

Model 7225BFP

DSP Lock-in Amplifier

Instruction Manual

190496-A-MNL-C

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Company Names

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This product conforms to EC Directives 89/336/EEC Electromagnetic Compatibility Directive, amended by 92/31/EEC and 93/68/EEC, and Low Voltage Directive 73/23/EEC amended by 93/68/EEC.

This product has been designed in conformance with the following IEC/EN standards:

EMC: BS EN55011 (1991) Group 1, Class A (CSPIR 11:1990)

BS EN50082-1 (1992):

IEC 801-2:1991

IEC 801-3:1994

IEC 801-4:1988

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Table of Contents

Chapter One, Introduction

1.1 How to Use This Manual.....	1-1
1.2 What is a Lock-in Amplifier?.....	1-2
1.3 Key Specifications and Benefits	1-3

Chapter Two, Installation & Initial Checks

2.1 Installation	2-1
2.1.01 Introduction	2-1
2.1.02 Rack Mounting	2-1
2.1.03 Inspection	2-1
2.1.04 Line Cord Plug	2-1
2.1.05 Line Voltage Selection and Line Fuses	2-1
2.2 Initial Checks	2-3
2.2.01 Introduction	2-3
2.2.02 Procedure	2-3

Chapter Three, Technical Description

3.1 Introduction.....	3-1
3.2 Principles of Operation.....	3-1
3.2.01 Block Diagram	3-1
3.2.02 Signal-Channel Inputs.....	3-1
3.2.03 Line Frequency Rejection Filter.....	3-3
3.2.04 AC Gain	3-3
3.2.05 Anti-Aliasing Filter.....	3-4
3.2.06 Main Analog to Digital Converter	3-5
3.2.07 Reference Channel DSP	3-6
3.2.08 Internal Oscillator	3-6
3.2.09 Demodulator DSP.....	3-7
3.2.10 Output Processor	3-7
3.2.11 Main Microprocessor.....	3-8
3.3 Accuracy.....	3-8
3.3.01 Absolute Accuracy Specifications	3-8
3.3.02 Relative Accuracy.....	3-8
3.4 Full-Scale Sensitivity and AC Gain Control	3-9
3.5 Dynamic Reserve.....	3-9
3.6 System Updates and Reference Frequency Changes.....	3-10
3.7 Reference Phase and Phase Shifter	3-10
3.8 Output Channel Filters	3-11
3.8.01 Slope.....	3-11
3.8.02 Time Constants and Synchronization.....	3-11
3.8.03 Output Offset and Expand	3-12
3.9 Use of Magnitude and Signal Phase Outputs	3-12
3.10 Noise Measurements.....	3-13

TABLE OF CONTENTS

3.11 Power-up Defaults	3-14
3.12 Auto Functions	3-14
3.12.01 Introduction.....	3-14
3.12.02 Auto-Sensitivity	3-14
3.12.03 Auto-Phase.....	3-15
3.12.04 Auto-Offset.....	3-15
3.12.05 Auto-Measure	3-16
3.12.06 Default Setting	3-16

Chapter Four, Front and Rear Panels

4.1 Front Panel.....	4-1
4.2 Rear Panel	4-1
4.2.01 Line Power Switch	4-1
4.2.02 Line Power Input Assembly	4-1
4.2.03 RS232 Connector	4-1
4.2.04 AUX RS232 Connector.....	4-2
4.2.05 GPIB Connector.....	4-2
4.2.06 DIGITAL OUTPUTS Connector.....	4-2
4.2.07 REF TTL Connector	4-2
4.2.08 REF IN Connector	4-2
4.2.09 OSC OUT Connector	4-2
4.2.10 REF MON Connector	4-2
4.2.11 PREAMP POWER Connector.....	4-2
4.2.12 SIG MON Connector	4-3
4.2.13 CH1, CH2 Connectors	4-3
4.2.14 A and B/I Signal Input Connectors	4-3
4.2.15 TRIG Connector	4-3
4.2.16 ADC1, ADC2 Connectors	4-3
4.2.17 DAC1, DAC2 Connectors	4-3
4.2.18 FAST X, FAST Y Connectors.....	4-3

Chapter Five, Computer Operation

5.1 Introduction	5-1
5.2 Capabilities.....	5-1
5.2.01 General	5-1
5.2.02 Curve Storage	5-1
5.2.03 Burst Mode Acquisition.....	5-1
5.2.04 Internal Oscillator Amplitude and Frequency Sweep Generator	5-1
5.3 RS232 and GPIB Operation	5-2
5.3.01 Introduction.....	5-2
5.3.02 RS232 Interface - General Features	5-2
5.3.03 Choice of Baud Rate	5-3
5.3.04 Choice of Number of Data Bits.....	5-3
5.3.05 Choice of Parity Check Option	5-3
5.3.06 Auxiliary RS232 Interface.....	5-4
5.3.07 GPIB Interface - General Features	5-4

5.3.08 Handshaking and Echoes.....	5-5
5.3.09 Terminators	5-6
5.3.10 Command Format	5-6
5.3.11 Delimiters.....	5-7
5.3.12 Compound Commands.....	5-7
5.3.13 Status Byte, Prompts and Overload Byte	5-7
5.3.14 Service Requests.....	5-8
5.4 Command Descriptions.....	5-9
5.4.01 Signal Channel.....	5-9
5.4.02 Reference Channel	5-12
5.4.03 Signal Channel Output Filters	5-13
5.4.04 Signal Channel Output Amplifiers.....	5-14
5.4.05 Instrument Outputs	5-15
5.4.06 Internal Oscillator	5-17
5.4.07 Auxiliary Outputs.....	5-19
5.4.08 Auxiliary Inputs.....	5-20
5.4.09 Output Data Curve Buffer	5-21
5.4.10 Computer Interfaces (RS232 and GPIB).....	5-27
5.4.11 Instrument Identification	5-29
5.4.12 Auto Default.....	5-29
5.5 Programming Examples.....	5-29
5.5.01 Introduction	5-29
5.5.02 Basic Signal Recovery	5-29
5.5.03 Frequency Response Measurement	5-30
5.5.04 X and Y Output Curve Storage Measurement.....	5-31
5.5.05 Transient Recorder	5-32
5.5.06 Frequency Response Measurement using Curve Storage and Frequency Sweep	5-32

Appendix A, Specifications

Appendix B, Pinouts

B1 RS232 Connector Pinout	B-1
B2 Pre-amplifier Power Connector Pinout.....	B-1
B3 Digital Output Port Connector.....	B-2

Appendix C, Demonstration Programs

C1 Simple Terminal Emulator	C-1
C2 RS232 Control Program with Handshakes.....	C-1
C3 GPIB User Interface Program	C-3

Appendix D, Cable Diagrams

D1 RS232 Cable Diagrams	D1
-------------------------------	----

Appendix E, Default Settings

Auto Default Function.....	E1
----------------------------	----

Appendix F, Command Set changes from the Model 7220

F.1 Introduction	F-1
F.2 Commands no longer available.....	F-1
F.3 Changed Commands	F-1
F.3.01 Instrument Identification.....	F-1
F.3.02 Auto-Default.....	F-1
F.3.03 Line Frequency Rejection Filter	F-1
F.3.04 Auxiliary I/O	F-2
F.3.05 Oscillator Amplitude Sweep	F-2
F.4 New Commands	F-3

Appendix G, Alphabetical Listing of Commands

Index

Warranty	End of Manual
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1.1 How to Use This Manual

This manual gives detailed instructions for setting up and operating the **SIGNAL RECOVERY** Model 7225BFP Digital Signal Processing (DSP) dual phase lock-in amplifier. It is split into the following chapters:-

Chapter 1 - Introduction

Provides an introduction to the manual, briefly describes what a lock-in amplifier is and the types of measurements it may be used for, and lists the major specifications of the model 7225BFP.

Chapter 2 - Installation and Initial Checks

Describes how to install the instrument and gives a simple test procedure which may be performed to check that the unit has arrived in full working order.

Chapter 3 - Technical Description

Provides an outline description of the design of the instrument and discusses the effect of the various controls. A good understanding of the design will enable you to get the best possible performance from the unit.

Chapter 4 - Front and Rear Panels

Describes the connectors, controls and indicators which are to be found on the unit and which are referred to in the subsequent chapters.

Chapter 5 - Remote Operation

This chapter provides detailed information on operating the instrument from a computer over either the GPIB (IEEE-488) or RS232 interfaces. It includes information on how to establish communications, the functions available, the command syntax and a detailed command listing.

Appendix A

Gives the detailed specifications of the unit.

Appendix B

Details the pinouts of the multi-way connectors on the rear panel.

Appendix C

Lists three simple terminal programs which may be used as the basis for more complex user-written programs.

Appendix D

Shows the connection diagrams for suitable RS232 null-modem cables to couple the unit to a PC operating under 32-bit Microsoft Windows.

Appendix E

Provides a listing of the instrument settings produced by using the default setting function.

Appendix F

Details the differences in the computer command set between the model 7225BFP and the model 7220BFP for the benefit of those who wish to modify software written for the older instrument so that it can function with the model 7225BFP.

Appendix G

Gives an alphabetical listing of the computer commands for easy reference.

If you are a new user, it is suggested that you unpack the instrument and carry out the procedure in chapter 2 to check that it is working satisfactorily. You should then make yourself familiar with the information in chapters 3, 4 and 5. Once you are familiar with the structure of the computer commands, appendix G will prove convenient as it provides a complete alphabetical listing of these commands in a single easy-to-use section.

1.2 What is a Lock-in Amplifier?

In its most basic form the lock-in amplifier is an instrument with dual capability. On the one hand it can recover signals in the presence of an overwhelming noise background or alternatively it can provide high resolution measurements of relatively clean signals over several orders of magnitude and frequency.

Modern instruments, such as the model 7225BFP, offer far more than these two basic characteristics and it is this increased capability which has led to their acceptance in many fields of scientific research, such as optics, electrochemistry, materials science, fundamental physics and electrical engineering, as units which can provide the optimum solution to a large range of measurement problems.

The model 7225BFP lock-in amplifier can function as a:-

- | | |
|---------------------------------|--------------------------|
| ■ AC Signal Recovery Instrument | ■ Transient Recorder |
| ■ Vector Voltmeter | ■ Precision Oscillator |
| ■ Phase Meter | ■ Frequency Meter |
| ■ Spectrum Analyzer | ■ Noise Measurement Unit |

These characteristics, all available in a single compact unit, make it an invaluable addition to any laboratory.

1.3 Key Specifications and Benefits

The **SIGNAL RECOVERY** Model 7225BFP is a cost-effective DSP lock-in amplifier suitable for many applications, and offers:-

- Frequency range: 0.001 Hz to 120 kHz
- Voltage sensitivity: 2 nV to 1 V full-scale
- Current input mode sensitivities: 2 fA to 1 μ A full-scale
2 fA to 10 nA full-scale
- Line frequency rejection filter
- Dual phase demodulator with X-Y and R- θ outputs
- Very low phase noise of < 0.0001° rms
- 5-digit output readings
- Direct Digital Synthesizer (DDS) oscillator with variable output amplitude and frequency
- Oscillator frequency and amplitude sweep generator via computer control
- Output time constant: 10 μ s to 100 ks
- 8-bit programmable digital output port for system control
- Two external ADCs, two external DACs
- Full range of auto-modes
- Standard IEEE-488 and RS232 interfaces with RS232 daisy-chain capability
- Dual back-lit liquid crystal display (LCD) with variable contrast control
- 32768 point curve storage buffer

Installation & Initial Checks

2.1 Installation

2.1.01 Introduction

Installation of the model 7225BFP in the laboratory or on the production line is very simple. Because of its low power consumption, the model 7225BFP does not incorporate forced-air ventilation. It can be operated on almost any laboratory bench or be rack mounted, using the optional accessory kit, at the user's convenience. With an ambient operating temperature range of 0 °C to 35 °C, it is highly tolerant to environmental variables, needing only to be protected from exposure to corrosive agents and liquids.

2.1.02 Rack Mounting

An optional accessory kit, part number K02002, is available from **SIGNAL RECOVERY** to allow the model 7225BFP to be mounted in a standard 19-inch rack.

2.1.03 Inspection

Upon receipt the model 7225BFP Lock-in Amplifier should be inspected for shipping damage. If any is noted, **SIGNAL RECOVERY** should be notified immediately and a claim filed with the carrier. The shipping container should be saved for inspection by the carrier.

2.1.04 Line Cord Plug

A standard IEC 320 socket is mounted on the rear panel of the instrument and a suitable line cord is supplied.

2.1.05 Line Voltage Selection and Line Fuses

Before plugging in the line cord, ensure that the model 7225BFP is set to the voltage of the AC power supply to be used.

A detailed discussion of how to check and, if necessary, change the line voltage setting follows.

CAUTION! The model 7225BFP may be damaged if the line voltage is set for 110 V AC operation and it is turned on with 220 V AC applied to the power input connector.

The model 7225BFP can operate from any one of four different line voltage ranges, 90-110 V, 110-130 V, 200-240 V, and 220-260 V, at 50-60 Hz. The change from one range to another is made by repositioning a plug-in barrel selector internal to the Line Input Assembly on the rear panel of the unit.

Instruments are normally shipped from the factory with the line voltage selector set to 110-130 V AC, unless they are destined for an area known to use a line voltage in the 220-260 V range, in which case, they are shipped configured for operation from the higher range.

The line voltage setting can be seen through a small rectangular window in the line input assembly on the rear panel of the instrument (figure 2-1). If the number showing is incorrect for the prevailing line voltage (refer to table 2-1), the barrel selector will need to be repositioned as follows.

Observing the instrument from the rear, note the plastic door immediately adjacent to the line cord connector (figure 2-1) on the left-hand side of the instrument. When the line cord is removed from the rear panel connector, the plastic door can be opened outwards by placing a small, flat-bladed screwdriver in the slot on the right-hand side and levering gently. This gives access to the fuse and to the voltage barrel selector, which is located at the right-hand edge of the fuse compartment. Remove the barrel selector with the aid of a small screwdriver or similar tool. With the barrel selector removed, four numbers become visible on it: 100, 120, 220, and 240, only one of which is visible when the door is closed. Table 2-1 indicates the actual line voltage range represented by each number. Position the barrel selector such that the required number (see table 2-1) will be visible when the barrel selector is inserted and the door closed.

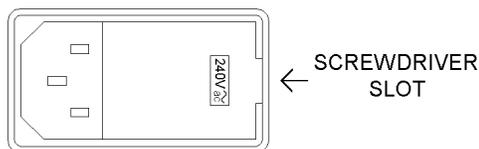


Figure 2-1, Line Input Assembly

VISIBLE #	VOLTAGE RANGE
100	90 - 110 V
120	110 - 130 V
220	200 - 240 V
240	220 - 260 V

Table 2-1, Range vs Barrel Position

Next check the fuse rating. For operation from a nominal line voltage of 100 V or 120 V, use a 20 mm slow-blow fuse rated at 1.0 A, 250 V. For operation from a nominal line voltage of 220 V or 240 V, use a 20 mm slow-blow fuse rated at 0.5 A, 250 V.

To change the fuse, first remove the fuse holder by pulling the plastic tab marked with an arrow. Remove the fuse and replace with a slow-blow fuse of the correct voltage and current rating. Install the fuse holder by sliding it into place, making sure the arrow on the plastic tab is pointing downwards. When the proper fuse has been installed, close the plastic door firmly. The correct selected voltage setting should now

be showing through the rectangular window. Ensure that only fuses with the required current rating and of the specified type are used for replacement. The use of makeshift fuses and the short-circuiting of fuse holders is prohibited and potentially dangerous.

2.2 Initial Checks

2.2.01 Introduction

The following procedure checks the performance of the model 7225BFP. In general, this procedure should be carried out after inspecting the instrument for obvious shipping damage.

NOTE: Any damage must be reported to the carrier and to *SIGNAL RECOVERY* immediately; take care to save the shipping container for inspection by the carrier.

Note that this procedure is intended to demonstrate that the instrument has arrived in good working order, not that it meets specifications. Each instrument receives a careful and thorough checkout before leaving the factory, and normally, if no shipping damage has occurred, will perform within the limits of the quoted specifications. If any problems are encountered in carrying out these checks, contact **SIGNAL RECOVERY** or the nearest authorized representative for assistance.

The model 7225BFP is supplied with a 3.5 inch floppy disk containing the Initial Checks software program. A PC operating under 32-bit Microsoft Windows with a standard RS232 interface COM1 or COM2 port is required to run the software which provides a quick and simple check of some of the main operating parameters of the instrument and allows various instrument outputs to be measured.

Note that before the initial checks procedure can be performed it is essential to establish proper RS232 communications between the host computer and the model 7225BFP. Please refer to appendix D, RS232 Cable Diagrams, for information on the correct cable type to be used with your computer.

2.2.02 Procedure

- 1) Ensure that the model 7225BFP is set to the line voltage of the power source to be used, as described in section 2.1.05
- 2) With the rear panel mounted power switch (located at the extreme left-hand side of the instrument when viewed from the rear) set to **0** (off), plug in the line cord to an appropriate line source.
- 3) Connect a 9-way RS232 cable to the lower RS232 connector on the model 7225BFP's rear panel, marked **RS232**. Connect the other end of the RS232 cable to the host computer's RS232 connector. If the host computer has a 25-way connector then a 25-way to 9-way cable must be used or alternatively a 9-way to 25-way adapter used with a 9-way to 9-way cable.
- 4) Using a BNC cable between the rear-panel **OSC** output and **A** input connectors.

- 5) Turn the model 7225BFP power switch to the I (on) position.
- 6) Turn on the host computer and wait for it to boot and display the Windows desktop.
- 7) Put the Initial Checks disk in the disk drive and use Run on the Start menu to start the program INITCHECKS.EXE
- 8) The Initial Checks program will now run. The opening screen will appear, as shown in figure 2-2.



Figure 2-2, Initial Checks Procedure, Opening Screen

Click the Next button to continue, which displays a second screen requesting the model number. Choose 7225BFP and click the Next button again. After a screen showing the required connections, the program options screen will be displayed, as shown in figure 2-3 below.

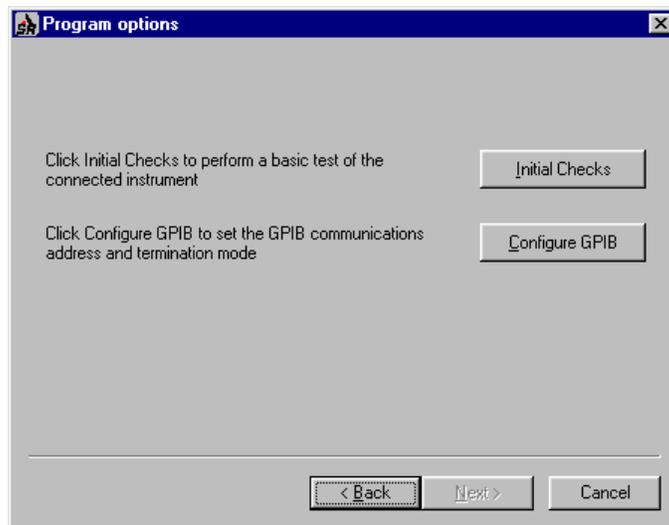


Figure 2-3, Initial Checks Procedure, Program Options screen

- 9) Click the Initial Checks button to access the Initial Checks procedure. The Perform Checks screen shown in shown in figure 2-4 below will be displayed.

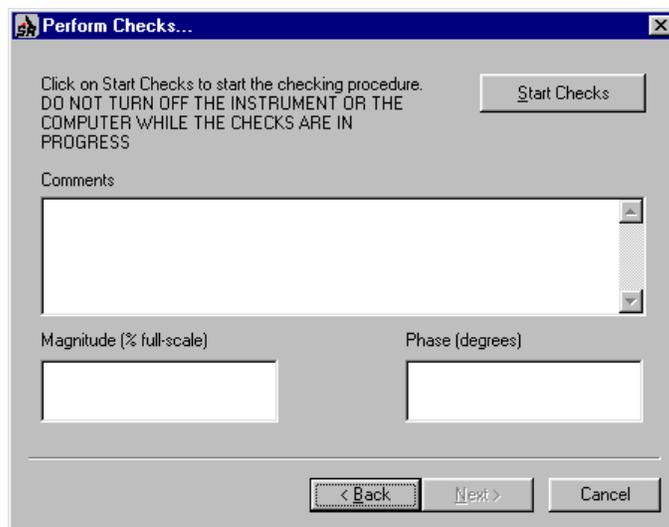


Figure 2-4, Initial Checks Procedure, Perform Checks Screen - Opening Display

- 10) Click on the Start Checks button. The program automatically checks for and switches to the COM port to which the lock-in amplifier is connected.

Note: The 7225BFP is factory set with a baud rate of 9600 and Echo enabled. The initial checks program can only implement a baud rate of either 9600 or 19200 and Echo handshaking. If Echo is not implemented then full communication will be lost. Therefore before any subsequent use of the Initial Checks disk, it is essential to make sure that the model 7225BFP is set for either 9600 or 19200 baud and Echo enabled.

- 11) Once communications have been established the Comments section shows a list of

commands being sent to the model 7225BFP which set it to a defined state. Once this has happened, the signal magnitude and reference phase are shown in the lower section of the display, as shown in figure 2-5.

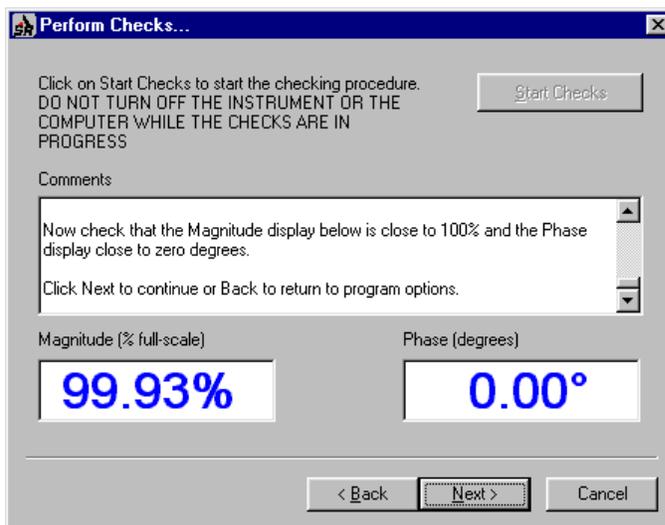


Figure 2-5, Initial Checks Procedure, Perform Checks Screen - Outputs Displayed

- 12) Note that although the actual output readings may vary from the those listed above, they should be close to 100 % full-scale (magnitude) and 0° (phase). If this is achieved then one can be reasonably confident that the model 7225BFP has not suffered any shipping damage and is in good working order. Click on the Next button to finish the procedure.

3.1 Introduction

The model 7225BPF lock-in amplifier is capable of outstandingly good signal recovery performance, provided that it is operated correctly. This chapter describes the design of the instrument, enabling the best use to be made of its facilities. Of particular importance is the correct adjustment of the AC Gain parameter, described in section 3.2.04.

3.2 Principles of Operation

3.2.01 Block Diagram

The model 7225BFP utilizes two digital signal processors, a microprocessor and a dedicated digital waveform synthesizer, together with very low-noise analog circuitry to achieve its specifications. A block diagram of the instrument is shown in figure 3-1, and the sections that follow describe how each functional block operates and the effect it has on the instrument's performance.

