. If this control is set to 'Scatter', right-click on the "Trace" control on the Data Acquisition panel to toggle between small and large plot points.

Start Freq (kHz): Sets the lowest frequency to be displayed in the Spectrum Analysis graph. If this setting is 0, and the frequency scale is logarithmic, the lowest frequency shown in the graph is 1 Hz, and the logarithm values along the horizontal axis start with 0.

Stop Freq (kHz): Sets the highest frequency to be displayed in the Spectrum Analysis graph. The "Start Freq" and "Stop Freq" controls can be used to select a part of a spectrum for a detailed study. Their settings are display parameters only, which have no effect on the spectrum analysis procedure.

Min Value: Sets the minimum spectrum value (in the present vertical axis units) that may be displayed in the Spectrum Analysis graph, if the Autoscale is Off. This parameter is ignored in the Autoscale mode.

Max Value: Sets the maximum spectrum value (in the present vertical axis units) that may be displayed in the Spectrum Analysis graph, if the Autoscale is Off. This parameter is ignored if the Autoscale is On.

Autoscale On/Off: Turns the Autoscale mode On and Off. In the Autoscale mode, the minimum and maximum values of the computed spectrum are determined for the frequency interval between the "Start Freq" and "Stop Freq" values. The vertical range of the Spectrum Analysis graph is then adjusted automatically to make sure that all the spectrum values in this frequency interval are properly displayed.

4.6.7 Cursor Operation

The graph on the Spectrum Analysis panel displays actual values of the computed spectrum, and all numbers along the graph axes can be used directly without any additional rescaling or unit conversion. One should remember, however, that the computed spectrum is always discrete. If the "Plot Style" control is set to 'Connect', individual points on the plot are connected by

straight lines. This is clearly visible in the low-frequency region in Figure 4-14. Thus, not every point of the trace is a part of the spectrum. Set the "Plot Style" control to 'Scatter' to view the computed spectrum points only.

The cursor of the Spectrum Analysis graph may be used to determine coordinates of any spectrum point. The coordinates are displayed by the "F" and "S" indicators, located below the graph. The "F" indicator shows the frequency value in kHz, even if the frequency scale is logarithmic. The corresponding spectrum value, displayed by the "S" indicator, has units specified by the vertical axis label. If the spectrum scale is linear, both the vertical axis and the "S" indicator values are in scientific format. If the spectrum scale is dB or dBm, both the axis and the indicator use decimal format.

The cursor may have two different forms: short cross and vertical line. Use the "cross/line" toggle switch below the graph to toggle between these two forms. Use the color control next to it to change the cursor color.

The cross cursor snaps to the nearest spectrum point when released. The default position of this cursor is in the right upper corner of the graph, and both "F" and "S" indicators display zero in this case. To operate the cross cursor, click on it, drag it to a selected point, and release. Alternatively, you may click somewhere within the plot area, and the cursor will automatically snap to the nearest spectrum point. The "F" and "S" indicators will exhibit parameters of this point. Note that these parameters are only meaningful immediately after the cursor release. If the spectrum changes, the cross cursor has to be re-positioned to give valid indicator readings. The cross cursor is convenient, *e.g.* when a static average spectrum (linear or exponential after stop) is to be studied in detail.

The vertical line cursor is used to continuously monitor the spectrum point closest to the vertical line. The "F" indicator exhibits the frequency for this spectrum point, and not the actual position of the line. To move the vertical line cursor, click on the line at any point, drag it to a desired position, and release. Alternatively, you may click on a desired point, and the vertical line will automatically shift to go through that point. Note that the "S" indicator is updated every time a new spectrum is plotted. Therefore, in order to continuously monitor the spectrum, the "Type" control on the AVERAGE panel should be set to 'Exponential' or 'No Average'. The vertical line cursor is convenient, *e.g.* if you wish to minimize the noise level at a given frequency.

4.6.8 Noise Measurements

The Spectrum Analysis Module of the PCS100DA Control Software can be successfully used for measurements of the noise spectral density at the PFL output. This is illustrated in Figure 4-13 and Figure 4-14. Because these measurements are rather sensitive, one has to remember several key points:

- All connections between the PCI unit and the DAQ board should be examined carefully to eliminate possible ground loops and minimize electromagnetic interference pickup.
- The internal test signal generator of the PCI-1000 should be turned off by clicking on the Off button on the PCI panel. Otherwise, the generator signal will be visible in the measured noise spectrum, even if the TEST SIGNAL control on the main panel of the SQUID Control Module is set to 'Off'.

- The “Source” control on the TRIGGER sub-panel of the Data Acquisition panel should be set to ‘Software’. External synchronization is not needed for noise measurements.
- With the SQUID in LOCK mode, the output voltage level should be moved as close to zero as possible. To achieve this, click on RESET if necessary and adjust the dc flux offset using the OFFSET control on the main panel of the SQUID Control Module. The “Input Range” control on the DISPLAY sub-panel of the Data Acquisition panel should then be set to ±50 mV (or ±100 mV for some NI DAQ boards) in order to maximize the voltage resolution.
- It is important to make a proper selection of the anti-aliasing filter using the “Filter” control on the PCI panel. The filter selection is explained in Section 4.5.3. If the filtering is insufficient, the noise spectral density from above the Nyquist critical frequency will be spuriously transferred into the region below this frequency. As a result, the low-frequency noise will seem higher than it really is.
- It is recommended to first use the exponential average to tune and optimize the SQUID parameters in order to find the working point that minimizes the SQUID noise.

4.6.9 Saving Spectra

The computed spectrum may be easily saved as a text file. If the “Type” control on the AVERAGE sub-panel of the Spectrum Analysis panel is set to ‘No average’, an individual spectrum, which is currently in memory, will be saved. If the average type is ‘Linear’ or ‘Exponential’, the currently stored spectrum average will be saved. The spectrum saving procedure is independent of the data acquisition process.

In order to save the spectrum, click on the SAVE button on the Spectrum Analysis panel. The Save Spectrum panel will be brought up. This panel is shown Figure 4-15. Click on the “Browse…” button to select a directory and specify a file name. The string indicator will display the file name and path. If the file name is not empty, the “Save Spectrum Now” button is visible. Click on this button to save the spectrum to the selected file. If the file does not exist, it will be created. After the spectrum is saved, the “Save Spectrum Now” button is dimmed to prevent writing to the same file. To save the same data in a different file, use the “Browse…” and “Save Spectrum Now” controls again. Click the OK button to hide the panel.

An example of a spectrum file format is presented below. The date and time in the header refer to the time when the spectrum was saved. The `CHANNELNUM` entry gives the number of the data acquisition channel for which the spectrum was computed. The `SPECPOINTS` is the number of points in the computed spectrum. Its present value of 2048 corresponds to 4096 data points from the measured waveform, which were used in the spectrum analysis. This is the maximum possible number of points. The `SPECUNITS` entry specifies the units of the computed spectrum. This is the vertical axis label of the Spectrum Analysis graph. The text below it is the text string, which was displayed in both the Data Acquisition and the Spectrum Analysis graphs. The `FREQ` column presents frequency values for all spectrum points. These are actual frequencies in kHz, even if the frequency scale for the spectrum display was logarithmic.

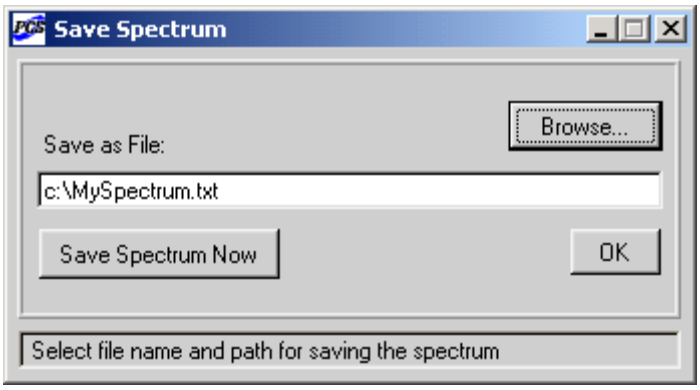


Figure 4-15. The Save Spectrum panel of the Spectrum Analysis module.

Sample spectrum file:

```
PCS100
DATE=06-01-2004
TIME=18:16:55
CHANNELNUM=1
SPECPOINTS=2048
SPECUNITS=Frms/rtHz

TEXT:  SQUID noise in LOCK mode, 5 us, filter 60 kHz

   FREQ(kHz) SPECTRUM
   0.000000  4.179155e-05
   0.048828  1.771471e-06
   0.097656  1.595608e-06
   0.146484  1.637809e-06
   0.195313  1.764908e-06
   0.244141  1.682989e-06
   0.292969  1.726909e-06
   0.341797  1.615332e-06
   0.390625  1.668407e-06
   0.439453  1.647241e-06
   0.488281  1.576964e-06
   0.537109  1.727516e-06
   0.585938  1.646558e-06
   0.634766  1.622987e-06
   0.683594  1.581977e-06
   0.732422  1.593238e-06
   0.781250  1.570423e-06
   0.830078  1.593466e-06
   0.878906  1.543955e-06
   0.927734  1.619812e-06
   0.976563  1.560950e-06
   1.025391  1.548768e-06
   1.074219  1.510428e-06
   1.123047  1.639817e-06
   1.171875  1.562449e-06
   1.220703  1.519171e-06
   1.269531  1.557412e-06
   1.318359  1.610492e-06
```

4.7 Autotune/Calibration Module

The Autotune/Calibration Module of the optional PCS100DA Control Software with Data Acquisition is designed to automatically tune and calibrate a SQUID sensor for optimal operation. This includes autotuning, calibration, and noise optimization. These tasks would normally require some experience on the part of the user, as well as some additional equipment (an oscilloscope, a multimeter, a spectrum analyzer). The Autotune/Calibration Module does all the work automatically and displays the results, thus saving time and eliminating the need for additional hardware.

Even though the Autotune/Calibration Module uses resources of both the Data Acquisition and Spectrum Analysis modules, its operation is fully independent. When any of the three procedures – autotuning, calibration, or noise optimization – is started, "normal" data acquisition and spectrum analysis are stopped. All settings of the Data Acquisition and Spectrum Analysis modules, used for the "normal" acquisition, remain unchanged. The SQUID tune parameters are optimized and correspond to a new working point.

To display the Autotune Procedure panel, select the AUTO>Show Autotune panel menu item on the Main panel of the SQUID Control Module. It is recommended to perform the three procedures in their natural order: autotuning, calibration, noise optimization. Any of them may be repeated as many times as necessary, and its parameters may be adjusted to increase resolution or make it more efficient for a particular type of SQUID sensor. The optimization is carried out for the channel selected on the main panel of the SQUID Control Module, provided that it is one of the first 8 channels. Note that all four standard anti-aliasing filters should be installed inside the PCI-1000 unit for every channel to be autotuned.

4.7.1 Autotune Procedure

The purpose of the autotune procedure is to find a working point with the largest SQUID output in the TUNE mode. In the DC bias mode, settings of the BIAS, MOD, and PHASE controls are optimized. In the AC bias mode, the COMP and SKEW parameters are also adjusted.

A test signal is required for autotuning. It is provided automatically by the internal test signal generator of the PCI-1000, if the "Test Signal" control on the AUTOTUNING sub-panel of the Autotune Procedure panel is set to 'Internal'. Parameters of the test signal may be selected using the "Frequency" and "Amplitude" controls on the same panel. The selected values are used during autotuning only; after this procedure is over, the test signal parameters specified on the PCI panel are restored. If the "Test Signal" control is set to 'External', an external test signal must be applied to the TEST INPUT BNC connector on the front panel of the PCI-1000. See Section 4.7.9 for more information.

The autotune procedure searches for the first maximum of the SQUID output voltage in the TUNE mode with respect to both bias current and modulation. This process includes two steps: rough sweep and fine adjustment. During the rough sweep, the peak-to-peak magnitude of the SQUID output voltage is measured at every point of the rough grid, which spans the selected parameter range. The ranges are set by the "Bias Range" and "Mod Range" controls. The number of points in the grid is specified by the "Rough Grid" control. It is the same for both the bias and modulation grids. This value is important, because it affects the result as well as the overall time to autotune. Higher settings should be used if maxima may be located close to one

another. Otherwise, the second or even third maximum may be detected instead of the first one. It is recommended to try different settings to ensure that the results are consistent. During the fine adjustment, the position of the first maximum is determined more precisely. The resolution is set by the "Fine Grid" control. Note that the bias and modulation values will change to some extent during the noise optimization procedure, so the autotuning precision is not that crucial.

To start the autotune procedure, click on the "Maximize Output" button. The "Measured Signal vs Time" graph on the Autotune Procedure panel displays the actual waveform acquired at every step of the procedure. The scan interval used for the autotuning is the shortest interval for the installed DAQ board. The waveform appearance depends on the settings of the "Data Points", "Frequency", and "Amplitude" controls. To ensure that the peak-to-peak magnitude of the output signal can be determined correctly, adjust these controls to observe at least one period of the measured waveform. When the autotuning is complete, the "Output" indicator will exhibit the final value of the signal magnitude. The appearance of the Autotune Procedure panel at this point is shown in Figure 4-16.

The text indicator below the "Measured Signal vs Time" graph displays information about the current process, and reports possible errors. If an error occurs, the message is red, and the ongoing procedure is terminated automatically. The original values of all the SQUID and PCI parameters are restored in this case. The most common error message during the autotune procedure is "Signal is below the threshold level". This error may occur, for example, if the four required filters are not installed inside the PCI-1000 interface for the selected channel, if the PFL unit is not connected to the SQUID sensor, or if the sensor itself is not working properly. The threshold voltage is set by the "Threshold" control.

In addition to the bias and modulation, the PHASE setting is also optimized. If the BIAS MODE control on the Main panel is set to AC, the COMP and SKEW parameters are adjusted as well. The autotuning in the AC bias mode may be performed only for 128 kHz and 64 kHz bias frequencies, and is not available for the 2 kHz frequency.

Because data acquisition during autotuning is performed at the highest possible rate, FILTER_D is automatically selected as an anti-aliasing filter. However, in the AC bias mode with 64 kHz bias frequency, FILTER_C is used instead for the PCI-6052E, PCI-6034E, and similar boards. During the COMP adjustment, the unfiltered PFL output signal is always selected.

Note that every time the autotune procedure is initiated, optimization of each SQUID tune parameter is started from zero. Thus, repetition of the autotuning with the same procedure settings does not improve the results.

4.7.2 Calibration Procedure

The calibration procedure automatically determines the system calibration factor, ***i.e.***, the number of flux quanta per 1 volt of the PFL output. Only the OFFSET parameter is changed during this process, and no test signal is required.

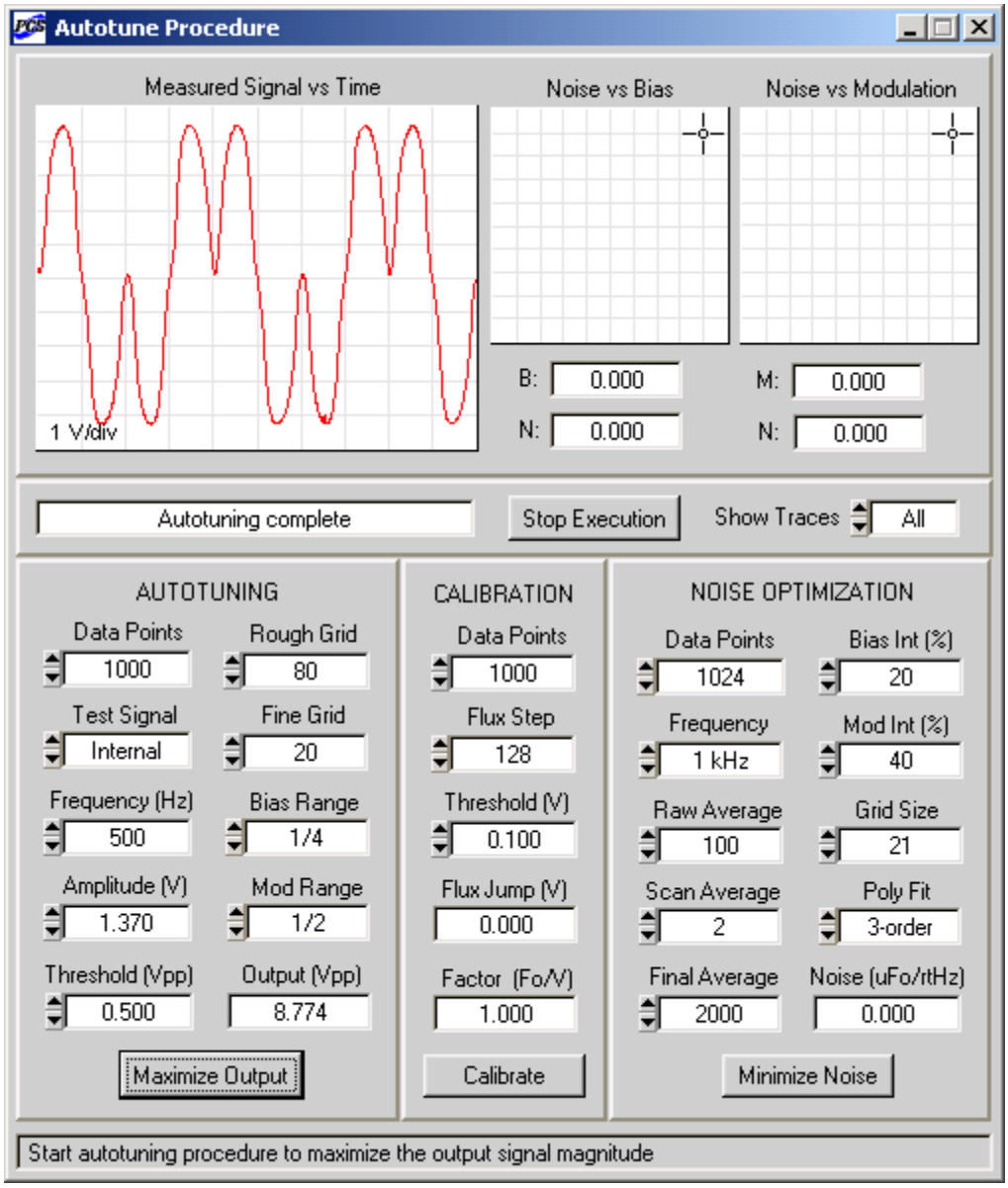


Figure 4-16. Appearance of the Autotune Procedure panel when autotuning is completed. The "Output" indicator displays the final magnitude of the PFL output voltage. Here, the bias search interval is from 0 to 1/4 of the maximum bias value, and the modulation search interval is from 0 to 1/2 of the maximum modulation.

The following calibration algorithm is used. First, the flux offset is adjusted in the LOCK mode to shift the output voltage level to zero. Then, the flux offset is increased (or decreased) in constant steps, and the RESET operation is performed after each step. At some point, a flux jump occurs, and the corresponding voltage change is detected. Because the process is started at zero voltage, this change will correspond to 1 Φ_0, provided that the flux step is sufficiently small. Thus, the calibration factor in units of Φ_0/V is determined. Finally, the flux offset is adjusted again to shift the output voltage level to zero in preparation for the noise optimization.

The flux step is set by the "Flux Step" control on the CALIBRATION sub-panel of the Autotune Procedure panel. This value is specified in DAC steps. The range of the OFFSET control on the main panel in terms of DAC steps is from -4096 to 4095. The flux step should be reduced if the calibration factor in units of Φ_0/V may be large. It is recommended to try different "Flux Step" settings to make sure the calibration results are consistent.

A voltage change after every RESET command is compared to the threshold level, set by the "Threshold" control. If this change is below the threshold, it is ignored; otherwise it is interpreted as a flux jump. The threshold voltage should be sufficiently high to eliminate the effect of voltage fluctuations, but lower than the inverse calibration factor for a given SQUID type.

The calibration procedure is started by clicking on the "Calibrate" button. The actual data acquired at every step are displayed in the "Measured Signal vs Time" graph. FILTER_A, *i.e.*, the anti-aliasing filter with the lowest cutoff frequency, is automatically selected. After the calibration is over, the "Flux Jump" indicator shows the detected voltage change, and the "Factor" indicator exhibits the corresponding value of the calibration factor. The appearance of the Autotune Procedure panel at this moment is shown in Figure 4-17.

4.7.3 Noise Optimization Procedure

The purpose of the noise optimization procedure is to find the working point corresponding to the lowest SQUID noise in the LOCK mode. The noise spectral density is minimized with respect to both bias and modulation. The flux offset is adjusted at every step to keep the mean output voltage as close to zero as possible. The noise optimization should be performed after autotuning and calibration. The bias and modulation are changed in the vicinities of their initial values, which are normally obtained as a result of the autotune procedure. The calibration factor is used to express the result in units of $\mu\Phi_0/Hz^{1/2}$.

