

Model 7220

DSP Lock-in Amplifier

Instruction Manual

190171-A-MNL-C

FCC Notice

This equipment generates, uses, and can radiate radio-frequency energy and, if not installed and used in accordance with this manual, may cause interference to radio communications. As temporarily permitted by regulation, operation of this equipment in a residential area is likely to cause interference, in which case the user at his own facility will be required to take whatever measures may be required to correct the interference.

Declaration of Conformity

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

Safety: BS EN61010-1: 1993 (IEC 1010-1:1990+A1:1992)

Trademarks

IBM is a registered trademark of International Business Machines Corporation.
Microsoft, MS-DOS, GW-BASIC, QBASIC and QUICKBASIC are registered trademarks and Windows is a trademark of Microsoft Corporation.

Table of Contents

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	3-2
3.2.03 Line Frequency Rejection Filter	3-3
3.2.04 AC Gain	3-4
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	3-7
3.2.09 Demodulator DSP	3-7
3.2.10 Output Processor	3-8
3.2.11 Main Microprocessor	3-8
3.3 Accuracy	3-8
3.3.01 Absolute Accuracy Specifications	3-8

TABLE OF CONTENTS

3.3.02 Relative Accuracy	3-9
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	3-12
3.8.03 Output Offset and Expand	3-12
3.9 Use of Magnitude and Signal Phase Outputs	3-12
3.10 Noise Measurements	3-14
3.11 Power-up Defaults	3-14
3.12 Auto Functions	3-14
3.12.01 Introduction	3-14
3.12.02 Auto-Sensitivity	3-15
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
4.1.01 A and B/I Signal Input Connectors	4-1
4.1.02 OSC OUT Connector	4-1
4.1.03 REF IN Connector	4-2
4.1.04 Left-hand LCD Display Panel	4-2
4.1.05 MENU Key	4-4
4.1.06 90° Key	4-5
4.1.07 SET Key	4-5
4.1.08 Right-hand LCD Display Panel	4-5
4.2 Rear Panel	4-6
4.2.01 Line Power Switch	4-6
4.2.02 Line Power Input Assembly	4-6
4.2.03 RS232 Connector	4-7
4.2.04 AUX RS232 Connector	4-7
4.2.05 GPIB Connector	4-7
4.2.06 DIGITAL OUTPUTS Connector	4-7

4.2.07 PREAMP POWER Connector	4-7
4.2.08 REF MON Connector	4-7
4.2.09 REF TTL Connector	4-7
4.2.10 SIG MON Connector	4-7
4.2.11 CH1, CH2 Connectors	4-8
4.2.12 TRIG Connector	4-8
4.2.13 ADC1, ADC2 Connectors	4-8
4.2.14 DAC1, DAC2 Connectors	4-8
4.2.15 FAST X, FAST Y Connectors	4-8

Chapter Five, Front Panel Operation

5.1 Introduction	5-1
5.2 Setup Menu Mode	5-1
5.2.01 Input Setup Menu	5-2
5.2.02 Reference Setup Menu	5-4
5.2.03 Output Setup Menu	5-5
5.2.04 Control Options Menu	5-8
5.2.05 Miscellaneous Options Menu	5-10
5.2.06 RS232 Setup 1 Menu	5-11
5.2.07 RS232 Setup 2 Menu	5-12
5.2.08 RS232 Setup 3 Menu	5-13
5.2.09 GPIB Setup 1 Menu	5-14
5.2.10 GPIB Setup 2 Menu	5-15
5.2.11 Digital Outputs Setup Menu	5-16
5.2.12 Control Setup Menu	5-17
5.3 Auto Functions Menu	5-18
5.4 Main Display Mode - Left-hand LCD	5-20
5.5 Main Display Mode - Right-hand LCD	5-26
5.6 Typical Lock-in Amplifier Experiment	5-35

Chapter Six, Computer Operation

6.1 Introduction	6-1
6.2 Capabilities	6-1
6.2.01 General	6-1
6.2.02 Curve Storage	6-1
6.2.03 Burst Mode Acquisition	6-1
6.2.04 Internal Oscillator Frequency Sweep Generator	6-2

TABLE OF CONTENTS

6.3 RS232 and GPIB Operation	6-2
6.3.01 Introduction	6-2
6.3.02 RS232 Interface - General Features	6-2
6.3.03 Choice of Baud Rate	6-3
6.3.04 Choice of Number of Data Bits	6-3
6.3.05 Choice of Parity Check Option	6-3
6.3.06 Auxiliary RS232 Interface	6-4
6.3.07 GPIB Interface - General Features	6-4
6.3.08 Handshaking and Echoes	6-5
6.3.09 Terminators	6-6
6.3.10 Command Format	6-6
6.3.11 Delimiters	6-7
6.3.12 Compound Commands	6-7
6.3.13 Status Byte, Prompts and Overload Byte	6-7
6.3.14 Service Requests	6-9
6.4 Command Descriptions	6-10
6.4.01 Signal Channel	6-10
6.4.02 Reference Channel	6-13
6.4.03 Signal Channel Output Filters	6-14
6.4.04 Signal Channel Output Amplifiers	6-15
6.4.05 Instrument Outputs	6-16
6.4.06 Internal Oscillator	6-19
6.4.07 Auxiliary Outputs	6-20
6.4.08 Auxiliary Inputs	6-21
6.4.09 Output Data Curve Buffer	6-23
6.4.10 Computer Interfaces (RS232 and GPIB)	6-27
6.4.11 Instrument Identification	6-29
6.4.12 Front Panel	6-30
6.4.13 Default Setting	6-30
6.5 Programming Examples	6-30
6.5.01 Introduction	6-30
6.5.02 Basic Signal Recovery	6-30
6.5.03 Frequency Response Measurement	6-31
6.5.04 X and Y Output Curve Storage Measurement	6-32
6.5.05 Transient Recorder	6-32
6.5.06 Frequency Response Measurement using Curve Storage and Frequency Sweep	6-33

Appendix A, Specifications

Appendix B, Pinouts

B.1 RS232 Connector Pinout	B-1
B.2 Preamplifier Power Connector Pinout	B-1
B.3 Digital Output Port Connector	B-2

Appendix C, Demonstration Programs

C.1 Simple Terminal Emulator	C-1
C.2 RS232 Control Program with Handshakes	C-1
C.3 GPIB User Interface Program	C-3

Appendix D, Cable Diagrams

D.1 RS232 Cable Diagrams	D-1
--------------------------------	-----

Appendix E, Alphabetical Listing of Commands

Appendix F, Default Settings

Default Setting Function	F-1
--------------------------------	-----

Index

WARRANTY	End of Manual
----------------	---------------

1.1 How to Use This Manual

This manual gives detailed instructions for setting up and operating the EG&G Instruments Model 7220 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 7220.

Chapter 2 - Installation and Initial Checks

Describes how to install the instrument and gives a simple test procedure which you may perform 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 - Front Panel Operation

Describes the capabilities of the instrument when used as a manually operated unit, and shows how to operate it using the front panel controls.

Chapter 6 - 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 an IBM-PC or 100 % compatible computer.

Appendix E

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

Appendix F

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

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, even if you intend that the unit will eventually be used under computer control. Only when you are fully conversant with operation from the front panel should you then turn to chapter 6 for information on how to use the instrument remotely. Once you are familiar with the structure of the computer commands, appendix E will prove to be 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 7220, 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 7220 lock-in amplifier can function as a:-

- AC Signal Recovery Instrument
- Vector Voltmeter
- Phase Meter
- Spectrum Analyzer
- Transient Recorder
- Precision Oscillator
- Frequency Meter
- 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 EG&G Instruments Model 7220 represents the latest in DSP Lock-in Amplifier technology at an affordable price, and offers:-

- **Frequency range:** 0.001 Hz to 120 kHz
- **Voltage sensitivity:** 20 nV to 1 V full-scale
- **Current input mode sensitivities:** 20 fA to 1 μ A full-scale
20 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 sweep generator**
- **Output time constant: 10 μ s to 5 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 7220 in the laboratory or on the production line is very simple. Because of its low power consumption, the model 7220 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 EG&G Instruments to allow the model 7220 to be mounted in a standard 19-inch rack.

2.1.03 Inspection

Upon receipt the model 7220 Lock-in Amplifier should be inspected for shipping damage. If any is noted, EG&G INSTRUMENTS 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 7220 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 7220 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 7220 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.

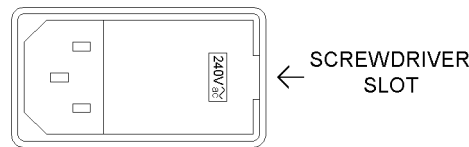


Figure 2-1, Line Input Assembly

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 7220. 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 EG&G INSTRUMENTS 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 EG&G INSTRUMENTS or the nearest authorized representative for assistance.