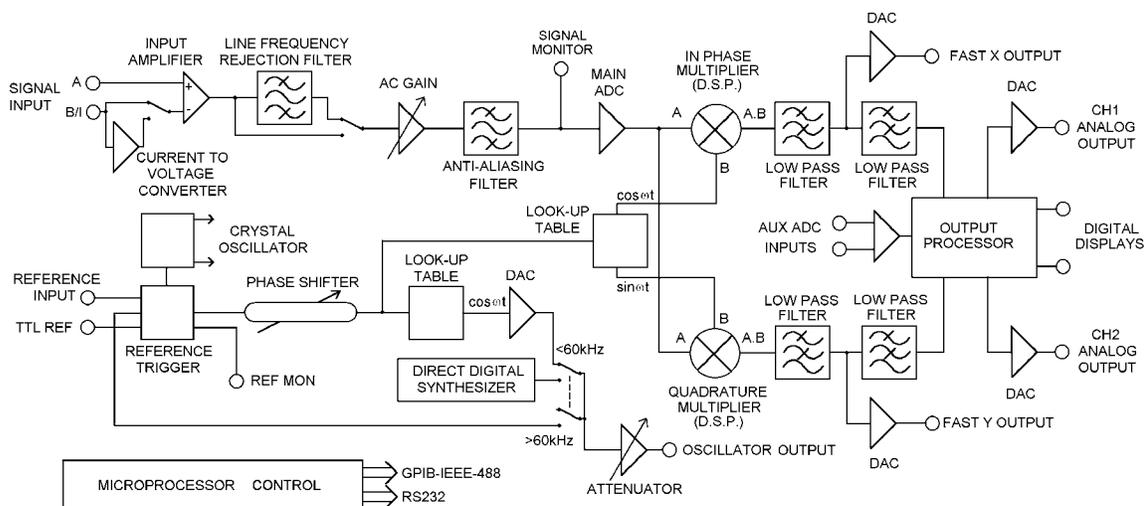


Figure 3-1, Model 7225BFP - Block Diagram

3.2.02 Signal-Channel Inputs

The signal input amplifier may be configured for either single-ended or differential voltage mode operation, or single-ended current mode operation. In voltage mode a choice of AC or DC coupling is available and the input may be switched between FET and bipolar devices. In current mode two conversion gains are selectable to allow for optimum matching to the signal input. In both modes the input connector "shells" may be either floated or grounded to the instrument's chassis ground. These various features are discussed in the following paragraphs.

Input Connector Selection, A / (A - B)

When set to the A mode, the lock-in amplifier measures the voltage between the center and the outer of the **A** input BNC connector, whereas when set to (A-B) mode it measures the difference in voltage between the center pins of the **A** and **B** input connectors.

The latter, differential, mode is often used to eliminate ground loops, although it is worth noting that at very low signal levels a substantial reduction in unwanted offsets can often be achieved by the use of this mode, with a short-circuit terminator on the **B** input, rather than simply using the A input mode.

The specification defined as the Common Mode Rejection Ratio, CMRR, defines how well the instrument rejects common mode signals applied to the A and B inputs when operating in differential input mode. It is usually given in decibels. Hence a specification of > 100 dB implies that a common mode signal (i.e. a signal simultaneously applied to both A and B inputs) of 1 V will give rise to less than $10 \mu\text{V}$ of signal out of the input amplifier.

Input Connector Shell Ground / Float

The input connector shells may be connected either directly to the instrument's chassis ground or they can be "floated" by being connected via a $1 \text{ k}\Omega$ resistor. When in the float mode, the presence of this resistor substantially reduces the problems which often occur in low-level lock-in amplifier measurements due to ground loops.

Input Device Selection, FET / Bipolar

The voltage preamplifier may be switched between bipolar and FET input devices. The bipolar device, which has an input impedance of $10 \text{ k}\Omega$, shows a relatively high level of added current noise ($2 \text{ pA}/\sqrt{\text{Hz}}$), but less than 50 percent of the voltage noise of the FET device. As such, it is intended for use where the source impedance is resistive or inductive with a resistance of 100Ω or less, and there is no input voltage offset.

WARNING: Signal channel overload may occur if the bipolar device is selected and no DC bias path is provided.

The FET device provides an input impedance of $10 \text{ M}\Omega$.

AC / DC Coupling

In normal operation, with reference frequencies above a few hertz, AC coupled operation is always used.

The primary purpose of the DC coupling facility is to enable the use of the instrument at reference frequencies below 0.5 Hz . It may also be used to reduce the effect of phase and magnitude errors introduced by the AC coupling circuitry below a few hertz.

However, the use of DC coupling introduces serious problems where the source has a DC offset or is of such high impedance that bias currents cause significant offsets. In these cases it may be necessary to include some form of signal conditioning between the signal source and the lock-in amplifier.

The instrument always reverts to the AC coupled mode on power-up, to protect the input circuitry.

Input Signal Selection, V / I

Although the voltage mode input is most commonly used, a current to voltage converter may be switched into use to provide current mode input capability, in which case the signal is connected to the B input of the **A,B** connector. High impedance sources ($> 100\text{ k}\Omega$) are inherently current sources and need to be measured with a low impedance current mode input. Even when dealing with a voltage source in series with a high impedance, the use of the current mode input may provide advantages in terms of improved bandwidth and immunity from the effects of cable capacitance.

The converter may be set to low-noise or wide bandwidth conversion settings, but it should be noted that even at the wide bandwidth setting the -3 dB point is at 50 kHz. Better performance may be achieved using a separate current preamplifier, such as the **SIGNAL RECOVERY** Model 5182.

3.2.03 Line Frequency Rejection Filter

Following the signal input amplifier, there is an option to pass the signal through a line frequency rejection filter, which is designed to give greater than 40 dB of attenuation at the power line frequencies of 50 Hz or 60 Hz and their second harmonics at 100 Hz and 120 Hz.

The filter uses two cascaded rejection stages with “notch” characteristics, allowing it to be set to reject signals at frequencies equal to either of, or both of, the fundamental and second harmonic of the line frequency. The command that sets the filter therefore allows settings of OFF, F, 2F or F & 2F.

Although instruments are supplied with the line frequency filter set to match the line frequency of the country for which they are destined, it should be appreciated that if a unit is moved from a 50 Hz area to a 60 Hz area then the filter will need to be adjusted. This is automatically done by the command used to set the operating mode of the line frequency filter, since one of the parameters sets the line frequency.

3.2.04 AC Gain

The signal channel contains a number of analog filters and amplifiers, the gain of which are defined by the “AC Gain” parameter, which is specified in terms of decibels (dB). For each value of AC Gain there is a corresponding value of the INPUT LIMIT parameter, which is the maximum instantaneous (peak) voltage or current that can be applied to the input without input overload, as shown in table 3-1 below.

It is a basic property of the DSP lock-in amplifier that the best demodulator performance is obtained by presenting as large a signal as possible to the main analog to digital converter. Therefore, in principle, the AC Gain value should be made as large as possible without causing amplifier or converter overload. This constraint is not too critical however and the use of a value 10 or 20 dB below the optimum value makes little difference.

Note that when signal overload occurs, the only action required is to reduce the AC Gain value.

AC Gain (dB)	INPUT LIMIT (mV)
0	3000
10	1000
20	300
30	10
40	30
50	10
60	3
70	1
80	0.3
90	0.1

Table 3-1, Input Limit vs AC Gain

Further information on the control of AC Gain is given in section 3.4

3.2.05 Anti-Aliasing Filter

Prior to the main analog to digital converter (ADC) the signal passes through an anti-aliasing filter to remove unwanted frequencies which would cause a spurious output from the ADC due to the nature of the sampling process.

Consider the situation when the lock-in amplifier is measuring a sinusoidal signal of frequency f_{signal} Hz, which is sampled by the main ADC at a sampling frequency f_{sampling} Hz. In order to ensure correct operation of the instrument the output values representing the f_{signal} frequency must have been uniquely generated by the signal to be measured, and not by any other process.

However, if the input to the ADC has, in addition, an unwanted analog sinusoid with frequency f_1 Hz, where f_1 is greater than half the sampling frequency, then this will appear in the output as a sampled-data sinusoid with frequency less than half the sampling frequency, $f_{\text{alias}} = |f_1 - nf_{\text{sampling}}|$, where n is an integer.

This alias signal is indistinguishable from the output generated when a genuine signal at frequency f_{alias} is sampled. Hence if the frequency of the unwanted signal were such that the alias signal frequency produced from it was close to, or equal to, that of the wanted signal then it is clear that a spurious output would result.

For example, if the sampling frequency were 160 kHz then half the sampling frequency would be 80 kHz. Let the instrument be measuring a signal of 55 kHz accompanied by an interfering signal of 100 kHz. The output of the ADC would therefore include a sampled-data sinusoid of 55 kHz (the required signal) and, applying the above formula, an alias signal of 60 kHz (i.e. $|100 \text{ kHz} - 160 \text{ kHz}|$). If the signal frequency were now increased towards 60 kHz then the output of the lock-in amplifier would increasingly be affected by the presence of the alias signal and the accuracy of the measurement would deteriorate.

To overcome this problem the signal is fed through the anti-aliasing filter, which restricts the signal bandwidth. When operating at reference frequencies below 60 kHz, the reference frequency is less than half the sampling frequency and a conventional elliptic-type, low-pass anti-alias filter is used. This enables the system to provide the lowest possible noise bandwidth. At frequencies above 60 kHz an adaptive bandpass anti-alias filter is used. The noise bandwidth of this filter is dependent on the reference frequency and is higher than that of the conventional type of filter, but typically the noise penalty is negligible.

It should be noted that the dynamic range of a lock-in amplifier is normally so high that practical anti-alias filters are not capable of completely removing the effect of a full-scale alias. For instance, even if the filter gives 100 dB attenuation, an alias at the input limit and at the reference frequency will give a one percent output error when the dynamic reserve is set to 60 dB, or a full-scale error when the dynamic reserve is set to 100 dB.

In a typical low-level signal recovery situation, many unwanted inputs need to be dealt with and it is normal practice to make small adjustments to the reference frequency until a clear point on the frequency spectrum is reached. In this context an unwanted alias is treated as just another interfering signal and its frequency is avoided when setting the reference frequency.

A buffered version of the analog signal just prior to the main ADC is available at the rear panel signal monitor (**SIG MON**) connector; it may be viewed on an oscilloscope to monitor the effect of the signal channel filters and amplifiers.

3.2.06 Main Analog to Digital Converter

Following the anti-alias filter the signal passes to the main 18-bit analog to digital converter running at a sampling rate of 166 kHz. This rate is not fixed but is adjusted automatically by up to $\pm 1\%$, as a function of the reference frequency, to ensure that the sampling process does not generate a “beat” frequency close to zero hertz. For example, if the reference frequency were 82.95 kHz and the sampling frequency were not adjusted, a beat frequency of 50 Hz ($|82.95 \text{ kHz} - (166 \text{ kHz}/2)|$) would be generated and would appear at the output if the time constant were not set to a large enough value.

There is one situation where this automatic correction might not be sufficient to give good performance. Consider the case where the signal being measured is at 73 kHz, which is 10 kHz away from half the sampling frequency. If there were also a strong interfering signal at 93 kHz (i.e. $166 \text{ kHz}/2 + 10 \text{ kHz}$), then an alias of this would give rise to a spurious output. Note that under these circumstances, the reference frequency is not sufficiently close to half the sampling frequency to cause the latter to be automatically adjusted. The problem is overcome by providing the Sample F (sample frequency) control which allows the user to adjust the main ADC sampling frequency in steps of about 1%. A 1% change moves the alias by about 1 kHz, which is normally sufficient to ensure rejection by the output low-pass filters and thereby remove any error.

The output from the converter feeds the first of the digital signal processors, which

implements the digital multiplier and the first stage of the output low-pass filtering for each of the X and Y channels.

3.2.07 Reference Channel DSP

The second DSP in the instrument is responsible for implementing the reference trigger/phase-locked loop, digital phase shifter and internal oscillator look-up table functional blocks on the block diagram. The processor generates two main outputs, the first being a series of *phase values* which are used to drive the other DSP's reference channel input and the second being a sinusoidal signal which may be used as the instrument's internal oscillator output.

The normal operating mode of the instrument incorporates two reference frequency ranges, namely the baseband from 1 mHz to 60 kHz and the highband from 60 kHz to 120 kHz. Different hardware configurations are used in the two bands, transitions between which are made automatically according to the value of the reference frequency. These transitions are generally transparent to the user.

External Reference Mode

In external reference mode at frequencies above 300 mHz, the reference source may be applied to either a general purpose input, designed to accept virtually any periodic waveform with a 50:50 mark-space ratio and of suitable amplitude, or to a TTL-logic level input. At frequencies below 300 mHz the TTL-logic level input must be used. Following the trigger buffering circuitry the reference signal is passed to a digital phase-locked loop (PLL) implemented in the reference DSP. This measures the period of the applied reference waveform and from this generates the phase values.

Internal Reference Mode

With internal reference operation in the baseband mode (i.e. at reference frequencies < 60 kHz), the reference processor is free-running at the selected reference frequency and is not dependent on a phase-locked loop (PLL), as is the case in most other lock-in amplifiers. Consequently, the phase noise is extremely low, and because no time is required for a PLL to acquire lock, reference acquisition is immediate. See appendix A for numerical values of phase noise.

In the internal reference highband mode (i.e. reference frequencies > 60 kHz), the instrument essentially operates as if in external mode, except that the reference trigger input is now provided by an internal link from the output of the direct digital synthesizer.

3.2.08 Internal Oscillator

The model 7225BFP, in common with many other lock-in amplifiers, incorporates an internal oscillator which may be used to drive an experiment. However, unlike most other instruments, the oscillator in the model 7225BFP is digitally synthesized with the result that the output frequency is extremely accurate and stable. The oscillator operates over the same frequency range as the lock-in amplifier, 1 mHz to 120 kHz.

The source of the oscillator depends on whether the instrument is operating on internal or external reference mode and on the selected frequency.

In internal reference baseband mode (< 60 kHz) the oscillator is derived from the reference channel DSP. This outputs a series of digital values, corresponding to a sinusoid at the required frequency, to a 16-bit DAC which in turn feeds a variable attenuator. The output of the attenuator is the internal oscillator output.

In internal reference highband mode (> 60 kHz) and external reference mode, the oscillator is derived from a dedicated direct digital synthesizer (DDS).

A further choice of output at the **OSC OUT** connector is offered when the unit is operating in external reference mode. In this situation, if the synchronous oscillator (also called the demodulator monitor) control is turned on, then the OSC OUT signal becomes a direct analog representation of the sinusoidal signal at the reference input to the X channel phase sensitive detector. Consequently it is affected by both the reference phase shifter and harmonic controls of the reference channel.

For example, if an external reference at 1 kHz were applied, the unit were set to operate in the 2F mode and the synchronous oscillator were turned on, then the signal at the **OSC OUT** connector would be a 2 kHz sinusoid whose phase could be adjusted using the reference phase shifter.

When used in the synchronous oscillator (demodulator monitor) mode, OSC OUT is updated at the rate at which the reference channel generates new values for the demodulators. Since this occurs approximately once every 6 μ s, this should be taken into account when viewing the waveform on an oscilloscope.

3.2.09 Demodulator DSP

The essential operation of the demodulator DSP is to multiply the digitized output of the signal channel by data sequences called the X and Y demodulation functions and to operate on the results with digital low-pass filters (the output filters). The demodulation functions, which are derived by use of a look-up table from the phase values supplied by the reference channel DSP, are sinusoids with frequency equal to an integer multiple, $n f_{\text{ref}}$, of the reference frequency f_{ref} . The Y demodulation function is the X demodulation function delayed by a quarter of a period. The integer n is called the reference harmonic number and in normal lock-in amplifier operation is set to unity. Throughout the remainder of this text, the reference harmonic number will be assumed to be unity unless specifically stated to have a non-unity value.

The outputs from the X channel and Y channel multipliers feed the first stage of the X and Y channel output filters. The outputs of these in turn drive two 16-bit digital to analog converters (DACs) which generate the instrument's FAST X and FAST Y analog outputs. In addition, the signals are fed to further low-pass filters before subsequent processing by the instrument's host microprocessor.

3.2.10 Output Processor

Although shown on the block diagram as a separate entity, the output processor is in fact part of the instrument's main microprocessor. It provides more digital filtering of the X and Y channel signals if required, calculates the vector magnitude, R, where $R = \sqrt{X^2 + Y^2}$ and phase angle, θ , where $\theta = \tan^{-1}(Y/X)$, and routes any of these

signals via two further 16-bit DACs to the unit's **CH1** and **CH2** output connectors. It also allows one of the two auxiliary analog inputs, **ADC1** and **ADC2**, which are digitized by a 16-bit analog to digital converter, to be used in ratio calculations.

3.2.11 Main Microprocessor

All functions of the instrument are under the control of a microprocessor which in addition supports the RS232 and GPIB (IEEE-488) computer interfaces. This processor also drives the instrument's 8-bit digital programmable output port, which may be used for controlling auxiliary apparatus.

The microprocessor has access to memory which may be used for storage of the instrument's outputs as curves prior to transferring them to a computer via the computer interfaces. In addition to using this function for the normal outputs, such as the X and Y output signals, it may also be used with the auxiliary ADC inputs to allow the instrument to operate as a transient recorder. The internal oscillator frequency sweep function is also controlled by the microprocessor.

A particularly useful feature of the design is that only part of the controlling firmware program code, which the microprocessor runs, is permanently resident in the instrument. The remainder is held in flash EEPROM and can be updated via the RS232 computer interface. It is therefore possible to change the functionality of the instrument, perhaps to include a new feature or update the computer command set, simply by connecting it to a computer and running an Update program.

3.3 Accuracy

3.3.01 Absolute Accuracy Specifications

When the demodulator is operating under correct conditions, the absolute gain accuracy of the instrument is limited by the analog components in the signal channel, and the absolute phase accuracy is limited by the analog components in both the signal channel and the reference channel. The resulting typical accuracy is ± 0.5 percent of the full-scale sensitivity and ± 0.5 degree. When the higher values of AC Gain are in use, the errors tend to increase in the upper part of the frequency range (above 25 kHz).

3.3.02 Relative Accuracy

The majority of lock-in amplifier measurements are concerned with the variation of the input signal with time, temperature, etc. or with the comparison of two different specimens. In these cases the absolute accuracy is of less importance than the accuracy with which readings can be transferred from range to range.

If the Automatic AC Gain control is turned off then in many cases the AC Gain control can be manually set to accommodate a given noise level. Subsequent changes in the instrument's full-scale sensitivity then only affect the digital gain thereby eliminating any of the errors which might arise from changes in the analog gain.

3.4 Full-Scale Sensitivity and AC Gain Control

The full-scale sensitivity is adjusted by the SEN command. The analog outputs and analog meter limit at a level a few percent above the full-scale sensitivity value, but the digital outputs returned over the interfaces do not limit until a level of ± 300 percent full-scale has been reached.

As stated in section 3.2.04, the best performance is obtained by making the AC Gain value as large as possible without causing amplifier overload.

Note that the demodulator gain is adjusted automatically when the AC Gain value is changed, in order to maintain the SEN value. However, the user is prevented from setting an illegal AC Gain value, i.e. one that would result in overload on a full-scale input signal. Similarly, if the user selects a SEN value which causes the present AC Gain value to be illegal, the AC Gain will change to the nearest legal value.

In practice, this system is very easy to operate. However, the user may prefer to make use of the Automatic AC Gain control which gives very good results in most circumstances.

Note that when signal channel overload occurs, the only action required is to reduce the AC Gain.

At reference frequencies above 1 Hz, the Auto-Sensitivity and Auto-Measure functions can be used to adjust the full-scale sensitivity.

3.5 Dynamic Reserve

At any given setting, the ratio

$$DR = 0.7 (\text{INPUT LIMIT}) / (\text{FULL-SCALE SENSITIVITY})$$

represents the factor by which the largest acceptable sinusoidal interference input exceeds the full-scale sensitivity and is called the Dynamic Reserve of the lock-in amplifier at that setting. (The factor 0.7 is a peak to rms conversion). The dynamic reserve is often expressed in decibels, for which

$$DR(\text{ in dB}) = 20 \log(DR(\text{ as a ratio}))$$

Applying this formula to the model 7225BFP with a maximum value of INPUT LIMIT (3 V) and the smallest available value of FULL-SCALE SENSITIVITY (20 nV) gives a value of about $1E8$ or 160 dB for the maximum available dynamic reserve. Figures of this magnitude are available from any DSP lock-in amplifier but are based only on arithmetical identities and do not give any indication of how the instrument actually performs. In fact, all current DSP lock-in amplifiers become too noisy and inaccurate for most purposes at reserves of greater than about 100 dB.

3.6 System Updates and Reference Frequency Changes

Both the signal channel and the reference channel contain calibration parameters which are dependent on the reference frequency. These include corrections to the anti-alias filter and to the analog circuits in the reference channel.

In external reference operation the processor uses the reference frequency meter to monitor the reference frequency and updates these parameters when a change of about 2 percent has been detected.

All the parameters are also updated when the LOCK command is executed. Therefore if the most accurate and reproducible settings are required, the LOCK command should be executed after every intentional change in reference frequency, when in the external reference modes. Note that sufficient time must be allowed for the frequency meter to give a fully accurate value.

With internal reference operation, regardless of the frequency mode, the frequency-dependent parameters are updated on any change of reference frequency, without the need to issue the LOCK command.

3.7 Reference Phase and Phase Shifter

In external reference mode, and where the reference input is a sinusoid, the reference phase is defined as the phase of the X demodulation function with respect to the reference input.

This means that when the reference phase is zero and the signal input to the demodulator is a full-scale sinusoid in phase with the reference input sinusoid, the X output of the demodulator is a full-scale positive value and the Y output is zero.

The circuit connected to the **REF IN** input actually detects a positive-going crossing of the mean value of the applied reference voltage. Therefore when the reference input is not sinusoidal, its effective phase is the phase of a sinusoid with a positive-going zero crossing at the same point in time, and accordingly the reference phase is defined with respect to this waveform. Similarly, the effective phase of an applied reference input to the **REF TTL** input is that of a sinusoid with a positive-going zero crossing at the same point in time. The actual reference mode in use is selected by the IE command.

The reference phase is adjusted to its required value by the use of a digital phase shifter, which is accessed by the command REFP or with the Auto-Phase function.

In basic lock-in amplifier applications the purpose of the experiment is to measure the amplitude of a signal which is of fixed frequency and whose phase with respect to the reference input does not vary. This is the *scalar* measurement, often implemented with a chopped optical beam. Many other lock-in amplifier applications are of the *signed scalar* type, in which the purpose of the experiment is to measure the amplitude and sign of a signal which is of fixed frequency and whose phase with respect to the

reference input does not vary apart from reversals of phase corresponding to changes in the sign of the signal. A well known example of this situation is the case of a resistive bridge, one arm of which contains the sample to be measured. Other examples occur in derivative spectroscopy, where a small modulation is applied to the angle of the grating (in optical spectroscopy) or to the applied magnetic field (in magnetic resonance spectroscopy). Double beam spectroscopy is a further common example.

In this signed scalar measurement the phase shifter must be set, after removal of any zero errors, to maximize the X or the Y output of the demodulator. This is the only method that will give correct operation as the output signal passes through zero, and is also the best method to be used in an unsigned scalar measurement where any significant amount of noise is present.

3.8 Output Channel Filters

3.8.01 Slope

As with most lock-in amplifiers, the output filter configuration in the model 7225BFP is controlled by the SLOPE variable. This may seem somewhat strange, and a few words of explanation may be helpful.

In traditional audio terminology, a first-order low-pass filter is described as having “a slope of 6 dB per octave” because in the high frequency limit its gain is inversely proportional to frequency (6 dB is approximately a factor of 2 in amplitude and an octave is a factor of 2 in frequency); similarly a second-order low-pass filter is described as having “a slope of 12 dB per octave”. These terms have become part of the accepted terminology relating to lock-in amplifier output filters and are used in the model 7225BFP to apply to the envelope of the frequency response function of the digital FIR (finite impulse response) output filters.

The 6 dB/octave filters are not satisfactory for most purposes because they do not give good rejection of periodic components in the demodulator output, including the inevitable component at double the reference frequency. However, the 6 dB/octave filter finds use where the lock-in amplifier is incorporated in a feedback control loop, and in some situations where the form of the time-domain response is critical. The user is recommended to use 12 dB/octave unless there is some definite reason for not doing so.

Note that the filter slope for the rear panel **FAST X** and **FAST Y** outputs is fixed at 6 dB/octave.

3.8.02 Time Constants and Synchronization

The output time constant can be varied between 10 μ s and 100 ks. Values from 10 μ s to 640 μ s are available at the rear panel **FAST X** and **FAST Y** outputs, while values from 5 ms to 100 ks apply to all other outputs, including **CH1**, **CH2** and the digital displays.

The filters are of the Finite Impulse Response (FIR) type with the averaging time of

each section being equal to double the nominal time constant. They offer a substantial advantage in response time compared with analog filters or digital Infinite Impulse Response (IIR) filters.

When the reference frequency is below 10 Hz the synchronous filter option is available. This means that the actual time constant of the filter is not generally the selected value T but a value which is equal to an integer number of reference cycles. If T is greater than 1 reference cycle, the time constant is between T/2 and T.

Where random noise is relatively small, synchronous filter operation gives a major advantage in low-frequency measurements by enabling the system to give a constant output even when the output time constant is equal to only 1 reference cycle.

3.8.03 Output Offset and Expand

The output offset facility enables $\pm 300\%$ full-scale offset to be applied to the X, Y or both displays. Note however that the rear panel analog outputs limit at $\pm 120\%$ full scale.