The noise optimization procedure is organized as follows. First, the noise spectral density is measured for different values of the bias current, while the modulation is kept constant. The optimum bias value is found. Then, the modulation is varied for the optimum bias, and the optimum modulation value is obtained. Finally, the noise spectral density is measured and averaged many times for the optimum parameter values, and the result is reported as final.

Note that the noise optimization procedure performs fine adjustment of the bias and modulation, using their current values as the starting point. Therefore, it may be repeated as many times as necessary with an appropriate adjustment of the procedure parameters (such as the "Bias Int" and "Mod Int" settings), and each repetition will normally give a lower noise value.

The frequency at which the noise spectral density is measured and minimized is specified by the "Frequency" control on the NOISE OPTIMIZATION sub-panel of the Autotune Procedure panel. The allowed settings of this control are 10 Hz, 100 Hz, 1 kHz, and 10 kHz. While the autotuning and calibration use the shortest possible scan interval, this interval is chosen automatically for the noise optimization, based on settings of the "Data Points" and "Frequency" controls. The scan interval is always selected to be as long as necessary to ensure that the frequency interval between the nearby components of the computed spectrum is at least 5 times smaller than the "Frequency" value. This means that the lower the frequency, the more time it takes to obtain a single noise value.

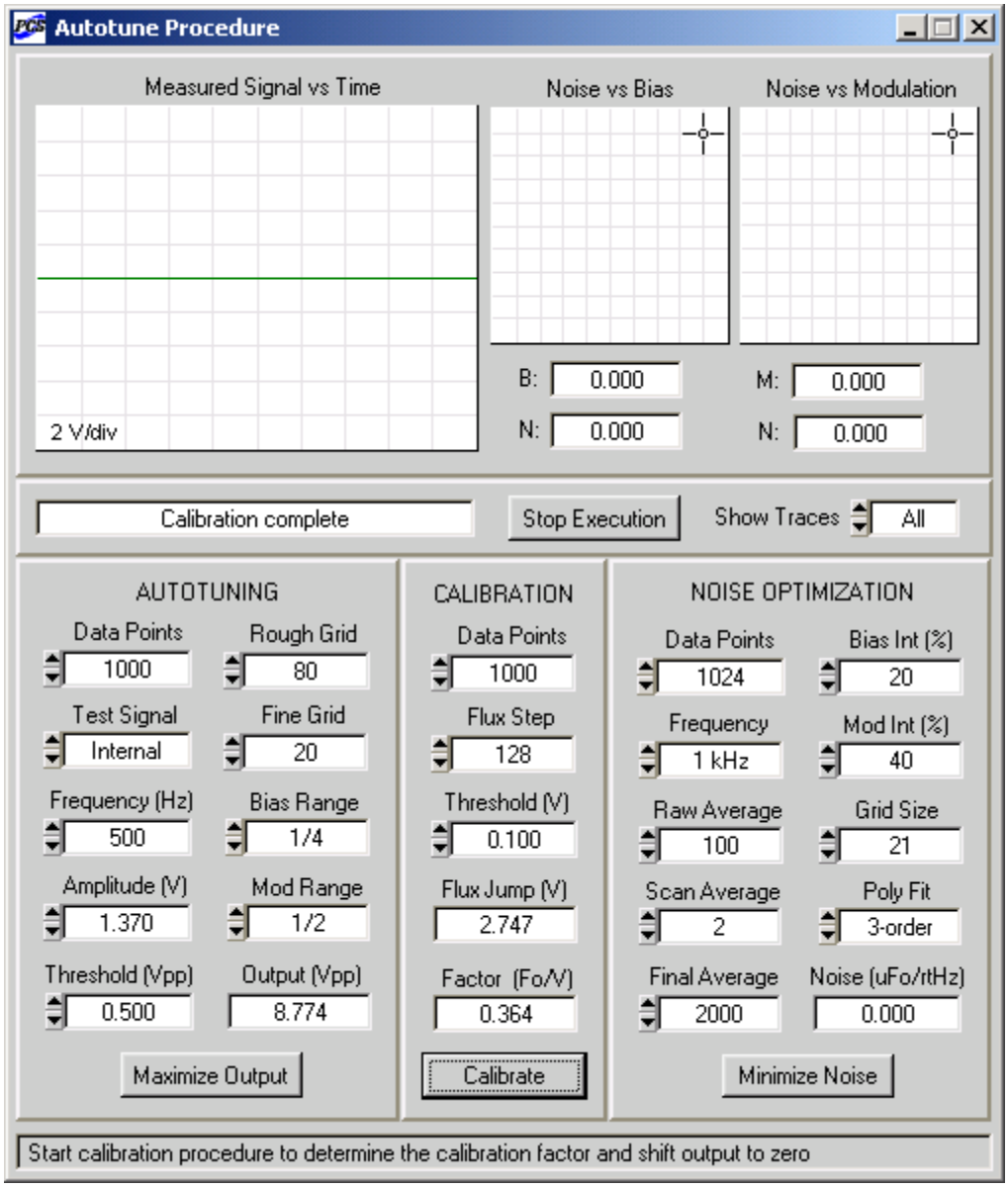


Figure 4-17. Appearance of the Autotune Procedure panel at the end of the calibration. The "Factor" indicator displays the calibration factor determined as a result of this procedure.

An anti-aliasing filter is selected automatically, based on the chosen value of the scan interval. It is assumed that the four low-pass filters (A, B, C, D) have standard cutoff frequencies.

The search interval for each parameter (bias or mod) is defined in percent of the initial value of this parameter, and is always symmetric with respect to this value. If, for example, the "Bias Int" control is set to 10%, the length of the search interval is 10% of the initial bias value, with 5% on each side of this value. The "Mod Int" control works in the same way. The search interval is spanned by a grid of points, and the noise level is measured at every point. The number of points for both bias and modulation is set by the "Grid Size" control. The grid

includes the initial parameter value and equal numbers of equidistant values on both sides of it. Thus, the grid size is always odd.

In order to obtain reliable and reproducible noise values, multiple noise readings should be averaged. Averaging is performed on four different levels.

First, the noise spectral density is determined many times at every grid point, and all readings are RMS averaged. The number of these readings is set by the "Raw Average" control.

Second, the entire grid (for either bias or modulation) is scanned several times, and the results for every grid point are averaged arithmetically. This is very useful because it allows one to compare results for different scans and check their reproducibility. The number of scans is selected by the "Scan Average" control. The minimum number of scans is 2, and the "Scan Average" setting is always even.

Third, the set of points, obtained by averaging several scans, may be fitted with a polynomial. The minimum of this polynomial fit is then found, and its position is taken as the optimum parameter value. The polynomial order is selected by the "Poly Fit" control. Typically, the 3- or 4-order fit works quite well. If the grid size is significantly larger than the polynomial order, the fitting procedure effectively averages out data fluctuations. If the "Poly Fit" control is set to 'None', the fitting is not performed. The optimum parameter value in this case is a grid point, at which the scan average has its minimum.

Fourth, after the optimum working point (bias and modulation) is found, the noise spectral density is measured many (several thousand) times at this point, and an RMS average of all these readings is reported as the final noise density value. The number of readings to be averaged is set by the "Final Average" control.

To begin the noise optimization procedure, click on the "Minimize Noise" button. The "Measured Signal vs Time" graph displays the actual measured signal with high resolution along the vertical axis. A specially designed algorithm keeps the signal level as close to zero as possible by means of a continuous flux adjustment. The lowest input range (±50 mV or ±100 mV) of the installed DAQ board is used to achieve the maximum voltage resolution. If the signal voltage goes beyond this range, the range setting is increased automatically.

The "Noise vs Bias" and "Noise vs Modulation" graphs exhibit the results. The horizontal range of each graph is the search interval for the corresponding parameter. The vertical range is adjusted automatically. Each scan is displayed in the graph as a thin gray line. The average of all the scans (or its polynomial fit, if the fitting is selected) is represented by a thick colored line.

During the bias optimization, the "B" indicator, located below the "Noise vs Bias" graph, shows the latest bias value in μA, and the "N" indicator displays the corresponding noise spectral density value in $\mu\Phi_0/Hz^{1/2}$. This value is a result of averaging as many noise readings at a given grid point as specified by the "Raw Average" control. The same applies to the mod optimization: the "M" indicator below the "Noise vs Modulation" graph displays the latest value of the modulation current in μA. One can use cursors to examine each plot in detail.

When the noise optimization is complete, the "Noise" indicator displays the final noise value at the optimal working point, corresponding to the best bias and modulation values. The typical appearance of the Autotune Procedure panel in this case is shown in Figure 4-18.

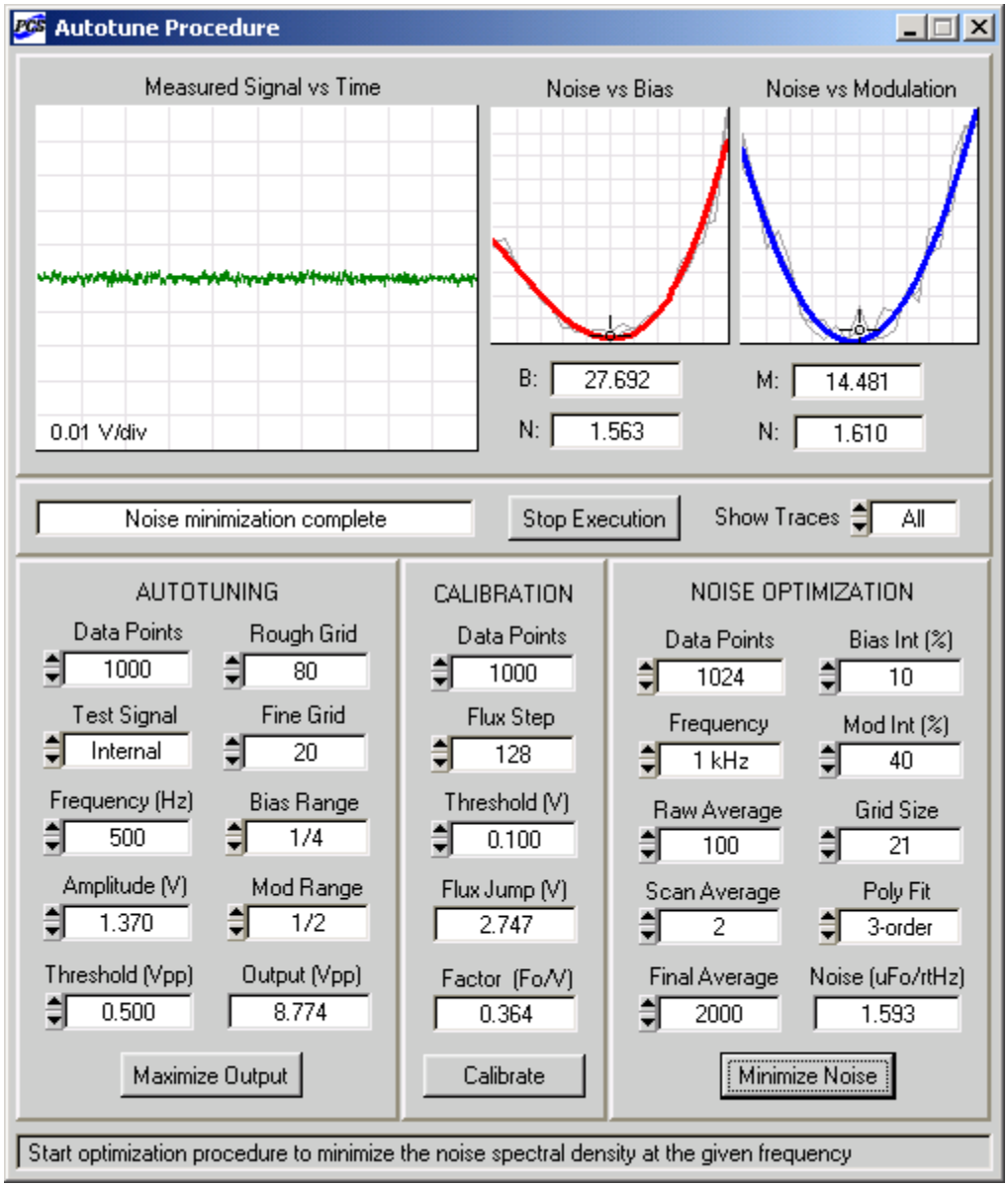


Figure 4-18. Appearance of the Autotune Procedure panel when the noise optimization is completed. The "Noise" indicator displays the noise spectral density at the optimum working point at 1 kHz.

In Figure 4-18, the noise optimization was performed for an LTS SQUID sensor in DC bias mode. One can see that the minima of the "Noise vs Bias" and "Noise vs Modulation" plots are very distinct, and both scans (represented by the thin gray lines) yield similar results. The 3rd-order polynomial fit gives a good approximation of the scan average. Note that if the "Bias Int" and "Mod Int" values are not large, the true minima may be outside the search intervals. In this case, one can simply repeat the noise optimization by clicking on the "Minimize Noise" button again. The partially optimized values of the bias and modulation will be used as the initial parameters for the new optimization process.

Figure 4-19 shows the results of the autotuning, calibration, and noise optimization for the same LTS SQUID, but operated in the AC bias mode. The bias reversal frequency is 64 kHz. In the AC mode, the SKEW and COMP parameters are optimized during the autotuning, in addition to the BIAS, MOD, and PHASE. One can see that the results in Figure 4-19 are very similar to those obtained in the DC bias mode and shown in Figure 4-18.

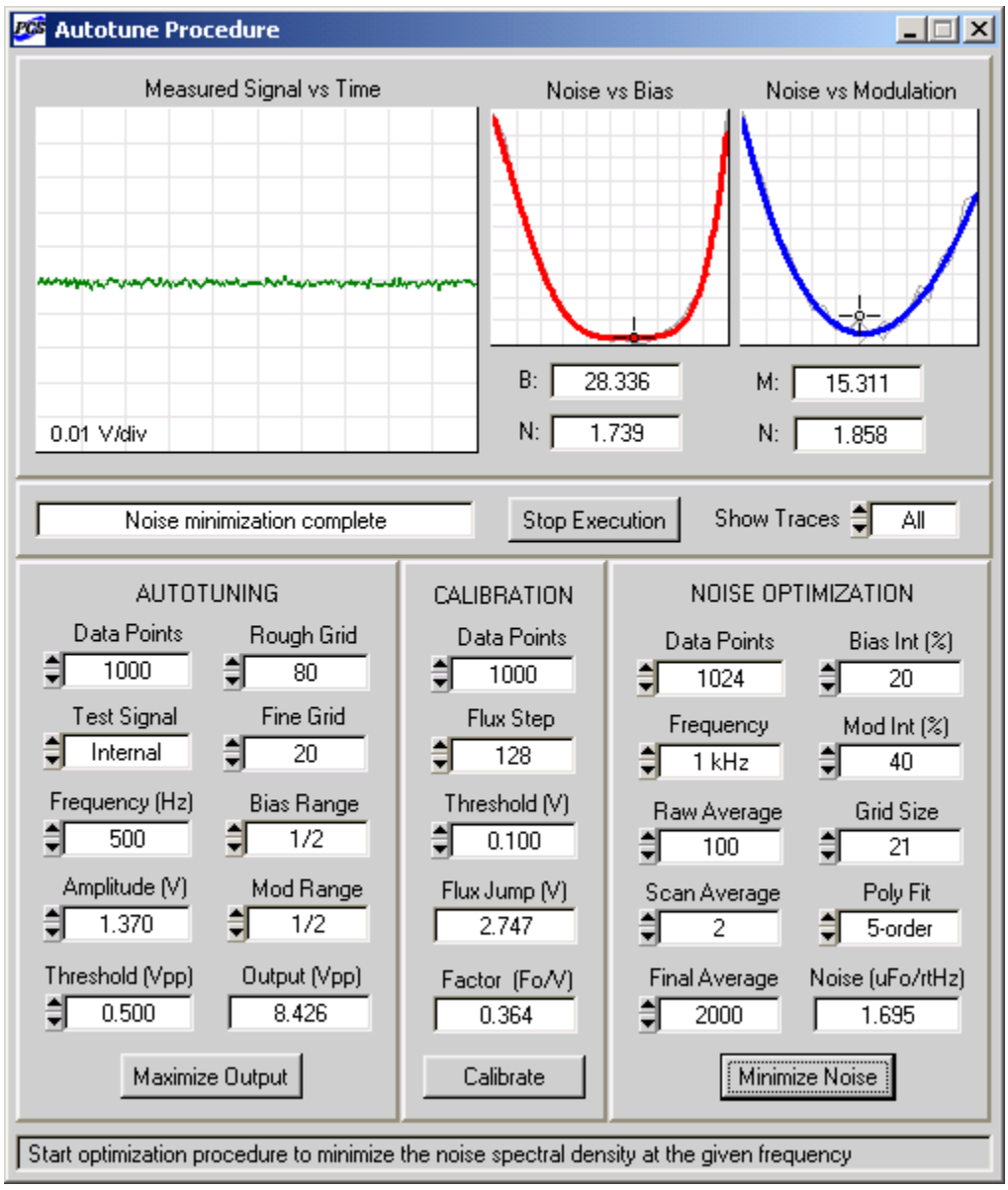


Figure 4-19. Results of the autotuning, calibration, and noise optimization procedures for the same LTS SQUID as in Figure 4-18, but in the AC bias mode with 64 kHz bias frequency.

One should remember that the maximum bias amplitude in the AC mode is 100 μA, instead of the 200 μA maximum bias in the DC mode. The SQUID sensor, used to obtain the data in Figure 4-18 and Figure 4-19, has the optimum bias current of about 27 μA. In Figure 4-18 (DC mode), the "Bias Range" control is set to 1/4, so that the bias search interval is from 0 to 50 μA. The same setting in the AC mode would give the bias amplitude search interval from 0 to 25 μA, and, as a result, the first maximum would not be found. This is why the "Bias Range" in Figure 4-19 is set to 1/2.

Figure 4-20 presents results of the three optimization procedures, performed for an HTS SQUID sensor, operated at 77 K. The AC bias mode with the bias reversal frequency of 128 kHz was used. The SQUID TYPE control on the main panel of the SQUID Control Module was set to 'Type I', so the modulation search interval was from 0 to 5 μA. One can see that the overall noise level is higher than for the LTS SQUID, and the noise minima with respect to both bias and modulation are less pronounced. As a result, more scans have to be averaged to reliably determine the optimal working point.

Results of the noise optimization procedure at 10 Hz frequency are exhibited in Figure 4-21. The same LTS SQUID as in Figure 4-18 was operated in the same DC bias mode. The maximum number of data points (4096) has to be used for noise optimization at low frequencies. The optimization time at 10 Hz is considerably longer than at 1 kHz, because a longer scan interval (0.2 ms) is needed to provide sufficient frequency resolution. This time increase may be partially offset by selecting lower "Raw Average" and "Final Average" settings. The spectrum window at 10 Hz is automatically set to 'Uniform' instead of the 'Blackman-Harris' window, used at higher frequencies. Figure 4-21 demonstrates that the noise optimization procedure works successfully and provides reasonable noise data at the optimization frequency as low as 10 Hz.