2.2.02 Procedure

- 1) Ensure that the model 7220 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) Turn the model 7220 power switch to the **I** (on) position.
- 4) The instrument's front panel displays will now briefly display the following message:-



Figure 2-2, Opening Display

- 5) Press the key marked **MENU** twice to enter the setup menu screens. (N.B. on early units this key was marked **AUTO**).
- 6) Press one of the keys on the left-hand side of the left-hand display repeatedly until

the CONTROL SETUP menu is displayed, which will look similar to the following:-

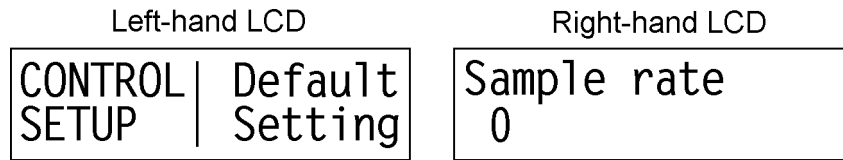


Figure 2-3, Control Setup Menu

- 7) Press one of the keys on the right-hand side of the left-hand display once. This will set all the instrument's controls and displays to a known state. The displays will revert to the normal mode, with the left-hand panel showing the AC Gain and Full Scale Sensitivity controls and the right-hand one the instrument's outputs in the form of magnitude as a percentage of full-scale and phase in degrees.
- 8) The right-hand display should now look as follows:-

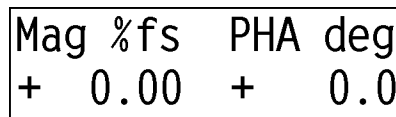


Figure 2-4, Right-hand LCD - Main Display

- 9) Connect a BNC cable between the **OSC OUT** and **A** input connectors on the front panel.
- 10) The right-hand display should now indicate a magnitude close to 100 % of full-scale (i.e. the sinusoidal oscillator output, which was set to 1 kHz and a signal level of 0.5 V rms by the Default Setting key is being measured with a full-scale sensitivity of 500 mV rms) and a phase of near zero degrees, if a short cable is used.

This completes the initial checks. Even though the procedure leaves many functions untested, if the indicated results were obtained the user can be reasonably sure that the unit incurred no hidden damage in shipment and is in good working order.

3.1 Introduction

The model 7220 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 7220 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.

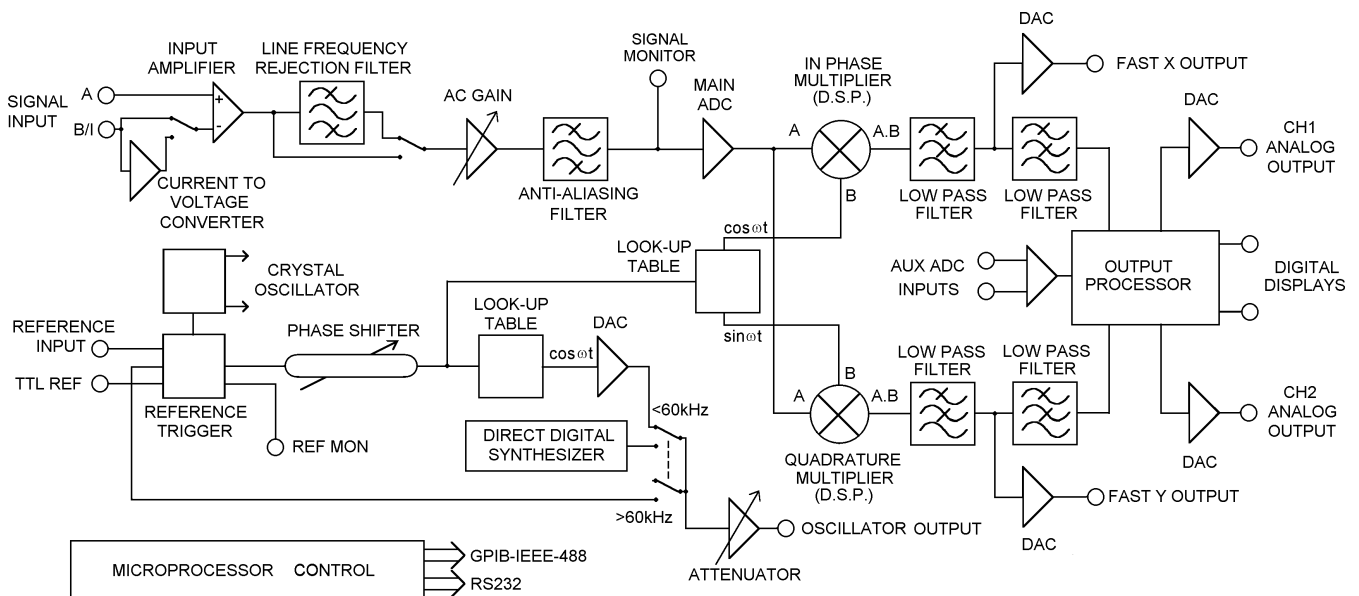


Figure 3-1, Model 7220 - Block Diagram

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 centre and the outer of the **A** input BNC connector, whereas when set to (A-B) mode it measures the difference in voltage between the centre 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 it may be possible to make a substantial reduction in unwanted offsets by using this mode, with a short-circuit terminator on the **B** connector, rather than by 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 μ 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 k Ω 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 k Ω , shows a relatively high level of added current noise (2 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 100 Ω 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 M Ω .

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/I** connector. High impedance sources (> 100 k Ω) 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 EG&G Instruments 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.

Early instruments use a simple single stage band-rejection filter, which has a relatively broad bandwidth. This introduces significant gain and phase errors, at least in the range 5 to 500 Hz, and this should be taken into account if it is used in conjunction with reference frequencies in or near to this range. The filter control settings for these units are simply “ON” or “OFF”.

Instruments manufactured after June 1996 use a more sophisticated type of filter, which uses two cascaded rejection stages with “notch” characteristics. This allows the filter to be set to reject signals at frequencies equal to either of, or both of, the fundamental and second harmonic of the line frequency. Hence the filter control settings for these instruments are “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. The later instruments therefore respond to a computer command, LINE50, which allows this to be done (see section 6.4).

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 Rate control which allows the user to adjust the main ADC sampling rate 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 7220, 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 7220 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, nf_{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 drives the front panel displays, processes front panel key operations and 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.

A new feature of the model 7220 is the introduction of a separate control function (“AC Gain”) for the gain of the signal channel. Where appropriate, this can be set to accommodate the existing noise level and subsequent changes in the instrument’s full-scale sensitivity do not cause any of the errors which might arise from a change in the analog gain.

3.4 Full-Scale Sensitivity and AC Gain Control

The full-scale sensitivity is indicated as SEN on the left-hand LCD and is adjusted by the use of the adjacent keys. The analog outputs and analog meter limit at a level a few percent above the full-scale sensitivity value, but the digital displays 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 facility 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

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

Applying this formula to the model 7220 we may put in the maximum value of INPUT LIMIT (3 V) and the smallest available value of FULL-SCALE SENSITIVITY (20 nV) to reach 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.

For the benefit of users who prefer to have the AC Gain value expressed in this form, the model 7220 displays the current value of Dynamic Reserve in decibels on the input full-scale sensitivity control.

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 **SET** key is pressed or the **LOCK** command is executed. Therefore if the most accurate and reproducible settings are required, the **SET** key should be pressed or the **LOCK** command 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 press the front panel **SET** key or to issue the **LOCK** command.

3.7 Reference Phase and Phase Shifter

If the reference input is a sinusoid applied to the **REF IN** socket, 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 circuits connected to the **REF IN** socket actually detect 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 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 a reference input to the **TTL REF IN** socket is that of a sinusoid with positive-going zero crossing at the same point in time.

The reference phase is adjusted to its required value by the use of a digital phase shifter, which is accessed from the front panel, by the REFP computer command or with the use of 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 7220 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 7220 to apply to the envelope of the frequency response function of the digital FIR (finite impulse response) output filters. Accordingly the front panel display control which selects the configuration of the output filters is labelled SLOPE and the options are labelled 6, 12, 18, 24 dB/octave.

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 5 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 5 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.

These filters 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 ± 300 % full-scale offset to be applied to the X, Y or both displays. Note however that the rear panel analog outputs limit at ± 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 analog meter indication and 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.

The user is strongly advised to use an oscilloscope attached to the rear panel **SIG MON** (signal monitor) output when making noise measurements as this is the best way of ensuring that one is measuring a random process 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 REMOTE parameter is set to zero (front panel control enabled).
- d) The curve buffer is cleared.
- e) Any sweep that was in progress at switch-off is terminated.
- f) Synchronous time constants are enabled.
- g) Display backlights are turned on

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 or two key-presses. 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, it must be nulled with an Auto-Offset operation before the signal is applied and Auto-Phase executed. If the error is due to unwanted interaction between signal and reference (crosstalk) the Auto-Phase, while actually setting the correct phase, will not give a zero value of signal phase. The final step is to remove the signal and execute another Auto-Offset operation. This is a powerful method of removing the effect of 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 7220, 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

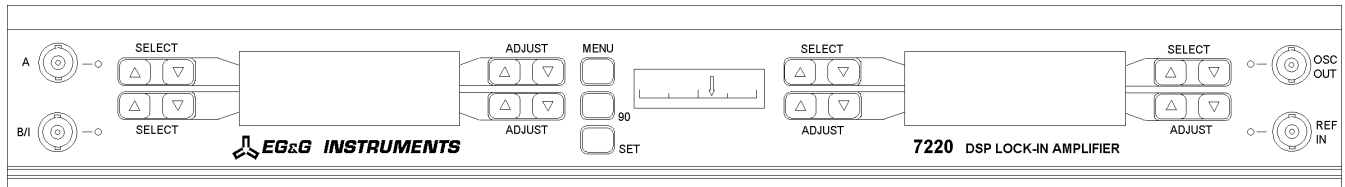


Figure 4-1, Model 7220 Front Panel Layout

As shown in figure 4-1 there are four BNC connectors with associated LED indicators, two LCD display panels, an edge-indicating analog meter, eight double and three single keys mounted on the model 7220's front panel. The following sections describe the function and location of these items.