The output expand facility allows a $\times 10$ expansion to be applied to the X, Y, both or neither outputs, and hence to the CH1 and CH2 analog outputs, if these are set to output X or Y values.

3.9 Use of Magnitude and Signal Phase Outputs

If the input signal $V_s(t)$ is a reference frequency sinusoid of constant amplitude, and the output filters are set to a sufficiently long time constant, the demodulator outputs are constant levels V_x and V_y . The function $\sqrt{V_x^2 + V_y^2}$ is dependent only on the amplitude of the required signal $V_s(t)$ (i.e. it is not dependent on the phase of $V_s(t)$ with respect to the reference input) and is computed by the output processor in the lock-in amplifier and made available as the “magnitude” output. The phase angle between $V_s(t)$ and the X demodulation function is called the “signal phase”: this is equal to the angle of the complex quantity $(V_x + jV_y)$ (where j is the square root of -1) and is also computed by the processor by means of a fast arctan algorithm.

The magnitude and signal phase outputs are used in cases where phase is to be measured, or alternatively where the magnitude is to be measured under conditions of uncertain or varying phase.

One case of varying phase is that in which the reference input is not derived from the same source as that which generates the signal, and is therefore not exactly at the same frequency. In this case, if the input signal is a sinusoid of constant amplitude, the X and Y demodulator outputs show slow sinusoidal variations at the difference frequency, and the magnitude output remains steady.

However, the magnitude output has disadvantages where significant noise is present at the outputs of the demodulator. When the required signal outputs (i.e. the mean values of the demodulator outputs) are less than the noise, the outputs take both positive and

negative values but the magnitude algorithm gives only positive values: this effect, sometimes called noise rectification, gives rise to a zero error which in the case of a Gaussian process has a mean value equal to 0.798 times the combined root-mean-square (rms) value of the X and Y demodulator noise. Note that unlike other forms of zero error this is not a constant quantity which can be subtracted from all readings, because when the square root of the sum of the squares of the required outputs becomes greater than the total rms noise the error due to this mechanism disappears.

A second type of signal-dependent error in the mean of the magnitude output occurs as a result of the inherent non-linearity of the magnitude formula: this error is always positive and its value, expressed as a fraction of the signal level, is half the ratio of the mean-square value of the noise to the square of the signal.

These considerations lead to the conclusion that when the magnitude output is being used, the time constants of the demodulator should be set to give the required signal/noise ratio at the X and Y demodulator outputs; improving the signal/noise ratio by averaging the magnitude output itself is not to be recommended.

For analogous reasons, the magnitude function also shows signal-dependent errors when zero offsets are present in the demodulator. For this reason, it is essential to reduce zero offsets to an insignificant level (usually by the use of the Auto-Offset function) when the magnitude output is to be used.

Note that the majority of signal recovery applications are scalar measurements, where the phase between the required signal and the reference voltage is constant apart from possible phase reversals corresponding to changes in the sign of the quantity being measured. In this situation the lock-in amplifier is used in the normal X-Y mode, with the phase shifter adjusted to maximize the X output and to bring the mean Y output to zero. (Refer to section 3.12.03 for further information on the correct use of the Auto-Phase function for this purpose.)

3.10 Noise Measurements

The noise measurement facility is available only in the baseband mode (i.e. at reference frequencies less than 60 kHz) and uses the output processor to perform a noise computation on the Y output where it is assumed that the waveform is *Gaussian with zero mean*. The zero mean is usually obtained by using the reference phase control or the Auto-Phase function with a comparatively long time constant (say 1 s) and the time constant is then reduced (to say 10 ms) for the noise measurement.

It is strongly recommended that an oscilloscope be used to monitor the signal at the rear panel **SIG MON** (signal monitor) output when making noise measurements as this is the best way of ensuring that a random process is being measured rather than line pick-up.

The indicated value of the noise (in $V/\sqrt{\text{Hz}}$ or $A/\sqrt{\text{Hz}}$) is the square root of the mean spectral density over the bandwidth defined by the setting of the output filter time constant.

3.11 Power-up Defaults

All instrument settings are retained when the unit is switched off. When the instrument is switched on again the settings are restored but with the following exceptions:-

- a) The signal channel reverts to AC coupling.
- b) The GPIB mask byte is set to zero.
- c) The curve buffer is cleared.
- d) Any sweep that was in progress at switch-off is terminated.
- e) Synchronous time constants are enabled.

3.12 Auto Functions

3.12.01 Introduction

The auto functions are groups of control operations which can be executed by means of a single command. The auto functions allow easier, faster operation in most applications, however, direct manual operation or special purpose control programs may give better results in certain circumstances. During application of several of the auto functions, decisions are made on the basis of output readings made at a particular moment. Where this is the case, it is important for the output time constant set by the user to be long enough to reduce the output noise to a sufficiently low level so that valid decisions can be made and sufficient time is allowed for the output to settle.

The following sections contain brief descriptions of the auto functions.

3.12.02 Auto-Sensitivity

This function only operates when the reference frequency is above 1 Hz. A single Auto-Sensitivity operation consists of increasing the full-scale sensitivity range if the magnitude output is greater than 90 % of full-scale, or reducing the range if the magnitude output is less than 30 % of full-scale. After the Auto-Sensitivity function is called, Auto-Sensitivity operations continue to be made until the required criterion is met.

In the presence of noise, or a time-varying input signal, it may be a long time before the Auto-Sensitivity sequence comes to an end, and the resulting setting may not be what is really required.

3.12.03 Auto-Phase

In an Auto-Phase operation the value of the signal phase is computed and an appropriate phase shift is then introduced into the reference channel so as to bring the value of the signal phase to zero. The intended result is to null the output of the Y channel while maximizing the output of the X channel.

Any small residual phase can normally be removed by calling Auto-Phase for a second time after a suitable delay to allow the outputs to settle.

The Auto-Phase facility is normally used with a clean signal which is known to be of the required phase. It usually gives very good results provided that the X and Y channel outputs are steady when the procedure is called.

If a zero error is present on the outputs, such as may be caused by unwanted coupling between the reference and signal channel inputs, then the following procedure should be adopted:-

- 1) Remove the source of input signal, without disturbing any of the connections to the signal input which might be picking up interfering signals from the reference signal. In an optical experiment, for example, this could be done by shielding the detector from the source of chopped light.
- 2) Execute an Auto-Offset operation, which will reduce the X and Y outputs to zero.
- 3) Re-establish the source of input signal. The X and Y channel outputs will now indicate the true level of the input signal, *at the present reference phase setting*.
- 4) Execute an Auto-Phase operation. This will set the reference phase shifter to the phase angle of the input signal. However, because the offset levels which were applied in step 2 were calculated at the original reference phase setting, they will not now be correct and the instrument will in general display a non-zero Y output value.
- 5) Remove the source of input signal again.
- 6) Execute a second Auto-Offset operation, which will reduce the X and Y outputs to zero at the new reference phase setting.
- 7) Re-establish the source of input signal.

This technique, although apparently complex, is the only way of effectively removing crosstalk which is not generally in the same phase as the required signal.

3.12.04 Auto-Offset

In an Auto-Offset operation the X offset and Y offset functions are turned on and are automatically set to the values required to give zero values at both the X and the Y outputs. Any small residual values can normally be removed by calling Auto-Offset for a second time after a suitable delay to allow the outputs to settle.

The primary use of the Auto-Offset is to cancel out zero errors which are usually caused by unwanted coupling or crosstalk between the signal channel and the reference channel, either in the external connections or possibly under some conditions in the instrument itself.

Note that if a zero error is present, the Auto-Offset function should be executed before any execution of Auto-Phase.

3.12.05 Auto-Measure

This function only operates when the reference frequency is greater than 1 Hz. It performs the following operations:

The line filter is disabled, AC coupling is established, the voltage measurement mode is entered, with the single-ended A input mode, the FET input device is selected and the FLOAT mode is set. If the reference frequency is more than 10 Hz the output time constant is set to 100 ms, otherwise it is set to the lowest synchronous value, the filter slope is set to 12 dB/octave, output expand is switched off, the reference harmonic mode is set to 1, the X offset and Y offset functions are switched off and the Auto-Phase and Auto-Sensitivity functions are called. The Auto-Sensitivity function also adjusts the AC Gain if required.

The Auto-Measure function is intended to give a quick setting of the instrument which will be approximately correct in typical simple single-ended measurement situations. For optimum results in any given situation, it may be convenient to start with Auto-Measure and to make subsequent modifications to individual controls.

3.12.06 Default Setting

With an instrument of the design of the model 7225BFP, where there are many controls of which only a few are regularly adjusted, it is very easy to overlook the setting of one of them. Consequently a Default Setting function is provided, which sets all the controls to a defined state. This is most often used as a rescue operation to bring the instrument into a known condition when it is giving unexpected results. A listing of the settings which are invoked by the use of this function can be found in appendix F.

4.1 Front Panel

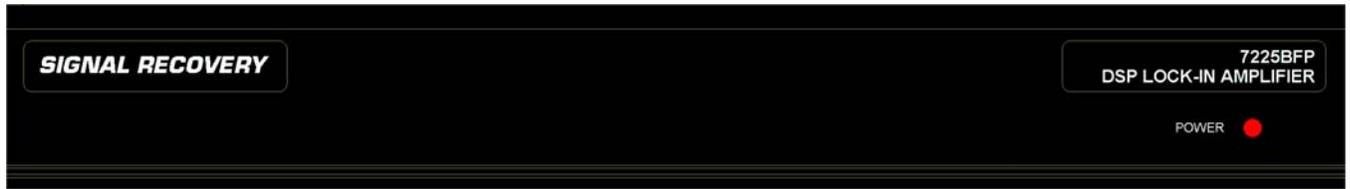


Figure 4-1, Model 7225BFP Front Panel Layout

As shown in figure 4-1 the front panel of the instrument is blank other than for the product identification labels and the **POWER** LED which glows when the unit is powered.

4.2 Rear Panel

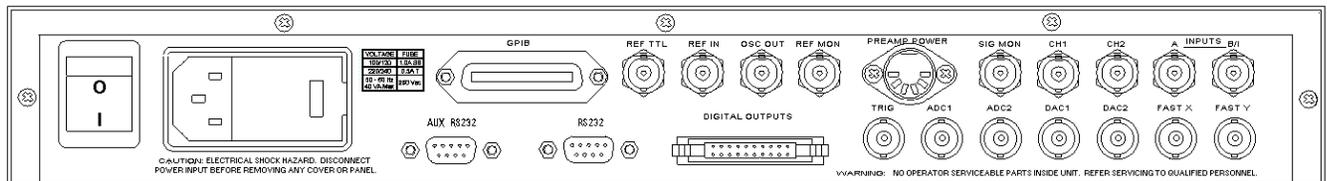


Figure 4-2, Model 7225BFP Rear Panel Layout

As shown in figure 4-2, the line power switch, line input voltage selector, two RS232 connectors, a GPIB (IEEE 488) connector, the digital output port, a preamplifier power socket, and 16 BNC signal connectors are mounted on the rear panel of the instrument.

4.2.01 Line Power Switch

Press the end of the switch marked **I** to turn on the instrument's power, and the other end, marked **O**, to turn it off.

4.2.02 Line Power Input Assembly

This houses the line voltage selector and line input fuse. To check, and if necessary change, the fuse or line voltage see the procedure in section 2.1.05.

4.2.03 RS232 Connector

This 9-pin D type RS232 interface connector implements pins 1, 2, 3 and 7 (Earth Ground, Transmit Data, Receive Data, Logic Ground) of a standard DTE interface. To make a connection to a PC-compatible computer, it is normally sufficient to use a three-wire cable connecting Transmit Data to Receive Data, Receive Data to Transmit Data, and Logic Ground to Logic Ground. Appendix D shows the connection diagrams of cables suitable for computers with 9-pin and 25-pin serial connectors. Pinouts for

this connector are given in appendix B.

4.2.04 AUX RS232 Connector

This connector is used to link other compatible **SIGNAL RECOVERY** equipment together in a “daisy-chain” configuration. Up to an additional 15 units can be connected in this way. Each unit must be set to a unique address. Pinouts for this connector are given in appendix B.

4.2.05 GPIB Connector

The GPIB interface connector conforms to the IEEE-488 1978 Instrument Bus Standard. The standard defines all voltage and current levels, connector specifications, timing and handshake requirements.

4.2.06 DIGITAL OUTPUTS Connector

This connector provides eight TTL output lines, each of which can be set high or low via the computer interfaces. It is most commonly used for controlling auxiliary apparatus, such as lamps, shutters and heaters. Pinouts for this connector are given in appendix B.

4.2.07 REF TTL Connector

This connector is provided to allow TTL compatible pulses to be used as the reference input.

4.2.08 REF IN Connector

This is the input connector for a general purpose external reference signal.

4.2.09 OSC OUT Connector

This is the output connector for the internal oscillator. Commands OA and OF set the amplitude and frequency of the oscillator respectively. The amplitude and frequency range at this connector is given below.

Output	Range	
Amplitude	0 V to 5 V rms	adjustable in 1 mV steps (min)
Frequency	0 Hz to 120 kHz	adjustable in 1 mHz steps (min)

4.2.10 REF MON Connector

The signal at this connector is a TTL-compatible waveform synchronous with the reference. This output monitors correct reference channel operation but its polarity is not uniquely defined so that it does not necessarily show the correct phase relationship with the **SIG MON** output.

4.2.11 PREAMP POWER Connector

This connector supplies ± 15 V at up to 100 mA and can be used for powering any of

several optional remote preamplifiers available from **SIGNAL RECOVERY**. Pinouts for this connector are given in appendix B.

4.2.12 SIG MON Connector

The signal at this connector is derived from a point immediately prior to the main analog to digital converter, and after the preamplifier, line filter and anti-alias filters.

4.2.13 CH1, CH2 Connectors

The signal at these connectors is an analog voltage corresponding to a selected output, such as X, Y, R, θ , etc., as specified by the CH n₁ [n₂] command. The minimum time constant that can be used is 5 ms. The full-scale output voltage range is ± 10.0 V although the outputs remain valid to ± 12.0 V to provide some overload capability.

4.2.14 A and B/I Signal Input Connectors

The **A** connector is the signal input connector for use in single-ended and differential voltage mode. The **B/I** connector is the signal input connector for use in differential voltage mode (A-B) and is also the signal input connector when current input mode is selected.

4.2.15 TRIG Connector

This connector accepts a TTL-compatible input and can be used for triggering the auxiliary Analog to Digital Converters (ADCs). The input operates on the positive edge only.

4.2.16 ADC1, ADC2 Connectors

The input voltages at these connectors may be digitized using the auxiliary ADCs and read either by the use of a computer interface command. The input voltages are sampled and held when the ADC is triggered, and several different trigger modes are available. The input voltage range is ± 10.0 V and the resolution is 1 mV.

4.2.17 DAC1, DAC2 Connectors

There are two DAC (Digital to Analog Converter) output connectors. The output voltages at these connectors can be set by the use of remote computer commands. The output range is ± 10.0 V and the resolution is 1 mV.

4.2.18 FAST X, FAST Y Connectors

The signals at these two connectors are the X channel and Y channel output signals derived from a point after the first stage of output low-pass filtering. The maximum time constant that can be used is 640 μ s, with a fixed slope of 6 dB/octave. Visual interpretation of the waveforms at these connectors, as displayed on an oscilloscope, when the instrument is operating in the highband mode (i.e. above 60 kHz) is difficult.

5.1 Introduction

The model 7225BFP includes both RS232 and IEEE-488 (also known as GPIB for General Purpose Interface Bus) interface ports, designed to allow full control of the lock-in amplifier using the comprehensive command set (see section 5.4).

This chapter describes the capabilities of the instrument when operated remotely and discusses how this is done.

5.2 Capabilities

5.2.01 General

All instrument controls can be set remotely and the present setting of each control may be determined by the computer. All instrument may be read remotely.

In addition to the normal signal recovery functions of a lock-in amplifier, the instrument also provides the following features:-

5.2.02 Curve Storage

A 32768 point memory is included in the instrument. This may be used as a single curve or split into a number of curves, each of which will record chosen instrument outputs when an acquisition is initiated. The memory is useful for overcoming speed limitations in the interfaces, allowing outputs to be recorded faster than would be possible by transferring them to the computer. It also finds use in experiments where data is recorded over a long period of time, since it frees the computer from the need to measure time intervals and send requests for output to the instrument. On completion of the acquisition, the stored curves are transferred to the computer for processing.

5.2.03 Burst Mode Acquisition

A special use of the curve storage memory is as a transient recorder, when the voltage at the ADC1 or ADC2 input is sampled and stored at rates up to 40 kHz. Again, stored curves are transferred to the computer for processing.

5.2.04 Internal Oscillator Amplitude and Frequency Sweep Generator

The instrument's internal oscillator may be swept in frequency and/or amplitude over a predefined range. Amplitude sweeps are always linear with time, but frequency sweeps may be of linear or logarithmic format. These facilities allow the instrument to function as a simple swept-frequency oscillator, or, in conjunction with the curve storage capability, allow frequency response curves to be recorded.

5.3 RS232 and GPIB Operation

5.3.01 Introduction

Control of the lock-in amplifier from a computer is accomplished by means of communications over the RS232 or GPIB interfaces. The communication activity consists of the computer sending commands to the lock-in amplifier, and the lock-in amplifier responding, either by sending back some data or by changing the setting of one of its controls. The commands and responses are encoded in standard 7-bit ASCII format, with one or more additional bits as required by the interface (see below).

The two ports cannot be used simultaneously, but when a command has been completed, the lock-in amplifier will accept a command at either port. Also when the test echo facility has been activated all output from the computer to the GPIB can be monitored by a terminal attached to the RS232 connector.

Although the interface is primarily intended to enable the lock-in amplifier to be operated by a computer program specially written for an application, it can also be used in the direct, or terminal, mode. In this mode the user enters commands on a keyboard and reads the results on a video screen.

The simplest way to establish the terminal mode is to connect a standard terminal, or a terminal emulator, to the RS232 port. A terminal emulator is a computer running special-purpose software that makes it act as a terminal. In the default (power-up) state of the port, the lock-in amplifier sends a convenient prompt character when it is ready to receive a command, and echoes each character that is received.

Microsoft Windows 9X includes a program called HyperTerminal, usually in the Accessories group, which may be used as a terminal emulator. On the other hand, a simple terminal program with minimal facilities can be written in a few lines of BASIC code (see appendix C.1).

5.3.02 RS232 Interface - General Features

The RS232 interface in the model 7225BFP is implemented with three wires; one carries digital transmissions from the computer to the lock-in amplifier, the second carries digital transmissions from the lock-in amplifier to the computer and the third is the Logic Ground to which both signals are referred. The logic levels are ± 12 V referred to Logic Ground, and the connection may be a standard RS232 cable in conjunction with a null modem or alternatively may be made up from low-cost general purpose cable. The pinout of the RS232 connectors are shown in appendix B and cable diagrams suitable for coupling the instrument to a computer are shown in appendix D.

The main advantages of the RS232 interface are:

- 1) It communicates via a serial port which is present as standard equipment on nearly all computers, using leads and connectors which are available from suppliers of

computer accessories or can be constructed at minimal cost in the user's workshop.

- 2) It requires no more software support than is normally supplied with the computer, such as the Windows HyperTerminal programs.

A single RS232 transmission consists of a start bit followed by 7 or 8 data bits, an optional parity bit, and 1 stop bit. The rate of data transfer depends on the number of bits per second sent over the interface, usually called the baud rate. In the model 7225BFP the baud rate can be set to a range of different values up to 19,200, corresponding to a minimum time of less than 0.5 ms for a single character.

Mostly for historical reasons, there are a very large number of different ways in which RS232 communications can be implemented. Apart from the baud rate options, there are choices of data word length (7 or 8 bits), parity check operation (even, odd or none), and number of stop bits (1 or 2). With the exception of the number of stop bits, which is fixed at 1, these settings may be adjusted by means of the RS command.

NOTE: In order to achieve satisfactory operation, the RS232 settings must be set to exactly the same values in the terminal or computer as in the lock-in amplifier.

5.3.03 Choice of Baud Rate

Where the lock-in amplifier is connected to a terminal or to a computer implementing an echo handshake, the highest available baud rate of 19,200 is normally used if, as is usually the case, this rate is supported by the terminal or computer. Lower baud rates may be used in order to achieve compatibility with older equipment or where there is some special reason for reducing the communication rate.

5.3.04 Choice of Number of Data Bits

The model 7225BFP lock-in amplifier uses the standard ASCII character set, containing 127 characters represented by 7-bit binary words. If an 8-bit data word is selected, the most significant bit is set to zero on output from the lock-in amplifier and ignored on input. The result is that either the 8-bit or the 7-bit option may be used, but the 7-bit option can result in slightly faster communication. The only exception to this is when it is intended to use the Dump Curve Binary command (DCB), which requires the 8-bit setting.

5.3.05 Choice of Parity Check Option

Parity checks are not required at the baud rates available in the model 7225BFP, that is up to 19,200 baud, with typical cable lengths of up to a few meters. Therefore no software is provided in the model 7225BFP for dealing with parity errors. Where long cables are in use, it may be advisable to make use of a lower baud rate. The result is that any of the parity check options may be used, but the no-parity option will result in slightly faster communication.

Where the RS232 parameters of the terminal or computer are capable of being set to any desired value, an arbitrary choice must be made. In the model 7225BFP the

combination set at the factory is even parity check, 7 data bits, and one stop bit (fixed) because these are the MS-DOS default.

5.3.06 Auxiliary RS232 Interface

The auxiliary RS232 interface allows up to sixteen model 7225BFPs or a mixture of compatible instruments to be connected to one serial port on the computer. The first lock-in amplifier is connected to the computer in the usual way. Additional lock-in amplifiers are connected in a daisy-chain fashion using null-modem cables, the **AUX RS232** port of the first to the **RS232** port of the second, the **AUX RS232** port of the second to the **RS232** port of the third, etc. The address of the lock-in amplifier must be set up before any communication takes place. At power-up the RS232 port of each lock-in amplifier is fully active irrespective of its address. Since this means that all lock-in amplifiers in the daisy-chain are active on power-up, the first command must be `\N n` where `n` is the address of one of the lock-in amplifiers. This will deselect all but the addressed lock-in amplifier. When it is required to communicate with another lock-in amplifier, send a new `\N n` command using the relevant address.

NOTE: When programming in C remember that in order to send the character `\` in a string it is necessary to type in `\\`.

5.3.07 GPIB Interface - General Features

The GPIB is a parallel digital interface with 8 bi-directional data lines, and 8 further lines which implement additional control and communication functions. Communication is through 24-wire cables (including 8 ground connections) with special-purpose connectors which are constructed in such a way that they can be stacked on top of one another to enable numerous instruments to be connected in parallel. By means of internal hardware or software switches, each instrument is set to a different address on the bus, usually a number in the range 0 to 31. In the model 7225BFP the address is set using the GP command.

A most important aspect of the GPIB is that its operation is defined in minute detail by the IEEE-488 standard, usually implemented by highly complicated special-purpose semiconductor devices that are present in each instrument and communicate with the instrument's microprocessor. The existence of this standard greatly simplifies the problem of programming the bus controller, i.e. the computer, to implement complex measurement and test systems involving the interaction of numerous instruments. There are fewer interface parameters to be set than with RS232 communications.

The operation of the GPIB requires the computer to be equipped with special-purpose hardware, usually in the form of a plug-in card, and associated software which enable it to act as a bus controller. The control program is written in a high-level language, usually BASIC or C, containing additional subroutines implemented by software supplied by the manufacturer of the interface card.

Because of the parallel nature of the GPIB and its very effective use of the control lines including the implementation of a three-wire handshake (see below), comparatively high data rates are possible, up to a few hundred thousand bytes per second. In typical setups the data rate of the GPIB itself is not the factor that limits the

rate of operation of the control program.

5.3.08 Handshaking and Echoes

A handshake is a method of ensuring that the transmitter does not send a byte until the receiver is ready to receive it, and, in the case of a parallel interface, that the receiver reads the data lines only when they contain a valid byte.

GPIB Handshaking

The GPIB interface includes three lines (*DAV, *NRFD, *NDAC) which are used to implement a three-wire handshake. The operation of this is completely defined by the IEEE-488 standard and is fully automatic, so that the user does not need to know anything about the handshake when writing programs for the GPIB. Note that each command must be correctly terminated.