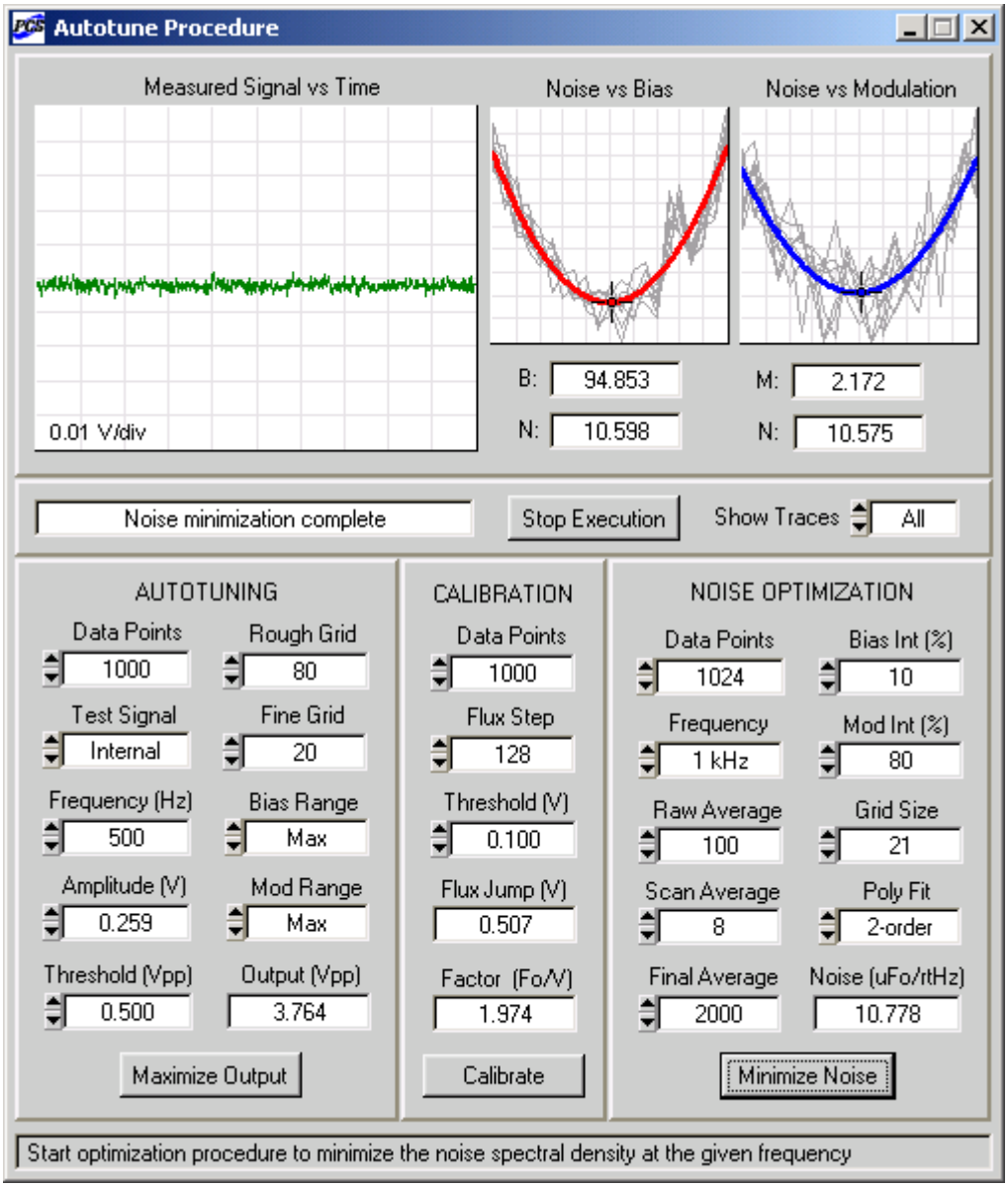


Figure 4-20. Results of the autotuning, calibration, and noise optimization for an HTS SQUID sensor in the AC bias mode with 128 kHz bias reversal frequency.

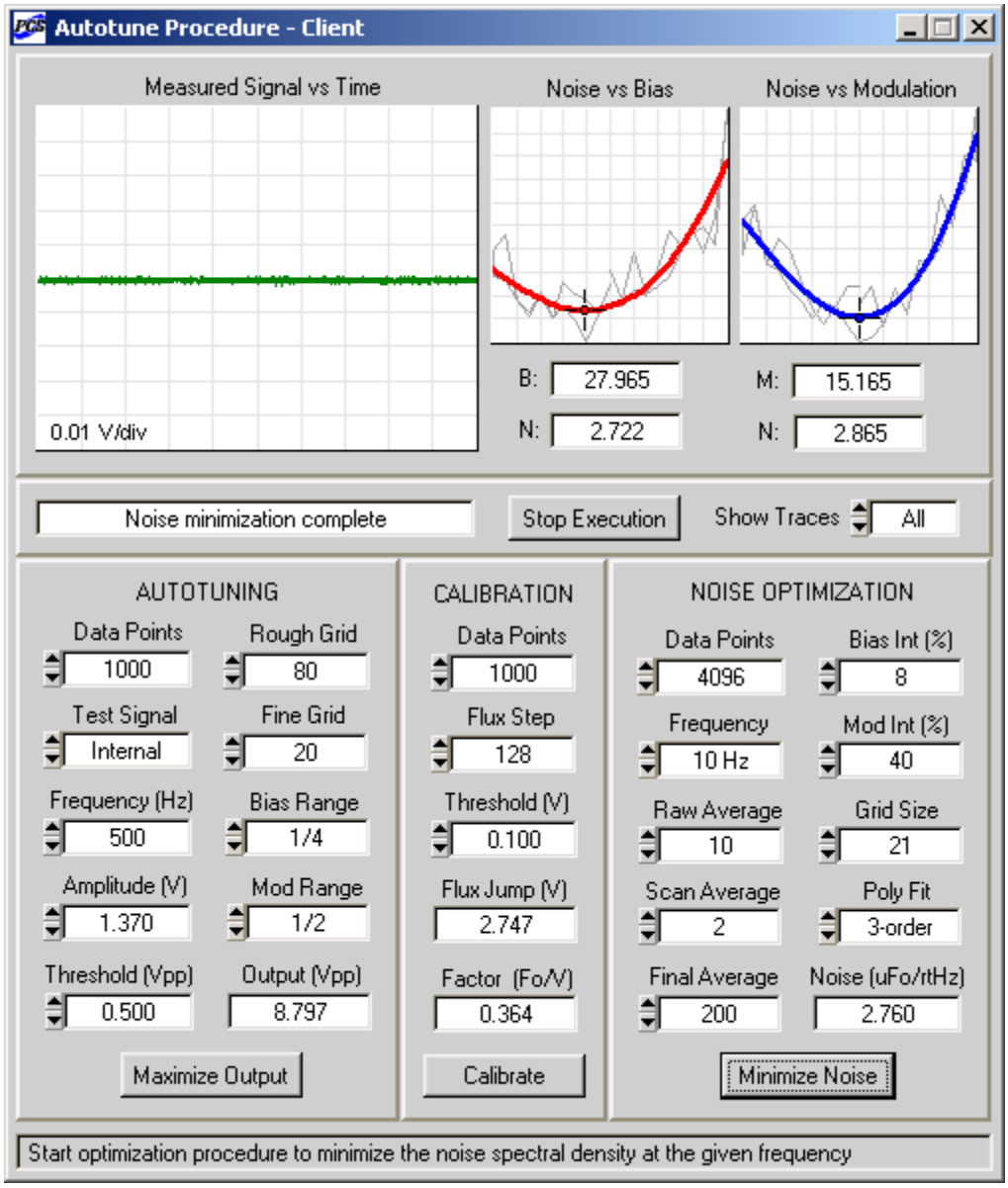


Figure 4-21. Results of the autotuning, calibration, and noise optimization procedures for the same LTS SQUID as in Figure 4-18, but with noise optimization at 10 Hz frequency.

The overall performance of the noise optimization procedure was confirmed in the following way. The optimal working points for 300 first-order LTS SQUID gradiometers (STAR Cryoelectronics Model GA1165) were found automatically using the noise optimization procedure described above. The noise amplitude spectral density was computed using 1024 data points and minimized at 1 kHz. A PCI-6034E board with 200 kS/s sampling rate was used for data acquisition. The noise spectral density at 1 kHz typically was 3 - 4 $\mu\Phi_0/Hz^{1/2}$, which corresponds to 15 - 20 $\mu V/Hz^{1/2}$. For each gradiometer, the noise spectral density was also measured at the optimal working point using a SRS760 FFT Spectrum Analyzer from Stanford Research Systems. This analyzer acquires 1024 data points at a sampling rate of 256 kS/s. The

noise density values determined by the Autotune/Calibration Module and by the spectrum analyzer (after being RMS averaged 2000 times) were compared for each gradiometer, and their relative difference (in %) was determined. The average (RMS) difference, based on results for 300 gradiometers, was only 1.4%. This confirms that the noise spectral density values, displayed by the "Noise" indicator, are quite precise.

4.7.4 Error Messages

As noted at the beginning of this chapter, all hardware and software modules are used during autotuning, calibration, or noise minimization. Any of these procedures may be successfully performed only if all the system components are correctly installed and functioning properly. The text indicator located below the "Measured Signal vs Time" graph on the Autotune Procedure panel displays information about the progress of the current procedure. If the text message is red, an error has occurred, and the execution has been terminated. Below is a list of all error messages that may be displayed.

"The selected port is disabled": The data could not be successfully sent to the selected computer port. Check the port status on the System Configuration panel, and try to select a different port.

"The DAQ board is not connected": The software could not connect to the DAQ device with the selected device number. Check the device type on the System Configuration panel, and try to set a different device number.

"No DAQ support for this channel": The number of the channel selected on the Main panel is greater than 8. The data acquisition is implemented for the first 8 channels, and only these channels may be autotuned.

"No PCI support for this channel": The selected channel number is greater than 1, while the "PCI Units" control on the System Configuration panel is set to PCI-100. Check the hardware configuration, and update the system parameters if necessary.

"The heater is in operation": An attempt to initiate one of the optimization procedures – autotuning, calibration, or noise minimization – was made during a heat cycle. The command is ignored. Wait for the end of the heat cycle, and then start the desired procedure.

"No autotune for 2 kHz bias": The BIAS FREQ control on the Main panel is set to 2 kHz. The autotuning and the other procedures cannot be performed at this frequency.

"The channel is in zero state": The analog outputs of the channel selected on the main panel are currently zeroed, and the autotuning is not allowed. Click on the RESTORE button to restore the outputs and enable the autotuning.

"No external trigger received": The autotune procedure could not be started due to the lack of external synchronization. Make sure that the SYNC OUT terminal of the PCI-1000 (or the synchronization output of an external test signal generator) is connected to the PFI0/TRIG1 input of the DAQ board.

"Signal is below threshold level": The peak-to-peak magnitude of the PFL output during the rough bias (or modulation) sweep is too small. Make sure a set of four filters is installed for the selected channel inside the PCI-1000 unit. Check all the hardware connections. Reduce the "Threshold" value, and increase the "Bias Range", "Mod Range", and "Rough Grid" settings if necessary. Make sure that the SQUID sensor is functional.

"Flux offset limit is reached": No flux jumps were detected during the calibration procedure, even though the maximum or minimum flux offset value was reached. Check all the hardware connections, the SQUID sensor, and reduce the "Threshold" setting if necessary.

"Step number limit is reached": The current procedure – autotuning, calibration, or noise minimization – is not complete, even though 2000 optimization steps have been performed. This condition is used to terminate the execution if the sensor response is unusual or the procedure is too slow due to an inadequate choice of parameters. Make sure that the SQUID sensor is functional. Reduce the "Rough Grid" and "Fine Grid" values if necessary.

"Error in the data acquisition": An error is returned by one of the data acquisition functions. The corresponding NI-DAQ error code is reported using the DAQ Error Report panel.

"Execution is terminated by user": The "Stop Execution" button was used during the current procedure. The procedure is terminated, and the initial values of the SQUID and PCI parameters are restored.

4.7.5 Autotuning Controls

Data Points: Sets the number of data points acquired at every step of the autotune procedure. The acquisition time is equal to the number of data points multiplied by the sampling time interval (5 μs, 10 μs, or 3 μs depending on the board type). All these points are displayed in real time in the "Measured Signal vs Time" graph on the Autotune Procedure panel.

Test Signal: Selects the test signal source for the autotune procedure. If it is set to 'Internal', the on-board test signal generator of the PCI-1000 is used. If the setting is 'External', the PCI-1000 generator is turned off automatically, and an external signal generator is required.

Frequency (Hz): Specifies frequency of the test signal (provided by the PCI-1000) used for the autotuning. The frequency setting should be high enough to ensure that at least one period of the PFL output in the TUNE mode is sampled and displayed in the "Measured Signal vs Time" graph.

Amplitude (V): Sets amplitude of the test signal (from the PCI-1000) used during the autotune procedure. If the frequency setting is low, the amplitude value should be increased to make sure that at least one period of the output waveform is sampled and displayed.

Rough Grid: Sets the rough grid size, *i.e.*, the number of different values of bias (or modulation), which are examined to find an approximate position of the first output maximum during the rough bias (or modulation) sweep. These values are spread over the interval specified by the "Bias Range" (or "Mod Range") control. The rough grid is geometric: the distance between nearby points increases with the point number. This makes it possible to cover the entire parameter range in a relatively short time, but also results in a gradual decrease in search resolution. If the first and second maxima may be close, the rough grid size should be increased to ensure that these maxima can be reliably distinguished.

Fine Grid: Sets the fine grid size, *i.e.*, the number of different bias (or modulation) values used for the fine parameter optimization. These values are spread over a short interval centered on the initial parameter value, which is found during the rough sweep. The fine grid is linear, *i.e.*, the points are equally spaced. Increase the fine grid size to determine position of the first maximum

with higher precision. Note, however, that the fine optimization procedure will not help if the maximum found during the rough sweep is not the first maximum.

Bias Range: Specifies range for the rough bias sweep. This control has three possible settings: 'Max', 1/2, and 1/4. If it is set to 'Max', the bias interval from 0 to the maximum bias value (*i.e.*, the maximum value of the BIAS control) is searched. One may set this control to 1/2 or 1/4 to reduce the sweep range down to a half or a quarter of the maximum bias, respectively. This is convenient if the first maximum of the SQUID output is known to lie below a certain bias value. For example, if the maximum bias current for a given PFL in the DC bias mode is 200 μA, and the bias value corresponding to the first output maximum for a given SQUID cannot exceed 50 μA, the "Bias Range" control may be set to 1/4. This will increase the search resolution, because all the grid points will be spread over the 50 μA interval instead of the entire 200 μA range. Note that, in the AC bias mode, the maximum bias amplitude is twice as low (100 μA instead of 200 μA in the DC mode).

Mod Range: Specifies the range for the rough modulation sweep. The function of this control is analogous to that of the "Bias Range" control discussed above.

Threshold (Vpp): Used to set the lower limit on the peak-to-peak magnitude of the PFL output voltage during the autotuning. If the output signal is smaller, an error is reported.

Output (Vpp): This indicator exhibits the peak-to-peak magnitude of the PFL output voltage after the autotuning is completed. Better optimization results in larger magnitude. The default setting of this indicator is 0.

Maximize Output: Click on this button to initiate the autotune procedure.

4.7.6 Calibration Controls

Data Points: Sets the number of data points acquired at every step of the calibration procedure. Voltages measured during the calibration are constant, so the number of data points may be lower than in the case of autotuning.

Flux Step: Used to specify the step size for the flux offset during the calibration procedure. Each setting of this control is a certain number of DAC steps. Note that the flux offset range in terms of DAC steps is from –4096 to 4095. The actual flux change corresponding to a given setting of the "Flux Step" control should not exceed 1 Φ_0. Otherwise, the SQUID calibration factor may be determined incorrectly.

Threshold (V): Sets the lower limit on a voltage change during a flux jump. Smaller voltage changes (which may result from noise pickup) are ignored, and not interpreted as flux jumps. The setting of this control may be a significant fraction of the expected voltage change.

Flux Jump (V): This indicator exhibits the measured voltage change during a flux jump, which is the inverse of the calibration factor.

Factor (Fo/V): This indicator displays the calibration factor in units of Φ_0/V, determined as a result of the calibration procedure. Note that this value is used during the noise optimization to convert Volts to Φ_0. The default setting of this indicator is 1.

Calibrate: Click on this button to start the calibration procedure.

4.7.7 Noise Optimization Controls

Data Points: Sets the number of data points acquired at each step of the noise optimization procedure. All settings of this control are powers of 2.

Frequency: Used to select the frequency at which the noise amplitude spectral density is minimized. Four values are available: 10 Hz, 100 Hz, 1 kHz, and 10 kHz. Note that the scan interval for data acquisition is determined using the settings of both the "Data Points" and "Frequency" controls. It is recommended to use the maximum number of points (4096) for 10 Hz and 100 Hz frequencies. The anti-aliasing filter is selected automatically based on the determined value of the scan interval.

Bias Int (%): Sets the bias search interval, which is centered at the initial bias value and measured in % of this value. For example, if the initial bias is 25 μA, and the bias interval is 20%, then the bias values examined during noise optimization will range from 22.5 μA to 27.5 μA. If the "Bias Int" control is set to 0, the bias optimization procedure is skipped, and the initial bias value is left unchanged.

Mod Int (%): Sets the modulation search interval, which is centered at the initial modulation value and measured in % of this value. The function of this control is analogous to that of the "Bias Int" control discussed above. If the "Mod Int" control is set to 0, the modulation optimization is not performed, and the initial modulation value remains unchanged.

Grid Size: Used to specify the grid size, *i.e.*, the number of different parameter values for which the noise level is measured. The grid includes the initial parameter value and equal numbers of equidistant parameter values on both sides of it. Thus, the grid size is always odd. The bias grid spans the bias interval, defined by the "Bias Int" control. Similarly, the modulation grid spans the modulation interval, set by the "Mod Int" control.

Raw Average: Sets the number of spectrum values that are consecutively measured and then averaged for the given values of bias and modulation. This number typically ranges from several dozens to several hundreds.

Scan Average: Used to specify the number of scans to average. The scan is a set of noise values, which includes one value for each grid point. The measurement sequence is defined in such a way that the search begins and ends at the center of the grid, and the parameter change at every step is small. For example, if the points are numbered as –2, -1, 0, +1, +2, the simplest measurement sequence is +1, +2, +2, +1, 0, -1, -2, -2, -1, 0. Here, the noise level is measured twice at every grid point, so the number of scans to average is 2. This sequence may be repeated as many times as necessary, and each repetition adds 2 scans. Thus, the setting of the "Scan Average" control is always an even number.

Poly Fit: Order of the polynomial fit to the scan average. This value is coerced to be lower than the number of points used for fitting, which is equal to the grid size. Set this control to 'None' to use the unfitted scan average. Note that the "Poly Fit" setting has to be selected before the noise optimization is started. If the dependence of noise on bias or modulation is complicated, increase the polynomial order, or switch to 'None'.

Final Average: Selects the number of noise values to be measured and averaged at the end of the noise optimization procedure after the optimum values of bias and modulation are found and set.

The final averaging is performed to obtain a reliable noise reading, and the setting of the "Final Average" control is typically several thousands. If it is set to 0, the final averaging is skipped.

Noise (uFo/rtHz): This indicator displays the value of the noise amplitude spectral density in units of $\mu\Phi_0/Hz^{1/2}$, determined as a result of the noise optimization procedure at the given frequency. The default setting of this indicator is 0. Note that the final noise density value exhibited by the "Noise" indicator may be a little higher than the minima of the "Noise vs Bias" and "Noise vs Modulation" plots. This is because those minima are found using averages of fewer readings, and, therefore, their values are less precise.

Minimize Noise: Click on this button to begin the noise optimization procedure.

4.7.8 Other Controls

Measured Signal vs Time: Displays the actual waveform measured at every step of the ongoing optimization procedure. The horizontal axis range is equal to a product of the "Data Points" setting and the currently used scan interval. The vertical axis scale is displayed in the lower left corner of the graph.

Noise vs Bias: Shows the noise amplitude spectral density as a function of the bias current. The horizontal axis range corresponds to the bias search interval, with the initial bias value at the center. Each thin gray line across the graph represents one scan. The thick red line is either an average of all the scans or a polynomial fit to this average. Drag the cursor to any point in the graph (or click on any point) to have its coordinates displayed by the "B" (bias in μA) and "N" (noise in $\mu\Phi_0/Hz^{1/2}$) indicators.

Noise vs Modulation: Displays the noise spectral density as a function of the modulation. The horizontal axis range is the modulation search interval, centered at the initial modulation value. Scans are represented by thin gray lines. The thick blue line is either a scan average, or a polynomial fit to this average. The cursor may be dragged to any point (or click on any point), and the coordinates of the point will be displayed by the "M" (modulation in μA) and "N" (noise in $\mu\Phi_0/Hz^{1/2}$) indicators.

Stop Execution: Click on this button to terminate an ongoing optimization procedure, and restore the initial values of the SQUID and PCI parameters.

Show Traces: Specifies how many traces are to be displayed in the "Measured Signal vs Time" graph during an optimization procedure. The 'All' setting means that every measured waveform is displayed as soon as it is acquired. 'None' corresponds to no display at all. If this control is set to 'Some', only several most important waveforms are shown to demonstrate main steps of each procedure. The 'Some' and 'None' settings are recommended during remote operation in order to reduce the network traffic.

4.7.9 Hardware Options

The Autotune/Calibration Module may be used with a single-channel PCI-100 interface instead of a multi-channel PCI-1000 unit. In this case, an external test signal generator is required for the autotune procedure. The test signal generator output should be connected to the TEST INPUT BNC on the front panel of the PCI-100, and its synchronization output to the PFI0/TRIG1 input of the DAQ board. The PFL signal is measured at the FILTERED output on the front panel of the PCI unit. Note that the PCI-100 interface is equipped with a standard low-

pass filter with a cutoff frequency of 5 kHz. In order to avoid distortion of the PFL output waveform in the TUNE mode, the test signal frequency should be relatively low. Triangular test signals with frequencies up to 300 Hz work well, and are usually quite sufficient for autotuning. The "Data Points" control on the AUTOTUNING sub-panel should be set to at least 1000 to ensure that the output signal peak-to-peak magnitude can be determined correctly.