4.1.01 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. LEDs adjacent to the connectors light to indicate which of them is active when a particular input mode is selected (see figure 4-2). One or both of these LEDs will flash to indicate that the input is in overload.

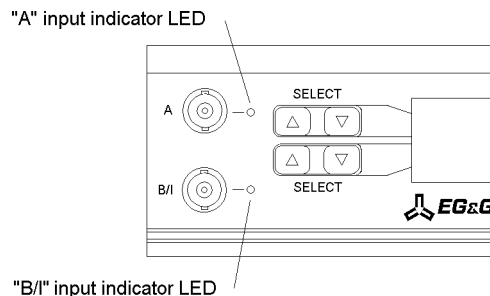


Figure 4-2, Signal Inputs

4.1.02 OSC OUT Connector

This is the output connector for the internal oscillator. When internal reference mode is selected the LED adjacent to the connector will be lit (see figure 4-3).

4.1.03 REF IN Connector

This is the input connector for a general purpose external reference signal. When external reference mode is selected the LED adjacent to the connector will be lit (see figure 4-3). Under unlock conditions the LED will flash.

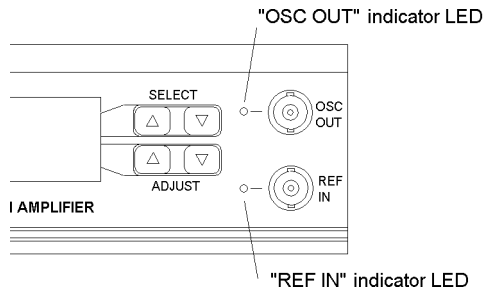


Figure 4-3, OSC OUT and REF IN Connectors

4.1.04 Left-hand LCD Display Panel

This panel and the two pairs of keys on each side of it are normally used to select and adjust the instrument's controls, such as the full-scale sensitivity, time constant, filter slope, oscillator frequency and voltage, etc. In this mode the display shows two of the possible range of controls and their present settings, one on the upper menu line and one on the lower (see figure 4-4).

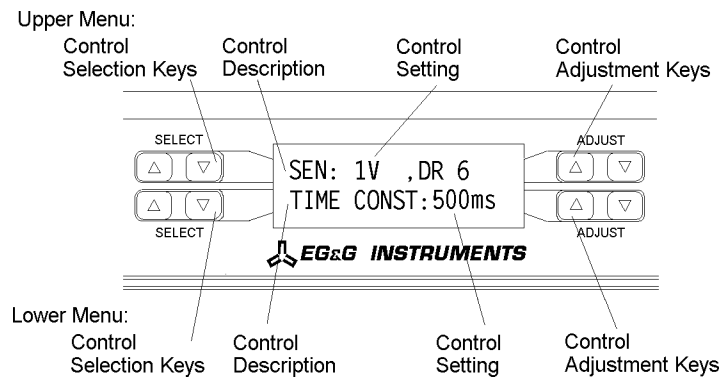


Figure 4-4, Main Display - Left-hand LCD

To select a given control, press the left-hand up or down **SELECT** keys repeatedly until it is displayed on the corresponding menu line. The current setting of the control is then shown adjacent to the description and may be adjusted using the corresponding left-hand up or down **ADJUST** keys.

Some controls, such as time constant and full-scale sensitivity, have only a limited range of settings, and so the use of the **ADJUST** keys allows the required value to be chosen with only a few keypresses. Other controls, such as the internal oscillator amplitude and frequency, may be set over a wide range of values and to a high

precision. In these cases a significant number of keypresses are required to make adjustments.

Adjustment of the latter type of control is made easier by the use of one or other of the two methods described below.

Auto Repeat

If an up or down **ADJUST** key is pressed and held, then its action is automatically repeated such that the displayed control setting will increment or decrement at a rate approximately ten times faster than that which could be achieved by repeated manual keypresses.

Active Cursor

The **ADJUST** keys can be used initially to place a cursor over a given digit in the displayed control setting, prior to changing that digit. This is done by using the procedure discussed below.

- Step 1 Press both the up and down **ADJUST** keys simultaneously. A cursor appears over one of the displayed digits (see figures 4-5 and 4-6).
- Step 2 With the cursor visible, repeating step 1 causes the cursor to move to the left. When the cursor reaches the most significant digit available (left end of control setting) the next keypress returns the cursor to the least significant digit (right end of control setting). Continue this action until the cursor covers the required digit.
- Step 3 Press the up or down **ADJUST** key to change the digit to the required value.

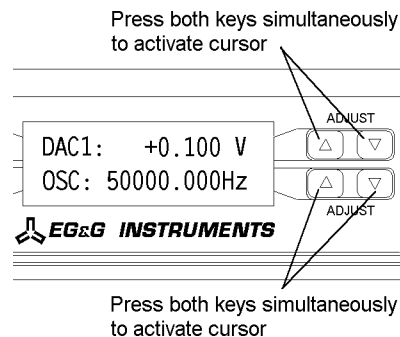


Figure 4-5, Active Cursor Activation

As an example of this operation, suppose that the oscillator frequency is 50 kHz and it is required to change it to 51 kHz. Simultaneously press both the up and down **ADJUST** keys adjacent to the oscillator frequency display. Move the cursor, by repeated double keypresses, until it is over the required digit, in this case the zero to the right of the leading 5. Then press the up **ADJUST** key to increment the frequency by 1 kHz. The cursor will disappear as soon as the frequency is adjusted but its position remains active until changed (see figure 4-6).

Action	Display after action
	OSC : 50000.000Hz
Press both keys	OSC : 50000.000Hz (where the cursor appears depends on where it was previously left)
Press both keys repeatedly until	OSC : 50000.000Hz
Press Δ key	OSC : 51000.000Hz

Figure 4-6, Active Cursor Operation

The double keypress action can also be performed with one finger by firmly pressing the center of the up and down **ADJUST** key rocker which will deform to press both keys. The active cursor can be used to set any particular digit. For example, if you only want to adjust the reference phase in 1 degree steps leave the cursor over the first digit to the left of the decimal point of the reference phase value.

4.1.05 MENU Key

The left-hand LCD is also used to access the four auto functions that are built into the instrument. To do this, from the power-up display default, press the key marked **MENU** once (Note: On early units this key was labelled **AUTO**).

The left-hand LCD now changes to that shown in figure 4-7.

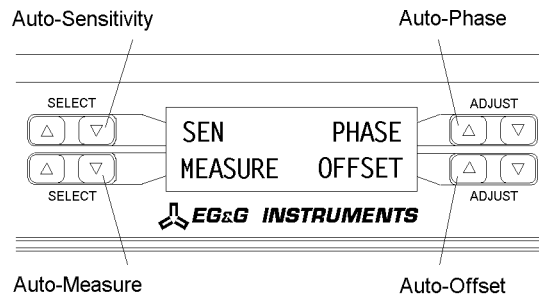


Figure 4-7, Auto Functions Menu - Left-hand Display

To activate one of the auto functions press the appropriate adjacent key, as shown in figure 4-7. The display will immediately change to a message indicating that the selected function is in progress, and will revert to the Main Display mode when the function is completed.

When in the AUTO menu, a second press of the **MENU** key affects both the left and right-hand displays and sets these to the setup menu mode. It is from this mode that the instrument controls, which rarely need adjusting once set for a given experiment, are activated (see figure 4-8 which shows a typical setup menu).