RS232 Handshaking

In the RS232 standard there are several control lines called handshake lines (RTS, DTR outputs and CTS, DSR, DCD inputs) in addition to the data lines (TD output and RD input). However, these lines are not capable of implementing the handshaking function required by the model 7225BFP on a byte-by-byte basis and are not connected in the model 7225BFP apart from the RTS and DTR outputs which are constantly asserted.

Note that some computer applications require one or more of the computer's RS232 handshake lines to be asserted. If this is the case, and if the requirement cannot be changed by the use of a software switch, the cable may be used in conjunction with a null modem. A null modem is an adapter which connects TD on each side through to RD on the other side, and asserts CTS, DSR, and DCD on each side when RTS and DTR are asserted on the other side.

With most modern software there is no need to assert any RS232 handshake lines and a simple three-wire connection can be used. The actual handshake function is performed by means of bytes transmitted over the interface.

The more critical handshake is the one controlling the transfer of a command from the computer to the lock-in amplifier, because the computer typically operates much faster than the lock-in amplifier and bytes can easily be lost if the command is sent from a program. (Note that because of the limited speed of human typing, there is no problem in the terminal mode.) Therefore an echo handshake is used, which works in the following way: after receiving each byte, the lock-in amplifier sends back an echo, that is a byte which is a copy of the one that it has just received, to indicate that it is ready to receive the next byte. Correspondingly, the computer does not send the next byte until it has read the echo of the previous one. Usually the computer makes a comparison of each byte with its echo, and this constitutes a useful check on the validity of the communications.

Where the echo is not required, it can be suppressed by negating bit 3 in the RS232 parameter byte. The default (power-up) state of this bit is for it to be asserted. The program RSCOM2.BAS in section C.2 illustrates the use of the echo handshake.

5.3.09 Terminators

In order for communications to be successfully established between the lock-in amplifier and the computer, it is essential that each transmission, i.e. command or command response, is terminated in a way which is recognizable by the computer and the lock-in amplifier as signifying the end of that transmission.

In the model 7225BFP there are three input termination options for GPIB communications, selected by means of the GP command. The lock-in amplifier may be set to expect the <CR> byte (ASCII 13) or the <CR,LF> sequence (ASCII 13 followed by ASCII 10) to be appended by the controller as a terminator to the end of each command, or alternatively instead of a terminator it may expect the EOI signal line (pin 5 on the GPIB connector) to be asserted during the transmission of the last character of the command. The third option is normally to be preferred with modern interface cards which can easily be set to a wide variety of configurations.

The selected GPIB termination option applies also to the output termination of any responses sent back by the lock-in amplifier to the controller, i.e. the lock-in amplifier will send <CR> or <CR,LF> or no byte as appropriate. In all cases the lock-in amplifier asserts the EOI signal line during the transmission of the last byte of a response.

In RS232 communications, the lock-in amplifier automatically accepts either <CR> or <CR,LF> as an input command terminator, and sends out <CR,LF> as an output response terminator except when the noprompt bit (bit 4 in the RS232 parameter byte) is set in which case the terminator is <CR>. The default (power-up) state of this bit is zero.

5.3.10 Command Format

The simple commands listed in section 5.4 have one of five forms:

CMDNAME terminator
CMDNAME n terminator
CMDNAME [n] terminator
CMDNAME [n₁ [n₂]] terminator
CMDNAME n₁ [n₂] terminator

where CMDNAME is an alphanumeric string that defines the command, and n, n₁, n₂ are parameters separated by spaces. When n is not enclosed in square brackets it must be supplied. [n] means that n is optional. [n₁ [n₂]] means that n₁ is optional and if present may optionally be followed by n₂. Upper-case and lower-case characters are equivalent. Terminator bytes are defined in section 5.3.09.

NOTE: *Where the command syntax includes optional parameters and the command is sent without the optional parameters, the response consists of a transmission of the present values of the parameter(s).*

Any response transmission consists of one or more numbers followed by a response terminator. Where the response consists of two or more numbers in succession, they are separated by a delimiter (section 5.3.11).

Some commands have an optional floating point mode which is invoked by appending a . (full stop) character to the end of the command and before the parameters. This allows some parameters to be entered or read in floating point format. The floating point output format is given below.

±1.234E±01

The number of digits between the decimal point and the exponent varies depending on the number but is a minimum of one and a maximum of eight. The input format is not as strict but if a decimal point is used there must be a digit before it. An exponent is optional. The following are all legal commands for setting the oscillator frequency to 100.1 Hz:

OF. 100.1
OF. 1.001E2
OF. +1.001E+02
OF. 1001E-1

5.3.11 Delimiters

Any response transmissions consist of one or two numbers followed by a response terminator. Where the response of the lock-in amplifier consists of two numbers in succession, they are separated by a byte called a delimiter. This delimiter can be any printing ASCII character and is selected by the use of the DD command.

5.3.12 Compound Commands

A compound command consists of two or more simple commands separated by semicolons (ASCII 59) and terminated by a single command terminator. If any of the responses involve data transmissions, each one is followed by an output terminator.

5.3.13 Status Byte, Prompts and Overload Byte

An important feature of the IEEE-488 standard is the serial poll operation by which a special byte, the status byte, may be read at any time from any instrument on the bus. This contains information which must be urgently conveyed from the instrument to the controller.

The function of the individual bits in the status byte is instrument dependent, apart from bit 6 (the request service bit) whose functions are defined by the standard.

In the model 7225BFP, bits 0 and 7 signify 'command complete' and 'data available' respectively. In GPIB communications, the use of these bits can lead to a useful simplification of the control program by providing a response subroutine which is the same for all commands, whether or not they send a response over the bus. The principle is that after any command is sent, serial poll operations are repeatedly

executed. After each operation bit 0 is tested; if this is found to be negated then bit 7 is tested, and if this is asserted then a read operation is performed. Serial poll operations continue until the lock-in amplifier asserts bit 0 to indicate that the command-response sequence is complete. This method deals successfully with compound commands.

In RS232 communications, comparatively rapid access to the status byte is provided by the prompt character which is sent by the lock-in amplifier at the same time as bit 0 becomes asserted in the status byte. This character is sent out by the lock-in amplifier after each command response (whether or not the response includes a transmission over the interface) to indicate that the response is finished and the instrument is ready for a new command. The prompt takes one of two forms. If the command contained an error, either in syntax or by a command parameter being out of range, or alternatively if an overload or reference unlock is currently being reported by the front-panel indicators, the prompt is ? (ASCII 63). Otherwise the prompt is * (ASCII 42).

These error conditions correspond to the assertion of bits 1, 2, 3 or 4 in the status byte. When the ? prompt is received by the computer, the ST command may be issued in order to discover which type of fault exists and to take appropriate action.

The prompts are a rapid way of checking on the instrument status and enable a convenient keyboard control system to be set up simply by attaching a standard terminal, or a simple computer-based terminal emulator, to the RS232 port. Where the prompt is not required it can be suppressed by setting the noprompt bit, bit 4 in the RS232 parameter byte. The default (power-up) state of this bit is zero.

Because of the limited number of bits in the status byte, it can indicate that an overload exists but cannot give more detail. An auxiliary byte, the overload byte returned by the N command, gives details of the location of the overload.

A summary of the bit assignments in the status byte and the overload byte is given below.

	Status Byte	Overload Byte
bit 0	command complete	not used
bit 1	invalid command	CH1 output overload
bit 2	command parameter error	CH2 output overload
bit 3	reference unlock	Y output overload
bit 4	overload	X output overload
bit 5	new ADC values available after external trigger	not used
bit 6	asserted SRQ	input overload
bit 7	data available	reference unlock

5.3.14 Service Requests

The interface defined by the IEEE-488 standard includes a line (pin 10 on the connector) called the SRQ (service request) line which is used by the instrument to signal to the controller that urgent attention is required. At the same time that the instrument asserts the SRQ line, it also asserts bit 6 in the status byte. The controller responds by executing a serial poll of all the instruments on the bus in turn and testing

bit 6 of the status byte in order to discover which instrument was responsible for asserting the SRQ line. The status byte of that instrument is then further tested in order to discover the reason for the service request and to take appropriate action.

In the model 7225BFP the assertion of the SRQ line is under the control of a byte called the SRQ mask byte which can be set by the user with the MSK command. If any bit in the status byte becomes asserted, and the corresponding bit in the mask byte has a non-zero value, the SRQ line is automatically asserted. If the value of the mask byte is zero, the SRQ line is never asserted.

Hence, for example, if the SRQ mask byte is set to 16, a service request would be generated as soon as an overload occurred; if the SRQ mask byte were set to 0, then service requests would never be generated.

5.4 Command Descriptions

This section lists the commands in logical groups, so that, for example, all commands associated with setting controls affecting the signal channel are shown together. Appendix G gives the same list of commands but in alphabetical order.

5.4.01 Signal Channel

IMODE [n] Current/Voltage mode input selector

The value of n sets the input mode according to the following table:

- | | |
|---|---------------------------------------------------------------------------------------|
| n | Input mode |
| 0 | Current mode off - voltage mode input enabled |
| 1 | High bandwidth (HB) current mode enabled - connect signal to B input connector |
| 2 | Low noise (LN) current mode enabled - connect signal to B input connector |

If n = 0 then the input configuration is determined by the VMODE command.

If n > 0 then current mode is enabled irrespective of the VMODE setting.

VMODE [n] Voltage input configuration

The value of n sets up the input configuration according to the following table:

- | | |
|---|----------------------------------|
| n | Input configuration |
| 0 | Both inputs grounded (test mode) |
| 1 | A input only |
| 3 | A-B differential mode |

Note that the IMODE command takes precedence over the VMODE command.

FET [n] Voltage mode input device control
 The value of n selects the input device according to the following table:

- n Selection
- 0 Bipolar device, 10 k Ω input impedance, 2 nV/ $\sqrt{\text{Hz}}$ voltage noise at 1 kHz
- 1 FET, 10 M Ω input impedance, 5 nV/ $\sqrt{\text{Hz}}$ voltage noise at 1 kHz

FLOAT [n] Input connector shield float/ground control
 The value of n sets the input connector shield switch according to the following table:

- n Selection
- 0 Ground
- 1 Float (connected to ground via a 1 k Ω resistor)

CP [n] Input connector coupling mode control
 The value of n sets the input coupling mode according to the following table:

- n Coupling mode
- 0 AC
- 1 DC

SEN [n]
 SEN. Full-scale sensitivity control
 The value of n sets the full-scale sensitivity according to the following table, depending on the setting of the IMODE control:

n	full-scale sensitivity		
	IMODE=0	IMODE=1	IMODE=2
1	2 nV	2 fA	n/a
2	5 nV	5 fA	n/a
3	10 nV	10 fA	n/a
4	20 nV	20 fA	n/a
5	50 nV	50 fA	n/a
6	100 nV	100 fA	n/a
7	200 nV	200 fA	2 fA
8	500 nV	500 fA	5 fA
9	1 μ V	1 pA	10 fA
10	2 μ V	2 pA	20 fA
11	5 μ V	5 pA	50 fA
12	10 μ V	10 pA	100 fA
13	20 μ V	20 pA	200 fA
14	50 μ V	50 pA	500 fA
15	100 μ V	100 pA	1 pA
16	200 μ V	200 pA	2 pA
17	500 μ V	500 pA	5 pA
18	1 mV	1 nA	10 pA
19	2 mV	2 nA	20 pA
20	5 mV	5 nA	50 pA
21	10 mV	10 nA	100 pA
22	20 mV	20 nA	200 pA

n	full-scale sensitivity		
	IMODE=0	IMODE=1	IMODE=2
23	50 mV	50 nA	500 pA
24	100 mV	100 nA	1 nA
25	200 mV	200 nA	2 nA
26	500 mV	500 nA	5 nA
27	1 V	1 μ A	10 nA

Floating point mode can only be used for reading the sensitivity, which is reported in volts or amps. For example, if IMODE = 0 and the sensitivity is 1 mV the command SEN would report 18 and the command SEN. would report +1.0E-03. If IMODE was changed to 1, SEN would still report 18 but SEN. would report +1.0E-09

AS Perform an Auto-Sensitivity operation

The instrument adjusts its full-scale sensitivity so that the magnitude output lies between 30% and 90% of full-scale.

ASM Perform an Auto-Measure operation

The instrument adjusts its full-scale sensitivity so that the magnitude output lies between 30% and 90% of full-scale, and then performs an auto-phase operation to maximize the X channel output and minimize the Y channel output.

ACGAIN [n] AC Gain control

Sets the gain of the signal channel amplifier. Values of n from 0 to 9 can be entered, corresponding to the range 0 dB to 90 dB in 10 dB steps.

AUTOMATIC [n] AC Gain automatic control

The value of n sets the status of the AC Gain control according to the following table:

n	Status
0	AC Gain is under manual control, using the ACGAIN command
1	Automatic AC Gain control is activated, with the gain being adjusted according to the full-scale sensitivity setting

LF [n₁ n₂] Signal channel line frequency rejection filter control

The LF command sets the mode and frequency of the line frequency rejection (notch) filter according to the following tables:

n ₁	Selection
0	Off
1	Enable 50 or 60 Hz notch filter
2	Enable 100 or 120 Hz notch filter
3	Enable both filters

n ₂	Notch Filter Center Frequencies
0	60 Hz (and/or 120 Hz)
1	50 Hz (and/or 100 Hz)

SAMPLE [n] Main analog-to-digital converter sample frequency control

The sampling frequency of the main analog-to-digital converter, which is nominally 166 kHz, may be adjusted from this value to avoid problems caused by the aliasing of

interfering signals into the output passband.

n may be set to 0, 1 or 2, corresponding to three different sampling frequencies (not specified) near 166 kHz.

5.4.02 Reference Channel

IE [n] Reference channel source control (Internal/External)

The value of n sets the reference input mode according to the following table:

- | n | Selection |
|---|-------------------------------------------------------------|
| 0 | INT (internal) |
| 1 | EXT logic (external rear panel REF TTL input) |
| 2 | EXT analog (external rear panel REF IN analog input) |

REFN [n] Reference harmonic mode control

The value of n sets the reference channel to one of the NF modes, or restores it to the default 1F mode. The value of n is in the range 1 to 32.

REFP[.] [n] Reference phase control

In fixed point mode n sets the phase in millidegrees in the range ± 360000 .

In floating point mode n sets the phase in degrees.

AQN Auto-Phase (auto quadrature null)

The instrument adjusts the reference phase to maximize the X channel output and minimize the Y channel output signals.

FRQ[.] Reference frequency meter

If the lock-in amplifier is in the external reference source modes, the FRQ command causes the lock-in amplifier to respond with 0 if the reference channel is unlocked, or with the reference input frequency if it is locked.

If the lock-in amplifier is in the internal reference source mode, it responds with the frequency of the internal oscillator.

In fixed point mode the frequency is in mHz.

In floating point mode the frequency is in Hz.

LOCK System lock control

Updates all frequency-dependent gain and phase correction parameters.

5.4.03 Signal Channel Output Filters

SLOPE [n] Output low-pass filter slope (roll-off) control

The value of n sets the slope of the output filters according to the following table:

n	Slope
0	6 dB/octave
1	12 dB/octave
2	18 dB/octave
3	24 dB/octave

TC [n]

TC. Filter time constant control

The value of n sets the time constant of the output according to the following table:

n	time constant
0	10 μ s
1	20 μ s
2	40 μ s
3	80 μ s
4	160 μ s
5	320 μ s
6	640 μ s
7	5 ms
8	10 ms
9	20 ms
10	50 ms
11	100 ms
12	200 ms
13	500 ms
14	1 s
15	2 s
16	5 s
17	10 s
18	20 s
19	50 s
20	100 s
21	200 s
22	500 s
23	1 ks
24	2 ks
25	5 ks
26	10 ks
27	20 ks
28	50 ks
29	100 ks

The TC. command is only used for reading the time constant, and reports the current setting in seconds. Hence if a TC 11 command were sent, TC would report 11 and TC. would report 1.0E-01, i.e. 0.1 s or 100 ms.

SYNC [n] Synchronous time constant control
At reference frequencies below 10 Hz, if the synchronous time constant is enabled, then the actual time constant of the output filters is not generally the selected value T but rather a value equal to an integer number of reference cycles. If T is greater than 1 cycle, the time constant is between T/2 and T. The parameter n has the following significance:

- n Effect
- 0 Synchronous time constant disabled
- 1 Synchronous time constant enabled

5.4.04 Signal Channel Output Amplifiers

XOF [n₁ [n₂]] X channel output offset control
The value of n₁ sets the status of the X offset facility according to the following table:

- n₁ Selection
- 0 Disables offset
- 1 Enables offset facility

The range of n₂ is ±30000 corresponding to ±300% full-scale.

YOF [n₁ [n₂]] Y channel output offset control
The value of n₁ sets the status of the Y offset facility according to the following table:

- n₁ Selection
- 0 Disables offset facility
- 1 Enables offset facility

The range of n₂ is ±30000 corresponding to ±300% full-scale.

AXO Auto-Offset
The X and Y channel output offsets are turned on and set to levels giving zero X and Y channel outputs. Any changes in the input signal then appear as changes about zero in the outputs.

EX [n] Output expansion control
Expands X and/or Y channel outputs by a factor of 10. Changes bar-graphs, **CH1** and **CH2** outputs full-scale to ±10% if X or Y selected. The value of n has the following significance:

- n Expand mode
- 0 Off
- 1 Expand X
- 2 Expand Y
- 3 Expand X and Y

CH n₁ [n₂] Analog output control
Defines what outputs appear on the **CH1** and **CH2** connectors on the rear panel according to the following table:

- n_2 Signal
- 0 X %FS
- 1 Y %FS
- 2 Magnitude %FS
- 3 Phase 1:- +9 V = +180°, -9 V = -180°
- 4 Phase 2:- +9 V = 360°, -9 V = 0°
- 5 Noise %FS
- 6 Ratio:- (1000 × X)/ADC 1
- 7 Log Ratio:- $\log_{10}(X/\text{ADC}1)$

n_1 is compulsory and is either 1 for CH1 or 2 for CH2

5.4.05 Instrument Outputs

X[.] X channel output

In fixed point mode causes the lock-in amplifier to respond with the X demodulator output in the range ± 30000 , full-scale being ± 10000 .

In floating point mode causes the lock-in amplifier to respond with the X demodulator output in volts or amps.

Y[.] Y channel output

In fixed point mode causes the lock-in amplifier to respond with the Y demodulator output in the range ± 30000 , full-scale being ± 10000 .

In floating point mode causes the lock-in amplifier to respond with the Y demodulator output in volts or amps.

XY[.] X, Y channel outputs

Equivalent to the compound command X[.];Y[.]

MAG[.] Magnitude

In fixed point mode causes the lock-in amplifier to respond with the magnitude value in the range 0 to 30000, full-scale being 10000.

In floating point mode causes the lock-in amplifier to respond with the magnitude value in the range +3.000E0 to +0.001E-9 volts or +3.000E-6 to +0.001E-15 amps.

PHA[.] Signal phase

In fixed point mode causes the lock-in amplifier to respond with the signal phase in centidegrees, in the range ± 18000 .

In floating point mode causes the lock-in amplifier to respond with the signal phase in degrees.

MP[.] Magnitude, phase

Equivalent to the compound command MAG[.];PHA[.]

RT[.] Ratio output

In integer mode the RT command reports a number equivalent to $1000 \times X / \text{ADC1}$ where X is the value that would be returned by the X command and ADC1 is the value that would be returned by the ADC1 command.

In floating point mode the RT. command reports a number equivalent to $X / \text{ADC1}$.

LR[.] Log Ratio output

In integer mode, the LR command reports a number equivalent to $1000 \times \log(X / \text{ADC1})$ where X is the value that would be returned by the X command and ADC1 is the value that would be returned by the ADC1 command. The response range is -3000 to +2079

In floating point mode, the LR. command reports a number equivalent to $\log(X / \text{ADC1})$. The response range is -3.000 to +2.079

NHZ.

Causes the lock-in amplifier to respond with the square root of the noise spectral density measured at the Y channel output, expressed in $\text{volt}/\sqrt{\text{Hz}}$ or $\text{amps}/\sqrt{\text{Hz}}$ referred to the input. This measurement assumes that the Y channel output is Gaussian with zero mean. (Section 3.3.16). The command is only available in floating point mode.

NOTE: This command is not available when the reference frequency exceeds 60 kHz.

ENBW[.] Equivalent noise bandwidth

In fixed point mode, reports the equivalent noise bandwidth of the output low-pass filters at the current time constant setting in microhertz.

In floating point mode, reports the equivalent noise bandwidth of the output low-pass filters at the current time constant setting in hertz.

NOTE: This command is not available when the reference frequency exceeds 60 kHz.

NN[.] Noise output

In fixed point mode causes the lock-in amplifier to respond with the mean absolute value of the Y channel output in the range 0 to 12000, full-scale being 10000. If the mean value of the Y channel output is zero, this is a measure of the output noise.

In floating point mode causes the lock-in amplifier to respond in volts.

STAR [n] Star mode setup command

The star mode allows faster access to instrument outputs than is possible using the conventional commands. The mode is set up using the STAR command to specify the output(s) required and invoked by sending an asterisk (ASCII 42) to request the data. The data returned is specified by the value of n, as follows:

n Data returned by * command
 0 X
 1 Y
 2 MAG
 3 PHA
 4 ADC1
 5 XY
 6 MP
 7 ADC1;ADC2

* Transfer command

This command establishes the high-speed transfer mode. Use the STAR command to set up the desired response to the * command, and then send an * (ASCII 42), without terminator, to the instrument. The instrument will reply with the selected output as quickly as possible, and then wait for another *. If the computer processes the reply quickly and responds immediately with another *, then very rapid controlled data transfer is possible.

The first transfer takes a little longer than subsequent ones because some overhead time is required for the model 7225BFP to get into the high-speed transfer mode.

The mode is terminated either by sending any command other than an *, when the instrument will exit the mode and process the new command, or after a period of 10 seconds following the last * command.

NOTE: Check that the computer program does not automatically add a carriage return or carriage return-line feed terminator to the * command, since these characters will slow down communications.

? Transfer command

This command is an alternative high-speed transfer mode. Use the CBD command to define the data output(s) that are to be read, in exactly the same way as is done when specifying the data to store in the curve buffer.

If the ? (ASCII 63) command is then sent to the instrument then it will respond with the present value(s) of the selected output(s), *expressed in floating point mode*. Note that because the instrument “knows” the present sensitivity setting, it is not necessary to select the Sensitivity curve in the CBD parameter.

5.4.06 Internal Oscillator

OA[.] [n] Oscillator amplitude control

In fixed point mode n sets the oscillator amplitude in μV . The range of n is 0 to 5000 representing 0 to 5 V rms.

In floating point mode n sets the amplitude in volts.

ASTART[.] [n] Oscillator amplitude sweep start amplitude

Sets the start amplitude for a subsequent sweep of the internal oscillator amplitude, in the range 0 to 5.000 V

In fixed point mode, n is in millivolts rms, and in floating point mode n is in volts rms

ASTOP[.] [n] Oscillator amplitude sweep stop amplitude
Sets the stop amplitude for a subsequent sweep of the internal oscillator amplitude, in the range 0 to 5.000 V

In fixed point mode, n is in millivolts rms, and in floating point mode n is in volts rms

ASTEPP[.] [n] Oscillator amplitude sweep step size
Sets the amplitude step size for a subsequent sweep of the internal oscillator amplitude, in the range 0 to 5.000 V

In fixed point mode, n is in millivolts rms, and in floating point mode n is in volts rms

OF[.] [n] Oscillator frequency control
In fixed point mode n sets the oscillator frequency in mHz. The range of n is 0 to 120,000,000 representing 0 to 120 kHz.

In floating point mode n sets the oscillator frequency in Hz. The range of n is 0 to 1.2E5

SYNCOSC [n] Synchronous oscillator (demodulator monitor) control
This control operates only in external reference mode. The parameter n has the following significance:

- n Effect
- 0 Synchronous Oscillator (Demodulator Monitor) disabled
- 1 Synchronous Oscillator (Demodulator Monitor) enabled

When enabled and in external reference mode, the instrument's **OSC OUT** connector functions as a demodulator monitor of the X channel demodulation function.

FSTART[.] [n] Oscillator frequency sweep start frequency
Sets the start frequency for a subsequent sweep of the internal oscillator frequency, in the range 0 to 120 kHz.

In fixed point mode, n is in millihertz., and in floating point mode n is in hertz.