The calibration and noise optimization procedures require neither the test signal, nor the external synchronization. The FILTERED output of the PCI-100 should be used for both procedures. The noise optimization may be performed at 1 kHz and below.

Sometimes it may be more convenient to use an external test signal generator instead of the internal generator of the PCI-1000. The output of the external generator should be connected to the TEST INPUT BNC on the front panel of the PCI-1000, and its synchronization output to the PFI0/TRIG1 input of the DAQ board. The internal generator has to be turned off. To do this, set the "Test Signal" control on the AUTOTUNING sub-panel to 'External'.

4.8 Remote Control Module

The Remote Control Module (SW-RC) of the PCS100 and PCS100DA Control Software allows remote operation of the pcSQUID™ system via a local network or the Internet. It is built on DataSocket technology developed by National Instruments.

DataSocket is a programming technology based on TCP/IP, which simplifies live exchange of measurement data between different applications on one computer or between computers connected via a network. This technology uses a special communication protocol, called the DataSocket Transfer Protocol (DSTP). This is an application-layer protocol for transferring measurement data to and from a DSTP server called a DataSocket Server.

Remote operation of the PCS100 or PCS100DA Control Software is based on a server/client scheme. By definition, a Server is a PCS100 or PCS100DA application that directly controls the hardware, including the PFL-100 feedback loops, PCI-1000 interfaces, a DAQ board, and a computer port connected to a PCI unit. The Server application also launches the DataSocket Server. A Client is a PCS100 or PCS100DA program that may only communicate with the Server and instruct it to send certain commands to the hardware. The Client essentially functions as a remote user interface for the Server. The present version of the software allows only one Server and one Client.

After a PCS100 or PCS100DA application is started, it may be configured for remote control purposes as either a Server or a Client. The Server and the Client, when properly connected to the DataSocket Server, may exchange remote control commands, containing parameters of various software modules and instructions to perform various operations. Acquired waveform data may only be transferred from the Server to the Client.

4.8.1 DataSocket Server

Communication between the Server and Client is handled by the DataSocket Server, which supports data exchange using the DSTP protocol. It can be launched by the Server application only. The Client application may then remotely connect to the DataSocket Server running on the Server computer. Both the Server and the Client programs are "clients" of the DataSocket Server.

The DataSocket Server may hold and control many measurement data items, such as numbers, arrays, strings, and their combinations. These data items are referred to as DataSocket items, or simply "items". Each DataSocket item is identified by a unique URL (universal resource locator). A DSTP URL specifies the computer on which the DataSocket Server is running, and defines the access path for a particular data item. Predefined DataSocket items are created when the DataSocket Server is started. They may exist without DataSocket connections. Dynamically created items are DataSocket items that are created only when an application connects to the DataSocket Server. They exist only during the DataSocket connection.

Before using the Remote Control Module to configure the PCS100 or PCS100DA application as a Server, you have to configure the DataSocket Server itself. This is done by means of a configuration utility called DataSocket Server Manager, which is installed automatically together with the PCS100 software. To launch this utility, click on the "Start" button in the lower left corner of your computer screen, and select the following:

Start>Programs>National Instruments>DataSocket>DataSocket Server Manager. The user interface of the DataSocket Server Manager is shown in Figure 4-22.

One of the functions of the DataSocket Server is to restrict access to data by administering security and permission. Permissions are set by adjusting "Permission Groups" parameters. DefaultReaders may read all dynamically created items from the DataSocket Server. DefaultWriters may write to all dynamically created items existing on the DataSocketServer. Creators may dynamically create new items on the DataSocket Server.

In order to operate the Server and the Client applications on two different computers connected via a network, set both the DefaultReaders and the DefaultWriters to 'everyhost'. Set the Creators to 'localhost'. Here, 'everynost' represents all computers, and 'localhost' refers to the local computer, *i.e.*, the computer on which the DataSocket Server (and the Server application) is running. After all changes are made, select Settings>Save Settings Now to save the new settings, and close the DataSocket Server Manager.

Note that changes made using the DataSocket Server Manager take effect the next time the DataSocket Server is launched. This is why it is important to adjust the DataSocket Server Manager variables before you configure the PCS100 or PCS100DA application to be a Server. If you plan to configure your PCS100 or PCS100DA application as a Client, there is no need to use the DataSocket Server Manager.

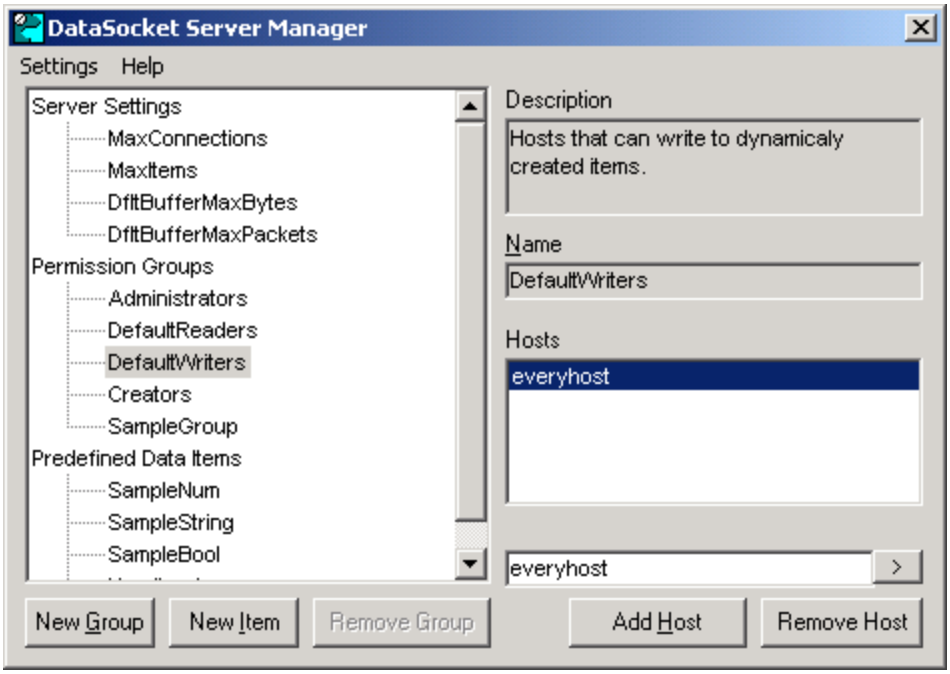


Figure 4-22. User interface of the DataSocket Server Manager.

4.8.2 Server Configuration

To configure your PCS100 or PCS100DA application as a Server, first open the Remote Control panel by selecting the REM>Show Remote panel menu item on the main panel of the SQUID Control Module. The Remote Control panel of the Server application is shown in Figure 4-23. Set the "Server/Client" control in the OPERATION MODE section to 'Server'. The SERVER ON/OFF toggle control is automatically displayed.

Launch the DataSocket Server by switching this control to SERVER ON state. The DataSocket Server panel will appear. This panel is exhibited in Figure 4-24. When the DataSocket Server is launched, the "Processes Connected" indicator shows 0, which means that no applications are connected to the server yet. You need not make any changes to the DataSocket Server panel.

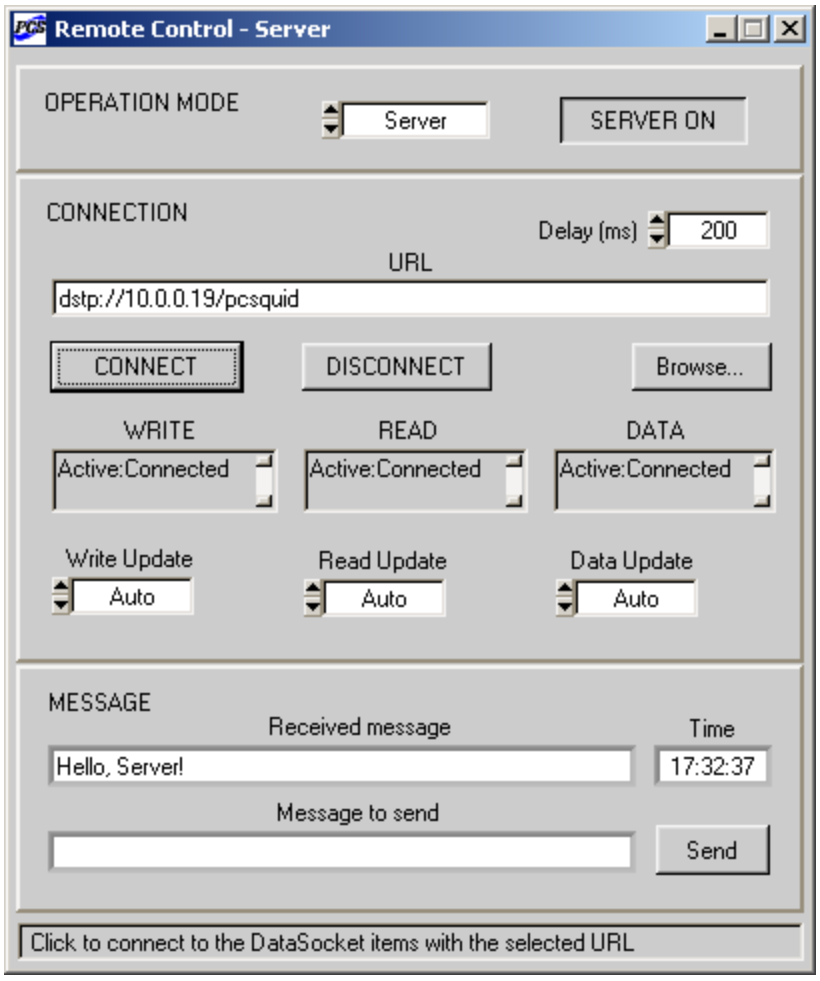


Figure 4-23. The Remote Control panel of the PCS100 or PCS100DA Control Software after it is configured as a Server, the DataSocket Server is launched, and the program is successfully connected to this server.

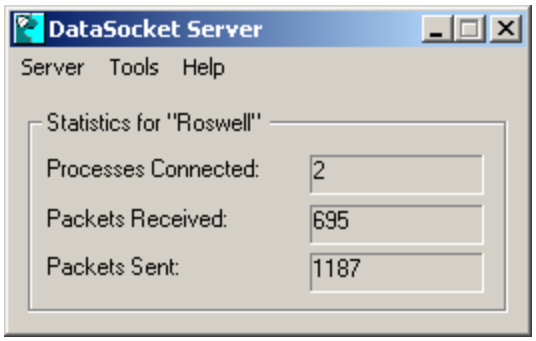


Figure 4-24. The DataSocket Server panel, displayed after the DataSocket Server is launched. Here, both the Server and the Client are connected, so the "Processes Connected" reading is 2.

The Remote Control Module uses three DataSocket items, which are dynamically created when the PCS100 or PCS100DA application, configured as a Server, is connected to the DataSocket Server. Their URLs have the following structure: **dstp://computer/pcsquid/item**. The **dstp://** indicates that the DSTP protocol is used for communication. The **computer** is the computer on which the DataSocket Server is running, *i.e.*, the Server computer. It may be specified by its IP address in dotted decimal notation, by the computer name on the network, or by the word 'localhost'. In Figure 4-23, the IP address is 10.0.0.19. The computer name (ROSWELL in this case) could be used instead. The **pcsquid** identifies the PCS100 or PCS100DA application. The **item** indicates location of a particular DataSocket item, and is set automatically to 'server', 'client', or 'data'.

The first DataSocket item (*e.g.*, dstp://10.0.0.19/pcsquid/server) contains the most recent remote control command, sent by the Server. The second item (*e.g.*, dstp://10.0.0.19/pcsquid/client) holds the latest remote control command issued by the Client. The third DataSocket item (*e.g.* dstp://10.0.0.19/pcsquid/data) contains the last acquired waveform transmitted by the Server.

The URL should be typed into the "URL" control in the CONNECTION section of the Remote Control panel (Figure 4-23). This is the core URL, from which the three actual URLs are derived automatically by adding /server, /client, and /data. Note that the computer IP address within a local network may be different from its IP address used for communication over the Internet. See Section 4.8.7 for more information.

After launching the DataSocket Server and selecting the URL, click on the CONNECT button to connect your PCS100 or PCS100DA application to the DataSocket Server. This command dynamically creates the three DataSocket items and opens a separate connection to each of them. Note that the URL, specified by the "URL" string control, is used only when the CONNECT button is clicked. To change the URL, disconnect the application from the DataSocket Server by clicking on the DISCONNECT button, then type in a new URL and click CONNECT again.

States of connections to the three DataSocket items (…/server, …/client, and …/data) are shown by the WRITE, READ, and DATA indicators, respectively. If a connection is established successfully, the corresponding indicator displays 'Active:Connected'. Remote operation is possible only if all three connections are successful. In this case, the names of the panels of all RC-enabled software modules have the word "- Server" attached (as in Figure 4-23), which

means that the PCS100 or PCS100DA application is ready to function as a Server. The "Processes Connected" indicator on the DataSocket Server panel shows 1 if at least one connection is active. To disconnect the program from the DataSocket Server, click on DISCONNECT. Readings of all three indicators will change to 'Unconnected', and the word "- Server" will disappear from all panel titles.

If an error occurs during the connection procedure, an error description is displayed (in red color) by the corresponding indicator. Any DataSocket error that occurs during remote operation is also reported together with its error code.

4.8.3 Client Configuration

To configure your PCS100 or PCS100DA application to become a Client, open the Remote Control panel, and set the "Server/Client" control in the OPERATION MODE section to 'Client'. The SERVER ON/OFF toggle control is automatically hidden. The Remote Control panel for the Client application is shown in Figure 4-25.

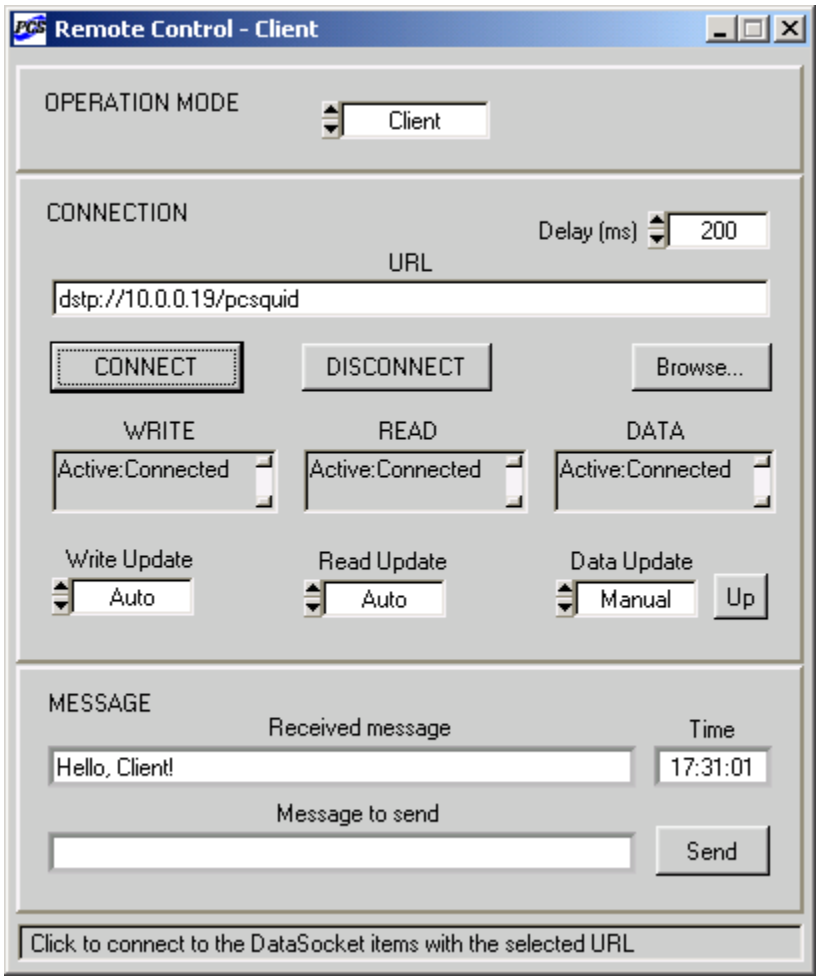


Figure 4-25. The Remote Control panel after it is configured as a Client and successfully connected to the DataSocket Server running on the Server computer.

Type the core URL corresponding to the target DataSocket items of the DataSocket Server into the "URL" string control. The URL includes the IP address or the network name of the Server computer. If there are no firewalls between the Server and the Client, this IP will be the same as the one specified on the Remote Control panel of the Server application (Figure 4-23). See Section 4.8.7 for information on how to select the URL if either computer is protected by a firewall. You may use the "Browse…" button to find a DataSocket Server within the network, and determine URLs of various DataSocket items. Note that the core URL, specified by the "URL" control, should not have /server, /client, or /data extensions.

Click on the CONNECT button and wait for several seconds. Two operations are performed at this point. First, the Client application tries to establish a connection with the DataSocket Server, running on the Server computer. If all three connections are successful, the WRITE, READ, and DATA indicators (which correspond, in case of a Client, to the …/client, …/server, and …/data DataSocket items, respectively) display 'Active:Connected'. Second, the Client application sends all present settings of all its RC-enabled software modules to the Server. This is done automatically to ensure that both the Client and the Server have the same SQUID, PCI, DAQ, and Autotune configurations (the Server's original settings are overwritten). After that, panel names for all RC-enabled software modules get the "- Client" ending, as shown in Figure 4-25, meaning that the program is ready to work as a Client. The "Processes Connected" reading on the DataSocket Server panel becomes 2, because both the Server and the Client are connected to the DataSocket Server.

If any of the three DataSocket connections fails, the corresponding indicator exhibits an error description (in red color). This is illustrated in Figure 4-26, where a PCS100 application, configured to be a Client, was not permitted to write a command to the DataSocket Server. This happened, because the DefaultWriters variable of the DataSocket Server Manager (Figure 4-22) was set to 'localhost' instead of 'everyhost'. The absence of "- Client" in the panel name indicates that remote operation is not possible. Note that each indicator has a scroll bar. A standard error code (in hexadecimal notation) is appended at the end of each error message.

The Server and the Client may exchange short text messages. Type a desired text string into the "Message to Send" control in the MESSAGE section of the Remote Control panel, and click the "Send" button. A received text string is displayed by the "Received Message" indicator. Because messages are sent through the same DataSocket items as used for command transmission (…/server and …/client) , they allow a quick check of these DataSocket connections.

It is always assumed that the same version of the PCS100 or PCS100DA Control Software is used for both the Server and the Client. Moreover, the properties of the software controls, corresponding to various settings in the `[HARDWARE]` section of an initialization file, are also assumed to be the same for both programs. These settings are not exchanged by the remote applications.

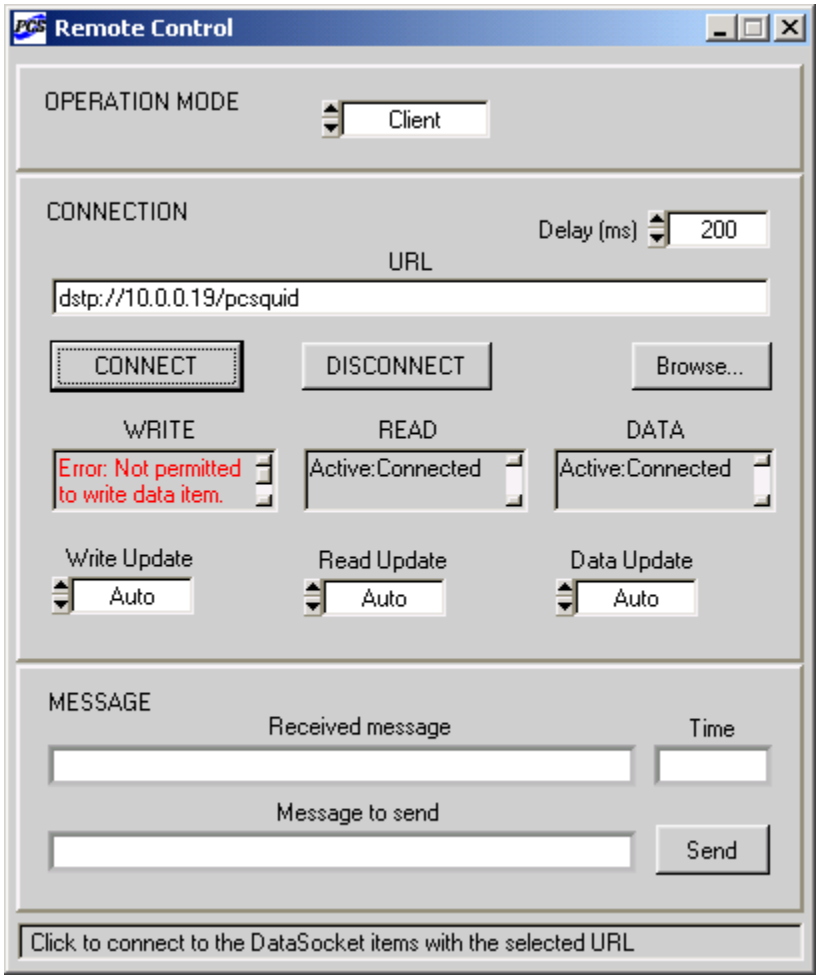


Figure 4-26. Appearance of the Remote Control panel when one of the DataSocket connections fails. Remote operation is not possible in this case.