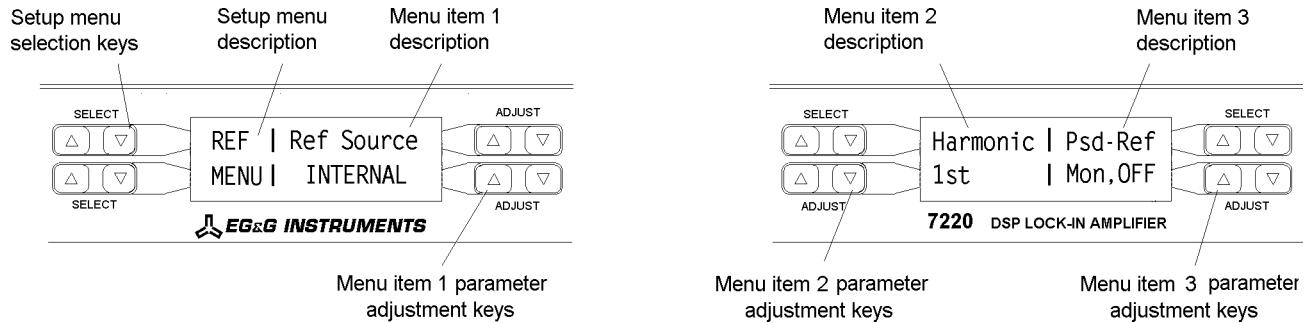


Figure 4-8, Setup Menu Mode - Left and Right-hand LCD Displays

In the setup menu mode, the left-hand **SELECT** keys adjacent to the left-hand display cycle through a series of twelve setup menus. In general each menu allows three controls to be adjusted, one via the right-hand side of the left-hand display and the other two via the right-hand display. The setup menu description is shown on the left-hand side of the left-hand display. Figure 4-8 makes this clear and the various menus are discussed more fully in chapter 5.

When in the setup menu mode a further single press of the **MENU** key returns the instrument to the normal Main Display mode.

4.1.06 90° Key

This key increments the reference phase shifter by 90° each time the key is pressed.

4.1.07 SET Key

This key updates all frequency dependent parameters within the lock-in amplifier. Press this key after any change to the External Reference frequency.

4.1.08 Right-hand LCD Display Panel

This panel is normally used to display two out of the set of fourteen possible instrument outputs, with the keys on each side of it being used to make the selection. In this mode it is also used to allow adjustment of the level of the output offsets applied to the X and Y outputs. In addition, the panel is used in the setup menu mode as described in section 4.1.05 above.

In the normal mode, the panel is divided vertically into two sections, with the output descriptions shown on the upper line and the output values on the lower line. The output type selection is made using the **SELECT** keys on each side of the upper line; simply press the key repeatedly until the required output type is shown. Note that it is not possible to set both sides of the display to the same output type. Figure 4-9 makes this clear.

The **SELECT** keys associated with the right-hand display also allow easy switching of the display between an output expressed as a percentage of full-scale and the corresponding output expressed in volts or amps using the “simultaneous double

keypress” feature. To perform such a switch, simply press both sides of the **SELECT** keys simultaneously. This feature avoids the need to cycle through a number of outputs, thereby reducing the number of keypresses needed.

The edge-indicating, analog panel meter is linked to the display on the left-hand side of the right-hand display, with full-scale corresponding to a digital reading of 100 %. However, the panel meter limits at a few percent above full-scale whereas the digital displays limit at $\pm 300\%$ full-scale.

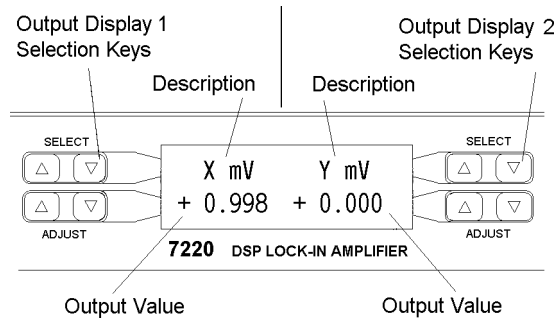


Figure 4-9, Main Display - Right-hand LCD

4.2 Rear Panel

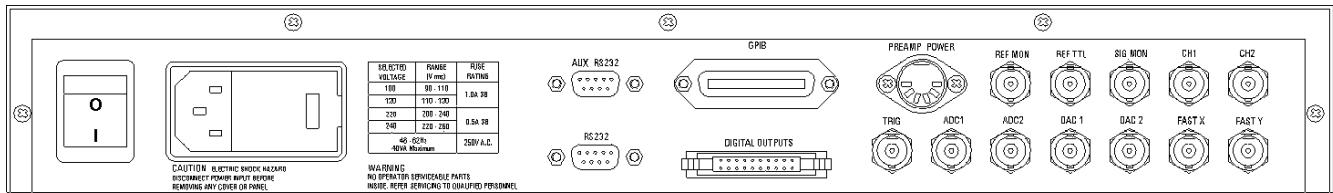


Figure 4-10, Model 7220 Rear Panel Layout

As shown in figure 4-10, the line power switch, line power voltage selector, two RS232 connectors, a GPIB (IEEE-488) connector, digital output port, preamplifier power connector and twelve BNC signal connectors are mounted on the rear panel of the instrument. Brief descriptions of these are given in the following text.

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 EG&G 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 (see section 5.2.08). 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 by the use of a front panel setup menu or 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 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 EG&G Instruments. Pinouts for this connector are given in appendix B.

4.2.08 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.

4.2.09 REF TTL Connector

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

4.2.10 SIG MON Connector

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

4.2.11 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 in the Output Setup menu. 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.

4.2.12 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.

4.2.13 ADC1, ADC2 Connectors

The input voltages at these connectors may be digitized using the auxiliary ADCs and read either from the front panel or 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. These modes can be set either from the front panel or by using a remote computer command. The input voltage range is ± 10.0 V and the resolution is 1 mV.

4.2.14 DAC1, DAC2 Connectors

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

4.2.15 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

This chapter describes how to operate the model 7220 using the front panel controls, and describes its capabilities when used in this way. Chapter 6 provides similar information in the situation where the unit is operated remotely using one of the computer interfaces.

Readers should refer to chapter 4 for a detailed description of the use of the **SELECT** and **ADJUST** keys, and the functions of the left and right-hand display panels. However, for ease of use, some of this information is repeated here.

The model 7220 uses a flexible, menu based, control structure which allows many instrument controls to be adjusted from the front panel with only a few keys. Furthermore this design makes it very easy to introduce new features or improve existing ones without the limitation resulting from a fixed front panel layout.

The following sections describe the instrument control menus in a logical sequence, from the setup menus, which typically only need changing occasionally, through to the output display selection.

5.2 Setup Menu Mode

When in the normal Main Display mode, two presses of the **MENU** key set the left and right-hand displays to the setup menu mode, (see figure 5-1 which shows a typical setup menu).

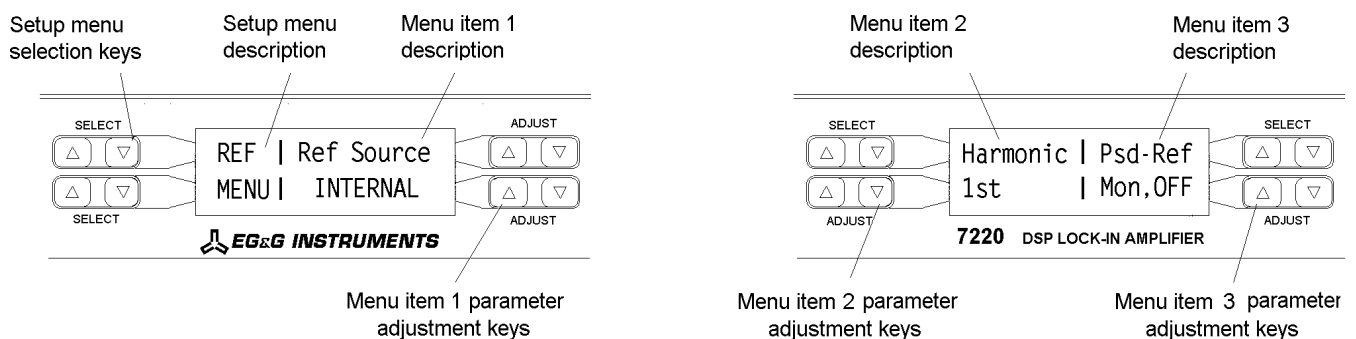


Figure 5-1, Setup Menu Mode - Left and Right-hand LCD Displays

In the setup menu mode, the left-hand **SELECT** keys of the left-hand display cycle through a series of twelve setup menus. In general each menu allows three controls to be adjusted, one via the right-hand side of the left-hand display and the other two via

the right-hand display. The setup menu description is shown on the left-hand side of the left-hand display. Figure 5-1 makes this clear.

One further press of the **MENU** key causes the instrument to leave the setup menu mode and return to the main display mode. On leaving the setup menu mode the last menu displayed is held in memory and will be displayed on re-entry. The following sections describe each menu in sequence.

5.2.01 Input Setup Menu

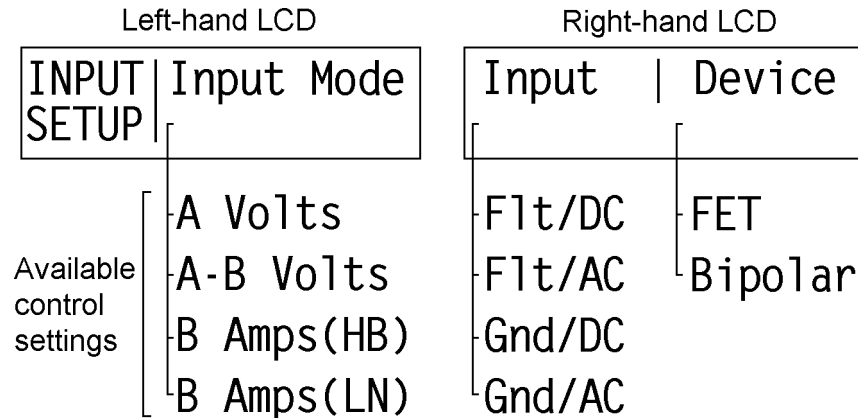


Figure 5-2, Input Setup Menu

In this menu, shown in figure 5-2, three controls affecting the lock-in amplifier's signal channel input are displayed. Changes to the setting of these controls can be made by using the **ADJUST** keys adjacent to the appropriate LCD.