FSTOP[.] [n] Oscillator frequency sweep stop frequency
Sets the stop frequency for a subsequent sweep of the internal oscillator frequency, in the range 0 to 120 kHz.

In fixed point mode, n is in millihertz., and in floating point mode n is in hertz.

FSTEP[.] [n₁ n₂] Oscillator frequency sweep step size and type
The frequency may be swept either linearly or logarithmically, as specified by parameter n₂. The step size is specified by parameter n₁.

Log sweep $n_2 = 0$

In fixed point mode, n_1 is the step size in thousandths of a percent.

In floating point mode n_1 is in percent. The range of n_1 is 0 to 100.00%

Linear sweep $n_2 = 1$

In fixed point mode, n_1 is the step size in millihertz.

In floating point mode n_1 is in hertz. The range of n_1 is 0 to 10 kHz

SRATE[.] [n] Oscillator frequency and amplitude sweep step rate
Sets the sweep rate in time per step in the range 50 ms to 1000 s, in 5 ms increments.

SWEEP [n] Oscillator frequency and amplitude sweep start/stop
Starts/stops the internal oscillator frequency and amplitude sweeps depending on the value of n according to the following table:

- | | |
|---|-------------------------------------------|
| n | Sweep status |
| 0 | Stop/Pause |
| 1 | Start frequency sweep |
| 2 | Start amplitude sweep |
| 3 | Start frequency sweep and amplitude sweep |

When a frequency and/or amplitude sweep has been defined, applying SWEEP 1 will start it. The sweep will continue until the stop frequency or amplitude is reached. If, during the sweep, SWEEP 0 is applied, the sweep will stop at the current frequency. If SWEEP 1 is then applied, the sweep will restart from this point. Once the sweep reaches the stop frequency or amplitude and stops, the next SWEEP 1 command will reset the frequency or amplitude to the start frequency or amplitude and restart the sweep.

5.4.07 Auxiliary Outputs

DAC[.] n_1 [n_2] Auxiliary DAC output controls
Sets the voltage appearing at the **DAC1** and **DAC2** outputs on the rear panel.

The first parameter n_1 , which specifies the DAC, is compulsory and is either 1 or 2.

The value of n_2 specifies the voltage to be output.

In fixed point mode it is an integer in the range -12000 to +12000, corresponding to voltages from -12.000 V to +12.000 V.

In floating point mode it is in volts.

BYTE [n] Digital output port control
The value of n, in the range 0 to 255, determines the bits to be output on the rear panel digital output port. When $n = 0$, all outputs are low, and when $n = 255$, all are high.

5.4.08 Auxiliary Inputs

ADC[.] n Read auxiliary analog-to-digital inputs
Reads the voltage appearing at the **ADC1** (n = 1) or **ADC2** (n = 2) inputs on the rear panel.

The response for ADC1 and ADC2 in fixed point mode is an integer in the range -12000 to +12000, corresponding to voltages from -12.000 V to +12.000 V.

In floating point mode it is in volts.

TADC [n] Auxiliary ADC trigger mode control
The value of n sets the trigger mode of the auxiliary **ADC** inputs according to the following table:

- | | |
|----|--------------------------------------------------------------------------------------------------------------------------------------|
| n | Trigger mode |
| 0 | Asynchronous (5 ms intervals) |
| 1 | External ADC1 and ADC 2 (rear panel TRIG input) |
| 2 | Burst mode, 25 μ s/point, triggered by command (ADC1 only) |
| 3 | Burst mode, 56 μ s/point, triggered by command (ADC1 and ADC2) |
| 4 | Burst mode, variable rate, triggered by command (ADC1 only) |
| 5 | Burst mode, variable rate, triggered by command (ADC1 and ADC2) |
| 6 | Burst mode, 25 μ s/point, External trigger with < 1.25 ms trigger indeterminacy (rear panel TRIG input) (ADC1 only) |
| 7 | Burst mode, 56 μ s/point, External trigger < 1.25 ms trigger indeterminacy (rear panel TRIG input) (ADC1 and ADC2) |
| 8 | Burst mode, variable rate, External trigger < 1.25 ms trigger indeterminacy (rear panel TRIG input) (ADC1 only) |
| 9 | Burst mode, variable rate, External trigger < 1.25 ms trigger indeterminacy (rear panel TRIG input) (ADC1 and ADC2) |
| 10 | Burst mode, 25 μ s/point, External trigger with < 25 μ s trigger indeterminacy (rear panel TRIG input) (ADC1 only) |
| 11 | Burst mode, 56 μ s/point, External trigger with < 25 μ s trigger indeterminacy(rear panel TRIG input) (ADC1 and ADC2) |
| 12 | Burst mode, variable rate, External trigger with < 25 μ s trigger indeterminacy(rear panel TRIG input) (ADC1 only) |
| 13 | Burst mode, variable rate, External trigger with < 25 μ s trigger indeterminacy(rear panel TRIG input) (ADC1 and ADC2) |

In the burst modes, data is stored in the curve buffer. Use the LEN command to set the number of points required. Note that it may be necessary to enter CBD 32 before setting the length, if the curve buffer has previously been used for more than one data type. The data is read out from the buffer using DC[.] 5 for ADC1 and DC[.] 6 for ADC2. If the length is set to more than 16384 and a burst mode which stores both ADC1 and ADC2 is specified then the curve length will automatically be reduced to 16384 points. Note also that setting the TADC parameter to any value other than 0 or 1 may affect the CBD parameter, as follows:

TADC parameter	Effect on CBD parameter
0	none
1	none
2	automatically set to 32
3	automatically set to 96
4	automatically set to 32
5	automatically set to 96
6	automatically set to 32
7	automatically set to 96
8	automatically set to 32
9	automatically set to 96

The maximum sampling rate depends on the number of ADC inputs used, and is either 25 μ s when sampling ADC1 only, or 56 μ s when sampling both ADC1 and ADC2. In the Variable Rate modes, the sampling speed is set by the BURSTTPP (burst time per point) command.

NOTE: TADC modes 10 to 13 cause all other functions of the host microprocessor to be suspended, including responding to computer commands, until a trigger is received at the TRIG input. Hence they should only be used when the user is certain that such a trigger will occur.

BURSTTPP [n] Sets the burst mode time per point rate for ADC1 and ADC2
n sets the time per point for the Variable Rate burst modes in microseconds, as follows:-

When storing only to ADC1:
(i.e. TADC 2, TADC 4, TADC 6, TADC 8, TADC10 and TADC12)

$$25 \leq n \leq 5000$$

When storing to ADC1 and ADC 2:
(i.e. TADC 3, TADC 5, TADC 7, TADC 9, TADC11 and TADC13)

$$56 \leq n \leq 5000$$

5.4.09 Output Data Curve Buffer

CBD [n] Curve buffer define
Defines which data outputs are stored in the curve buffer when subsequent TD (take data), TDT (take data triggered) or TDC (take data continuously) commands are issued. Up to 15 curves, or outputs, may be acquired, as specified by the CBD parameter.

The CBD parameter is an integer between 1 and 65,535, being the decimal equivalent of a 16-bit binary word. When a given bit is asserted, the corresponding output is selected for storage. When a bit is negated, the output is not stored. The bit function and range for each output are shown in the table below:

Bit	Decimal value	Output and range
0	1	X Output (± 10000 FS)
1	2	Y Output (± 10000 FS)
2	4	Magnitude Output (0 to +10000 FS)
3	8	Phase ($\pm 18000 = \pm 180^\circ$)
4	16	Sensitivity setting (1 to 27) + IMODE (0, 1, 2 = 0, 32, 64)
5	32	ADC1 ($\pm 10000 = \pm 10.0$ V)
6	64	ADC2 ($\pm 10000 = \pm 10.0$ V)
7	128	Not Used
8	256	DAC1 ($\pm 10000 = \pm 10.0$ V)
9	512	DAC2 ($\pm 10000 = \pm 10.0$ V)
10	1024	Noise (0 to +10000 FS)
11	2048	Ratio (± 10000 FS)
12	4096	Log ratio (-3000 to +2000)
13	8192	EVENT variable (0 to 32767)
14	16384	Reference frequency bits 0 to 15 (mHz)
15	32768	Reference frequency bits 16 to 32 (mHz)

32768 points are available for data storage, shared equally between the specified curves. For example, if 16 outputs are stored then the maximum number of storage points would be 2048 (i.e. $32768/16$). The LEN command sets the actual curve length, which cannot therefore be longer than 32768 divided by the number of curves selected. If more curves are requested than can be stored with the current buffer length, then the buffer length will be automatically reduced. Its actual length can of course be determined by sending the LEN command without a parameter.

The reason why bit 4, which stores both the sensitivity and the IMODE setting, is needed, is to allow the instrument to transfer the acquired curves to the computer in floating point mode. Without this information, the unit would not be able to determine the correct calibration to apply.

Curves 14 and 15 store the reference frequency in millihertz. The calculation needed to translate these two 16-bit values to one 32-bit value is:

$$\text{Reference Frequency} = (65536 \times \text{value in Curve 15}) + (\text{value in Curve 14})$$

Note that the CBD command directly determines the allowable parameters for the DC and HC commands. It also interacts with the LEN command and affects the values reported by the M command.

LEN [n] Curve length control

The value of n sets the curve buffer length in effect for data acquisition. The maximum permitted value depends on the number of curves requested using the CBD command, and a parameter error results if the value given is too large. For this reason, if the number of points is to be increased and the number of curves to be stored is to be reduced using the CBD command, then the CBD command should be issued first.

- NC** **New curve**
 Initializes the curve storage memory and status variables. All record of previously taken curves is removed.
- STR [n]** **Storage interval control**
 Sets the time interval between successive points being acquired under the TD or TDC commands. n specifies the time interval in ms with a resolution of 5 ms, input values being rounded up to a multiple of 5. The longest interval that can be specified is 1000000 s corresponding to one point in about 12 days.
- In addition, n may be set to 0, which sets the rate of data storage to the curve buffer to 1.25 ms/point (800 Hz). However this only allows storage of the X and Y channel outputs. There is no need to issue a CBD 3 command to set this up since it happens automatically when acquisition starts.
- If the time constant is set to 5 ms or longer, then the actual time constant applied to the stored X and Y channel output values will be 640 μ s, but if it is set to a shorter value then this will be the time constant actually used.
- TD** **Take data**
 Initiates data acquisition. Acquisition starts at the current position in the curve buffer and continues at the rate set by the STR command until the buffer is full.
- TDT n** **Take data triggered**
 Sets the instrument so that data acquisition will be initiated on receipt of a trigger at the **TRIG** connector on the rear panel. Two triggered modes are possible, as set by the value of n:
- n function
- 0 One complete curve or set of curves, each one consisting of the number of points specified by the LEN command parameter, is acquired for each trigger
- 1 One data point or set of data points is acquired for each trigger. Hence in order to store a complete curve or set of curves, the number of triggers applied must equal the number of points specified by the LEN command parameter. Note that in this mode the maximum trigger rate is 200 Hz and the storage interval control setting has no effect.
- TDC** **Take data continuously**
 Initiates data acquisition. Acquisition starts at the current position in the curve buffer and continues at the rate set by the STR command until halted by an HC command. The buffer is circular in the sense that when it has been filled, new data overwrites earlier points.
- EVENT [n]** **Event marker control**
 During a curve acquisition, if bit 13 in the CBD command has been asserted, the lock-in amplifier stores the value of the Event variable at each sample point. This can be used as a marker indicating the point at which an experimental parameter was changed. The EVENT command is used to set this variable to any value between 0 and 32767.

HC Halt curve acquisition
 Halts curve acquisition in progress. It is effective during both single (data acquisition initiated by TD command) and continuous (data acquisition initiated by TDC command) curve acquisitions. The curve may be restarted by means of the TD, TDT or TDC command, as appropriate.

M Curve acquisition status monitor
 Causes the lock-in amplifier to respond with four values that provide information concerning data acquisition, as follows:

First value, Curve Acquisition Status: a number with five possible values, defined by the following table:

First Value	Significance
0	No curve activity in progress.
1	Acquisition via TD command in progress and running.
2	Acquisition via TDC command in progress and running.
5	Acquisition via TD command in progress but halted by HC command.
6	Acquisition via TDC command in progress but halted by HC command.

Second value, Number of Sweeps Acquired: This number is incremented each time a TD is completed and each time a full cycle is completed on a TDC acquisition. It is zeroed by the NC command and also whenever a CBD or LEN command is applied without parameters.

Third value, Status Byte: The same as the response to the ST command. The number returned is the decimal equivalent of the status byte and refers to the previously applied command.

Fourth value, Number of Points Acquired: This number is incremented each time a point is taken. It is zeroed by the NC command and whenever CBD or LEN is applied without parameters.

DC[.] n Dump acquired curve(s) to computer
 In fixed point mode, causes a stored curve to be dumped via the computer interface in decimal format.

In floating point mode the SEN curve (bit 4 in CBD) must have been stored if one or more of the following outputs are required in order that the lock-in amplifier can perform the necessary conversion from %FS to volts or amps:- X, Y, Magnitude, Noise.

One curve at a time is transferred. The value of n is the bit number of the required curve, which must have been stored by the most recent CBD command. Hence n can range from 0 to 15. If for example CBD 5 had been sent, equivalent to asserting bits 0 and 2, then the X and Magnitude outputs would be stored. The permitted values of n would therefore be 0 and 2, so that DC 0 would transfer the X channel output curve and DC 2 the Magnitude curve.

The computer program's subroutine which reads the responses to the DC command needs to run a FOR...NEXT loop of length equal to the value set by the LEN (curve length) command.

Note that when using this command with the GPIB interface the serial poll must be used. After sending the DC command, perform repeated serial polls until bit 7 is set, indicating that the instrument has an output waiting to be read. Then perform repeated reads in a loop, waiting each time until bit 7 is set indicating that a new value is available. The loop should continue until bit 1 is set, indicating that the transfer is completed.

DCB n Dump acquired curve(s) to computer in binary format

This command causes a stored curve to be dumped via the computer interface in binary format, using two bytes per point to transfer each 16-bit 2's complement value, with the MSB transmitted first. The number of data bytes sent is therefore equal to twice the current curve length. Each point is sent in fixed point mode, there being no floating point version of the command, and hence if floating point values are required the user may need to additionally store and read the Sensitivity curve and then perform the correction in his own software. In order to achieve the maximum transfer rate, no terminators are used within the transmission, although the response is terminated normally at the end.

One curve at a time is transferred. The value of n is the bit number of the required curve, which must have been stored by the most recent CBD command. Hence n can range from 0 to 15. If for example CBD 5 had been sent, equivalent to asserting bits 0 and 2, then the X and Magnitude outputs would be stored. The permitted values of n would therefore be 0 and 2, so that DC 0 would transfer the X channel output curve and DC 2 the Magnitude curve.

The computer program's subroutine which reads the responses to the DCB command needs to be able to handle the potentially very large data blocks (64 k bytes in the case of one 32 k curve) that can be generated.

NOTE: When using RS232 communications, the interface must be set to use 8 data bit transmission.

DCT n Dump acquired curves to computer in table format

This command is similar to the DC command described above, but allows transfer of several curves at a time and only operates in fixed point mode. Stored curve(s) are transferred via the computer interface in decimal format.

In single reference mode, the DCT parameter is an integer between 1 and 65,535, being the decimal equivalent of a 16-bit binary number. When a given bit in the number is asserted, the corresponding curve is selected for transfer. When a bit is negated, the curve is not transferred. The bit corresponding to each curve is shown in the table below:

Bit	Decimal value	Curve and output range
0	1	X Output (± 10000 FS)
1	2	Y Output (± 10000 FS)
2	4	Magnitude Output (0 to +10000 FS)
3	8	Phase ($\pm 18000 = \pm 180^\circ$)
4	16	Sensitivity setting (1 to 27) + IMODE (0, 1, 2 = 0, 32, 64)
5	32	ADC1 ($\pm 10000 = \pm 10.0$ V)
6	64	ADC2 ($\pm 10000 = \pm 10.0$ V)
7	128	Not Used
8	256	DAC1 ($\pm 10000 = \pm 10.0$ V)
9	512	DAC2 ($\pm 10000 = \pm 10.0$ V)
10	1024	Noise (0 to +10000 FS)
11	2048	Ratio (± 10000 FS)
12	4096	Log ratio (-3000 to +2000)
13	8192	EVENT variable (0 to 32767)
14	16384	Reference frequency bits 0 to 15 (mHz)
15	32768	Reference frequency bits 16 to 32 (mHz)

The values of the selected curves at the same sample point are transferred as a group in the order of the above table, separated by the chosen delimiter character and terminated with the selected terminator. This continues until all the points have been transferred.

As an example, suppose CBD 5 had been sent, equivalent to asserting bits 0 and 2, then the X and Magnitude outputs would be stored. The permitted values of n would therefore be 1, 4 and 5. DCT 1 and DCT 4 would only transfer one curve at a time, but DCT 5 would transfer the X channel output curve and the Magnitude curve simultaneously. A typical output data sequence would be:

```
<X channel output value1><delim><Magnitude value1><term>
<X channel output value2><delim><Magnitude value2><term>
<X channel output value3><delim><Magnitude value3><term>
<X channel output value4><delim><Magnitude value4><term>
<X channel output value5><delim><Magnitude value5><term>
```

etc., where <delim> and <term> are the delimiter and terminator characters respectively.

The computer program's subroutine which reads the responses to the DCT command needs to run a FOR...NEXT loop of length equal to the value set by the LEN (curve length) command, and must be able to separate the responses on each line for storage or processing.

Note that when using this command with the GPIB interface the serial poll must be used. After sending the DCT command, perform repeated serial polls until bit 7 is set, indicating that the instrument has an output waiting to be read. Then perform repeated reads in a loop, waiting each time until bit 7 is set indicating that a new value is available. The loop should continue until bit 1 is set, indicating that the transfer is completed.

5.4.10 Computer Interfaces (RS232 and GPIB)

RS [n_1 [n_2]] Set/read RS232 interface parameters

The value of n_1 sets the baud rate of the RS232 interface according to the following table:

n_1	Baud rate (bits per second)
0	75
1	110
2	134.5
3	150
4	300
5	600
6	1200
7	1800
8	2000
9	2400
10	4800
11	9600
12	19200

The lowest five bits in n_2 control the other RS232 parameters according to the following table:

bit number	bit negated	bit asserted
0	data + parity = 8 bits	data + parity = 9 bits
1	no parity bit	1 parity bit
2	even parity	odd parity
3	echo disabled	echo enabled
4	prompt disabled	prompt enabled

GP [n_1 [n_2]] Set/Read GPIB parameters

n_1 sets the GPIB address in the range 0 to 31

n_2 sets the GPIB terminator and the test echo function according to the following table:

n_2	Terminator
0	[CR], test echo disabled
1	[CR], test echo enabled
2	[CR,LF], test echo disabled
3	[CR,LF], test echo enabled
4	no terminator, test echo disabled
5	no terminator, test echo enabled

In all cases the EOI line is asserted with the last byte of a response.

When the test echo is on, every character transmitted or received via the GPIB port is echoed to the RS232 port. This is provided solely as an aid to program development and should not be enabled during normal operation of the instrument.

\N n Address command

When the model 7225BFP is daisy-chained with other compatible instruments this command will change which instrument is addressed. All daisy-chained instruments receive commands but only the currently addressed instrument will implement or respond to the commands. The exception is the **\N n** command. If *n* matches the address already set then instrument will switch into addressed mode. If *n* does not match the address already set the instrument will switch into unaddressed mode. Note that the **\N n** command does not change the address of an instrument but which instrument is addressed.

NOTE: All instruments must have a unique address.

DD [n] Define delimiter control

The value of *n*, which can be set to 13 or from 32 to 125, determines the ASCII value of the character sent by the lock-in amplifier to separate two numeric values in a two-value response, such as that generated by the MP (magnitude and phase) command.

ST Report status byte

Causes the lock-in amplifier to respond with the status byte, an integer between 0 and 255, which is the decimal equivalent of a binary number with the following bit-significance:

Bit 0	Command complete
Bit 1	Invalid command
Bit 2	Command parameter error
Bit 3	Reference unlock
Bit 4	Overload
Bit 5	New ADC values available after external trigger
Bit 6	Asserted SRQ
Bit 7	Data available

NOTE: this command is not normally used in GPIB communications, where the status byte is accessed by performing a serial poll.

N Report overload byte

Causes the lock-in amplifier to respond with the overload byte, an integer between 0 and 255, which is the decimal equivalent of a binary number with the following bit-significance:

Bit 0	not used
Bit 1	CH1 output overload (> ±120 %FS)
Bit 2	CH2 output overload (> ±120 %FS)
Bit 3	Y channel output overload (> ±300 %FS)
Bit 4	X channel output overload (> ±300 %FS)
Bit 5	not used
Bit 6	input overload
Bit 7	reference unlock

MSK [n] Set/read service request mask byte
 The value of n sets the SRQ mask byte in the range 0 to 255

5.4.11 Instrument Identification

ID Identification
 Causes the lock-in amplifier to respond with the number 7225BFP.

REV Report firmware revision
 Causes the lock-in amplifier to respond with the firmware revision number. This gives a multi-line response which the controlling program must be able to accept.

VER Report firmware version
 Causes the lock-in amplifier to respond with the firmware version number. The firmware version number is the number displayed on the Communications menu.

5.4.12 Auto Default

ADF n Auto Default command
 This command will automatically set all the instrument controls and displays to the predefined states. The value of n is used to define what controls are affected, according to the following table:

n	effect
0	Complete reset to factory set default values (listed in Appendix G). However, if this command is used when the interface parameters are at values other than their default settings, then communication will be lost.
1	Reset to factory set default values (listed in Appendix G), with the exception of the RS232 and GPIB communications interface settings.

5.5 Programming Examples

5.5.01 Introduction

This section gives some examples of the commands that need to be sent to the lock-in amplifier for typical experimental situations.

5.5.02 Basic Signal Recovery

In a typical simple experiment, the computer is used to set the instrument controls and then to record the chosen outputs, perhaps as a function of time. At sampling rates of up to a few points per second, there is no need to use the internal curve buffer. The commands to achieve this would therefore be similar to the following sequence:

IE 2	Set reference to external REF IN input
VMODE 1	Single-ended voltage input mode
FET 1	10 M Ω input impedance using FET stage
AUTOMATIC 1	AC Gain control automatic

FLOAT 1	Float input connector shell using 1 k Ω to ground
LF 0 0	Turn off line frequency rejection filter
ASM	Auto-Measure (assumes reference frequency > 1 Hz)
TC 12	Set time constant to 200 ms, since previous ASM changed it

Then the outputs could be read as follows:

X.	Reads X output in volts
Y.	Reads Y output in volts
MAG.	Reads Magnitude in volts
PHA.	Reads Phase in degrees
FRQ.	Reads reference frequency in hertz

The controlling program would send a new output command each time a new reading were required. Note that a good “rule of thumb” is to wait for a period of five time-constants after the input signal has changed before recording a new value. Hence in a scanning type experiment, the program should issue the commands to whatever equipment causes the input signal to the lock-in amplifier to change, wait for five time-constants, and then record the required output.

5.5.03 Frequency Response Measurement

In this example, the lock-in amplifier’s internal oscillator output signal is fed via the filter stage under test back to the instrument’s signal input. The oscillator frequency is stepped between a lower and an upper frequency and the signal magnitude and phase recorded. At sampling rates of up to a few points per second, there is no need to use the internal curve buffer or oscillator frequency sweep generator. The commands to achieve this would therefore be similar to the following sequence:

IE 0	Set reference mode to internal
VMODE 1	Single-ended voltage input mode
FET 1	10 M Ω input impedance using FET stage
AUTOMATIC 1	AC Gain control automatic
FLOAT 1	Float input connector shell using 1 k Ω to ground
LF 0 0	Turn off line frequency rejection filter
OA. 1.0	Set oscillator amplitude to 1.0 V rms
OF. 100.0	Set oscillator frequency to 100 Hz (starting frequency)
SEN 27	Set sensitivity to 1 V full-scale
TC 10	Set time constant to 50 ms
AQN	Auto-Phase

The frequency sweep would be performed and the outputs recorded by sending the following commands from a FOR...NEXT program loop:

OF. XX	Set oscillator frequency to new value XX hertz
Software delay of 250 ms (5×50 ms) allowing output to stabilize	
MAG.	Read Magnitude in volts
PHA.	Read Phase in degrees
FRQ.	Read reference frequency in hertz. This would be same as the oscillator frequency since the unit is operating in internal reference mode.

until the stop frequency is reached.