4.8.4 Update Modes

After both the Server and the Client are successfully connected to the DataSocket Server, they may send remote control commands to each other. Each command is an array of several dozen long (4-byte) integers. This array may contain various configuration parameters, as well as instructions to perform certain actions. The DataSocket items (…/server and …/client), which are used for command transmission, can hold only one command at a time. Note that commands are sent and received without buffering, so if a command is missed, it cannot be recovered.

Parameters of each RC-enabled software module are divided into groups. When one parameter is changed, all parameters, belonging to the same group, are copied to the array and transmitted together as a single command. Below is a list of these parameter groups:

- System parameters from the System Configuration panel (Figure 2-1). They include the number of channels, the number of PCI units, the port name and status, the device number and status. The initialization file settings are not remotely controllable.

- All parameters for a given SQUID channel, displayed in the Control, Tune, and Configuration sections of the Main panel (Figure 4-1). They do not include the Master mode and the heater parameters.
- Heater parameters from the Configuration section of the Main panel (which are the same for all channels), as well as instructions to start or stop a heat cycle.
- All configuration parameters for a given PCI unit from the corresponding PCI panel (Figure 4-4).
- Configuration parameters for the DAQ device from the Data Acquisition (Figure 4-6) and Enable Channels (Figure 4-8) panels. They include settings of controls on the TIMEBASE and TRIGGER sub-panels, settings of the "Input Range" control on the DISPLAY sub-panel, and all configuration settings from the Enable Channels panel.
- Display parameters for the DAQ Module from the DISPLAY sub-panel of the Data Acquisition panel (Figure 4-6). They include settings of all controls on that sub-panel, except for the "Input Range" control.
- Status parameters for the DAQ Module. They include a setting of the DAQ ON/OFF control, a trigger request issued with the SHOT button, an error type and code.
- All configuration parameters for the Autotune/Calibration Module from the Autotune Procedure panel (Figure 4-16).
- Status parameters for the Autotune/Calibration Module. They include the procedure type, instructions to start or stop the procedure, and the noise data to be displayed in the "Noise vs Bias" and "Noise vs Modulation" graphs.
- The text message from the "Message to send" control on the Remote Control panel (Figure 4-23).

All these commands are described here for the following reason. Each connection to a DataSocket item may be configured for either automatic or manual update mode. The update modes are selected with the "Write Update", "Read Update", and "Data Update" toggle controls on the Remote Control panel (Figure 4-23). The first two controls set update modes for writing and reading commands, respectively. The "Data Update" mode applies to sending waveform data by the Server, or to receiving waveform data by the Client. All three settings are independent.

If the "Write Update" toggle control is set to 'Auto', a command is written to a DataSocket item automatically as soon as it is sent by the application. If this control is set to 'Manual', it is necessary to click on the "Up(date)" button (which appears next to the "Write Update" control) to write the most recently sent command to a DataSocket item. Similarly, if the setting of the "Read Update" toggle control is 'Auto', any new command is read automatically from a DataSocket item as soon as it appears there. In the 'Manual' mode, information is read from a DataSocket item only when one clicks on the "Up" button next to the "Read Update". The "Data Update" control works in the same way. In Figure 4-25, the "Data Update" mode for the Client application is 'Manual', so a waveform is received only when the "Up" button is used.

An obvious advantage of the 'Auto' update mode is that it ensures that all commands and waveforms are sent and received fully and promptly. Its main disadvantage is an often

unnecessary increase in network traffic. Imagine, for example, that you need to adjust the tune parameters of one SQUID channel from the Client application. Every time you change the BIAS value, all settings for this channel will be sent to the Server and forwarded to the hardware. The same will occur during the subsequent MOD adjustment, and so on.

An advantage of the 'Manual' update mode is that it reduces traffic, because information can be sent or received only when it's really needed. In the above example, you may adjust all settings for a given SQUID channel, and then click on the "Up" button next to the "Send Update" control once to send all parameters together to the Server. The 'Manual' mode is also useful when several parameters have to be sent or received simultaneously. A disadvantage of this mode is that it requires a lot of attention from the user, because only the most recent command or waveform is transmitted. For example, if you adjust the parameters of several SQUID channels using the Client program, and then click the "Up" button, only the parameters of the most recently adjusted channel will be sent to the Server.

Every time the PCS100 or PCS100DA Control Software is started, the "Write Update", "Read Update", and "Data Update" toggle controls are set to 'Auto'. It is recommended to first establish the DataSocket connections using 'Auto' settings for the "Write Update" and "Read Update" controls, because the Client in this case can perform initialization by sending all parameters to the Server, and receive the Server's response. Then one can change either mode (or both) to 'Manual', and re-connect the application. As explained below in Section 4.8.5, certain Client commands are followed by Server responses. Thus, if the "Read Update" mode for the Client is 'Manual', the corresponding "Up(date)" button has to be clicked after sending each of these commands to the Server to receive a response. Because the Server usually runs on its own without the constant presence of a user, all three update modes for the Server should normally be set to 'Auto'.

It is important to keep in mind that transmission of a command over the Internet or within a local area network requires some time, partially due to latency of the operating system, which performs many other tasks besides running the application. Additional time is needed for the pcSQUID™ hardware to receive and execute the software commands. This time is longer during remote operation, because a remote control command usually entails re-adjustment of many hardware parameters, such as all parameters of a given SQUID channel. If commands are issued faster than they can be processed, some data may be lost, or an error may occur in the DataSocket operation. To prevent this from happening, a delay is added between two consecutive commands, if the "Write Update" mode is 'Auto'. The delay time in milliseconds is specified by the "Delay" control on the Remote Control panel. This parameter is remotely selectable, and has the same value for both the Server and the Client. The delay time has to be determined experimentally to ensure reliable remote operation. Typically, it should be at least 200 ms.

Because of the time delay, numeric controls cannot be scrolled fast in the 'Auto' update mode. The best way to operate these controls is to type a desired number into the control field, and press Enter. If the "Write Update" setting is 'Manual', all controls may be scrolled freely, because no commands are sent until the corresponding "Up(date)" button is clicked. Acquired waveforms are transmitted by the Server without any delay in both 'Auto' and 'Manual' modes.

4.8.5 Remote Operation

Remote operation of the PCS100 or PCS100DA Control Software over the Internet is very similar to the operation of a stand-alone, unconnected application. One should keep in mind, however, that the transmission of any command takes time, so remote operation is inevitably somewhat slower. This Section provides more details about remote control using the various software modules.

System Configuration

If the PCS100 or PCS100DA program is configured as a Client, it does not send any commands to the hardware, and essentially serves as a remote user interface for the Server program. Moreover, it disconnects from the computer port and the DAQ device to which it had been connected before becoming the Client, so that these resources may be used by other applications. This is why the DAQ panel disappears when you click the CONNECT button of the Client program. All control settings in the PORT OPERATION and DATA ACQUISITION sections of the System Configuration panel refer to the Server port and DAQ. This works in the following way. If the "Port" selection is changed on the System Configuration panel of the Client application, the new setting is sent to the Server program, which tries to connect to the selected port. The port status and transmission parameters are then sent back to the Client, and displayed by the "Status" and "Transmission" indicators on the Client's System Configuration panel. The same steps are performed if the "Device Number" setting is changed: the new number is tried by the Server, and the resulting status parameters are transmitted to the Client. This way, the System Configuration panels of both the Server and the Client are updated simultaneously and exhibit the same settings. When the Client program is disconnected from the DataSocket Server, it automatically re-connects to the original port and DAQ device.

The "File" and other controls in the INITIALIZATION FILE section cannot be operated remotely. If you wish to restart the Client program with a different initialization file, first disconnect it from the DataSocket Server by clicking on the DISCONNECT button. After the program is restarted, use the CONNECT button to re-establish the remote connection. The new Client settings from the selected initialization file will be automatically transmitted to the Server.

SQUID Control Module

The parameters of any SQUID channel are transmitted together as a single command. The selected channel is always the same for the Server and the Client. The Master mode may be enabled independently for either program. In this mode, if a SQUID parameter is changed for the selected channel, the new parameter value is copied to all the other channels. Because all settings for a channel are transmitted together, each operation in the Master mode results in a transmission of parameters for all SQUID channels. This applies to both the Server and the Client. All parameters of a given PCI unit are transmitted together as well.

The Master mode may be used to estimate the optimum value of the delay time, set by the "Delay" control on the Remote Control panel. To do this, set the number of SQUID channels to at least 8. Turn the Master mode On for either the Server or the Client. Click on the LOCK button. All State indicators in the Control section of the Main panel will turn green. Check the State indicators of the remote application. If all of them are green, the delay is sufficiently long. If, however, some indicators remain yellow, it means that not all commands went through, and the delay time should be increased.

Heater operation looks the same for both the Server and the Client. A heat cycle is initiated by clicking on the HEAT button of either program. However, the heat cycle is performed independently by the Server and the Client: the Client program follows the same heating algorithm without constant exchange of information with the Server. This is because transmission of the fast sequence of heater commands between two remote applications would disrupt precise timing of the heating procedure. The current segment of the heat cycle may be terminated by clicking on any State indicator. Several heaters may be remotely operated in the Master mode, the same way as for a stand-alone application.

Data Acquisition Module

During remote operation, the DAQ Module of the Server application acquires waveform data, displays waveform traces, and transmits data to the Client program. Each data set is transmitted as an array of short (2-byte) integers, and the array size may be quite large. The transfer of waveform data is performed through a separate DataSocket item, so that it does not interfere with command exchange between the Server and the Client. The Client application receives waveform data from the Server and displays them in the graph without actually running any data acquisition process.

If any of the DAQ configuration parameters is changed by the Client program, all configuration settings are sent to the Server, which tries to implement them. If it succeeds, the new configuration (which may be somewhat different from the received one due to parameter coercion) is returned to the Client, and displayed by the Client's user interface. This way, all control settings of the Server and the Client are synchronized, and always refer to the same DAQ configuration. If the configuration attempt fails, an error is reported using the DAQ Error Report panel of both the Server and the Client. The DAQ Modules of both applications are then disconnected, and both Data Acquisition panels are hidden. To re-connect the DAQ, select the DAQ>Connect DAQ menu item on the Main panel of either the Server or the Client. Note that the DAQ Error Report panel is not a popup, and its appearance does not halt the execution.

Both the Server and the Client should allocate the same amount of memory to store acquired data. If the "Buffer Size" setting is changed by the Client, the new buffer size, together with the other configuration parameters, is transmitted to the Server. The Server tries to allocate the buffer, and reduces its size if there is not enough memory. Then it returns the new buffer size to the Client, which, in turn, tries to allocate a buffer of this size. If the requested memory cannot be allocated, an error is reported, and the buffer size is reduced by the Client. The described cycle is repeated. As a result, the Server and the Client have acquisition buffers of the same size. The minimum buffer size is 10 Kbytes, which corresponds to 5000 data points.

The procedure of saving data to a file is not remotely controllable, because it is not related to any hardware functions. As soon as a valid data set is acquired by the Server and transmitted to the Client, it may be saved independently on both computers. Saving data on the Client computer is easier, because the Client's buffer stores the latest data set while a new data set is being acquired by the Server. If the acquisition time is sufficiently long, the Client data may be saved during an ongoing acquisition in the 'Continuous' trigger mode, as long as the "Data" indicator is green.

The cursor position and readings of the cursor indicators are independent for the Server and the Client. Also, the color of the "Trigger" indicator is not updated by the Client program. The "Information" string cannot be shared by remote applications.

Spectrum Analysis Module

The Spectrum Analysis Module is not RC-enabled, because it does not control any hardware operations. Its main function is to analyze data, provided by the Data Acquisition Module. Thus, as long as the DAQ Module of the Client program receives waveform data from the DAQ Module of the Server, spectrum analysis may be performed independently by the Server and the Client. However, because the channel for spectrum analysis is specified by the "Channel" control on the DISPLAY sub-panel of the Data Acquisition panel, and this control setting is remotely selectable, both the Server and the Client will analyze spectra for the same data acquisition channel.

Autotune/Calibration Module

Remote operation of the Autotune/Calibration Module is virtually indistinguishable from its operation in case of a stand-alone application. The Client program sends a command to launch an optimization procedure, and the procedure itself is executed by the Autotune/Calibration Module of the Server application. All configuration settings from the Autotune Procedure panel are transmitted together as a single command. During the execution, the Server sends to the Client waveform data for the "Measured Signal vs Time" graph, and all optimization results, including data to be plotted in the "Noise vs Bias" and "Noise vs Modulation" graphs. It also transmits all execution and error messages, which are displayed by the text indicator below the "Measured Signal vs Time" graph. After the noise minimization procedure is over, the cursors of the "Noise vs Bias" and "Noise vs Modulation" graphs are independently controllable by the Server and the Client. An ongoing procedure may be stopped by using the "Stop Execution" button.

In order to minimize the network traffic during any optimization procedure, it is recommended to set the "Show Traces" ring control to either 'Some' or 'None'. This greatly reduces the number of waveform traces transmitted by the Server and displayed in the "Measured Signal vs Time" graph. If the setting is 'None', no waveform data are sent. If this control is set to 'Some', only several of the most important traces are transmitted and displayed, giving a general idea as to the procedure performance.

4.8.6 Control Descriptions

Server/Client: Selects the remote operation mode. Each PCS100 or PCS100DA application may be configured either as a Server or a Client.

SERVER ON/OFF: Launches or shuts down the DataSocket Server (Figure 4-24), if the operation mode is 'Server'.

URL: The core URL associated with the DataSocket items used for remote communication. The three actual URLs, corresponding to three different DataSocket items, are automatically derived by adding /server, /client, and /data to the core URL. The URL is used only when the CONNECT button is clicked.

Browse: Opens the "Select URL" dialog box, which allows the user to locate a DataSocket Server and determine a URL for a specific DataSocket item. After the OK button is clicked, this URL appears in the "URL" string control. While the three actual URLs used by the PCS100 or PCS100DA Control Software have the /server, /client, and /data extensions, the core URL in the "URL" control does not.

CONNECT: This button connects the PCS100 or PCS100DA application to the DataSocket Server, and configures connections to the DataSocket items specified by the URL. The connection is terminated automatically if settings of any of the "Server/Client", SERVER ON/OFF, "Write Update", "Read Update", and "Data Update" controls are changed.

DISCONNECT: Disconnects the PCS100 or PCS100DA program from the DataSocket Server. This button is used to terminate all three DataSocket connections, even if some of them are not active.

Delay (ms): Time delay introduced between two consecutive commands if the "Write Update" toggle control is set to 'Auto'. The delay is not used if the "Write Update" mode is 'Manual'. See Section 4.8.4 for explanation.

WRITE: Indicator which shows the status of the DataSocket connection for writing commands.

READ: Indicator which shows the status of the DataSocket connection for reading commands.

DATA: Indicator which shows the status of the DataSocket connection for waveform data.

Write Update: Sets the update mode for writing commands. If this control is set to 'Manual', the "Up(date)" button appears next to it. This button should be used to send any new command to the remote application. See Section 4.8.4 for details.

Read Update: Selects the update mode for reading commands. If its setting is 'Manual', use the "Up(date)" button on the right of the "Read Update" control to receive the most recent command from the remote application. See Section 4.8.4 for more information.

Data Update: Sets the update mode for data exchange. If this update mode is 'Manual', the "Up(date)" button has to be used to send the most recent waveform data (if the present application is the Server), or to receive the latest waveform (if this application is the Client). Refer to Section 4.8.4 for further details.

Received Message: This indicator exhibits the text message received from a remote program.

Time: Time when the displayed text message was received.

Message to Send: Type in a text string you wish to send to a remote application.

Send: Click to send the text string from the "Message to Send" control to a remote program.

4.8.7 Firewall Configuration

Two PCS100 applications (or two PCS100DA applications) may establish direct DataSocket connection if they run on the same computer, or on two computers belonging to the same network. However, if the computers are separated by a firewall, you need to configure the firewall to allow DataSocket communication. Ask your System Administrator for help, if necessary.

The DataSocket Server always uses port 3015. A Client connects from an ephemeral high port (1024 up to 65536) to the Server port following the client/server networking model. If either application is behind a firewall, an exact firewall configuration depends on your specific firewall. Below are some general ideas.

If the Client is behind a firewall, generally there is no problem, because many firewalls have permissive outgoing rules that allow all client connections to outside servers. A server's

response to a client is treated as “established”, and their communication is permitted. Some firewalls do restrict high ports. In this case, configure your firewall to allow outside source port 3015 TCP/UDP to inside high port.

If the Server is behind a firewall, one method is to map outside destination port 3015 TCP/UDP to the Server’s internal IP. This is the best solution when your firewall has only one public IP. If only specific outside IPs need to access the DataSocket Server, add IP statements to the port 3015 TCP/UDP allow rules for better security. If you have multiple public IPs, one-to-one NAT is a possibility. Your firewall rule would need to map one public IP to one private IP (the Server), and map all ports one to one. Then add an allow rule for outside destination port 3015 TCP/UDP to the Server’s internal IP. Allow other ports as needed.

Otherwise, ask your System Administrator to allow outside source port 3015 TCP/UDP, if your application is the Client, or outside destination port 3015 TCP/UDP if it is the Server.

5 Model PFL-100 Programmable Feedback Loop

The Model PFL-100 Programmable Feedback Loop (PFL) is designed using 13-bit digital-to-analog converters (DACs) to enable wide yet precise full-scale ranges for the bias, modulation and offset signal drives. Four different modulation techniques and three different feedback ranges are supported. The three feedback ranges, nominally ±2, ±20, and ±200 Φ_0 full scale, provide optimal matching to standard, 16-bit analog-to-digital converter hardware. In addition, the PFL-100 can be configured to support SQUIDs having weak or tight feedback coupling, nominally 5 $\mu A/\Phi_0$ and 50 $\mu A/\Phi_0$, defined as corresponding to Type I and Type II SQUIDs, respectively. In this way, the PFL-100 is capable of controlling and operating wide variety of SQUID sensors with optimal performance.

A digital interface based on a programmable gate array is included in the PFL-100. The digital interface in the PFL-100 is driven using STAR Cryoelectronics Serial Control Code (SCC). A transmitter for the SCC is located in a separate personal computer interface (PCI) unit, which also provides DC power to operate the loop. Communication with the PCI unit is accomplished using either the parallel port or standard RS-232C port on an IBM-compatible personal computer. The 32-bit SCC contains an 8-bit address so that multiple PFLs may be uniquely addressed.

All SQUID signal levels and control functions may be set remotely using STAR Cryoelectronics' SQUID Control Module software running under Microsoft Windows™. The analog output signal (or signals in the case of a multichannel system) may be digitized using an optional Data Acquisition (DAQ) system.

5.1 Preamplifier and Transformer Coupling

The first stage of the PFL-100 preamplifier consists of a matching transformer and transconductance preamplifier circuit based on a low-noise field-effect transistor. The voltage noise referred to the input of the transconductance preamplifier circuit is about 1 $nV/Hz^{1/2}$.

The matching transformer may be configured for single- or dual-transformer coupling configurations, as illustrated in Figure 5-1. In the single transformer configuration, a transformer with a turns ratio of 25:1 located within the PFL-100 is used, and the voltage leads of the SQUID are connected directly to this transformer. In the dual transformer configuration, a "cold" transformer mounted in the sensor package with a turns ratio of 5:1 is used in addition to a 5:1 transformer in the PFL-100. In either configuration, the effective transformer turns ratio is 25, so the voltage noise referred to the input of the matching transformer is better than 40 $pV/Hz^{1/2}$. For a SQUID with 100 $\mu V/\Phi_0$ transfer function, this corresponds to 0.4 $\mu\Phi_0/Hz^{1/2}$ flux noise.

The PFL-100 is normally factory configured for single-transformer input coupling unless specified otherwise by the customer. To convert the PFL to dual-transformer operation, remove the unlabeled cover from the PFL-100. Locate the miniature double-pole switch labeled "Transformer Configuration" in Figure 5-2, and switch pole 1 to OFF and switch pole 2 to ON. To configure the unit for single-transformer operation, reverse these switch settings. Replace the cover of the PFL-100.