Input Mode

This control has four settings:-

A Volts

In this setting the signal channel input is a single-ended voltage input connected to the front panel BNC connector marked "A".

A-B Volts

In this setting the signal channel input is a differential voltage input connected to the front panel BNC connectors marked "A" and "B/I".

B Amps (HB)

In this setting the signal channel input is a single-ended current input connected to the front panel BNC connector marked "B/I", and uses a high bandwidth (HB) current to voltage converter.

B Amps (LN)

In this setting the signal channel input is a single-ended current input connected to

the front panel BNC connector marked “**B/I**”, and uses a low-noise (LN) current to voltage converter.

Input

This control has four settings:-

F1t/DC

The shells of the “**A**” and “**B/I**” connectors are connected to chassis ground via a 1 k Ω resistor and the signal channel input is DC coupled.

F1t/AC

The shells of the “**A**” and “**B/I**” connectors are connected to chassis ground via a 1 k Ω resistor and the signal channel input is AC coupled. Note that DC coupling should be used at frequencies of < 1 Hz.

Gnd/DC

The shells of the “**A**” and “**B/I**” connectors are connected to chassis ground and the signal channel input is DC coupled.

Gnd/AC

The shells of the “**A**” and “**B/I**” connectors are connected to chassis ground and the signal channel input is AC coupled. Note that DC coupling should be used at frequencies of < 1 Hz.

Device

This control allows the selection of the input device when operating in voltage input mode and has two settings:-

FET

Uses a FET as the input device, for which case the input impedance is 10 M Ω . This is the usual setting.

Bipolar

Uses a bipolar device in the input stage, for the lowest possible voltage input noise. In this case the input impedance is 10 k Ω . Note that this selection is not possible when using the DC coupled input modes.

5.2.02 Reference Setup Menu

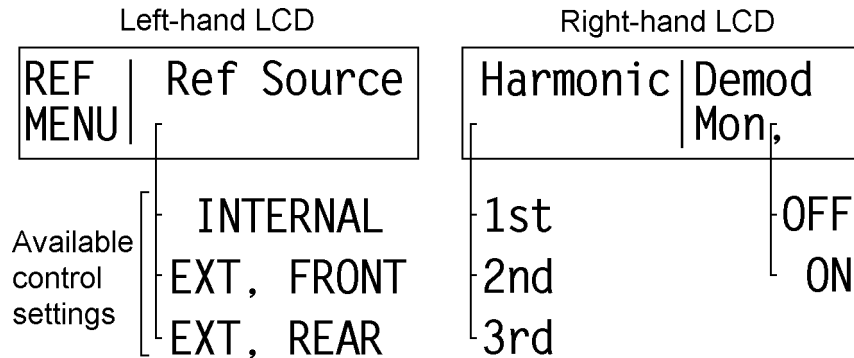


Figure 5-3, Reference Setup Menu

In this menu, shown in figure 5-3, there are three controls affecting the reference channel of the instrument. They are:-

Ref Source

This control allows selection of the source of reference signal used to drive the reference circuitry, and has three settings:-

INTERNAL

The lock-in amplifier's reference is taken from the instrument's internal oscillator. Note that this setting gives the best phase and gain measurement accuracy under all operating conditions, and is always to be preferred if it is possible to design the experiment so that the lock-in amplifier acts as a source of reference signal.

EXT, FRONT

In this setting, suitable for use with reference frequencies above 300 mHz, the lock-in amplifier's reference should be applied to the front panel **REF IN** connector. A wide variety of signal waveforms may be employed but at frequencies lower than 1 Hz, square waveforms should be used.

EXT, REAR

In this setting, the lock-in amplifier's reference should be applied to the rear panel TTL compatible **REF TTL** connector. The use of this input is preferable to the front panel input when a TTL logic reference signal is available.

Harmonic

This control allows selection of the harmonic at which the lock-in amplifier will detect. It has three settings, but most commonly is set to "1st". Note that the "2F" setting found on other lock-in amplifiers corresponds to setting this control to "2nd".

Demod Mon,

The Demodulator Monitor control has two settings, ON and OFF, which are only meaningful when the lock-in amplifier is operated in external reference mode:-

ON

When the Demodulator Monitor is switched ON and the instrument is operating in External Reference mode, the signal at the **OSC OUT** connector changes from that of the internal oscillator to an analog representation of the drive from the reference channel to the X output demodulator. The amplitude of this signal may be controlled by the internal oscillator amplitude controls, but the internal oscillator frequency control is inactive since the frequency is related to the external reference.

If the harmonic mode is set to 1st, the signal at the **OSC OUT** connector will be at the same frequency as the applied reference, but if set to 2nd or 3rd then the output will be at two or three times the reference frequency respectively.

OFF

When the Demodulator Monitor is switched OFF the **OSC OUT** connector functions as the output from the internal oscillator. The signal provided at it may be adjusted both in amplitude and frequency using the instrument's controls. This is the most common setting.

5.2.03 Output Setup Menu

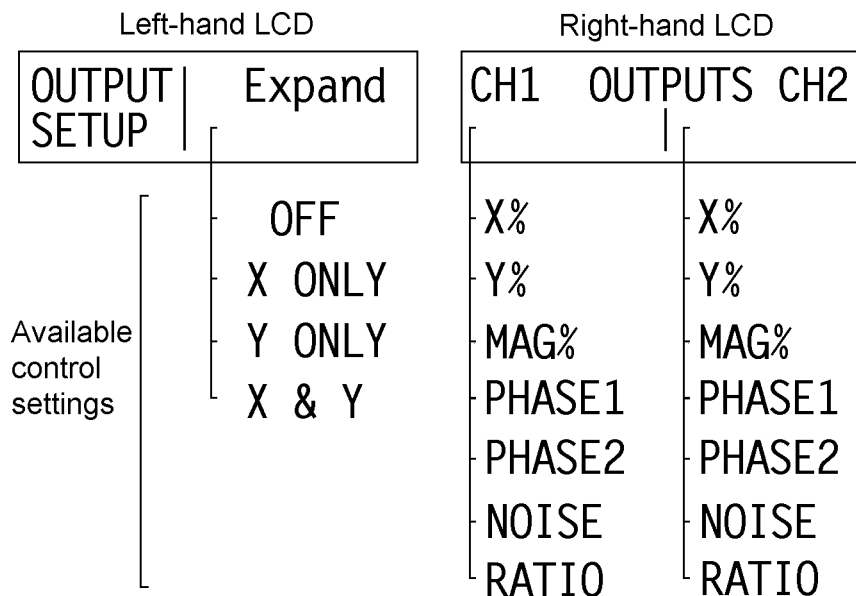


Figure 5-4, Output Setup Menu

This menu, shown in figure 5-4, has three controls affecting the output channels of the instrument. They are:-

Expand

This control allows a $\times 10$ output expansion to be applied to the X, Y or both output channels, or to be switched off:-

OFF

Output expansion is turned off.

X ONLY

A $\times 10$ output expansion is applied to the X output only.

Y ONLY

A $\times 10$ output expansion is applied to the Y output only.

X & Y

A $\times 10$ output expansion is applied to both the X and Y outputs.