5.5.04 X and Y Output Curve Storage Measurement

In this example, the lock-in amplifier is measuring a current input signal applied to the **B** input connector and the measured X output and Y output are recorded for 10 seconds at a 100 Hz sampling rate. The acquired curves as read back to the computer are required in floating point mode.

The sequence of commands is therefore as follows:

IE 2	Set reference mode to external REF IN input
IMODE 1	High bandwidth current input mode
AUTOMATIC 1	AC Gain control automatic
FLOAT 1	Float input connector shell using 1 k Ω to ground
LF 0 0	Turn off line frequency rejection filter
SEN 18	Set sensitivity to 1 nA full-scale
TC 10	Set time constant to 50 ms
AQN	Auto-Phase

Now the curve storage needs to be set up:

NC	Clear and reset curve buffer
CBD 19	Stores X output, Y output and sensitivity (i.e. bits 0, 1 and 4)
LEN 1000	Number of points = 100 Hz \times 10 seconds
STR 10	Store a point every 10 ms (1/100 Hz)

The data is acquired by issuing:

TD	Acquires data
----	---------------

As the acquisition is running, the M command reports the status of the curve acquisition. Once this indicates the acquisition is complete (i.e. parameter 1 = 0, parameter 2 = 1), the acquired data may be transferred to the computer using:

DC. 0	Transfers X output values in floating point mode.
DC. 1	Transfers Y output values in floating point mode.

The input routine of the program must be prepared to read and store 1000 responses to

each of these commands.

5.5.05 Transient Recorder

In this example, the signal recovery capabilities of the lock-in amplifier are not used, but the auxiliary inputs are. The voltage applied to the rear panel **ADC1** input is sampled and digitized at a rate of approximately 40 kHz, with the values being stored to the curve buffer. Sampling is required to start on receipt of a trigger at the rear panel **TRIG IN** connector and must last for 500 ms.

The sequence of commands is therefore as follows:

NC	Clear and reset curve buffer
LEN 20000	500 ms recording time at 40 kHz = 20,000 points
TADC 6	Set ADC1 sampling to burst mode, fixed rate (\approx 40 kHz), external trigger, and arm trigger

As soon as a trigger occurs, the acquisition starts. Once it completes the acquired data may be transferred to the computer using:-

DC. 5	Transfers ADC1 values in floating point mode
-------	----------------------------------------------

The input routine of the program must be prepared to read and store 20,000 responses to this command.

5.5.06 Frequency Response Measurement using Curve Storage and Frequency Sweep

In this example, a more sophisticated version of that given in section 5.5.03, the internal oscillator frequency sweep generator is used in conjunction with curve storage, allowing the acquisition of a frequency response without the need for the computer to perform the frequency setting function for each point.

As before, the lock-in amplifier's internal oscillator output signal is fed via the filter stage under test to the signal input. The oscillator frequency is stepped between a lower and an upper frequency and the signal magnitude and phase are recorded.

The required sequence of commands is therefore as follows:-

IE 0	Set reference mode to internal
VMODE 1	Single-ended voltage input mode
FET 1	10 M Ω input impedance using FET stage
AUTOMATIC 1	AC Gain control automatic
FLOAT 1	Float input connector shell using 1 k Ω to ground
LF 0 0	Turn off line frequency rejection filter
OA. 1.0	Set oscillator amplitude to 1.0 V rms
OF. 100.0	Set initial oscillator frequency to 100 Hz so that AQN runs correctly
SEN 27	Set sensitivity to 1 V full-scale

TC 8	Set time constant to 10 ms
AQN	Auto-Phase

The next group of commands set up the frequency sweep:

FSTART. 100.0	Set initial oscillator frequency to 100 Hz
FSTOP. 1000.0	Set final oscillator frequency to 1000 Hz
FSTEP. 10 1	Step size = 10 Hz, linear law
SRATE. 0.1	100 ms per step

There will therefore be 100 steps (100 Hz to 1000 Hz inclusive in 10 Hz steps). Now we need to specify the curve storage:

NC	Clear and reset curve buffer
CBD 49180	Stores Magnitude, Phase, Sensitivity and Frequency (i.e. bits 2, 3, 4, 14 and 15)
LEN 100	Number of points = 100
STR 100	Store a point every 100 ms - must match SRATE parameter

The data may now be acquired by issuing the compound command:

TD; SWEEP 1	Starts sweep and curve acquisition
-------------	------------------------------------

Note that the order of these two commands is important. If used as shown then the data will be acquired and then the oscillator frequency will be changed at each data point, prior to waiting the time set by the SRATE and STR commands. This gives sufficient time for the instrument output to stabilize after each change of frequency.

If the commands were used in the reverse order (i.e. SWEEP 1; TD) then the output(s) would never have time to settle by the time at which they were recorded.

The frequency sweep starts and the magnitude and phase outputs are recorded to the curve buffer. As it runs the M command reports the status of the acquisition, and once this indicates it is complete (i.e. parameter 1 = 0, parameter 2 = 1), the acquired data may be transferred to the computer using:

DC. 2	Transfers Magnitude curve
DC. 3	Transfers Phase curve
DC 14	Transfers Reference frequency - lower 16 bits
DC 15	Transfers Reference frequency - upper 16 bits

Specifications

Measurement Modes

X In-phase))	The unit can simultaneously present any two of these as outputs
Y Quadrature		
R Magnitude		
θ Phase Angle		
Noise		
Harmonic	nF, $n \leq 32F$	
Noise	Measures noise in a given bandwidth centered on frequency F	

Displays

Two LED backlit, two-line, 16-character alphanumeric dot-matrix LCDs giving digital indication of current instrument set-up and output readings. Edge indicating analog panel meter. Menu system with dynamic key function allocation.

Signal Channel

Voltage Inputs

Modes	A only or Differential (A-B)
Full-scale Sensitivity	2 nV to 1 V in a 1-2-5 sequence
Dynamic Reserve	> 100 dB
Impedance	
FET Device	10 M Ω // 30 pF
Bipolar Device	10 k Ω // 30 pF
Voltage Noise	
FET Device	5 nV/ $\sqrt{\text{Hz}}$ at 1 kHz
Bipolar Device	2 nV/ $\sqrt{\text{Hz}}$ at 1 kHz
CMRR	> 100 dB at 1 kHz degrading by 6 dB/octave
Frequency Response	0.001 Hz to 120 kHz
Gain Accuracy	0.5 % typ (full bandwidth)
Distortion	-90 dB THD (60 dB AC Gain, 1 kHz)
Line Filter	attenuates 50, 60, 100, 120 Hz
Grounding	BNC shields can be grounded or floated via 1 k Ω to ground

Current Input

Mode	Low Noise or Wide Bandwidth
Full-scale Sensitivity	
Low Noise	2 fA to 10 nA in a 1-2-5 sequence
Wide Bandwidth	2 fA to 1 μ A in a 1-2-5 sequence
Dynamic Reserve	> 100 dB (with no signal filters)
Frequency Response	
Low Noise	-3 dB at 500 Hz
Wide Bandwidth	-3 dB at 50 kHz
Impedance	
Low Noise	< 2.5 k Ω at 100 Hz
Wide Bandwidth	< 250 Ω at 1 kHz
Noise	
Low Noise	13 fA/ $\sqrt{\text{Hz}}$ at 500 Hz
Wide Bandwidth	130 fA/ $\sqrt{\text{Hz}}$ at 1 kHz
Gain Accuracy (midband)	
Low Noise	\leq 0.6 % typ
Wide Bandwidth	\leq 0.6 % typ
Line Filter	attenuates 50, 60, 100, 120 Hz
Grounding	BNC shield can be grounded or floated via 1 k Ω to ground

Reference Channel

TTL Input (REF TTL Mode)

Frequency Range	1 mHz to 120 kHz
-----------------	------------------

Analog Input (EXT REF Mode - factory default)

Impedance	1 M Ω // 30 pF
Sinusoidal Input	
Level	1.0 V rms**
Frequency Range	1 Hz to 120 kHz
Squarewave Input	
Level	100 mV rms**
Frequency Range	300 mHz to 120 kHz

**Note: Lower levels can be used with the analog input at the expense of increased phase errors.

Phase

Set Resolution	0.01 $^\circ$ increments
Accuracy	0.5 $^\circ$ typ
Noise at 100 ms TC, 12 dB/octave	
Internal Reference	< 0.0001 $^\circ$ rms
External Reference	< 0.01 $^\circ$ rms at 1 kHz
Orthogonality	90 $^\circ$ \pm 0.0001 $^\circ$
Drift	< 0.01 $^\circ$ /C below 10 kHz < 0.1 $^\circ$ /C above 10 kHz

Acquisition Time	
Internal Reference	instantaneous acquisition
External Reference	2 cycles + 50 ms
Reference Frequency Meter Accuracy	
120 kHz > F > 40 kHz	±4 Hz
40 kHz > F > 400 Hz	±0.8 Hz at F = 40 kHz improving to ±0.008 Hz at F = 400 Hz
400 Hz > F > 1 mHz	±0.040 Hz at F = 400 Hz improving to better than ±0.0001 Hz at F = 1 mHz

Demodulator and Output Processing

Description	
	2 × 18-bit ADCs driving two DSP elements managed by a powerful 68000-series host processor
Output Zero Stability	
Digital Outputs	No zero drift on all settings
Displays	No zero drift on all settings
Analog Outputs	< 5 ppm/°C
Harmonic Rejection	-90 dB
Time Constants	
Digital Outputs	5 ms to 100 ks in a 1-2-5 sequence
Fast Outputs	10 μs to 640 μs in a binary sequence
Roll-off	6, 12, 18 and 24 dB/octave
Synchronous Filter Operation	Available for F < 10 Hz
Offset	Auto and Manual on X and Y: ±300 % FS

Oscillator

Frequency	
Range	0.001 Hz to 120 kHz
Setting Resolution	0.001 Hz
Absolute Accuracy	25 ppm + 30 μHz
Distortion (THD)	-80 dB at 1 kHz
Amplitude	
Range	1 mV to 5 V
Setting Resolution	
1 mV to 500 mV	1 mV
501 mV to 2 V	4 mV
2.001 V to 5 V	10 mV

Accuracy	
0.001 Hz to 60 kHz	±0.3 %
60 kHz to 120 kHz	±0.5 %
Stability	50 ppm/°C
Output Impedance	50 Ω

Auxiliary Inputs ADC1 & 2

Maximum Input	±10 V
Resolution	1 mV
Accuracy	±20 mV
Input Impedance	1 MΩ // 30 pF
Sample Rate	
ADC 1 only	40 kHz max
ADC 1 and 2	13 kHz max
Trigger Mode	Int, ext or burst
Trigger input	TTL compatible

Outputs

CH1 CH2 Outputs	
Function	X, Y, R, θ, Noise and aux functions
Amplitude	±10 V
Impedance	1 kΩ
Fast X and Fast Y Outputs	
Time Constant	≤ 640 μs
Amplitude	±10 V
Update Rate	166 kHz nominal
Output Impedance	1 kΩ
Signal Monitor	
Amplitude	±10 V FS
Impedance	1 kΩ
Aux D/A Output 1, 2	
Maximum Output	±10 V
Resolution	1 mV
Accuracy	±10 mV
Output Impedance	1 kΩ
8-bit Digital Output	8 TTL compatible lines that can be independently set high or low to activate external equipment
Power - Low Voltage	±15 V at 100 mA rear panel DIN connector for powering SIGNAL RECOVERY preamplifiers

Data Storage

Data Buffer Size	32k 16-bit data points, may be organized as 1×32k, 2×16k, 3×10.6k, 4×8k, etc.
Max Storage Rate	
From LIA	up to 800 16-bit values per second
From ADC	up to 40,000 16-bit values per second

Interfaces

RS232, IEEE-488. A auxiliary RS232 port is provided to allow "daisy-chain" connection and control of multiple units from a single RS232 computer port.

Power Requirements

Voltage	110/120/220/240 VAC
Frequency	50/60 Hz
Power	< 40 VA

General

Dimensions	
Width	432 mm (17 ")
Depth	415 mm (16.4 ")
Height	
With feet	74 mm (2.9 ")
Without feet	60 mm (2.4 ")
Weight	7.4 kg (16.3 lb)

B.1 RS232 Connector Pinout

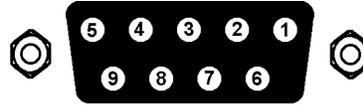


Figure B-1, RS232 and AUX RS232 Connector (Female)

PIN	FUNCTION	COMMENT
2	RXD	Data In
3	TXD	Data Out
5	GND	Signal Ground
7	RTS	(Always at +12 V)

All other pins are not connected.

B.2 Preamplifier Power Connector Pinout

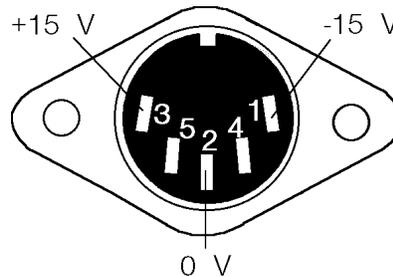


Figure B-2, Preamplifier Power Connector

PIN	FUNCTION
1	-15 V
2	GROUND
3	+15 V

All other pins are unused.

Shell is shield ground.

B.3 Digital Output Port Connector

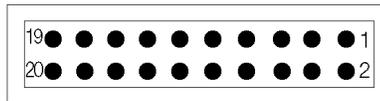


Figure B-3, Digital Output Port Connector

8-bit TTL-compatible output set from via the computer interfaces; each line can drive 3 LSTTL loads. This connector mates with a 20-pin IDC Header Plug. The pinout is as follows.

PIN #	FUNCTION
1	GROUND
2	GROUND
3	D0
4	GROUND
5	D1
6	GROUND
7	D2
8	GROUND
9	D3
10	GROUND
11	D4
12	GROUND
13	D5
14	GROUND
15	D6
16	GROUND
17	D7
18	GROUND
19	+5 V
20	+5 V

D0 = Least Significant Bit

D7 = Most Significant Bit

Demonstration Programs

C.1 Simple Terminal Emulator

This is a short terminal emulator with minimal facilities, which will run on a PC-compatible computer in a Microsoft GW-BASIC or QuickBASIC environment, or can be compiled with a suitable compiler.

```
10 'MINITERM 9-Feb-96
20 CLS: PRINT "Lockin RS232 parameters must be set to 9600 baud, 7 data bits, 1 stop bit
and even parity"
30 PRINT "Hit <ESC> key to exit"
40 OPEN "COM1:9600,E,7,1,CS,DS" FOR RANDOM AS #1
50 '.....
60 ON ERROR GOTO 180
70 '.....
100 WHILE (1)
110   B$ = INKEY$
120   IF B$=CHR$(27) THEN CLOSE #1: ON ERROR GOTO 0: END
130   IF B$<>" " THEN PRINT#1, B$;
140   LL% = LOC(1)
150   IF LL%>0 THEN A$ = INPUT$(LL%,#1): PRINT A$;
160 WEND
170 '.....
180 PRINT "ERROR NO.";ERR: RESUME
```

C.2 RS232 Control

RSCOM2.BAS is a user interface program which illustrates the principles of the echo handshake. The program will run on a PC-compatible computer either in a Microsoft GW-BASIC or QuickBASIC environment, or in compiled form.

The subroutines in RSCOM2 are recommended for incorporation in the user's own programs.

```
10 'RSCOM2 9-Feb-96
20 CLS: PRINT "Lockin RS232 parameters must be set to 9600 baud, 7 data bits, 1 stop bit
and even parity"
30 OPEN "COM1:9600,E,7,1,CS,DS" FOR RANDOM AS #1
40 CR$=CHR$(13)           ' carriage return
50 '
60 '...main loop.....
70 WHILE 1               ' infinite loop
80   INPUT "command (00 to exit) ";B$   ' no commas are allowed in B$
90   IF B$="00" THEN END
100  B$=B$+CR$           ' append a carriage return
110  GOSUB 180           ' output the command B$
```

Appendix C, DEMONSTRATION PROGRAMS

```

120  GOSUB 310: PRINT Z$;           ' read and display response
130  IF A$="?" THEN GOSUB 410: GOSUB 470 ' if "?" prompt fetch STATUS%
140                                     ' and display message
150 WEND                             ' return to start of loop
160 '
170 '
180 '...output the string B$.....
190 ON ERROR GOTO 510                ' enable error trapping
200 IF LOC(1)>0 THEN A$=INPUT$(LOC(1),#1) ' clear input buffer
210 ON ERROR GOTO 0                  ' disable error trapping
220 FOR J1%=1 TO LEN(B$)             ' LEN(B$) is number of bytes
230  C$=MID$(B$,J1%,1): PRINT#1,C$;  ' send byte
240  WHILE LOC(1)=0: WEND            ' wait for byte in input buffer
250  A$=INPUT$(1,#1)                 ' read input buffer
260  IF A$<>C$ THEN PRINT"handshake error" ' input byte should be echo
270 NEXT J1%                          ' next byte to be sent or
280 RETURN                            ' return if no more bytes
290 '
300 '
310 '...read response.....
320 A$="": Z$=""
330 WHILE (A$<>"*" AND A$<>"?")     ' read until prompt received
340  Z$=Z$+A$                          ' append next byte to string
350  WHILE LOC(1)=0: WEND                ' wait for byte in input buffer
360  A$=INPUT$(1,#1)                    ' read byte from buffer
370 WEND                                 ' next byte to be read
380 RETURN                               ' return if it is a prompt
390 '
400 '
410 '...fetch status byte.....
420 B$="ST"+CR$                          ' "ST" is the status command
430 GOSUB 180                             ' output the command
440 GOSUB 310                             ' read response into Z$
450 STATUS%=VAL(Z$)                       ' convert to integer
460 RETURN
470 '...instrument error message.....
480 PRINT"Error prompt, status byte = ";STATUS% ' bits are defined in manual
490 PRINT
500 RETURN
510 '...I/O error routine.....
520 RESUME

```

C.3 GPIB User Interface Program

GPCOM.BAS is a user interface program which illustrates the principles of the use of the serial poll status byte to coordinate the command and data transfer.

The program runs under Microsoft GW-BASIC or QuickBASIC on a PC-compatible computer fitted with a National Instruments IEEE-488 interface card and the GPIB.COM software installed in the CONFIG.SYS file. The program BIB.M, and the first three lines of GPCOM, are supplied by the card manufacturer and must be the correct version for the particular version of the interface card in use. The interface card may be set up, using the program IBCONF.EXE, to set EOI with the last byte of Write in which case no terminator is required. (Read operations are automatically terminated on EOI which is always sent by the lock-in). Normally, the options called 'high-speed timing', 'interrupt jumper setting', and 'DMA channel' should all be disabled.

The principles of using the Serial Poll Status Byte to control data transfer, as implemented in the main loop of GPCOM, are recommended for incorporation in the user's own programs.

```

10 'GPCOM 9-Feb-96
20 '...the following three lines and BIB.M are supplied by the.....
30 '...manufacturer of the GPIB card, must be correct version.....
40 CLEAR,60000!:IBINIT1=60000!:IBINIT2=IBINIT1+3:BLOAD"BIB.M",IBINIT1
50 CALL
IBINIT1(IBFIND,IBTRG,IBCLR,IBPCT,IBSIC,IBLOC,IBPPC,IBBNA,IBONL,IBRSC,IBSRE,IBRSV,IBPAD,
IBSAD,IBIST,IBDMA,IBEOS,IBTMO,IBEOT,IBRDF,IBWRTF,IBTRAP)
60 CALL
IBINIT2(IBGTS,IBCAC,IBWAIT,IBPOKE,IBWRT,IBWRTA,IBCMD,IBCMDA,IBRD,IBRDA,IBSTOP,
IBRPP,IBRSP,IBDIAG,IBXTRC,IBRDI,IBWRTI,IBRDIA,IBWRTIA,IBSTA%,IBERR%,IBCNT%)
70 '.....
80 CLS: PRINT"DEVICE MUST BE SET TO CR TERMINATOR"
90 '...assign access code to interface board.....
100 BDNOME$="GPIB0"
110 CALL IBFIND(BDNOME$,GPIB0%)
120 IF GPIB0%<0 THEN PRINT "board assignment error":END
130 '...send INTERFACE CLEAR.....
140 CALL IBSIC(GPIB0%)
150 '...set bus address, assign access code to device.....
160 SUCCESS% = 0
170 WHILE SUCCESS% = 0
180   INPUT "BUS ADDRESS ";A%
190   DEVNAME$ = "DEV"+RIGHT$(STR$(A%),LEN(STR$(A%))-1)
200   CALL IBFIND(DEVNAME$,DEV%)           ' assign access code
210   IF DEV%<0 THEN PRINT "device assignment error": END
220   A$ = CHR$(13): GOSUB 480             ' test: write <CR> to bus
230   IF IBSTA%>0 THEN SUCCESS% = 1
240   IF (IBSTA%<0 AND IBERR%=2) THEN BEEP: PRINT "NO DEVICE AT THAT ADDRESS"
250 WEND
260 '...send SELECTED DEVICE CLEAR.....
270 CALL IBCLR(DEV%)

```

Appendix C, DEMONSTRATION PROGRAMS

```
280 '....set timeout to 1 second.....
290 V%=11: CALL IBTMO(DEV%,V%)
300 '....set status print flag.....
310 INPUT "Display status byte y/n "; R$
320 IF R$="Y" OR R$="y" THEN DS% = 1 ELSE DS% = 0
330 '....main loop.....
340 WHILE 1                                ' infinite loop
350   INPUT "command (00 to exit) ";A$
360   IF A$="00" THEN END
370   A$ = A$ + CHR$(13)                    ' terminator is <CR>
380   GOSUB 480                              ' write A$ to bus
390   S% = 0                                  ' initialize S%
400   WHILE (S% AND 1)=0                    ' while command not complete
410     GOSUB 530                              ' serial poll, returns S%
420     IF DS% THEN PRINT "S%= ";S%
430     IF (S% AND 128) THEN GOSUB 500: PRINT B$ ' read bus into B$ and print
440   WEND
445   IF (S% AND 4) THEN PRINT "parameter error"
450   IF (S% AND 2) THEN PRINT "invalid command"
460 WEND
470 '....end of main loop.....
480 '....write string to bus.....
490 CALL IBWRT(DEV%,A$): RETURN
500 '....read string from bus.....
510 B$ = SPACE$(32)                          ' B$ is buffer
520 CALL IBRD(DEV%,B$): RETURN
530 '.....serial poll.....
540 CALL IBRSP(DEV%,S%): RETURN
```

Cable Diagrams

D.1 RS232 Cable Diagrams

Users who choose to use the RS232 interface to connect the model 7225BFP lock-in amplifier to a standard serial port on a computer, will need to use one of two types of cable. The only difference between them is the number of pins used on the connector which goes to the computer. One has 9 pins and the other 25; both are null modem (also called modem eliminator) cables in that some of the pins are cross-connected.

Users with reasonable practical skills can easily assemble the required cables from parts which are widely available through computer stores and electronics components suppliers. The required interconnections are given in figures D-1 and D-2.