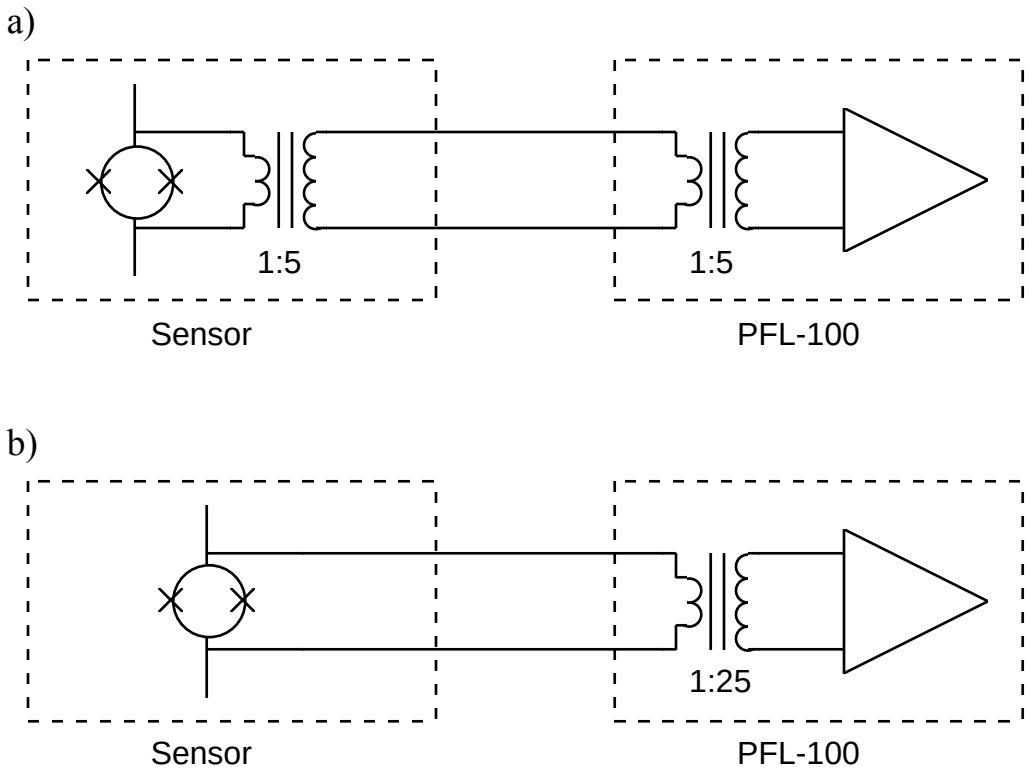


Figure 5-1. Transformer coupling options for the PFL-100. a) Dual transformer coupling. b) Single transformer coupling. Note: In the single-transformer configuration, a blocking capacitor (not shown in the figure above) is used to prevent the shunting of the SQUID bias current by the warm transformer primary.

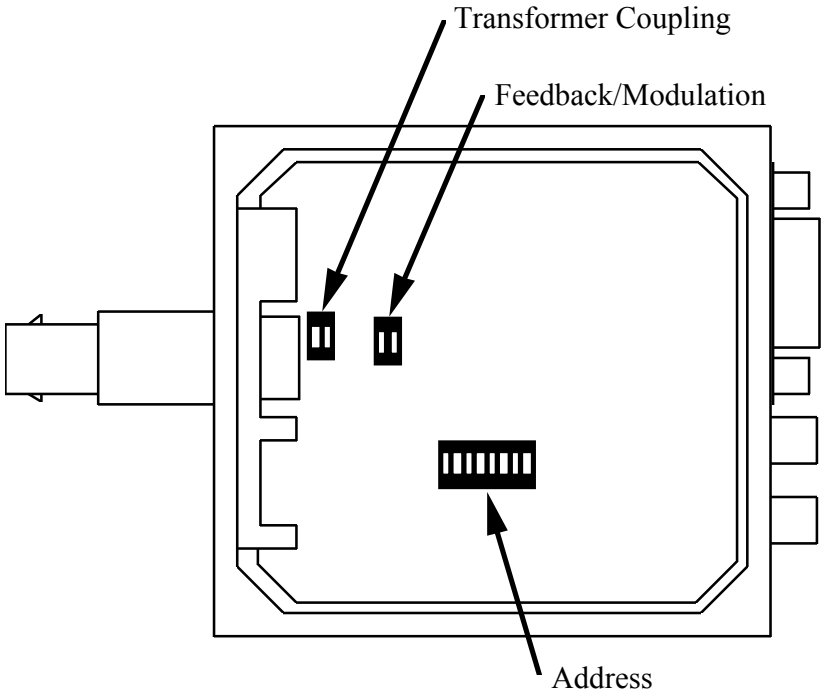


Figure 5-2. Locations of the transformer configuration switch, feedback/modulation connection switch, and the address switch within the PFL-100. Note that in the case of the address switch only, the ON setting actually corresponds to a binary 0 (see text in Section 5.12).

5.2 Multiplier

The preamplifier output feeds one differential input of a multiplier, and a 256 kHz reference square wave signal is applied to the other differential input. The multiplier is configured to accommodate a maximum ±12.5V input signal.

A trimpot inside the PFL-100 is used to eliminate any dc offset on the multiplier output. This is the only manually adjustable trim component inside the PFL. The trimpot is adjusted at the factory and normally does not require re-adjustment. However, if you find you need to adjust this component, you should use the following procedure. Connect the SQUID output to an oscilloscope, and make sure the oscilloscope is dc coupled and there are no offsets relative to ground. In the TUNE mode, adjust the SQUID tuning parameters to find the maximum output signal. Remove the labeled cover from the PFL-100 unit and locate the trimpot on the circuit board near the 9-pin D connector (it is on the side of the circuit board opposite that illustrated in Figure 5-2). Using a screwdriver, adjust the trimpot until the output signal is centered about zero volts (ground). Replace the cover of the PFL unit.

The multiplier has an intrinsic voltage noise referred to its input of 0.8 $\mu V/Hz^{1/2}$ at 1 kHz and 2 $\mu V/Hz^{1/2}$ at 1 Hz. The $1/f$ knee is at 10 Hz. The multiplier noise contribution is about 0.75 $\mu\Phi_0/Hz^{1/2}$ at 1 Hz for a SQUID with 100 $\mu V/\Phi_0$ transfer function.

5.3 Integrator

The multiplier output is followed by an integrator circuit. For small signals, the -3dB cut-off frequency f_{-3dB} is given by the following expression:

$$f_{-3\mathrm{dB}} = \left(\frac{\partial V}{\partial \Phi}\right)_{\mathrm{m}} \cdot \frac{M_m}{2\pi\tau R_{\mathrm{fb}}}$$

where $(\partial V/\partial\Phi)_{\mathrm{m}}$ is the sensor flux-to-voltage transfer function referred to the multiplier output, $\tau = RC$ is the integrator time constant, R_{fb} is the feedback resistor selected, and M_m mutual inductance of the modulation coil. To maintain constant bandwidth, the integrator time constant $\tau = RC$ is switched for the three PFL-100 sensitivity ranges. The time constants for the 'High', 'Medium' and 'Low' ranges are 1τ, 10τ and 100τ, respectively, where $\tau = 10$ µs. The integrator time constant for a given range has the same value regardless of the SQUID type (see Table 5-1 below). In the 'Custom' mode (see Section 4.2.10), the user may also remotely select the time constant.

In the TUNE mode, the integrator becomes a unity gain inverting amplifier so the *V*-Φ characteristic of the sensor may be observed at the PFL analog output to set the optimal working point of the SQUID.

Table 5-1. Feedback resistance and integrator time constant as a function of the SQUID TYPE and SENSITIVITY settings.

PFL Sensitivity Range	Type I SQUIDs, 5 µA/Φ_0 R_{fb}	Type II SQUIDs, 50 µA/Φ_0 R_{fb}	Int. Time Const. ($\tau = 10^{-5}$ sec)
High	1 MΩ	100 kΩ	τ
Medium	100 kΩ	10 kΩ	10τ
Low	10 kΩ	1 kΩ	100τ

5.4 Reset

The feedback loop may be reset by shunting the integrator capacitance. This action is initiated remotely via the SCC interface. Alternatively, a TTL signal may be injected into the external reset port on the rear panel of the PC interface. See Section 6 and Section 7 for detailed information on using the TTL reset feature. Briefly, when the TTL external reset signal goes HI, the feedback loop is opened; when the TTL signal goes LO, the loop is closed. The minimum time required to execute a software reset via the SQUID Control Module is about 50 µs. If faster reset times are required, the external reset option should be used. Using a TTL signal and the external reset option, reset times of less than 5 µs can be achieved.

5.5 Feedback Circuit

The feedback circuit is designed to support SQUIDs covering a wide range of feedback coupling strengths. STAR Cryoelectronics offers SQUID sensors that are classified according to their feedback coupling parameter. Type I and Type II sensors have nominal 5 μA/Φ_0 and 50 μA/Φ_0 feedback coupling, respectively. For each SQUID type, the PFL-100 feedback circuit provides three different SENSITIVITY ranges in order to enable optimal matching to standard, high-performance 16-bit analog to digital converter hardware. For sensors with feedback coupling values which match the nominal Type I or Type II values exactly, the 'High', 'Medium', and 'Low' SENSITIVITY settings will result in PFL gains of 5 V/Φ_0, 500 mV/Φ_0 and 50 mV/Φ_0, and full-scale ranges of ±2, ±20, and ±200 Φ_0, respectively. Typically, however, these values are sensor-specific and must be determined, or calibrated, by the user. The SENSITIVITY and SQUID TYPE settings are selected remotely via the SCC interface using the PCS100 or PCS100DA Control Software.

The three SENSITIVITY ranges for the two SQUID types are implemented via software according to the following scheme: For Type I SQUIDs, the feedback resistors for the PFL-100 sensitivity ranges 'High', 'Medium', and 'Low' are equal to 1 MΩ, 100 kΩ and 10 kΩ, respectively, while for Type II SQUIDs, the feedback resistors are equal to 100 kΩ, 10 kΩ and 1 kΩ, respectively (see also Table 5-1). The 'Custom' setting is also available, and enables a user to independently select the feedback resistor from any of these four values. Further discussion of this topic may be found in Section 4.2.10, while the PFL-100 characteristics for arbitrary SQUIDs are discussed in detail Section 5.14.

The feedback current is supplied differentially to the sensor. The feedback current driver noise is less than 50 nV/Hz^{½} at 1 Hz. Thus, for operation in the 50 mV/Φ_0 range (worst case situation), the total noise contribution from the feedback circuit will not exceed 1 μΦ_0/Hz^{½} for a SQUID with 100 μV/Φ_0 transfer function.

5.6 Bias, Modulation, Skew and DC Offset Drivers

The differential bias, modulation, skew and dc offset signals are derived from a 13-bit digital-to-analog converter (DAC) controlled by a field programmable gate array (FPGA). All signal levels are set remotely via the SCC interface. Owing to the high resolution of the DAC used, all signal ranges have ample headroom so that a wide range of SQUID parameters can be accommodated.

For all drivers, the DAC is simply used as a digitally controlled voltage divider with the resolution determined by the 13-bit digital code stored in the internal DAC register. The output noise of the DAC is < 6 μV/Hz^{½} at 1 Hz for all drivers.

5.6.1 Bias Current Driver

Both DC bias and AC bias modes are possible. AC bias is commonly used to drive HTS SQUIDs in order to reduce 1/*f* noise caused by critical current fluctuations.

In the AC bias mode, a square wave reference signal is used with frequencies of 128 kHz, 64 kHz, or 2 kHz, remotely configurable. The DC bias range is 0 - 200 μA, and the AC bias amplitude range is 0 - 100 μA. A remotely adjustable compensation signal enables the user to

eliminate the voltage spikes across the input transformer caused by the alternating current in the AC bias mode.

5.6.2 Modulation Driver

The modulation frequency is 256 kHz for DC bias as well as for 2 and 64 kHz AC bias reversal frequencies. For 128 kHz AC bias, the modulation frequency is 128 kHz. Two ranges for modulation output current are used: 0 - 5 μA_{p-p} for Type I SQUIDs and 0 - 50 μA_{p-p} for Type II SQUIDs. The modulation range is selected automatically when the user selects the SQUID feedback coil range via the SCC interface.

5.6.3 Skew Driver

The skew signal is applied to the modulation coil in the AC bias mode in order to compensate the undesirable portion of the flux added by switching bias current. The skew range is 0 - 5 μA_{p-p} for Type I SQUIDs and 0 - 50 μA_{p-p} for Type II SQUIDs. The skew range is selected automatically when the user selects the SQUID feedback coil range via the SCC interface.

5.6.4 DC Offset Driver

The differential current drive used for the dc flux offset allows improved ground noise suppression. This is critical for tightly coupled SQUIDs (Type I, nominally 5 $\mu A/\Phi_0$). The DC offset driver operates on two ranges in order to accommodate a nominal dc flux offset range of about $\pm 1\ \Phi_0$ for both types of SQUID feedback coupling configurations. The actual output ranges are nominally ±5 μA (for Type I SQUIDs) and ±50 μA (for Type II SQUIDs). The offset range is selected automatically when the user selects the SQUID feedback coil range via the SCC interface.

Since the output noise of the DAC is < 6 $\mu V/Hz^{1/2}$ at 1 Hz, the corresponding flux noise contribution is < 1 $\mu\Phi_0/Hz^{1/2}$ at 1 Hz.

5.7 Phase Shift Circuit

This circuit delays the multiplier reference signal in order to compensate the SQUID output signal delay. The delay time is remotely controlled via the SCC interface. The phase can be adjusted in the range of ±90° with 8-bit resolution (better than 1°).

5.8 External Signal Input

The external signal input allows the user to inject an external signal into the SQUID feedback coil. For example, a test waveform may be injected to tune the SQUID with the PFL-100 in the TUNE mode, or the external signal input may be used in conjunction with electronic noise suppression techniques such as the formation of electronic gradiometers.

The external signal is coupled differentially to the SQUID feedback coil through three pairs of matched resistors, 1 kΩ, 10 kΩ, and 100 kΩ, in order to accommodate three different input sensitivity ranges of 1000 $\mu A/V_{in}$, 100 $\mu A/V_{in}$, and 10 $\mu A/V_{in}$, respectively. The input sensitivity range is selected remotely via the SCC interface.

5.9 Operation using External Feedback

The PFL-100 is normally configured at the factory with the feedback and modulation signals summed inside the PFL. For some applications, it may be necessary to separate the feedback and modulation signals. To do this, you must remove the unlabeled cover to access the 2-pole DIP switch labeled "Feedback/Modulation" in Figure 5-2. Set both poles of the Feedback/Modulation switch to OFF. Replace the cover. In this configuration, the feedback signal is available at pins 5 and 6 on the 10-pin LEMO plug on the PFL-100.

5.10 Buffered Analog Output

The analog PFL-100 output signal is buffered using a low-noise, low-drift operational amplifier with an output signal range of ±11 V.

5.11 Heater

The heater circuit consists of a 100 mA current generator. This circuit provides a constant 100 mA current for heater resistors up to 100 Ω (if the PFL is powered with ±12 VDC; for special applications the PFL may be powered up to ±18 VDC in which case more power may be delivered to the sensor heater). When the heater is enabled via the SCC interface, the heater LED on the PFL-100 is activated and a 100 mA current is applied to the heater resistor in the SQUID sensor package. The duration of the heater current is limited to 1/2 second, unless the heater is reactivated via the SCC interface. This action is performed automatically by the SQUID Control Module software. This feature is a safety precaution that eliminates the potential for damage to the sensor in case of a computer malfunction. When the heater is disabled, the heater LED is de-activated and the heater circuit is shorted to ground.

5.12 PFL Hardware Address and Digital Interface

The 8-bit hardware address of each PFL-100 is configured by manually setting an 8-pole DIP switch inside the PFL to the binary representation of the address. The unlabeled cover of the PFL-100 must be removed to access the switch to change the address. The location of the address switch is illustrated in Figure 5-2. ***NOTE: The switch positions labeled "ON" on the DIP switch represent binary 0, NOT binary 1.*** The position labeled "1" represents the least significant bit (decimal 1), the position labeled "2" represents the second least significant bit (decimal 2), and so on. Thus, for example, the Channel 1 PFL-100 address switch should be configured with the first pole OFF (binary 1) and all others set to ON (binary 0), setting the address to 1.

The SCC receiver circuitry inside the PFL-100 is implemented using a field programmable gate array (FPGA). Other ICs are used for work with mixed analog and digital signals that cannot be implemented with the FPGA.

5.13 Master/Slave Operation

For multichannel applications, it is often desirable to synchronize the clock frequency of all PFLs in order to eliminate beating effects. For this reason, each PFL-100 has a buffered clock signal output, which is twice the modulation frequency, and a clock signal input. One PFL may then be designated as master with any number of slave PFLs connected in a daisy-chain fashion.

Each PFL with a clock signal connected to the clock input automatically reverts to the slave mode and its internal clock generator is disabled.

5.14 PFL-100 Characteristics for Arbitrary SQUIDs

5.14.1 Loop Gain and Full Scale Range

The programmable feedback loop design is optimized to accommodate SQUID designs having two different feedback coupling ranges: Type I SQUIDs with 5 μA/Φ_0 and Type II SQUIDs with 50 μA/Φ_0. The PFL sensitivity or gain depends on the feedback resistor selected and the modulation coupling of the SQUID. The PFL gain and full-scale range for an arbitrary SQUID may be calculated as follows.

For Type I SQUIDs, the feedback resistors for the sensitivity ranges 5 V/Φ_0 ('High'), 500 mV/Φ_0 ('Medium') and 50 mV/Φ_0 ('Low') are equal to 1 MΩ, 100 kΩ and 10 kΩ, respectively, while for Type II SQUIDs, the feedback resistors are equal to 100 kΩ, 10 kΩ and 1 kΩ, respectively. For each range and SQUID type, the maximum feedback current is given by the maximum voltage output of the integrator, $V_{\text{out,m}}$ = 10 Volts, divided by the feedback resistor R_{fb}. Then, the full-scale range *FS* is given by

$$FS = \frac{V_{\text{out,m}} \cdot M_m}{R_{\text{fb}}}$$

where M_m is the mutual inductance of the feedback coil, and the PFL gain *G* is given by

$$G = \frac{V_{\text{out,m}}}{FS}$$

These relations are shown graphically below for each SQUID type and feedback resistor choice.

5.14.2 Bandwidth

The system bandwidth depends on the feedback resistor selected, the feedback coupling of the SQUID, and the flux-to-voltage transfer function $\partial V/\partial\Phi$ of the bare (unamplified) SQUID. The -3dB cut-off frequency is given by

$$f_{-3\text{db}} = \frac{(\partial V/\partial\Phi)(G_A V_{\text{ref}}/14) M_m f_{\text{int}}}{R_{\text{fb}}}$$

where G_A = 160,000 is the total amplifier gain of the PFL, V_{ref} = 5 V is the multiplier reference signal amplitude, and $f_{\text{int}} = 1/2\pi RC = 1/2\pi\tau$ is the integrator frequency. Here, τ = 10 μs. The factor of 14 shown above is the voltage scale factor of the multiplier.

The bandwidth is shown graphically below as a function of the sensor feedback coupling for each SQUID type and several values of the transfer function $\partial V/\partial\Phi$. Since the integrator time constant is switched along with the feedback resistor pair, the bandwidth is independent of the PFL-100 sensitivity range.