CH1 OUTPUTS CH2

This control, shown on the right-hand LCD, allows the two rear panel analog outputs **CH1** and **CH2** to be connected to the required instrument outputs. The left-hand **ADJUST** keys are used to select the output provided at the **CH1** connector and the right-hand ones select that at the **CH2** connector. Each output may be set to one of the following settings:-

X %

When set to X % the corresponding rear panel **CH1/CH2** connector will output a voltage related to the X %fs front panel display as follows:-

X %fs	CH1/2 Voltage
+120	12.0 V
+100	10.0 V
0	0.0 V
-100	-10.0 V
-120	-12.0 V

Y %

When set to Y % the corresponding rear panel **CH1/CH2** connector will output a voltage related to the Y %fs front panel display as follows:-

Y %fs	CH1/2 Voltage
+120	12.0 V
+100	10.0 V
0	0.0 V
-100	-10.0 V
-120	-12.0 V

MAG %

When set to MAG % the corresponding rear panel **CH1/CH2** connector will output a voltage related to the MAG %fs front panel display as follows:-

MAG %fs	CH1/2 Voltage
+120	12.0 V
+100	10.0 V
0	0.0 V
-100	-10.0 V
-120	-12.0 V

PHASE1

When set to PHASE1 the corresponding rear panel **CH1/CH2** connector will output a voltage related to the PHA deg front panel display as follows:-

PHA deg	CH1/2 Voltage
+180	9.0 V
+90	4.5 V
0	0.0 V
-90	-4.5 V
-180	-9.0 V

PHASE2

When set to PHASE2 the corresponding rear panel **CH1/CH2** connector will output a voltage related to the PHA deg front panel display as follows:-

PHA deg	CH1/2 Voltage
+360	+9.0 V
+180	0.0 V
0	-9.0 V

NOISE

When set to NOISE the corresponding rear panel **CH1/CH2** connector will output a voltage related to the N %fs front panel display as follows:-

N %fs	CH1/2 Voltage
+120	12.0 V
+100	10.0 V
0	0.0 V
-100	-10.0 V
-120	-12.0 V

RATIO

When set to RATIO the corresponding rear panel **CH1/CH2** connector will output a voltage related to the RATIO front panel display as follows:-

RATIO	CH1/2 Voltage
+12	12.0 V
+10	10.0 V
0	0.0 V
-10	-10.0 V
-12	-12.0 V

5.2.04 Control Options Menu

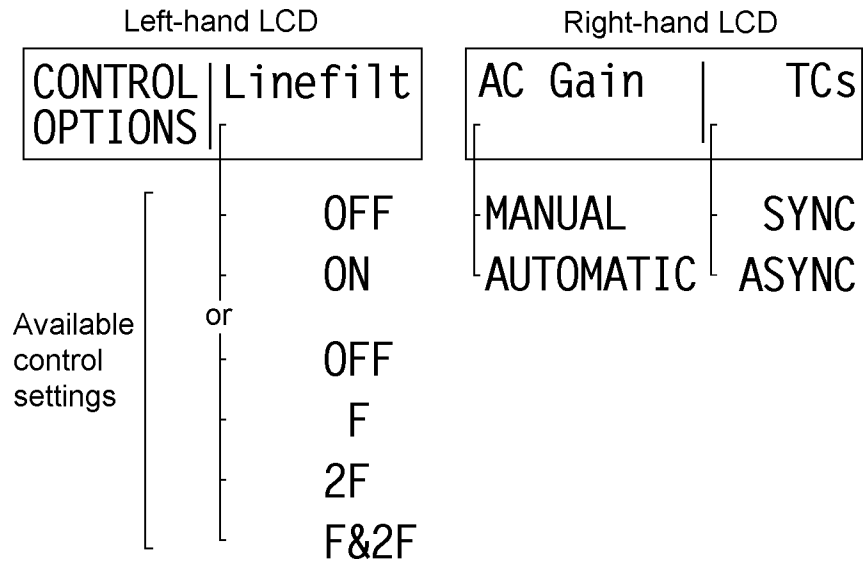


Figure 5-5, Control Options Setup Menu

This menu, shown in figure 5-5, has three controls affecting the line frequency rejection filter, AC Gain control and output time constants, as follows:-

Linefilt

This control sets the mode of operation of the internal line frequency rejection filter.

Early instruments have two possible settings for this control, ON or OFF. Note that in these units the filter introduces significant gain and phase errors when measuring signals in the frequency range from 5 Hz to 500 Hz.

Instruments manufactured after June 1996 which are fitted with the updated filter hardware offer four possible settings for the control, as defined by the following table:-

Legend	Function
OFF	Line filter inactive
F	Enable 50 or 60 Hz notch filter
2F	Enable 100 or 120 Hz notch filter
F&2F	Enable both filters

AC Gain

As discussed in section 3.2.04, the correct adjustment of the AC Gain in a DSP lock-in amplifier is necessary to achieve the best results. This control allows the user to select whether this adjustment is carried out automatically or remains under manual control.

MANUAL

In this setting the AC Gain may be manually adjusted from the main display.

AUTOMATIC

In this setting the AC Gain value is automatically selected by the instrument, depending on the full-scale sensitivity.

TC's

This control affects the output time constants, and has two settings:-

SYNC

When set to SYNC, the actual time constant used is chosen to be some multiple of the reference frequency period. In this mode the output will be much more stable at low frequencies than it would otherwise be. Note: when set to this mode, output time constants shorter than 100 ms cannot be used.

ASYNC

In this setting, the normal mode, time constants are not related to the reference frequency period.

5.2.05 Miscellaneous Options Menu

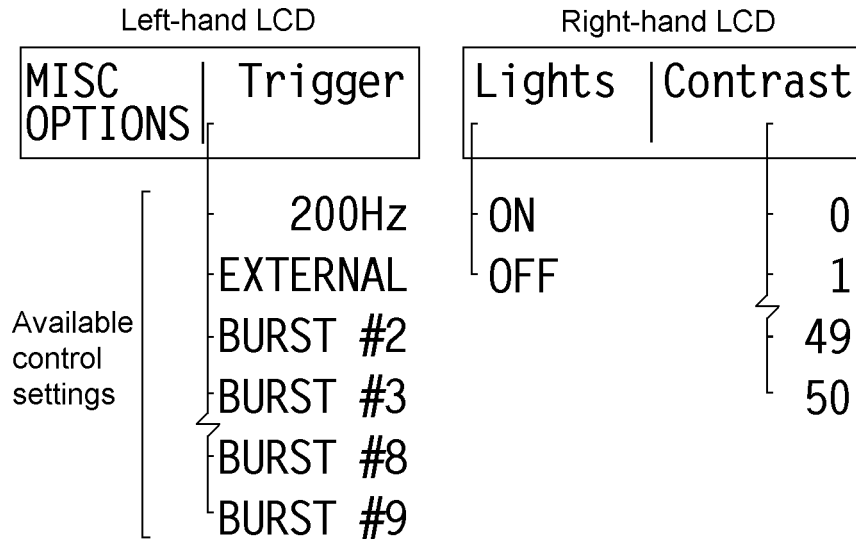


Figure 5-6, Miscellaneous Options Setup Menu

This menu, shown in figure 5-6, has three controls affecting the auxiliary ADC trigger rate and the front panel display as follows:-

Trigger

This control selects the trigger which is used to initiate the conversion of voltages applied to the rear panel **ADC1** and **ADC2** connectors, as follows:-

200Hz

In this setting, ADC conversions occur at a 200 Hz rate.

EXTERNAL

In this setting, ADC conversions are started by an external trigger signal applied to the rear panel **TRIG** connector.

The other eight settings of this control, BURST #2 to BURST #9 are only meaningful when using the instrument under computer control, since they cause data to be stored to the internal curve buffer. They will not therefore be discussed further here, but their function is described in chapter 6.

Lights

This control switches the back lighting of the two LCD displays and the LEDs adjacent to the front panel BNC connectors ON or OFF.

Contrast

This control adjusts the contrast of the LCD displays and may be set to a value between 0 and 50.

5.2.06 RS232 Setup 1 Menu

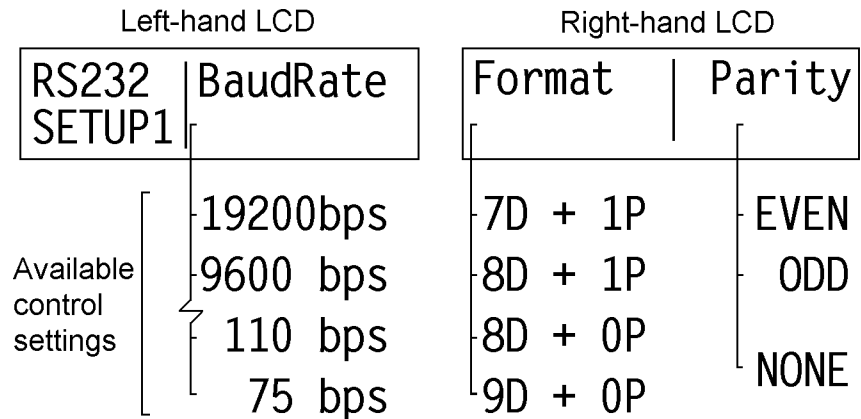


Figure 5-7, RS232 Setup 1 Menu

This menu, shown in figure 5-7, has three controls affecting the RS232 computer interface, as follows:-

BaudRate

Thirteen values of Baud Rate are available in the range 75 to 19200 bits per second.

Format

There are four data formats available:

7D + 1P

Sets up 7 Data Bits + 1 Parity bit (1 = Parity ON)

8D + 1P

Sets up 8 Data Bits + 1 Parity bit (1 = Parity ON)

8D + 0P

Sets up 8 Data Bits + 0 Parity bit (0 = Parity OFF)

9D + 0P

Sets up 9 Data Bits + 0 Parity bit (0 = Parity OFF)

Parity

If the Format control is set to a mode with the Parity bit enabled, the Parity control offers two modes, ODD and EVEN. If however, the Parity bit is not enabled then the Format control displays NONE.