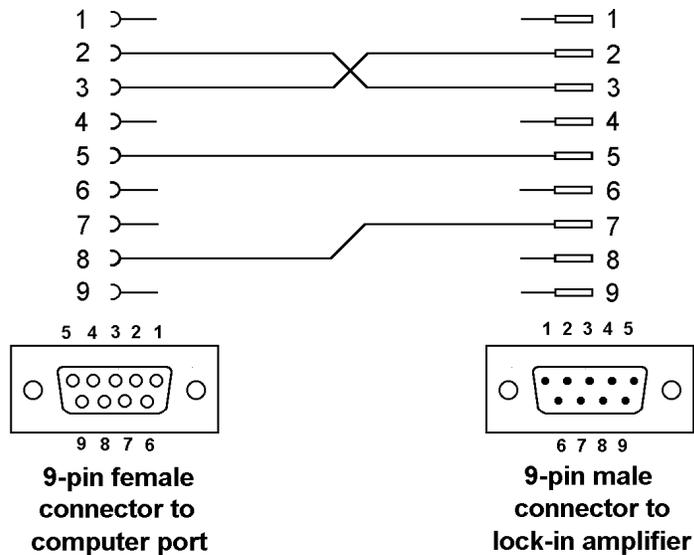


Figure D-1, Interconnecting RS232 Cable Wiring Diagram

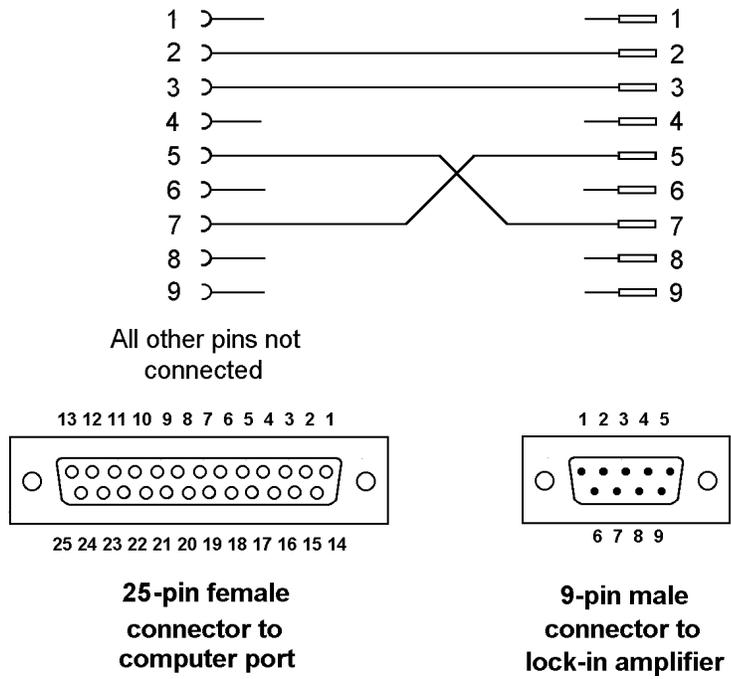


Figure D-2, Interconnecting RS232 Cable Wiring Diagram

Default Settings

Default Setting Function

The Auto-Default computer command ADF 1 sets the model 7225BFP's controls as follows:-

Controls

Full-scale sensitivity	500 mV
AC Gain	0 dB
Time constant	100 ms
Slope	12 dB/octave
Oscillator frequency	1000.000 Hz
Oscillator amplitude	0.500 mV rms
DAC1 output	0.000 V
DAC2 output	0.000 V
Output offsets	OFF
Phase	0.00°
X channel output offset	0.00 %
Y channel output offset	0.00 %
Input mode	Single-ended voltage mode, A input connector
Coupling	AC
Input connector shell	Floating
Input device	FET
Reference mode	Internal
Reference harmonic	1st
Demodulator monitor	Off
Output expansion	Off
CH1 analog output	X %
CH2 analog output	Y %
Line frequency rejection filter	Off
AC Gain control	Manual
Time constant mode	Sync
ADC trigger rate	200 Hz
Front panel lights	On
Digital outputs	0 (i.e. D0 - D7 are at logic zero)
Sample frequency control	0

The ADF 0 computer command set the model 7225BFP's controls as above, and in addition set the communications interface parameters as follows:-

RS232 interface settings

Baud rate	9600
Data bits	7
Stop bits	1
Parity	Even
Prompt character	On
Character echo	On

Appendix F, DEFAULT SETTINGS

Delimiter	, (044)
Address	1

GPIB interface settings

Address	12
Terminator	CR,LF
SRQ mask byte	0
Test Echo	Disabled

Command Set Changes from Model 7220BFP

F.1 Introduction

Software programs written to control the model 7220BFP lock-in amplifier can be used to run the model 7225BFP if they are modified to reflect the differences in the command set detailed in the following paragraphs. These changes were necessary to allow the updated features of the model 7225BFP to be accessed.

F.2 Commands no longer available

The following 7220BFP command is not available in the model 7225BFP:

BURSTRATE [n] Burst sampling rate for ADC1 & ADC2
This command is replaced in the 7225BFP by the BURSTTP [n] command which allows the sampling time to be set in microsecond increments.

F.3 Changed Commands

F.3.01 Instrument Identification

ID Identify Command
The response to the ID command is 7225BFP for the model 7225BFP instead of 7220BFP for the model 7220BFP.

F.3.02 Auto-Default

ADF [n] Auto Default
Two levels of auto-default function are now provided, as set by the value of parameter n, according to the following table:

- n Significance
- 0 All instrument settings are returned to their factory default values
- 1 All instrument settings, with the exception of the communications settings, are returned to their factory default values

If n is omitted then the command operates as if n=0, which has the same effect as the 7220BFP's ADF command.

This change makes the command much more useful in cases where non-standard communications settings are being used.

F.3.03 Line Frequency Rejection Filter

In the model 7225BFP, the setting of the line-frequency rejection filter (60 Hz or 50 Hz) is now set as a parameter in the LF command, which has therefore been

changed so that it always needs, or responds with, two parameters:-

LF [n₁ n₂] Signal channel line frequency rejection filter control
The LF command sets the mode and frequency of the line frequency rejection (notch) filter according to the following tables:

- n₁ Selection
- 0 Off
 - 1 Enable 50 or 60 Hz notch filter
 - 2 Enable 100 or 120 Hz notch filter
 - 3 Enable both filters
- n₂ Notch Filter Center Frequencies
- 0 60 Hz (and/or 120 Hz)
 - 1 50 Hz (and/or 100 Hz)

F.3.04 Auxiliary I/O

BURSTTPP [n] Sets the burst mode time per point rate for ADC1 and ADC2
This command replaces the 7220BFP's BURSTRATE command. The value of n sets the time per point for the Variable Rate burst modes in microseconds, as follows:-

When storing only to ADC1:

(i.e. TADC 2, TADC 4, TADC 6, TADC 8, TADC10 and TADC12)

$$25 \leq n \leq 5000$$

When storing to ADC1 and ADC 2:

(i.e. TADC 3, TADC 5, TADC 7, TADC 9, TADC11 and TADC13)

$$56 \leq n \leq 5000$$

F.3.05 Oscillator Amplitude Sweep

SWEEP [n] Oscillator frequency and amplitude sweep start/stop

- n Sweep status
- 0 Stop/Pause
 - 1 Start frequency sweep
 - 2 Start amplitude sweep
 - 3 Start frequency sweep and amplitude sweep

This command now allows n = 2 or 3. Previously it was restricted to n = 0 or 1.

F.4 New Commands

The following new commands have no equivalent in the model 7220BFP. They are described in more detail both in chapter 6 and in appendix G.

- ? Transfer command
 Alternative high-speed transfer mode. Use the CBD command to define the data output(s) that are to be returned when the ? command is sent, in exactly the same way as is done when specifying the data to store in the curve buffer.
- DCB n Dump acquired curve(s) to computer in binary format
 Gives much faster data transfer to computer than the DC command.
- TDT n Take data triggered
 n function
 0 One complete curve or set of curves, each one consisting of the number of points specified by the LEN command parameter, is acquired for each trigger
 1 One data point or set of data points is acquired for each trigger. Hence in order to store a complete curve or set of curves, the number of triggers applied must equal the number of points specified by the LEN command parameter. Note that in this mode the maximum trigger rate is 200 Hz and the storage interval control setting has no effect.
- ASTART[.] [n] Oscillator amplitude sweep start amplitude
 Sets the start amplitude for a subsequent sweep of the internal oscillator amplitude.
- ASTOP[.] [n] Oscillator amplitude sweep stop amplitude
 Sets the stop amplitude for a subsequent sweep of the internal oscillator amplitude.
- ASTEPP[.] [n] Oscillator amplitude sweep step size
 Sets the amplitude step size for a subsequent sweep of the internal oscillator.

Alphabetical Listing of Commands

- ? Transfer command
This command is an alternative high-speed transfer mode. Use the CBD command to define the data output(s) that are to be read, in exactly the same way as is done when specifying the data to store in the curve buffer.

If the ? (ASCII 63) command is then sent to the instrument then it will respond with the present value(s) of the selected output(s), *expressed in floating point mode*. Note that because the instrument “knows” the present sensitivity setting, it is not necessary to select the Sensitivity curve in the CBD parameter.
- ACGAIN [n] AC Gain control
Sets the gain of the signal channel amplifier. Values of n from 0 to 9 can be entered, corresponding to the range 0 dB to 90 dB in 10 dB steps.
- ADC[.] n Read auxiliary analog-to-digital inputs
The response for ADC1 and ADC2 in fixed point mode is an integer in the range -12000 to +12000, corresponding to voltages from -12.000 V to +12.000 V. In floating point mode it is in volts.
- ADF n Auto Default
The ADF command performs an auto-default operation according to the following table:
- | | |
|---|--------------------------------------------------------------------------------------------------------------------------|
| n | Significance |
| 0 | All instrument settings are returned to their factory default values |
| 1 | All instrument settings, with the exception of the communications settings, are returned to their factory default values |
- NOTE: If the ADF 0 command is used when the communications settings are at values other than their default settings, then communication will be lost.***
- AQN Auto-Phase (auto quadrature null)
- AS Perform an Auto-Sensitivity operation
- ASM Perform an Auto-Measure operation
- ASTART[.] [n] Oscillator amplitude sweep start amplitude
Sets the start amplitude for a subsequent sweep of the internal oscillator amplitude, in the range 0 to 5.000 V

In fixed point mode, n is in millivolts rms, and in floating point mode n is in volts rms
- ASTEP[.] [n] Oscillator amplitude sweep step size
Sets the amplitude step size for a subsequent sweep of the internal oscillator amplitude, in the range 0 to 5.000 V

In fixed point mode, n is in millivolts rms, and in floating point mode n is in volts rms

ASTOP[.] [n] Oscillator amplitude sweep stop amplitude
Sets the stop amplitude for a subsequent sweep of the internal oscillator amplitude, in the range 0 to 5.000 V

In fixed point mode, n is in microvolts rms and in floating point mode n is in volts rms

AUTOMATIC [n] AC Gain automatic control
n Status
0 AC Gain is under manual control, using the ACGAIN command
1 Automatic AC Gain control is activated, with the gain being adjusted according to the full-scale sensitivity setting

AXO Auto-Offset

BURSTTPP [n] Sets the burst mode time per point rate for ADC1 and ADC2
n sets the time per point for the Variable Rate burst modes in microseconds, as follows:-

When storing only to ADC1:
(i.e. TADC 2, TADC 4, TADC 6, TADC 8, TADC10 and TADC12)

$$25 \leq n \leq 5000$$

When storing to ADC1 and ADC 2:
(i.e. TADC 3, TADC 5, TADC 7, TADC 9, TADC11 and TADC13)

$$56 \leq n \leq 5000$$

BYTE [n] Digital output port control
The value of n, in the range 0 to 255, determines the bits to be output on the rear panel digital output port. When n = 0, all outputs are low, and when n = 255, all are high.

CBD [n] Curve buffer define
Defines which data outputs are stored in the curve buffer when subsequent TD (take data), TDT (take data triggered) or TDC (take data continuously) commands are issued. Up to 15 curves, or outputs, may be acquired, as specified by the CBD parameter.

The CBD parameter is an integer between 1 and 65,535, being the decimal equivalent of a 16-bit binary word. When a given bit is asserted, the corresponding output is selected for storage. When a bit is negated, the output is not stored. The bit function and range for each output are shown in the table below:

Bit	Decimal value	Output and range
0	1	X Output (± 10000 FS)
1	2	Y Output (± 10000 FS)
2	4	Magnitude Output (0 to +10000 FS)
3	8	Phase ($\pm 18000 = \pm 180^\circ$)
4	16	Sensitivity setting (1 to 27) + IMODE (0, 1, 2 = 0, 32, 64)
5	32	ADC1 ($\pm 10000 = \pm 10.0$ V)
6	64	ADC2 ($\pm 10000 = \pm 10.0$ V)
7	128	Not used
8	256	DAC1 ($\pm 10000 = \pm 10.0$ V)
9	512	DAC2 ($\pm 10000 = \pm 10.0$ V)
10	1024	Noise (0 to +10000 FS)
11	2048	Ratio (± 10000 FS)
12	4096	Log ratio (-3000 to +2000)
13	8192	EVENT variable (0 to 32767)
14	16384	Reference frequency bits 0 to 15 (mHz)
15	32768	Reference frequency bits 16 to 32 (mHz)

32768 points are available for data storage, shared equally between the specified curves. For example, if 16 outputs are stored then the maximum number of storage points would be 2048 (i.e. 32768/16). The LEN command sets the actual curve length, which cannot therefore be longer than 32768 divided by the number of curves selected. If more curves are requested than can be stored with the current buffer length, then the buffer length will be automatically reduced. Its actual length can of course be determined by sending the LEN command without a parameter.

The reason why bit 4, which stores both the sensitivity and the IMODE setting, is needed, is to allow the instrument to transfer the acquired curves to the computer in floating point mode. Without this information, the unit would not be able to determine the correct calibration to apply.

Curves 14 and 15 store the reference frequency in millihertz. The calculation needed to translate these two 16-bit values to one 32-bit value is:

$$\text{Reference Frequency} = (65536 \times \text{value in Curve 15}) + (\text{value in Curve 14})$$

Note that the CBD command directly determines the allowable parameters for the DC and HC commands. It also interacts with the LEN command and affects the values reported by the M command.

CH n_1 [n_2] Analog output control
 Defines what outputs appear on the **CH1** and **CH2** connectors on the rear panel according to the following table:

- n₂ Signal
- 0 X %FS
- 1 Y %FS
- 2 Magnitude %FS
- 3 Phase 1:- +9 V = +180°, -9 V = -180°
- 4 Phase 2:- +9 V = 360°, - 9 V = 0°
- 5 Noise %FS
- 6 Ratio:- (1000 × X)/ADC 1
- 7 Log Ratio:- log₁₀ (X/ADC1)
- 8 Equation 1
- 9 Equation 2

n₁ is compulsory and is either 1 for CH1 or 2 for CH2

- CP [n] Input connector coupling mode control
- n Coupling mode
 - 0 AC
 - 1 DC

- DAC[.] n₁ [n₂] Auxiliary DAC output controls
- The first parameter n₁, which specifies the DAC, is compulsory and is either 1 or 2.

The value of n₂ specifies the voltage to be output.

In fixed point mode it is an integer in the range -12000 to +12000, corresponding to voltages from -12.000V to +12.000V, and in floating point mode it is in volts.

- DC[.] n Dump acquired curve(s) to computer
- In fixed point mode, causes a stored curve to be dumped via the computer interface in decimal format.

In floating point mode the SEN curve (bit 4 in CBD) must have been stored if one or more of the following outputs are required in order that the lock-in amplifier can perform the necessary conversion from %FS to volts or amps:- X, Y, Magnitude, Noise.

One curve at a time is transferred. The value of n is the bit number of the required curve, which must have been stored by the most recent CBD command. Hence n can range from 0 to 15. If for example CBD 5 had been sent, equivalent to asserting bits 0 and 2, then the X and Magnitude outputs would be stored. The permitted values of n would therefore be 0 and 2, so that DC 0 would transfer the X channel output curve and DC 2 the Magnitude curve.

The computer program's subroutine which reads the responses to the DC command needs to run a FOR...NEXT loop of length equal to the value set by the LEN (curve length) command.

Note that when using this command with the GPIB interface the serial poll must be used. After sending the DC command, perform repeated serial polls until bit 7 is set, indicating that the instrument has an output waiting to be read. Then perform repeated

reads in a loop, waiting each time until bit 7 is set indicating that a new value is available. The loop should continue until bit 1 is set, indicating that the transfer is completed.

DCB n Dump acquired curve(s) to computer in binary format
 This command causes a stored curve to be dumped via the computer interface in binary format, using two bytes per point to transfer each 16-bit 2's complement value, with the MSB transmitted first. The number of data bytes sent is therefore equal to twice the current curve length. Each point is sent in fixed point mode, there being no floating point version of the command, and hence if floating point values are required the user may need to additionally store and read the Sensitivity curve and then perform the correction in his own software. In order to achieve the maximum transfer rate, no terminators are used within the transmission, although the response is terminated normally at the end.

One curve at a time is transferred. The value of n is the bit number of the required curve, which must have been stored by the most recent CBD command. Hence n can range from 0 to 15. If for example CBD 5 had been sent, equivalent to asserting bits 0 and 2, then the X and Magnitude outputs would be stored. The permitted values of n would therefore be 0 and 2, so that DC 0 would transfer the X channel output curve and DC 2 the Magnitude curve.

The computer program's subroutine which reads the responses to the DCB command needs to be able to handle the potentially very large data blocks (64 k bytes in the case of one 32 k curve) that can be generated.

DCT n Dump acquired curves to computer in table format
 This command is similar to the DC command described above, but allows transfer of several curves at a time and only operates in fixed point mode. Stored curve(s) are transferred via the computer interface in decimal format.

In single reference mode, the DCT parameter is an integer between 1 and 65,535, being the decimal equivalent of a 16-bit binary number. When a given bit in the number is asserted, the corresponding curve is selected for transfer. When a bit is negated, the curve is not transferred. The bit corresponding to each curve is shown in the table below:

Bit	Decimal value	Curve and output range
0	1	X Output (± 10000 FS)
1	2	Y Output (± 10000 FS)
2	4	Magnitude Output (0 to +10000 FS)
3	8	Phase ($\pm 18000 = \pm 180^\circ$)
4	16	Sensitivity setting (1 to 27) + IMODE (0, 1, 2 = 0, 32, 64)
5	32	ADC1 ($\pm 10000 = \pm 10.0$ V)
6	64	ADC2 ($\pm 10000 = \pm 10.0$ V)
7	128	Not Used
8	256	DAC1 ($\pm 10000 = \pm 10.0$ V)
9	512	DAC2 ($\pm 10000 = \pm 10.0$ V)
10	1024	Noise (0 to +10000 FS)

Bit	Decimal value	Curve and output range
11	2048	Ratio (± 10000 FS)
12	4096	Log ratio (-3000 to +2000)
13	8192	EVENT variable (0 to 32767)
14	16384	Reference frequency bits 0 to 15 (mHz)
15	32768	Reference frequency bits 16 to 32 (mHz)

The values of the selected curves at the same sample point are transferred as a group in the order of the above table, separated by the chosen delimiter character and terminated with the selected terminator. This continues until all the points have been transferred.

DD [n] Define delimiter control
 The value of n, which can be set to 13 or from 32 to 125, determines the ASCII value of the character sent by the lock-in amplifier to separate two numeric values in a two-value response, such as that generated by the MP (magnitude and phase) command.

ENBW[.] Equivalent noise bandwidth
 In fixed point mode, reports the equivalent noise bandwidth of the output low-pass filters at the current time constant setting in microhertz.

In floating point mode, reports the equivalent noise bandwidth of the output low-pass filters at the current time constant setting in hertz.

NOTE: This command is not available when the reference frequency exceeds 60 kHz.

EVENT [n] Event marker control
 During a curve acquisition, if bit 13 in the CBD command has been asserted, the lock-in amplifier stores the value of the Event variable at each sample point. This can be used as a marker indicating the point at which an experimental parameter was changed. The EVENT command is used to set this variable to any value between 0 and 32767.

EX [n] Output expansion control

n	Expand mode
0	Off
1	Expand X
2	Expand Y
3	Expand X and Y

FET [n] Voltage mode input device control

n	Selection
0	Bipolar device, 10 k Ω input impedance, 2 nV/ $\sqrt{\text{Hz}}$ voltage noise at 1 kHz
1	FET, 10M Ω input impedance, 5 nV/ $\sqrt{\text{Hz}}$ voltage noise at 1 kHz

FLOAT [n] Input connector shield float/ground control

n	Selection
0	Ground
1	Float (connected to ground via a 1 k Ω resistor)

- FRQ[.]** Reference frequency meter
 If the lock-in amplifier is in the external reference source modes, the FRQ command causes the lock-in amplifier to respond with 0 if the reference channel is unlocked, or with the reference input frequency if it is locked.
- If the lock-in amplifier is in the internal reference source mode, it responds with the frequency of the internal oscillator.
- In fixed point mode the frequency is in mHz.
- In floating point mode the frequency is in Hz.
- FSTART[.] [n]** Oscillator frequency sweep start frequency
 Sets the start frequency for a subsequent sweep of the internal oscillator frequency, in the range 0 to 120 kHz.
- In fixed point mode, n is in millihertz, and in floating point mode n is in hertz.
- FSTEP[.] [n₁ n₂]** Oscillator frequency sweep step size and type
 The frequency may be swept either linearly or logarithmically, as specified by parameter n₂. The step size is specified by parameter n₁.
- Log sweep n₂ = 0
 In fixed point mode, n₁ is the step size in thousandths of a percent.
 In floating point mode n₁ is in percent. The range of n₁ is 0 to 100.00%
- Linear sweep n₂ = 1
 In fixed point mode, n₁ is the step size in millihertz.
 In floating point mode n₁ is in hertz. The range of n₁ is 0 to 10 kHz
- FSTOP[.] [n]** Oscillator frequency sweep stop frequency
 Sets the stop frequency for a subsequent sweep of the internal oscillator frequency, in the range 0 to 120 kHz.
- In fixed point mode, n is in millihertz and in floating point mode n is in hertz.
- GP [n₁ [n₂]]** Set/Read GPIB parameters
 n₁ sets the GPIB address in the range 0 to 31
- n₂ Terminator
- | | |
|---|-----------------------------------|
| 0 | [CR], test echo disabled |
| 1 | [CR], test echo enabled |
| 2 | [CR,LF], test echo disabled |
| 3 | [CR,LF], test echo enabled |
| 4 | no terminator, test echo disabled |
| 5 | no terminator, test echo enabled |
- HC** Halt curve acquisition

- ID** Identification
Causes the lock-in amplifier to respond with the number 7225BFP.
- IE [n]** Reference channel source control (Internal/External)
The value of n sets the reference input mode according to the following table:
- | | |
|---|-------------------------------------------------------------|
| n | Selection |
| 0 | INT (internal) |
| 1 | EXT logic (external rear panel REF TTL input) |
| 2 | EXT analog (external rear panel REF IN analog input) |
- IMODE [n]** Current/Voltage mode input selector
- | | |
|---|---------------------------------------------------------------------------------------|
| n | Input mode |
| 0 | Current mode off - voltage mode input enabled |
| 1 | High bandwidth (HB) current mode enabled - connect signal to B input connector |
| 2 | Low noise (LN) current mode enabled - connect signal to B input connector |
- If n = 0 then the input configuration is determined by the VMODE command.
If n > 0 then current mode is enabled irrespective of the VMODE setting.
- LEN [n]** Curve length control
The value of n sets the curve buffer length in effect for data acquisition. The maximum allowed value depends on the number of curves requested using the CBD command, and a parameter error results if the value given is too large. For this reason, if the number of points is to be increased and the number of curves to be stored is to be reduced using the CBD command, then the CBD command should be issued first.
- LF [n₁ n₂]** Signal channel line frequency rejection filter control
The LF command sets the mode and frequency of the line frequency rejection (notch) filter according to the following tables:
- | | |
|----------------|-----------------------------------|
| n ₁ | Selection |
| 0 | Off |
| 1 | Enable 50 or 60 Hz notch filter |
| 2 | Enable 100 or 120 Hz notch filter |
| 3 | Enable both filters |
- | | |
|----------------|---------------------------------|
| n ₂ | Notch Filter Center Frequencies |
| 0 | 60 Hz (and/or 120 Hz) |
| 1 | 50 Hz (and/or 100 Hz) |
- LOCK** System lock control
Updates all frequency-dependent gain and phase correction parameters.
- LR[.]** Log Ratio output
In integer mode, the LR command reports a number equivalent to $1000 \times \log(X/ADC1)$ where X is the value that would be returned by the X command and ADC1 is the value that would be returned by the ADC1 command. The response range is -3000 to +2079

In floating point mode, the LR. command reports a number equivalent to $\log(X/ADC1)$. The response range is -3.000 to +2.079

M Curve acquisition status monitor
 Causes the lock-in amplifier to respond with four values that provide information concerning data acquisition, as follows:

First value, Curve Acquisition Status: a number with five possible values, defined by the following table:

First Value	Significance
0	No curve activity in progress.
1	Acquisition via TD command in progress and running.
2	Acquisition via TDC command in progress and running.
5	Acquisition via TD command in progress but halted by HC command.
6	Acquisition via TDC command in progress but halted by HC command.

Second value, Number of Sweeps Acquired: This number is incremented each time a TD is completed and each time a full cycle is completed on a TDC acquisition. It is zeroed by the NC command and also whenever a CBD or LEN command is applied without parameters.

Third value, Status Byte: The same as the response to the ST command. The number returned is the decimal equivalent of the status byte and refers to the previously applied command.

Fourth value, Number of Points Acquired: This number is incremented each time a point is taken. It is zeroed by the NC command and whenever CBD or LEN is applied without parameters.

MAG[.] Magnitude
 In fixed point mode causes the lock-in amplifier to respond with the magnitude value in the range 0 to 30000, full-scale being 10000.