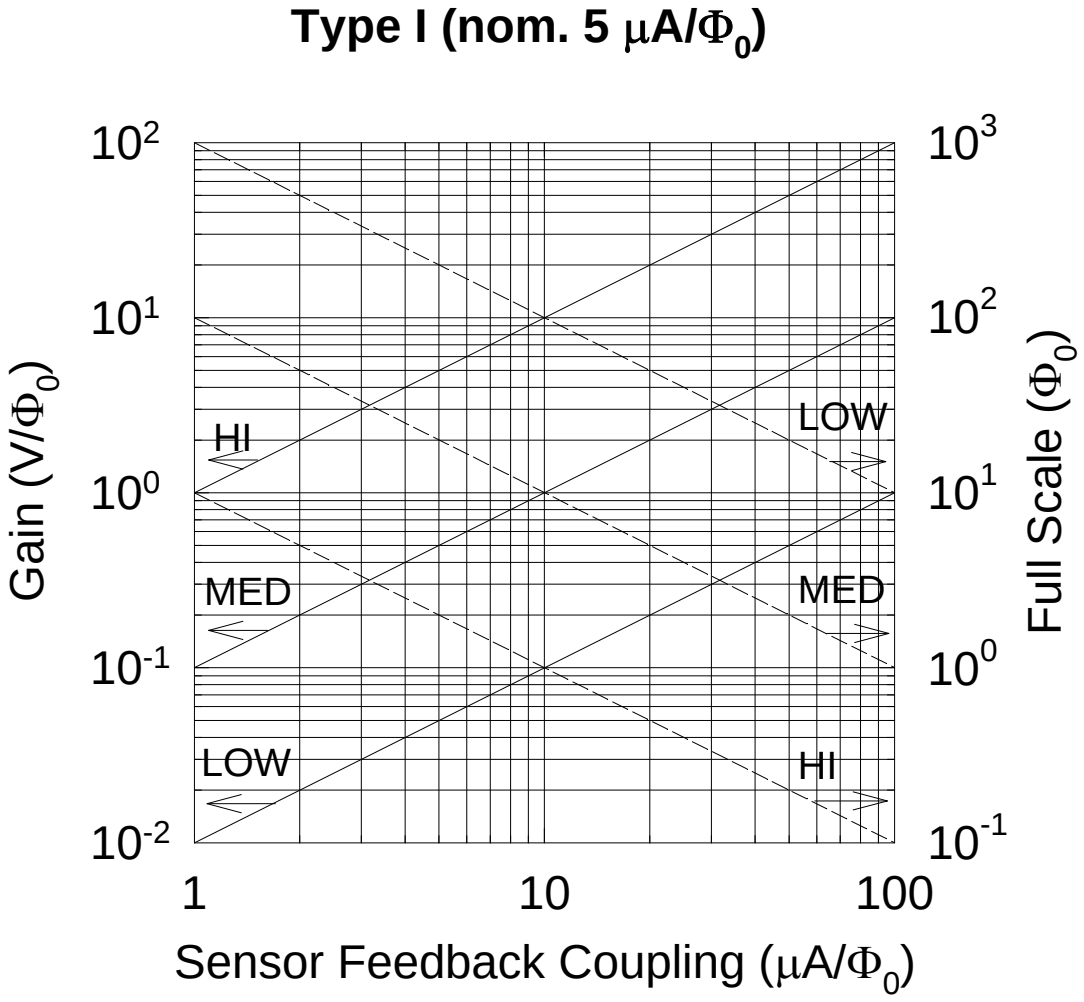


Figure 5-3. Feedback loop gain and full scale range as a function of sensor feedback coupling with the PFL-100 programmed for Type I SQUIDs which have a nominal 5 $\mu A/\Phi_0$ coupling. In this case, the feedback resistors for the sensitivity ranges 'High', 'Medium' and 'Low' are equal to 1 MΩ, 100 kΩ and 10 kΩ, respectively.

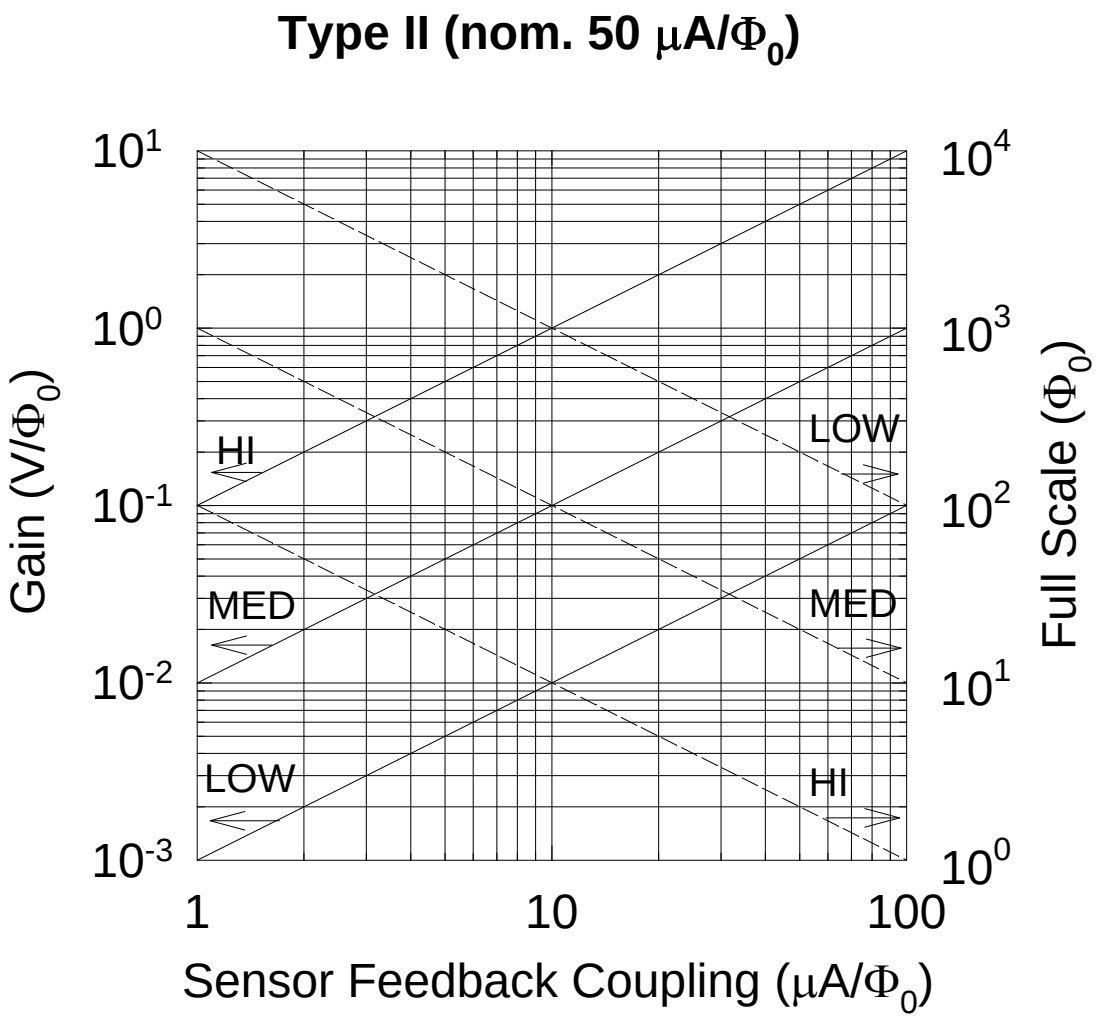


Figure 5-4. Feedback loop gain and full scale range as a function of sensor feedback coupling with the PFL-100 programmed for Type II SQUIDs which have a nominal 50 μA/Φ0 coupling. In this case, the feedback resistors for the sensitivity ranges 'High', 'Medium' and 'Low' are equal to 100 kΩ, 10 kΩ and 1 kΩ, respectively.

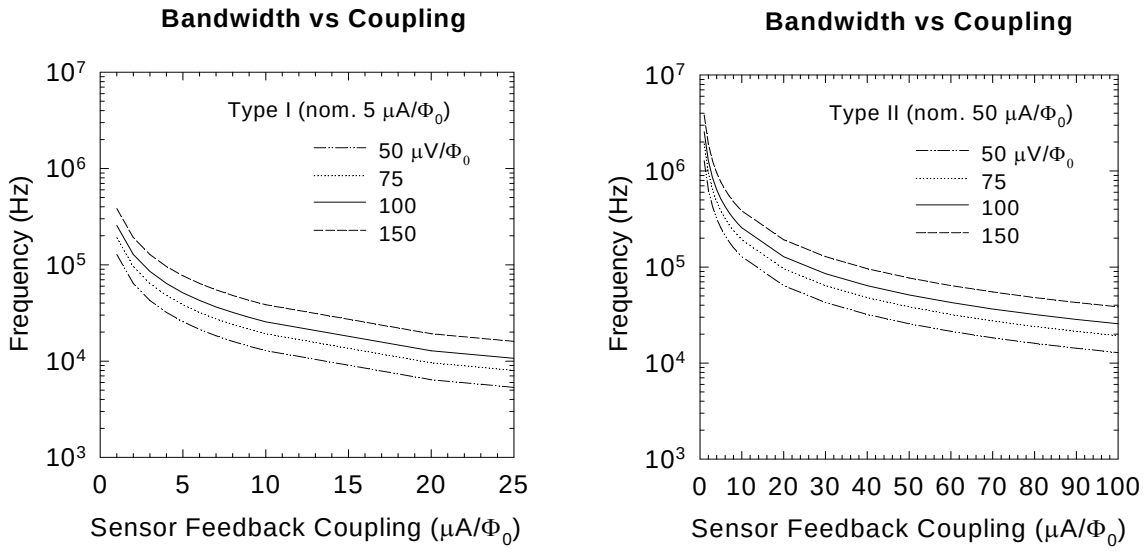


Figure 5-5. The -3dB cut-off frequency as a function of sensor feedback coupling for SQUID Types I and II and several values of the transfer function $\partial V/\partial\Phi$.

5.15 PFL-100 Connector Pinouts

5.15.1 Sensor Connections

The colors in the table below refer to the 10-pin LEMO connector wiring inside the PFL-100.

Sensor Input	10-pin LEMO plug (See Figure 5-6) Pin 1 Heater (+), green Pin 2 Voltage (+), white Pin 3 Voltage (-), white/black Pin 4 Heater (-), green/black Pin 5 Feedback (-), brown/black Pin 6 Feedback (+), brown Pin 7 Modulation (+), yellow Pin 8 Bias Current (+), red Pin 9 Bias Current (-), red/black Pin 10 Modulation Current (-), yellow/black Shell connected to PFL-100 chassis

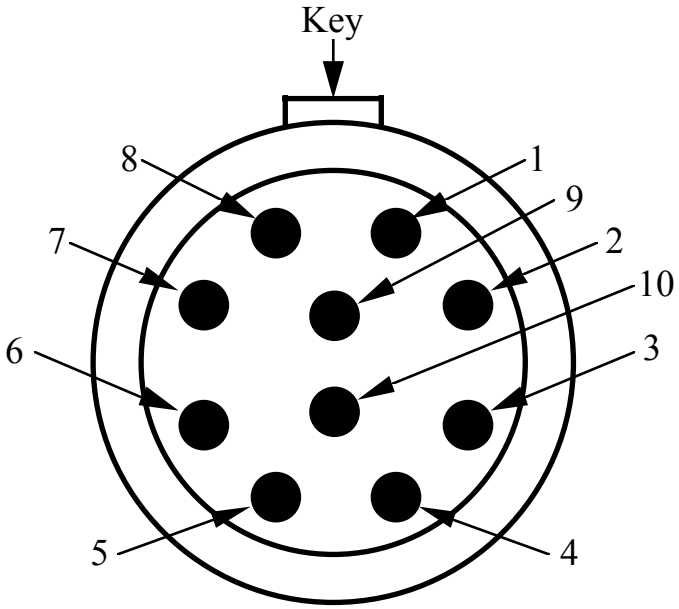


Figure 5-6. The pin numbering scheme for the sensor input connector (LEMO plug style) on the PFL-100, as seen when looking into the connector on the PFL-100.

5.15.2 I/O Connections

PFL input/output	DB-9 male connector Pin 1 +12 VDC Pin 2 -12 VDC Pin 3 External Reset Pin 4 Output (-); PFL chassis ground Pin 5 Output (+) Pin 6 STAR Cryoelectronics Serial Control Code Pin 7 Ground Pin 8 Input (+) Pin 9 Input (-); PCI chassis ground
$2\times f_{\text{Modulation}}$ output	1-pin LEMO Coax
$2\times f_{\text{Modulation}}$ input	1-pin LEMO Coax

5.16 PFL-100 Specifications

PFL Operation	Remote control using proprietary Serial Control Code (SCC) 8-bit internally configurable hardware address; Address 0 controls all PFLs Up to 255 channels may be controlled independently Master PFL can drive any number of Slave PFLs Each PFL self-recognizes Master or Slave mode
Sensor Types	LTS or HTS
Sensor Coupling	Single (warm) or Dual (warm plus cooled) input transformer options Set via internal hardware switch
Bias	0 - 200 μA DC or 0 - 200 μA_{p-p} AC; both 1 part in 4096 resolution AC Bias Frequency: 128 kHz (2 and 64 kHz reversal frequencies available as an option, remotely configurable) Remotely adjustable compensation minimizes noise peaks caused by AC bias
Modulation	0 - 5 μA_{p-p} or 0 - 50 μA_{p-p}, remotely configurable 1 part in 4096 resolution, provided by internal oscillator Modulation Frequency: 256 kHz (for DC and optional 2 and 64 kHz AC Bias), 128 kHz (128 kHz AC Bias)
Skew	0 - 5 μA_{p-p} or 0 - 50 μA_{p-p}, remotely configurable, 1 part in 4096 resolution
Feedback	Internal or External Two sensor coupling configurations, Type I and Type II, remotely configurable Three feedback ranges for each sensor configuration, remotely configurable
Type I SQUIDs	Nominal 5 μA/Φ_0 sensor feedback coupling 0 - ±10 μA, High Sensitivity Mode 0 - ±100 μA, Medium Sensitivity Mode 0 - ±1 mA, Low Sensitivity Mode
Type II SQUIDs	Nominal 50 μA/Φ_0 sensor feedback coupling 0 - ±100 μA, High Sensitivity Mode 0 - ±1 mA, Medium Sensitivity Mode 0 - ±10 mA, Low Sensitivity Mode
Integrator	10 μs, 100 μs, or 1 ms time constants, remotely configurable
Output	±10 V
Bandwidth	50 kHz minimum, up to 100 kHz depending on SQUID voltage swing
DC Offset	Two ranges for Type I and Type II sensor coupling, remotely configurable
Type I SQUIDs	0 - ±5 μA, 1 part in 8192 resolution, <5 pA/√Hz noise at 1 Hz 0.1 nA_{p-p} drift over 24 hours typical
Type II SQUIDs	0 - ±50 μA, 1 part in 8192 resolution, <50 pA/√Hz noise at 1 Hz 1 nA_{p-p} drift over 24 hours typical
Test Signal Input	Differential; configurable for each channel 1 mV/μA, 10 mV/μA, 100 mV/μA, remotely configurable 10 mA maximum current, 10 kΩ input impedance
Sensor Heater Supply	100 mA, voltage limited to + power supply voltage
Power Requirements	±12 VDC, +72/-56 mA, +184/-56 mA with heater on
Size (W×H×D)	2.8 × 0.77 × 4.4 (in) (71 × 19.5 × 112 (mm))
Weight	0.33 lb (150 g)

6 Model PCI-100 Single Channel PC Interface

The Model PCI-100 PC Interface is a low-cost, single channel personal computer interface for the Model PFL-100 Programmable Feedback Loop.

The PCI-100 PC Interface contains a STAR Cryoelectronics Serial Control Code (SCC) transmitter for uni-directional communication with the PFL. Communication with the PCI-100 is established using either the parallel port or RS-232C interface on an IBM-compatible PC. Power is provided by a standard wall plug or desktop AC power source, or an external battery power pack may be used.

The test signal input on the front panel of the PCI-100 enables the user to inject an external signal to the SQUID modulation coil for tuning. The analog output of the PFL is also available on the front panel of the PCI-100 either wideband or filtered (4-pole Butterworth, 5 kHz). The plug-in filter is readily accessible and may easily be changed for special applications.

Additional channels may be daisy-chained in a master/slave configuration to extend the basic system for small channel count applications. For this purpose, SCC input and SCC output ports are available on the rear panel of the PCI-100. The SCC output of the master interface may be daisy-chained to several slave interfaces. Each PCI-100 auto-recognizes if it is a master or slave unit; for the master unit, the front panel LED indicator is activated.

The following are standard features of the PCI-100:

- Front panel status indicator LEDs.
- Integral STAR Cryoelectronics Serial Control Code (SCC) transmitter for uni-directional communications with the PFL.
- Integral 4-pole low-pass Butterworth filter (5 kHz) for PFL analog output signal.
- Optoisolated, fast external PFL reset.
- Optoisolated SCC Input and SCC Output to enable any PCI-100 to drive any number of slave PCI-100 interfaces in a daisy-chain configuration.

6.1 PCI-100 Front Panel Description

Located on the front panel of the PCI-100 are the main power switch, a TEST INPUT BNC, WIDEBAND and FILTERED output BNCs, and three status indicator LEDs.

The wideband analog output of the PFL is always available at the WIDEBAND output BNC. A 4-pole Butterworth filter with a cutoff frequency of 5 kHz (Frequency Devices Model D74L4B 16-pin DIP anti-alias filter, factory installed) is provided for the FILTERED output BNC.

The user may inject a test signal from an external source to the PFL channel via the TEST INPUT BNC. The external signal may be enabled or disabled remotely.

Three LED indicators on the front panel of the PCI-100 provide interface status information for the user. The READY indicator is activated when the proper interface with the host PC is established and power to the PCI-100 is switched on. If no signal is present at the SCC INPUT on the rear panel, the PCI-100 auto-recognizes it is the master interface and the MASTER indicator LED is activated. The DATA indicator flashes whenever SCC data is sent to the PFL.

6.2 PCI-100 Rear Panel Description

The FEEDBACK LOOP DB-9 connector on the rear panel of the PCI-100 is used for interfacing to the PFL. The connector pinout is given in Section 6.4.1.

A fast external reset may be executed by injecting a TTL signal into the EXT RESET BNC connector where it is passed directly to the PFL-100. Since the reset function is implemented in hardware, fast reset times of <5 μs are possible. A TTL HI signal discharges the integrator and opens the feedback loop, and a TTL LO signal restores normal feedback operation. The voltages of the TTL signal must be in the range -0.5 V min. to +5.5 V max. to avoid damage to the external reset circuit.

The SCC IN and SCC OUT 1-pin LEMO connectors are used to connect any number of slave interfaces to a master PCI-100. Each interface auto-recognizes whether it is a master or slave. For the master interface, the MASTER indicator LED on the front panel is activated.

The EXT RESET, SCC IN, SCC OUT and SYNC OUT connectors are all grounded to the PCI-100 chassis. Each is optoisolated from the PCI-100 analog signal ground.

An IBM-compatible PC is used for uni-directional communications with the PCI-100. The DB-25 male PARALLEL PORT connector may be used to interface to a standard parallel port on the PC, or the DB-25 female RS-232 connector may be used with a standard RS-232C interface. The PARALLEL PORT and RS-232 interface may not be used simultaneously. For multi-unit operation, only the master interface unit should be connected to the PC communication port.

The POWER entry socket is a standard 5-pin DIN connector. Power is provided by a standard wall plug or desktop AC power source included with the PC-100 system, or an external battery power pack may be used.

6.3 Changing the Filter in the PCI-100

The PCI-100 is factory configured with a 4-pole Butterworth low-pass filter (Frequency Devices D74L4B-5 kHz). This filter may be easily replaced if your application requires a different filter characteristic. Contact STAR Cryoelectronics or Frequency Devices about obtaining a replacement or substitute filter.

To replace the filter, make sure the power supply is disconnected from the PCI-100 and remove the top cover. The filter is located on the printed circuit board near the front of the unit. Pull the filter straight up out of its mounting socket, directly away from the circuit board so as not to bend the pins on the filter. Replacement of the filter is the reverse of its removal, taking care to orient the filter properly. The pin assignment is identical to that shown at the bottom of Figure 7-1 for the PCI-1000.

6.4 PCI-100 Connector Pinouts

6.4.1 PCI-100 Rear Panel Pinouts

FEEDBACK LOOP	DB-9 Female Connector for PFL input/output Pin 1 +12 VDC Pin 2 -12 VDC Pin 3 External Reset Pin 4 Output (-); PFL chassis ground Pin 5 Output (+) Pin 6 STAR Cryoelectronics Serial Control Code Pin 7 Ground Pin 8 Input (+) Pin 9 Input (-); PCI chassis ground
EXT RESET	BNC for external reset; TTL-compatible input (-0.5 V min. to +5.5 V max.)
SCC IN	1-pin LEMO Coax for Serial Control Code input
SCC OUT	1-pin LEMO Coax for Serial Control Code input
PARALLEL PORT	DB-25 Male Connector
RS-232	DB-25 Female Connector
POWER	5-pin DIN (see Figure 6-1) Pin 1 Common Pin 2 Ground Pin 3 No Connection Pin 4 -12 VDC Pin 5 +12 VDC

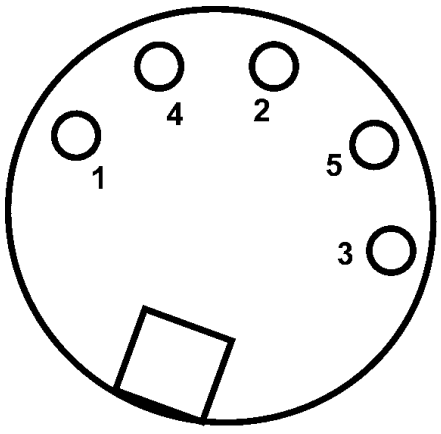


Figure 6-1. Pin assignments for the DIN 5-pin power connector on the rear panel of the PCI-100.