5.2.07 RS232 Setup 2 Menu

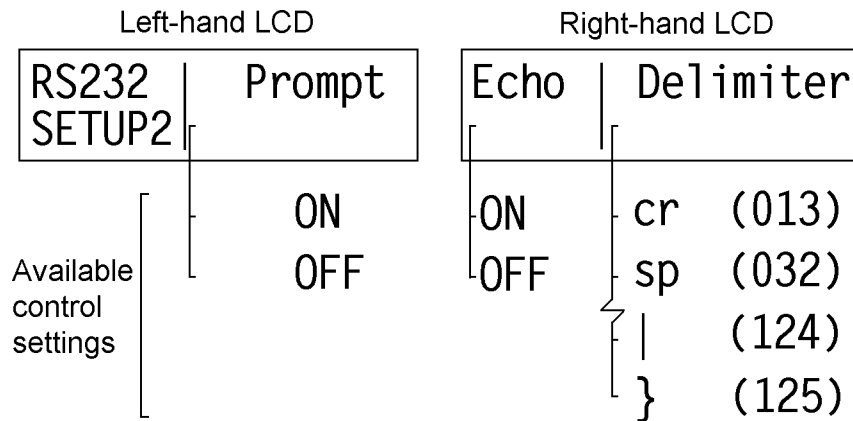


Figure 5-8, RS232 Setup 2 Menu

This menu, shown in figure 5-8, has three controls affecting the RS232 computer interface, as follows:-

Prompt

This function can be switched ON or OFF:-

ON

The prompt character is sent out by the lock-in amplifier after each command response to indicate that the response is finished and the instrument is ready for a new command. It can also be used to signal overload conditions (see section 6.3.13 for further information).

OFF

No prompt character is sent.

Echo

This function can be switched ON or OFF (see section 6.3.08 for further information):-

ON

The lock-in amplifier echoes each character received over the RS232 interface back to the controlling computer, to indicate it is ready to receive the next one. In order for this to work, the controlling computer should ensure that it does not send the next character until it has read the echo.

OFF

No character echo occurs.

Delimiter

Some instrument control commands generate more than one output value, such as the

MP command (report Magnitude and Phase). Hence it is necessary for the controlling program to be able to determine when all of the first value has been sent. The delimiter is a separator character sent between each response which may be used for this purpose. The control allows any ASCII character with decimal value between 32 and 125, or 13, to be used.

5.2.08 RS232 Setup 3 Menu

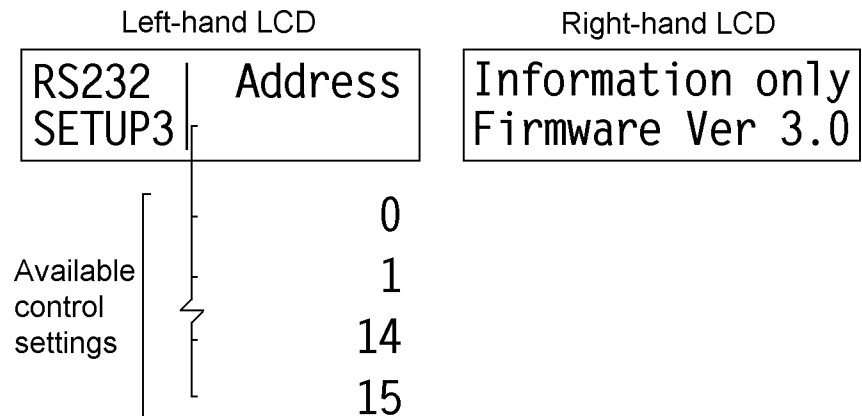


Figure 5-9, RS232 Setup 3 Menu

The third setup menu with controls affecting the RS232 interface is shown in figure 5-9.

Address

This control sets the RS232 address which is used when daisy-chaining other compatible instruments. Each instrument used in the chain must be set to a unique address in the range 0 to 15. All instruments receive commands, but only the currently addressed instrument will implement or respond to the commands, except, of course, the command to change the instrument to be addressed.

Information only

The right-hand LCD displays the version level of the instrument's internal firmware. Please be prepared to give this number when contacting EG&G Instruments with a technical query.

5.2.09 GPIB Setup 1 Menu

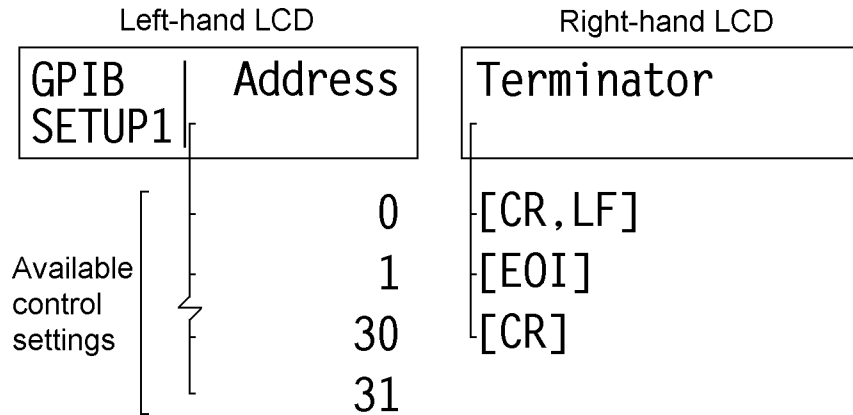


Figure 5-10, GPIB Setup 1 Menu

This menu, shown in figure 5-10, has two controls affecting the GPIB computer interface, as follows:-

Address

Each instrument used on the GPIB interface must have a unique address, in the range 0 to 31, and this control is used to set this address. The default setting is 12.

Terminator

This control selects the method by which the instrument signals to the controlling computer the completion of transmission of a response to a command. Three choices are available:-

CR, LF

A carriage return followed by a line feed are transmitted at the end of a response string, and in addition the GPIB interface line EOI (end of instruction) is asserted with the line feed character.

EOI

The GPIB interface line EOI (end of instruction) is asserted at the end of a response string. This gives the fastest possible operation since other termination characters are not needed.

CR

A carriage return is transmitted at the end of a response string and in addition the GPIB interface line EOI (end of instruction) is asserted.

5.2.10 GPIB Setup 2 Menu

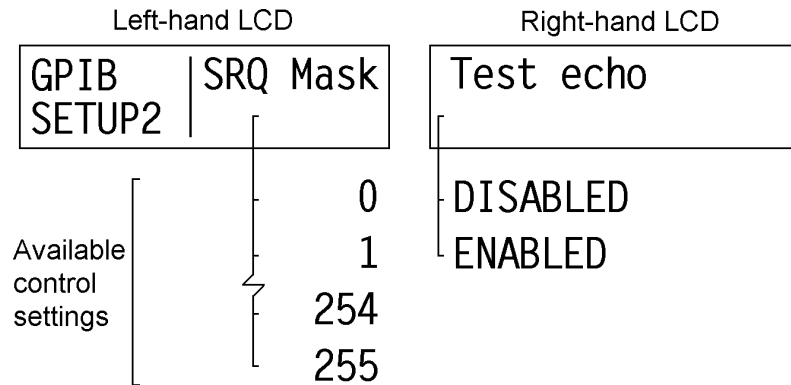


Figure 5-11, GPIB Setup 2 Menu

This menu, shown in figure 5-11, has two controls affecting the GPIB computer interface, as follows:-

SRQ Mask

The instrument includes the ability to generate a Service Request on the GPIB interface, to signal to the controlling computer that urgent attention is required. The request is generated when the result of a logical bit-wise AND operation between the Service Request Mask byte, set by this control, and the instrument's Status Byte, is non-zero. The bit assignments of the Status Byte are as follows:-

Bit	Decimal value	Function
0	1	command complete
1	2	invalid command
2	4	command parameter error
3	8	reference unlock
4	16	overload
5	32	auto-mode active or new ADC values available after external trigger
6	64	asserted SRQ
7	128	data available

Hence, for example, if the SRQ mask byte is set to decimal 16 (i.e. bit 4 is asserted), a service request would be generated as soon as an overload occurred; if the SRQ mask byte were set to 0 (i.e. no bits asserted), then service requests would never be generated.

Test echo

When this control is enabled, all transmissions to and from the instrument via the GPIB interface are echoed to the RS232 interface. Hence if a terminal is connected to the latter port, it will display any commands sent to the instrument and any responses generated, which can be useful during program development. When disabled, echoing does not occur. The control should always be disabled when not using this feature, since it slows down communications.

5.2.11 Digital Outputs Setup Menu

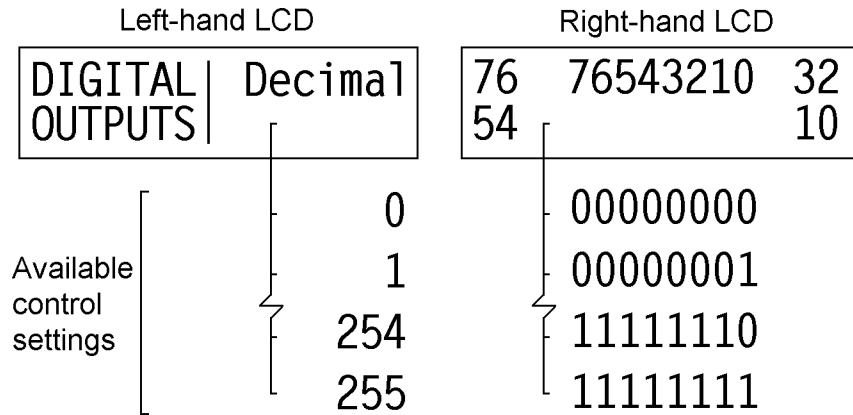


Figure 5-12, Digital Outputs Setup Menu

This menu, shown in figure 5-12, is used to control the 8 TTL lines of the rear panel digital output port, used for controlling external equipment.