In floating point mode causes the lock-in amplifier to respond with the magnitude value in the range +3.000E0 to +0.001E-9 volts or +3.000E-6 to +0.001E-15 amps.

MP[.] Magnitude, phase
 Equivalent to the compound command MAG[.];PHA[.]

MSK [n] Set/read service request mask byte
 The value of n sets the SRQ mask byte in the range 0 to 255

\N n Address command
 When the model 7225BFP is daisy-chained with other compatible instruments this command will change which instrument is addressed. All daisy-chained instruments receive commands but only the currently addressed instrument will implement or respond to the commands. The exception is the \N n command. If n matches the

address already set the instrument will switch into addressed mode. If n does not match the address already set the instrument will switch into unaddressed mode. Note that the \N n command does not change the address of an instrument but which instrument is addressed.

NOTE: All instruments must have a unique address.

N Report overload byte
 Causes the lock-in amplifier to respond with the overload byte, an integer between 0 and 255, which is the decimal equivalent of a binary number with the following bit-significance:

- Bit 0 not used
- Bit 1 CH1 output overload ($> \pm 120\%$ FS)
- Bit 2 CH2 output overload ($> \pm 120\%$ FS)
- Bit 3 Y channel output overload ($> \pm 300\%$ FS)
- Bit 4 X channel output overload ($> \pm 300\%$ FS)
- Bit 5 not used
- Bit 6 input overload
- Bit 7 reference unlock

NC New curve
 Initializes the curve storage memory and status variables. All record of previously taken curves is removed.

NHZ.
 Causes the lock-in amplifier to respond with the square root of the noise spectral density measured at the Y channel output, expressed in volt/ $\sqrt{\text{Hz}}$ or amps/ $\sqrt{\text{Hz}}$ referred to the input. This measurement assumes that the Y channel output is Gaussian with zero mean (see Section 3.3.16). The command is only available in floating point mode.

NOTE: This command is not available when the reference frequency exceeds 60 kHz.

NN[.] Noise output
 In fixed point mode causes the lock-in amplifier to respond with the mean absolute value of the Y channel output in the range 0 to 12000, full-scale being 10000. If the mean value of the Y channel output is zero, this is a measure of the output noise.

In floating point mode causes the lock-in amplifier to respond in volts.

OA[.] [n] Oscillator amplitude control
 In fixed point mode n sets the oscillator amplitude in μV . The range of n is 0 to 5000 representing 0 to 5 V rms.

In floating point mode n sets the amplitude in volts.

- OF[.] [n] Oscillator frequency control
 In fixed point mode n sets the oscillator frequency in mHz. The range of n is 0 to 120,000,000 representing 0 to 120 kHz.
- In floating point mode n sets the oscillator frequency in Hz. The range of n is 0 to 1.2E5
- PHA[.] Signal phase
 In fixed point mode causes the lock-in amplifier to respond with the signal phase in centidegrees, in the range ± 18000 .
- In floating point mode causes the lock-in amplifier to respond with the signal phase in degrees.
- REFN [n] Reference harmonic mode control
 The value of n sets the reference channel to one of the NF modes, or restores it to the default 1F mode. The value of n is in the range 1 to 32.
- REFP[.] [n] Reference phase control
 In fixed point mode n sets the phase in millidegrees in the range ± 360000 .
- In floating point mode n sets the phase in degrees.
- REV Report firmware revision
 Causes the lock-in amplifier to respond with the firmware revision number. This gives a four line response which the controlling program must be able to accept.
- RS [n₁ [n₂]] Set/read RS232 interface parameters
- | n ₁ | Baud rate (bits per second) |
|----------------|-----------------------------|
| 0 | 75 |
| 1 | 110 |
| 2 | 134.5 |
| 3 | 150 |
| 4 | 300 |
| 5 | 600 |
| 6 | 1200 |
| 7 | 1800 |
| 8 | 2000 |
| 9 | 2400 |
| 10 | 4800 |
| 11 | 9600 |
| 12 | 19200 |
- The lowest five bits in n₂ control the other RS232 parameters according to the following table:

Appendix G, ALPHABETICAL LISTING OF COMMANDS

bit number	bit negated	bit asserted
0	data + parity = 8 bits	data + parity = 9 bits
1	no parity bit	1 parity bit
2	even parity	odd parity
3	echo disabled	echo enabled
4	prompt disabled	prompt enabled

RT[.] Ratio output

In integer mode the RT command reports a number equivalent to $1000 \times X / \text{ADC1}$ where X is the value that would be returned by the X command and ADC1 is the value that would be returned by the ADC1 command.

In floating point mode the RT. command reports a number equivalent to $X / \text{ADC1}$.

SAMPLE [n] Main analog-to-digital converter sample frequency control
n may be set to 0, 1 or 2, corresponding to three different sampling frequencies (not specified) near 166 kHz.

SEN [n]

SEN. n	Full-scale sensitivity control		
	full-scale sensitivity		
	IMODE=0	IMODE=1	IMODE=2
1	2 nV	2 fA	n/a
2	5 nV	5 fA	n/a
3	10 nV	10 fA	n/a
4	20 nV	20 fA	n/a
5	50 nV	50 fA	n/a
6	100 nV	100 fA	n/a
7	200 nV	200 fA	2 fA
8	500 nV	500 fA	5 fA
9	1 μ V	1 pA	10 fA
10	2 μ V	2 pA	20 fA
11	5 μ V	5 pA	50 fA
12	10 μ V	10 pA	100 fA
13	20 μ V	20 pA	200 fA
14	50 μ V	50 pA	500 fA
15	100 μ V	100 pA	1 pA
16	200 μ V	200 pA	2 pA
17	500 μ V	500 pA	5 pA
18	1 mV	1 nA	10 pA
19	2 mV	2 nA	20 pA
20	5 mV	5 nA	50 pA
21	10 mV	10 nA	100 pA
22	20 mV	20 nA	200 pA
23	50 mV	50 nA	500 pA

n	full-scale sensitivity		
	IMODE=0	IMODE=1	IMODE=2
24	100 mV	100 nA	1 nA
25	200 mV	200 nA	2 nA
26	500 mV	500 nA	5 nA
27	1 V	1 μ A	10 nA

SLOPE [n] Output low-pass filter slope (roll-off) control

n	Slope
0	6 dB/octave
1	12 dB/octave
2	18 dB/octave
3	24 dB/octave

SRATE[.] [n] Oscillator frequency and amplitude sweep step rate
Sets the sweep rate in time per step in the range 50 ms to 1000 s, in 5 ms increments.

ST Report status byte
Causes the lock-in amplifier to respond with the status byte, an integer between 0 and 255, which is the decimal equivalent of a binary number with the following bit-significance:

Bit 0	Command complete
Bit 1	Invalid command
Bit 2	Command parameter error
Bit 3	Reference unlock
Bit 4	Overload
Bit 5	New ADC values available after external trigger
Bit 6	Asserted SRQ
Bit 7	Data available

NOTE: this command is not normally used in GPIB communications, where the status byte is accessed by performing a serial poll.

STAR [n] Star mode setup command

n	Data returned by * command
0	X
1	Y
2	MAG
3	PHA
4	ADC1
5	XY
6	MP
7	ADC1;ADC2

* Transfer command
This command establishes the high-speed transfer mode. Use the STAR command to set up the desired response to the * command, and then send an * (ASCII 42), without terminator, to the instrument. The instrument will reply with the selected output as quickly as possible, and then wait for another *. If the computer processes the reply

quickly and responds immediately with another *, then very rapid controlled data transfer is possible.

The first transfer takes a little longer than subsequent ones because some overhead time is required for the model 7225BFP to get into the high-speed transfer mode.

The mode is terminated either by sending any command other than an *, when the instrument will exit the mode and process the new command, or after a period of 10 seconds following the last * command.

NOTE: Check that the computer program does not automatically add a carriage return or carriage return-line feed terminator to the * command, since these characters will slow down communications.

STR [n] Storage interval control

Sets the time interval between successive points being acquired under the TD or TDC commands. n specifies the time interval in ms with a resolution of 5 ms, input values being rounded up to a multiple of 5. The longest interval that can be specified is 1000000 s corresponding to one point in about 12 days.

In addition, n may be set to 0, which sets the rate of data storage to the curve buffer to 1.25 ms/point (800 Hz). However this only allows storage of the X and Y channel outputs. There is no need to issue a CBD 3 command to set this up since it happens automatically when acquisition starts.

If the time constant is set to 5 ms or longer, then the actual time constant applied to the stored X and Y channel output values will be 640 μ s, but if it is set to a shorter value then this will be the time constant actually used.

SWEEP [n] Oscillator frequency and amplitude sweep start/stop

- n Sweep status
- 0 Stop/Pause
- 1 Start frequency sweep
- 2 Start amplitude sweep
- 3 Start frequency sweep and amplitude sweep

SYNC [n] Synchronous time constant control

- n Effect
- 0 Synchronous time constant disabled
- 1 Synchronous time constant enabled

SYNCOSC [n] Synchronous oscillator (demodulator monitor) control

This control operates only in external reference mode.

- n Effect
- 0 Synchronous Oscillator (Demodulator Monitor) disabled
- 1 Synchronous Oscillator (Demodulator Monitor) enabled

TADC [n] Auxiliary ADC trigger mode control
 The value of n sets the trigger mode of the auxiliary **ADC** inputs according to the following table:

- | | |
|----|--------------------------------------------------------------------------------------------------------------------------------------|
| n | Trigger mode |
| 0 | Asynchronous (5 ms intervals) |
| 1 | External ADC1 and ADC 2 (rear panel TRIG input) |
| 2 | Burst mode, 25 μ s/point, triggered by command (ADC1 only) |
| 3 | Burst mode, 56 μ s/point, triggered by command (ADC1 and ADC2) |
| 4 | Burst mode, variable rate, triggered by command (ADC1 only) |
| 5 | Burst mode, variable rate, triggered by command (ADC1 and ADC2) |
| 6 | Burst mode, 25 μ s/point, External trigger with < 1.25 ms trigger indeterminacy (rear panel TRIG input) (ADC1 only) |
| 7 | Burst mode, 56 μ s/point, External trigger < 1.25 ms trigger indeterminacy (rear panel TRIG input) (ADC1 and ADC2) |
| 8 | Burst mode, variable rate, External trigger < 1.25 ms trigger indeterminacy (rear panel TRIG input) (ADC1 only) |
| 9 | Burst mode, variable rate, External trigger < 1.25 ms trigger indeterminacy (rear panel TRIG input) (ADC1 and ADC2) |
| 10 | Burst mode, 25 μ s/point, External trigger with < 25 μ s trigger indeterminacy (rear panel TRIG input) (ADC1 only) |
| 11 | Burst mode, 56 μ s/point, External trigger with < 25 μ s trigger indeterminacy(rear panel TRIG input) (ADC1 and ADC2) |
| 12 | Burst mode, variable rate, External trigger with < 25 μ s trigger indeterminacy(rear panel TRIG input) (ADC1 only) |
| 13 | Burst mode, variable rate, External trigger with < 25 μ s trigger indeterminacy(rear panel TRIG input) (ADC1 and ADC2) |

NOTE: TADC modes 10 to 13 cause all other functions of the host microprocessor to be suspended, including responding to computer commands, until a trigger is received at the TRIG input. Hence they should only be used when the user is certain that such a trigger will occur.

TC [n]
 TC. Filter time constant control

- | | |
|----|---------------|
| n | time constant |
| 0 | 10 μ s |
| 1 | 20 μ s |
| 2 | 40 μ s |
| 3 | 80 μ s |
| 4 | 160 μ s |
| 5 | 320 μ s |
| 6 | 640 μ s |
| 7 | 5 ms |
| 8 | 10 ms |
| 9 | 20 ms |
| 1 | 50 ms |
| 11 | 100 ms |
| 12 | 200 ms |

- n time constant
- 13 500 ms
- 14 1 s
- 15 2 s
- 16 5 s
- 17 10 s
- 18 20 s
- 19 50 s
- 20 100 s
- 21 200 s
- 22 500 s
- 23 1 ks
- 24 2 ks
- 25 5 ks
- 26 10 ks
- 27 20 ks
- 28 50 ks
- 29 100 ks

The TC. command is only used for reading the time constant, and reports the current setting in seconds. Hence if a TC 11 command were sent, TC would report 11 and TC. would report 1.0E-01, i.e. 0.1 s or 100 ms.

- TD Take data
Initiates data acquisition. Acquisition starts at the current position in the curve buffer and continues at the rate set by the STR command until the buffer is full.
- TDC Take data continuously
- TDT n Take data triggered
 - n function
 - 0 One complete curve or set of curves, each one consisting of the number of points specified by the LEN command parameter, is acquired for each trigger
 - 1 One data point or set of data points is acquired for each trigger. Hence in order to store a complete curve or set of curves, the number of triggers applied must equal the number of points specified by the LEN command parameter. Note that in this mode the maximum trigger rate is 200 Hz and the storage interval control setting has no effect.
- VER Report firmware version
Causes the lock-in amplifier to respond with the firmware version number.
- VMODE [n] Voltage input configuration
 - n Input configuration
 - 0 Both inputs grounded (test mode)
 - 1 A input only
 - 3 A-B differential mode

Note that the IMODE command takes precedence over the VMODE command.

VRLOCK [n] Virtual reference mode lock
The Seek option of the frequency sweep mode must be used before issuing this command, for which the value of n has the following significance:

- n Mode
- 0 Disables virtual reference mode
- 1 Enters virtual reference mode by enabling tracking of the signal frequency

X[.] X channel output
In fixed point mode causes the lock-in amplifier to respond with the X demodulator output in the range ± 30000 , full-scale being ± 10000 .

In floating point mode causes the lock-in amplifier to respond with the X demodulator output in volts or amps.

XOF [n₁ [n₂]] X channel output offset control
n₁ Selection
0 Disables offset
1 Enables offset facility

The range of n₂ is ± 30000 corresponding to $\pm 300\%$ full-scale.

XY[.] X, Y channel outputs
Equivalent to the compound command X[.];Y[.]

Y[.] Y channel output
In fixed point mode causes the lock-in amplifier to respond with the Y demodulator output in the range ± 30000 , full-scale being ± 10000 .

In floating point mode causes the lock-in amplifier to respond with the Y demodulator output in volts or amps.

YOF [n₁ [n₂]] Y channel output offset control
n₁ Selection
0 Disables offset facility
1 Enables offset facility

The range of n₂ is ± 30000 corresponding to $\pm 300\%$ full-scale.

- * command 5-17, G-13
- ? command 5-17, F-3, G-1
- \N n command 5-28, G-9
- 2F reference mode 3-6
- 8-bit programmable output port 3-8
- Absolute accuracy 3-8
- AC Gain
 - and full-scale sensitivity 3-9
 - and input overload 3-4
 - description of 3-3
- AC/DC input coupling 3-2
- Accuracy 3-8
- ACGAIN [n] command 5-11, G-1
- ADC
 - sampling frequency 3-4
- ADC[.] n command 5-20, G-1
- ADC1
 - auxiliary input 3-7
 - connector 4-3
- ADC2
 - auxiliary input 3-7
 - connector 4-3
- ADF n command 5-29, G-1
- Analog meter 3-9
- Analog to digital converter (ADC) 3-4
- Anti-aliasing filter 3-4
- AQN command 5-12, G-1
- AS command 5-11, G-1
- ASM command 5-11, G-1
- ASTART[.] [n] command 5-17, F-3, G-1
- ASTEPP[.] [n] command 5-18, F-3, G-1
- ASTOP[.] [n] command 5-18, F-3, G-2
- Auto functions
 - Auto-Measure 3-9, 3-16
 - Auto-Offset 3-15
 - Auto-Phase 3-15
 - Auto-Sensitivity 3-9, 3-14
 - introduction 3-14
- AUTOMATIC [n] command 5-11, G-2
- AUX RS232 connector 4-2
- Auxiliary ADCs 3-7
- Auxiliary RS232 interface 5-4
- AXO command 5-14, G-2
- Baseband reference mode 3-6
- Bipolar input device 3-1
- Burst mode acquisition 5-1
- BURSTTPP [n] command 5-21, F-2
- BYTE [n] command 5-19, G-2
- CBD [n] command 5-21, G-2
- CH n₁ [n₂] command 5-14, G-3
- CH1
 - connector 4-3
 - output 3-7
- CH2
 - connector 4-3
 - output 3-7
- Commands
 - alphabetical listing of F-3, G-1
 - compound 5-7
 - descriptions of 5-9
 - for Auto-Default function 5-29
 - for auxiliary inputs 5-20
 - for auxiliary outputs 5-19
 - for computer interfaces 5-27
 - for data curve buffer 5-21
 - for instrument identification 5-29
 - for instrument outputs 5-15
 - for internal oscillator 5-17
 - for reference channel 5-12
 - for signal channel inputs 5-9
 - for signal channel output amplifiers 5-14
 - for signal channel output filters 5-13
 - format 5-6
- Computer control, sample programs 5-29
- Computer operation, introduction 5-1
- CP [n] command 5-10, G-4
- Current input mode 3-1
- Current/voltage input mode selection 3-3
- Curve storage 5-1
 - commands for 5-21
- DAC[.] n₁ [n₂] command 5-19, G-4
- DAC1
 - auxiliary output 3-7
 - connector 4-3
- DAC2
 - auxiliary output 3-7
 - connector 4-3
- DC[.] n command 5-24, G-4
- DCB n command 5-25, F-3, G-5
- DCT n command 5-25, G-5
- DD [n] command 5-7, 5-28, G-6
- Default setting 3-16

- Default settings, list of E-1
- Delimiters 5-7
- Demodulator
 - DSP 3-7
 - gain 3-9
 - monitor 3-6
- Differential voltage input mode 3-2, 4-3
- Digital displays 3-9
- Digital low-pass filter 3-7
- Digital output port 3-8
- DIGITAL OUTPUTS connector 4-2
- Digital phase locked loop 3-6
- Digital phase shifter 3-6
- Direct digital synthesizer (DDS) 3-6
- Direct mode 5-2
- Dynamic range 3-4
- Dynamic reserve 3-9
- ENBW[.] command 5-16, G-6
- Equivalent noise bandwidth 3-13
- EVENT [n] command 5-23, G-6
- EX [n] command 5-14, G-6
- External reference mode 3-6
- FAST X
 - connector 4-3
 - output 3-7
- FAST Y
 - connector 4-3
 - output 3-7
- FET [n] command 5-10, G-6
- FET input device 3-1
- FIR filters 3-11
- FLOAT [n] command 5-10, G-6
- Floating point command format 5-7
- FRQ[.] command 5-12, G-7
- FSTART[.] [n] command 5-18, G-7
- FSTEP[.] [n₁ n₂] command 5-18, G-7
- FSTOP[.] [n] command 5-18, G-7
- Full-scale sensitivity 3-9
- Fuses, line 2-1, 2-2
- General purpose reference input 3-6
- GP [n1 [n2]] command 5-4, 5-6, 5-27, G-7
- GPIB interface
 - address 5-4
 - connector 4-2
 - general features 5-4
 - handshaking 5-5
 - microprocessor support of 3-8
 - service request 5-8
- Handshaking and echos 5-5
- Harmonic measurements 3-6
- HC command 5-24, G-7
- Highband reference mode 3-6
- ID command 5-29, G-8
- IE [n] command 5-12, G-8
- IMODE [n] command 5-9, G-8
- Initial checks 2-3
- Input
 - connector shell ground/float 3-2
 - coupling 3-1
 - device selection 3-2
 - float/ground control 3-2
 - impedance 3-2
 - mode selection 3-3
 - overload 3-4
 - overload indicators 4-3
 - selection 3-2
- Inspection 2-1
- Installation 2-1
- Internal oscillator 3-6
- Internal oscillator frequency sweep 3-8
- Internal reference mode 3-6
- Key specifications 1-3
- LEN [n] command 5-22, G-8
- LF [n₁ n₂] command 3-3, 5-11, F-2, G-8
- Line cord 2-1
- Line frequency rejection filter 3-3
- Line fuses 2-1, 2-2
- Line power input assembly 4-1
- Line power switch 4-1
- Line voltage selection 2-1
- LOCK command 3-10, 5-12, G-8
- LR[.] command 5-16, G-8
- M command 5-24, G-9
- MAG[.] command 5-15, G-9
- Main microprocessor 3-8
- Microsoft Windows Terminal program 5-2
- MP[.] command 5-15, G-9
- MSK [n] command 5-8, 5-29, G-9
- N command 5-8, 5-28, G-10
- NC command 5-23, G-10
- nF reference mode 3-6
- NHZ. command 5-16, G-10
- NN[.] command 5-16, G-10
- Noise measurements 3-13
- Null modem 5-2, 5-5
- OA[.] [n] command 5-17, G-10
- OF[.] [n] command 5-18, G-11
- Operating environment 2-1
- OSC OUT connector 3-6, 4-2
- Oscillator amplitude sweep generator 5-1
- Oscillator frequency sweep generator 5-1
- Output

- channel filters 3-7, 3-11
- expand 3-12
- offset 3-12
- processor 3-7
- Overload byte 5-7
- PHA[.] command 5-15, G-11
- Phase 3-7
- Phase noise 3-6
- Phase sensitive detector 3-6
- Phase shifter 3-10
- Phase values 3-6
- Power consumption 2-1
- Power input assembly 2-1
- Power-up defaults 3-14
- PREAMP POWER connector 4-2
- Programming examples 5-29
- Prompt character 5-7
- Rack mounting 2-1
- Ratio calculations 3-7
- Rear panel layout 4-1
- REF IN connector 3-10, 4-2
- REF MON connector 4-2
- REF TTL connector 4-2
- Reference channel DSP 3-6
- Reference frequency changes 3-10
- Reference harmonic number 3-7
- Reference mode
 - external 3-6
 - internal 3-6
- Reference phase 3-10
- REFN [n] command G-11
- REFP[.] [n] command 5-12, G-11
- Relative accuracy 3-8
- REV command 5-29, G-11
- RS [n₁ [n₂]] command 5-27, G-11
- RS232 interface
 - address 5-4
 - choice of baud rate 5-3
 - choice of number of data bits 5-3
 - choice of parity check option 5-3
 - connector 4-1
 - general features 5-2
 - handshaking 5-5
 - input terminator 5-6
 - microprocessor support of 3-8
 - output terminator 5-6
- RT[.] command 5-16, G-12
- SAMPLE [n] command 5-11, G-12
- SEN [n] command 5-10, G-12
- SEN. command 5-10, G-12
- SIG MON connector 3-4, 4-3
- Signal channel inputs 3-1
- Signal channel overload 3-9
- Signal input connectors 4-3
- Single-ended voltage input mode 4-3
- Slope 3-11
- SLOPE [n] command 5-13, G-13
- Specifications
 - detailed listing of A-1
 - for Auxiliary Inputs A-4
 - for Data Storage A-5
 - for Demodulator and Output Processing A-3
 - for Measurement Modes A-1
 - for Oscillator A-3
 - for Outputs A-4
 - for Reference Channel A-2
 - for Signal Channel A-1
- SRATE[.] [n] command 5-19, G-13
- ST command 5-8, 5-28, G-13
- STAR [n] command 5-16, G-13
- Status byte 5-7
- STR [n] command 5-23, G-14
- SWEEP [n] command 5-19, F-2, G-14
- SYNC [n] command 5-14, G-14
- Synchronous filters 3-11
- Synchronous oscillator 3-6
- SYNCOSC [n] command 5-18, G-14
- System updates 3-10
- TADC [n] command 5-20, G-15
- TC [n] command 5-13, G-15
- TC. command 5-13, G-15
- TD command 5-23, G-16
- TDC command 5-23, G-16
- TDT n command 5-23, F-3, G-16
- Technical description 3-1
- Terminal emulator 5-2
- Terminal mode 5-2
- Terminators 5-6
- Time constants 3-11
- Transient recorder 3-8
- TRIG connector 4-3
- TTL logic reference input 3-6
- Update program 3-8
- Vector magnitude 3-7
- Ventilation 2-1
- VER command 5-29, G-16
- VMODE [n] command 5-9, G-16
- Voltage input mode 3-1
- VRLOCK [n] command G-17
- What is a lock-in amplifier? 1-2
- X & Y demodulation functions 3-7
- X[.] command 5-15, G-17

INDEX

XOF [n_1 [n_2]] command 5-14, G-17
XY[.] command 5-15, G-17
Y[.] command 5-15, G-17

YOF [n_1 [n_2]] command 5-14, G-17
Zero error 3-15

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