6.4.2 PCI-100 Front Panel Pinouts

TEST INPUT	BNC
OUTPUT, WIDEBAND	BNC
OUTPUT, FILTERED	BNC
READY	LED indicator
MASTER	LED indicator
DATA	LED indicator
POWER	Push-button on/off switch

6.5 PCI-100 Specifications

Specification	
No. of channels	1; master/slave mode supported
Communications	From PC: RS-232C or parallel port To PFL: STAR Cryoelectronics Serial Control Code
Analog Outputs	±10 V buffered PFL output, wideband or filtered
Test Signal Input	Front panel; differential, ±10 V max., 50 Ω
Ext. Reset Input	TTL-compatible (-0.5 V min, +5.5 V max.)
Filter	5 kHz plug-in 4-pole low pass
Type	Butterworth (Frequency Devices D74L4B-5 kHz)
Power Requirement	±12 VDC, current load with PFL-100 is +100/-71 mA in quiescent mode, +212/-71 mA with heater on. Wall or desktop plug-in power source for 120 or 240 VAC included.
Cable Length	At least 50 m to Programmable Feedback Loop
Size (W×H×D)	8.31 × 1.69 × 6.7 (in) (211 × 44 × 171 (mm))
Weight	1.62 lb (738 g)

7 Model PCI-1000 Multichannel PC Interface

The Personal Computer Interface Model PCI-1000 serves as a computer interface for communications from an IBM-compatible PC to up to eight Model PFL-100 Programmable Feedback Loops. The following are standard features of the PCI-1000:

- Front panel status indicator LEDs.
- Supplies ±12 VDC power for up to 8 PFL channels.
- Integral STAR Cryoelectronics Serial Control Code (SCC) transmitter for uni-directional communications with all eight PFLs.
- Internal signal generator with adjustable amplitude and frequency to supply test signal.
- Optoisolated synchronization output for test signal to simplify triggering when an oscilloscope is used.
- Remotely controlled multiplexer to enable internal or external test signal coupling to 1 to 8 SQUID channels for tuning.
- Optional 4-pole low-pass Butterworth filters for all eight analog output signals.
- Remotely selectable reference voltage or ground for each channel for data acquisition calibration.
- Optoisolated, fast external TTL reset for each of the eight PFLs.
- Optoisolated SCC Input and SCC Output to enable any PCI-1000 to drive any number of PCI-1000 slaves in a daisy-chain configuration.

7.1 PCI-1000 Front Panel Description

Located on the front panel of the PCI-1000 are the main power switch with embedded indicator, a TEST INPUT BNC, WIDEBAND and FILTERED output BNCs, and three status indicator LEDs.

The user may remotely select which analog PFL output is available at the front panel of the PCI-1000. For the FILTERED output, the user may remotely select one of four 4-pole Butterworth filters for each channel, or 'Unfiltered' for wideband. The unfiltered, wideband analog output of the selected PFL is always available at the WIDEBAND BNC connector.

The user may inject a test signal from an external source to any remotely selected channel via the TEST INPUT BNC connector. The external signal may be enabled or disabled remotely.

Three LED indicators on the front panel of the PCI-1000 provide interface status information for the user. The READY indicator is activated when the proper interface with the host PC is established and power to the PCI-1000 is switched on. If no signal is present at the SCC INPUT on the rear panel, the PCI-1000 auto-recognizes it is the master interface and the MASTER indicator LED is activated. The DATA indicator flashes whenever SCC data is sent to any PFL.

7.2 PCI-1000 Rear Panel Description

Eight DB-9 connectors on the rear panel of the PCI-1000 are available for interfacing to PFL CHANNEL 1 through CHANNEL 8. The connector pinout is given in Section 7.4.1.

Two DB-25 connectors are located in the middle of the rear panel. The DB-25 male INPUT connector may be used to connect an external test or feedback signal to any of the eight PFL channels. Such signals may be used, for example, to tune a selected SQUID, to form electronic gradiometer configurations, or for filtering. All inputs are differential. The input resistance is 5 kΩ, and the linear range of the input voltage is ±10 V. The maximum allowed input voltage is ±12 V. The pinout of the 25-pin INPUT connector is given in Section 7.4.1.

The analog outputs of all PFL channels are available at the DB-25 female OUTPUT connector. This port may be used to interface with the optional Data Acquisition system (DAQ). The linear range of the output signals is ±10 V, but the amplitudes of the output signals can reach ±12 V. The output resistance is 620 Ohm, and the maximum load capacitance is 10 nF. The pinout of the 25-pin OUTPUT connector is given in Section 7.4.1.

The shells of the INPUT and OUTPUT connectors as well as the CHANNEL 1 through CHANNEL 8 PFL connectors are connected to the analog signal ground of the PCI-1000, which is isolated from the chassis.

A fast external reset of any channel may be executed by injecting a TTL signal into the appropriate pin on the DB-9 male EXT RESET connector where it is passed directly to the corresponding PFL-100. Since the reset function is implemented in hardware, fast reset times of <5 μs are possible. A TTL "HI" signal discharges the integrator and opens the feedback loop, and a TTL "LO" signal restores normal feedback operation. The voltages of the TTL signal must be in the range -0.5 V min. to +5.5 V max. to avoid damage to the external reset circuit. The pinout of the 9-pin EXT RESET connector is given in Section 7.4.1.

The SCC IN and SCC OUT 1-pin LEMO connectors are used to connect any number of slave interfaces to a master PCI-1000. Each interface auto-recognizes whether it is a master or slave. For the master interface, the MASTER indicator LED on the front panel is activated.

A synchronization signal derived from the PCI-1000 internal signal generator is available at the SYNC OUT BNC. This synchronization signal may be used to simplify triggering when using an oscilloscope or the optional Data Acquisition system to monitor the PFL analog outputs.

The EXT RESET, SCC IN, SCC OUT and SYNC OUT connectors are all grounded to the PCI-1000 chassis. Each is optoisolated from the PCI-1000 analog signal ground.

An IBM-compatible PC is used for uni-directional communications with the PCI-1000. The DB-25 male PARALLEL PORT connector may be used to interface to a standard parallel port on the PC, or the DB-25 female RS-232 connector may be used with a standard RS-232C interface. The PARALLEL PORT and RS-232 interface may not be used simultaneously. For multi-unit operation, only the master unit should be connected to the PC communication port.

The ac power entry module allows the user to select the proper operating voltage depending on the available mains voltage. Included in the module are rf filters and a fuse.

To change the fuse in the PCI-1000, remove the power cord from the unit. The plastic part which shows a fuse icon is the fuse holder, which should be pulled outward away from the unit to remove. You may find it necessary to use a screwdriver to pry the fuse holder loose.

7.3 Changing the Address and Filters in the PCI-1000

The address of the PCI-1000 interface is set using an 8-pole DIP switch inside the unit. It must be chosen according to the scheme outlined in Section 2.3. To change the address, make sure the power cord is disconnected from the PCI-1000 and remove the top cover. Locate the address switch on the main printed circuit board, as shown in Figure 7-1. Set the switch to the binary representation of the address, noting that the position marked as ON corresponds to a binary "0". The pole marked "1" is the least significant bit, and the pole marked "7" is the most significant bit (128 decimal). Thus, the first PCI-1000 unit (channels 1 to 8) should be set with all switches in the OFF position (1111111 binary or 255 decimal).

Four optional 4-pole Butterworth low-pass filters (D74L4B-series from Frequency Devices) are available for each channel of the PCI-1000. The filter cutoff frequencies should be chosen to provide the appropriate anti-aliasing filtration and depend on the sampling rates of the DAQ board as discussed in Section 4.5.3. For National Instruments PCI-6034E and similar boards with the maximum sampling rate of 200 kS/s, the recommended filter frequencies are 60 kHz, 20 kHz, 10 kHz, and 6 kHz. For the PCI-6030E and the other boards with 100 kS/s maximum sampling rate, these frequencies should be 30 kHz, 10 kHz, 6 kHz, and 3 kHz. Finally, for the PCI-6052E board with the maximum sampling rate of 333 kS/s, the 100 kHz, 30 kHz, 20 kHz, and 10 kHz filters are recommended. The recommended filters and filter assignments are summarized in Table 4-5.

The optional LP-SET is factory installed inside the PCI-1000 if ordered along with the PCI-1000. The filters may easily be installed by the user if the Model LP-SET is purchased at a later time. The filters may also be easily replaced if your application requires different filter characteristics. Contact STAR Cryoelectronics or Frequency Devices about obtaining replacement or substitute filters.

To replace or install a filter, make sure the power cord is disconnected from the PCI-1000 and remove the top cover. The filters are located on the printed circuit board as shown in Figure 7-1. Note that the filter with the highest cutoff frequency (FILTER_D) is the filter closest to the front panel of the PCI-1000 unit, while the filter with the lowest frequency (FILTER_A) is the one closest to the rear of the unit. Find the position of the filter you wish to install or replace. To remove a filter, pull the filter straight up out of its mounting socket, directly away from the circuit board so as not to bend the pins. When installing the filters, make sure each filter is oriented properly as shown at the bottom of Figure 7-1. Note that the filter cutoff frequencies shown in Figure 7-1 are for the PCI-6034E and similar boards only.

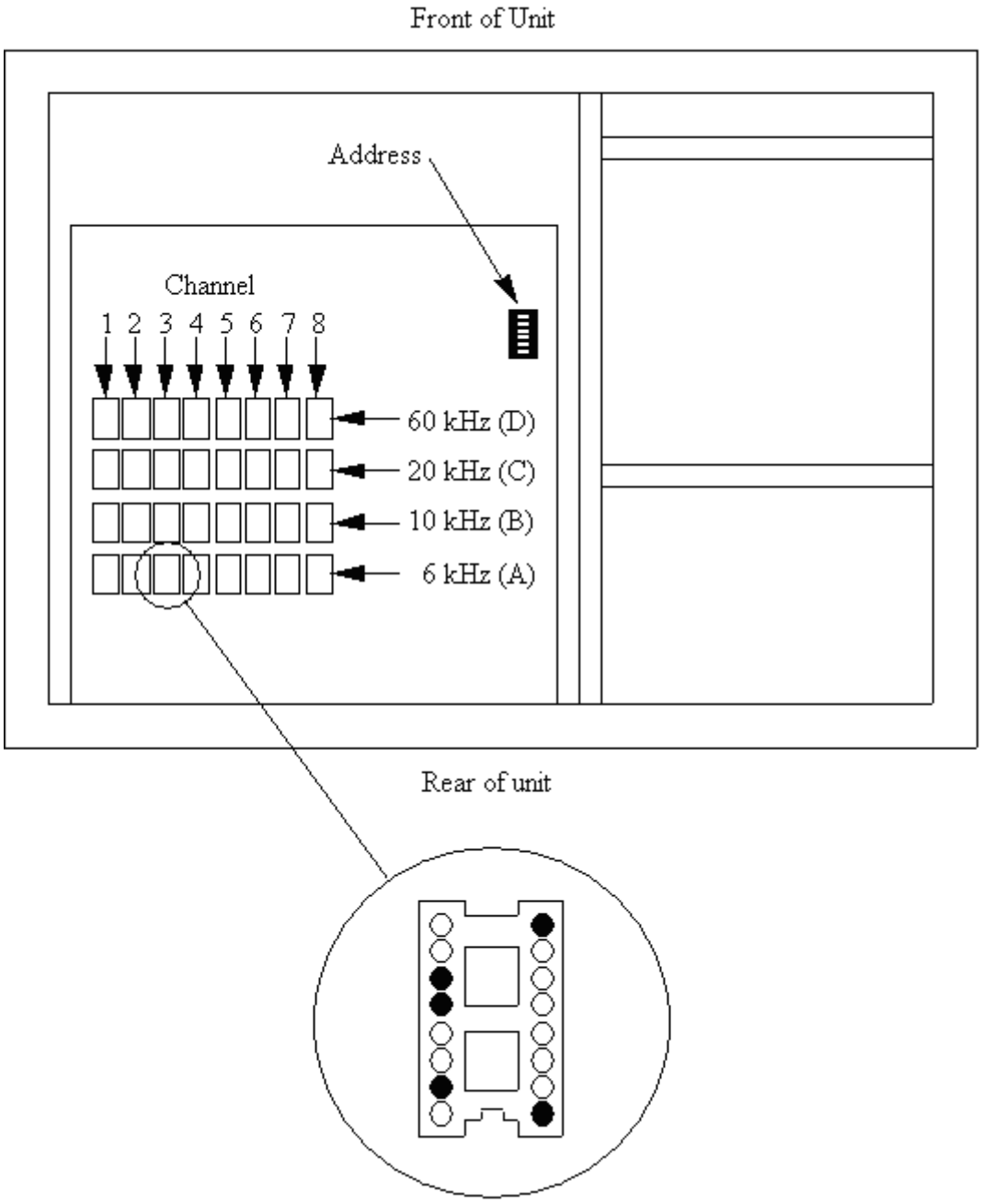


Figure 7-1. Schematic drawing of the inside of the PCI-1000 unit (viewed from above) showing locations of the address switch and the filter sockets. Note that the polarity of the address switch is reversed such that ON represents a binary "0" (see text). Each channel has four associated filters. The cutoff frequencies increase from FILTER_ A to FILTER_D. The proper insertion orientation for the filters is indicated at the bottom of the Figure. The sockets drawn as filled circles in the Figure indicate where filter package pins plug in (see text). See Table 4-5 for recommended filter specifications depending on DAQ sampling rate.

7.4 PCI-1000 Connector Pinouts

7.4.1 PCI-1000 Rear Panel Pinouts

CHANNEL 1 - 8 — DB-9 Female Connectors for PFL input/outputs

Pin 1 +12 VDC
Pin 2 -12 VDC
Pin 3 External Reset
Pin 4 Output (-); PFL chassis ground
Pin 5 Output (+)
Pin 6 STAR Cryoelectronics Serial Control Code
Pin 7 Ground
Pin 8 Input (+)
Pin 9 Input (-); PCI chassis ground

INPUT — DB-25 Male Connector for PFL input signals

Pin 1: CH1 External Signal Differential Input (+)
Pin 2: CH1 External Signal Differential Input (-)
Pin 3: PCI-1000 Signal Ground
Pin 4: CH3 External Signal Differential Input (+)
Pin 5: CH3 External Signal Differential Input (-)
Pin 6: PCI-1000 Signal Ground
Pin 7: CH5 External Signal Differential Input (+)
Pin 8: CH5 External Signal Differential Input (-)
Pin 9: PCI-1000 Signal Ground
Pin 10: CH7 External Signal Differential Input (+)
Pin 11: CH7 External Signal Differential Input (-)
Pin 12: PCI-1000 Signal Ground
Pin 13: PCI-1000 Signal Ground
Pin 14: PCI-1000 Signal Ground
Pin 15: CH2 External Signal Differential Input (+)
Pin 16: CH2 External Signal Differential Input (-)
Pin 17: PCI-1000 Signal Ground
Pin 18: CH4 External Signal Differential Input (+)
Pin 19: CH4 External Signal Differential Input (-)
Pin 20: PCI-1000 Signal Ground
Pin 21: CH6 External Signal Differential Input (+)
Pin 22: CH6 External Signal Differential Input (-)
Pin 23: PCI-1000 Signal Ground
Pin 24: CH8 External Signal Differential Input (+)
Pin 25: CH8 External Signal Differential Input (-)

OUTPUT	DB-25 Female Connector for PFL output signals Pin 1: CH1 Single-ended Output Pin 2: PCI-1000 Signal Ground Pin 3: PCI-1000 Signal Ground Pin 4: CH3 Single-ended Output Pin 5: PCI-1000 Signal Ground Pin 6: PCI-1000 Signal Ground Pin 7: CH5 Single-ended Output Pin 8: PCI-1000 Signal Ground Pin 9: PCI-1000 Signal Ground Pin 10: CH7 Single-ended Output Pin 11: PCI-1000 Signal Ground Pin 12: PCI-1000 Signal Ground Pin 13 : PCI-1000 Signal Ground Pin 14: PCI-1000 Signal Ground Pin 15: CH2 Single-ended Output Pin 16: PCI-1000 Signal Ground Pin 17: PCI-1000 Signal Ground Pin 18: CH4 Single-ended Output Pin 19: PCI-1000 Signal Ground Pin 20: PCI-1000 Signal Ground Pin 21: CH6 Single-ended Output Pin 22: PCI-1000 Signal Ground Pin 23: PCI-1000 Signal Ground Pin 24: CH8 Single-ended Output Pin 25: PCI-1000 Signal Ground
EXT RESET	DB-9 Male Connector for external reset; TTL-compatible input (-0.5 V min. to +5.5 V max.) Pin 1: CH 1 External Reset Input (TTL) Pin 2: CH 2 External Reset Input (TTL) Pin 3: CH 3 External Reset Input (TTL) Pin 4: CH 4 External Reset Input (TTL) Pin 5: CH 5 External Reset Input (TTL) Pin 6: CH 6 External Reset Input (TTL) Pin 7: CH 7 External Reset Input (TTL) Pin 8: CH 8 External Reset Input (TTL) Pin 9: PCI-1000 Chassis Ground
SYNC OUT	BNC
SCC IN	1-pin LEMO Coax for Serial Control Code input
SCC OUT	1-pin LEMO Coax for Serial Control Code output

PARALLEL PORT	DB-25 Male connector
RS-232	DB-25 Female connector
Power	IEC 320 Power Entry Module Selectable for 110/220 VAC operation

7.4.2 PCI-1000 Front Panel Pinouts

TEST INPUT	BNC
OUTPUT, WIDEBAND	BNC
OUTPUT, FILTERED	BNC
READY	LED indicator
MASTER	LED indicator
DATA	LED indicator
POWER	Rocker on/off switch with embedded LED indicator

7.5 PCI-1000 Specifications

Specification	
No. of channels	1 – 8; master/slave mode supported.
Communications	From PC: RS-232C or parallel port. To PFL: STAR Cryoelectronics Serial Control Code.
Analog Outputs	±10 V buffered PFL output, wideband or filtered.
Filters	Four optional plug-in low-pass filters for each channel, remotely selectable[1].
Type	4-pole Butterworth (Frequency Devices D74L4B-series)
Test Signal Inputs	Front panel: differential, remotely selectable for each channel, ±10 V max., 50 Ω; Rear panel: 8 differential, ±10 V max., 10 kΩ.
External Reset	TTL compatible (-0.5 V min. to +5.5 V max.)
Power Requirement	120 or 240 VAC (selectable), 50/60 Hz, 40W
Cable Length	At least 50 m to Programmable Feedback Loop.
Size (W×H×D)	8.31 × 1.69 × 6.7 (in) (211 × 44 × 171 (mm))
Weight	1.62 lb (738 g)

[1]The low pass filter set is available as an option for the PCI-1000 (Model LP-SET). The filter cutoff frequencies depend on the maximum sampling rate of the DAQ device to be used. See Table 4-5 for recommended filter specifications.

8 STAR Cryoelectronics Serial Control Code

STAR Cryoelectronics' Serial Control Code (SCC) interface is designed for uni-directional command transmission from an IBM-compatible PC to the Model PFL-100 Programmable Feedback Loop (PFL) and to the PCI-1000 Interface Unit. It allows up to 255 channels to be uniquely addressed and can accommodate up to 50,000 commands/sec.

The DATA indicator on the front panel of the Model PCI-100 or PCI-1000 Personal Computer Interface (PCI) flashes whenever data transmission occurs. Commands are transmitted in the form of 32-bit packets. Each packet includes an 8-bit header, an 8-bit command byte, and a 16-bit data word. The header is either the receiver address or broadcast address (00). The command byte defines the type of data in the packet and the target register description. The data word is handled by the receiver according to the command byte. Typically it is loaded into one of the receiver output registers.

Data Packet (32 bits)		
Packet Header	Packet Data (24 bits)	
Address	Command Byte	Data Word
8 bits	8 bits	16 bits

The SCC transmitter provides easy computer interfacing to the SCC data link. It can be connected to an IBM-compatible PC parallel port or RS-232C interface. Up to 255 transmitters can be used together in a multichannel system. In this configuration, only the first transmitter (master) is connected to the computer and generates the SCC code; all other transmitters (slaves) simply repeat the code produced by the master transmitter. Master/slave switching is automatic and based on SCC input signal sensing. The master transmitter is configured for automatic parity bit generation.

The communications signal channel is a coaxial cable or twisted pair. A 5V logic with CMOS threshold is used on both ends of the line. The driver output has 50 – 300 Ω impedance. The receiver was designed with high input impedance to minimize current pulses in the line and magnetic interference. Up to 32 receivers can be connected to one line. A low voltage level (~0V) is present in the line if there is no transmission in progress.

A detailed description of the SCC architecture and implementation, as well as device-specific commands for the PFL-100 and PCI-1000 may be found in the document, "STAR Cryoelectronics Serial Control Code (SCC) Architecture Specifications".