Decimal

The bit pattern appearing at the digital output port is set by an unsigned eight-bit binary number, the decimal equivalent of which can range from 0 to 255. This decimal value may be set using the left-hand display, so that for example if it were 0 the eight output lines would all be low, whereas if set to 255, then they would all be high.

The centre of the right-hand display shows the number in binary format, with the value of each bit shown below its bit number. Each of the keys around this display will toggle one bit, as indicated by the numbers adjacent to them, providing a second way of controlling the port.

Any changes made to the digital output in decimal format will be reflected in the binary display and vice-versa.

5.2.12 Control Setup Menu

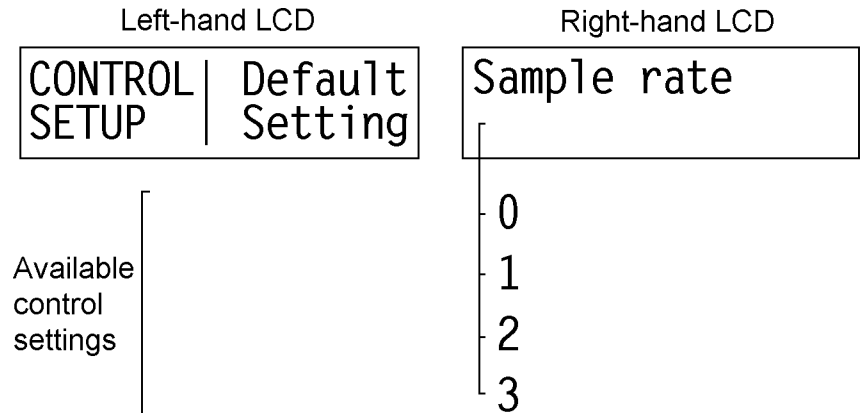


Figure 5-13, Control Setup Menu

The final setup menu, shown in figure 5-13, is used to set the instrument to a known state and to adjust the sampling rate of the main analog to digital converter.

Default Setting

Pressing a key adjacent to this label will set all of the instrument's controls to a known state. This can be useful when performing the initial checks procedure, or after taking the instrument over from another user. Note that on completion, the instrument will leave the setup menu mode and revert to the main display mode. A listing of the settings invoked by the use of this function can be found in appendix F.

Caution

The default setting includes controls affecting the RS232 and GPIB interfaces, so these will need to be readjusted following use of this function unless you have used their default settings.

Sample rate

This control adjusts the sampling rate of the instrument's main ADC, offering four possible settings. It should only be necessary to use it if you suspect that an interfering signal is being aliased into the instrument's output.

5.3 Auto Functions Menu

When in the Main Display mode, one press of the **MENU** key accesses the AUTO MENU showing four auto functions that are built into the instrument. The left-hand LCD changes to that shown in figure 5-14.

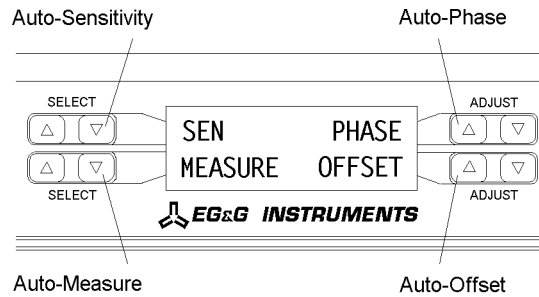


Figure 5-14, Auto Functions Menu - Left-hand Display

To activate one of the auto functions press one of the keys adjacent to it, as shown in figure 5-14. The display will immediately change to a message indicating that the selected function is in progress, and will revert to the Main Display mode when the function is completed.

The four functions operate as follows:-

AUTO SEN

This function only operates when the reference frequency is greater than 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.

AUTO PHASE

In an Auto-Phase operation the value of the signal phase is computed and an appropriate phase shift is 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 error 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 usually gives good results when the X and Y channel outputs

are steady, implying the signal phase is stable, 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.

AUTO OFFSET

In an Auto-Offset operation the X offset and Y offset functions are turned on and are automatically set to the levels required to give zero values at both the X and the Y outputs. Any small residual values remaining after the initial Auto-Offset operation can normally be removed by calling the function 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.

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, using the single-ended, A, input; the FET input devices are enabled; 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; 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 provide a means of setting the instrument's controls quickly to conditions which will be approximately correct for typical simple, single-ended measurement situations. For optimum results in any given situation it may be convenient to start with an Auto-Measure operation and subsequently fine tune the setup conditions manually.

The Auto-Measure function is most often used as a rescue operation to bring the instrument into a well-defined state when it is giving unexpected results. The length of the above list demonstrates that one or more items can easily be overlooked if performed manually.

5.4 Main Display Mode - Left-hand LCD

The Main Display Mode is the default mode on instrument power-up. Two controls, chosen from a possible ten, may be adjusted using the left-hand display, although it is not possible to show the same control on both lines of the display simultaneously. The choice of control is made using the **SELECT** keys adjacent to the left-hand side of the left-hand display. Once selected, the control is adjusted using the **ADJUST** keys adjacent to the right-hand side of the left-hand display.

The ten controls are now discussed in turn. Note that in the following figures the vertical lines below the heading "Left-hand LCD" depict the horizontal limits of the display to indicate how control information is shown. It should be remembered that there are two lines available on the display and the user may choose to show a control on either the upper or the lower line (see figure 4-4).

Sensitivity

When set to voltage input mode, the instrument's full-scale voltage sensitivity may be set to any value between 20 nV and 1 V in a 1-2-5 sequence.

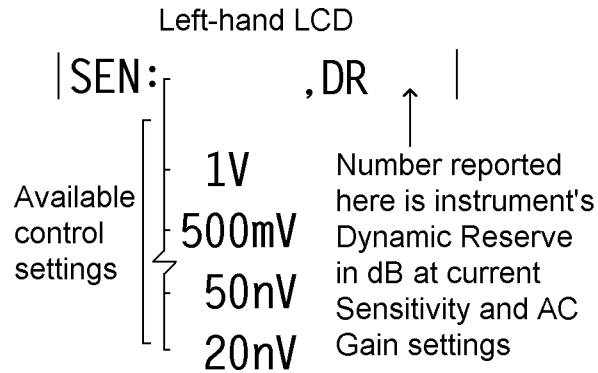


Figure 5-15, Sensitivity Control - Voltage Input Mode

When set to current input mode, the instrument's full-scale current sensitivity may be set to any value between 20 fA and 1 μ A (wide bandwidth mode) or 20 fA and 10 nA (low-noise mode), in a 1-2-5 sequence.

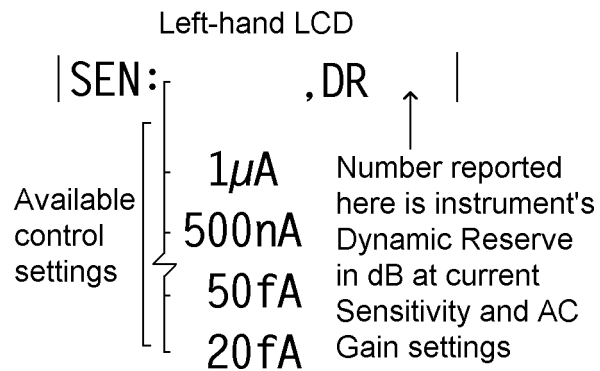


Figure 5-16, Sensitivity Control - Wide Band Current Input Mode

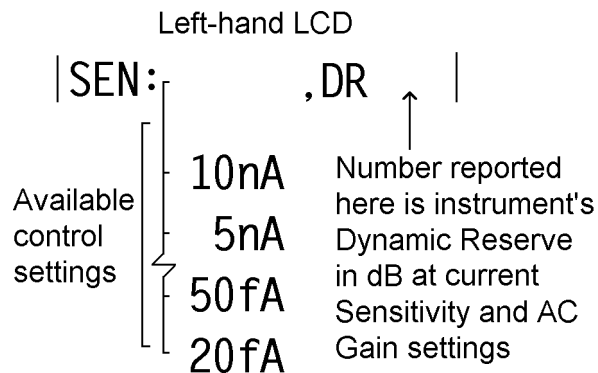


Figure 5-17, Sensitivity Control - Low-noise Current Input Mode

AC Gain

If the AC Gain control is set to Manual (using the Input Setup menu), then this control allows it to be adjusted from 0 dB to 90 dB in 10 dB steps, although not all settings are available at all full-scale sensitivity settings.

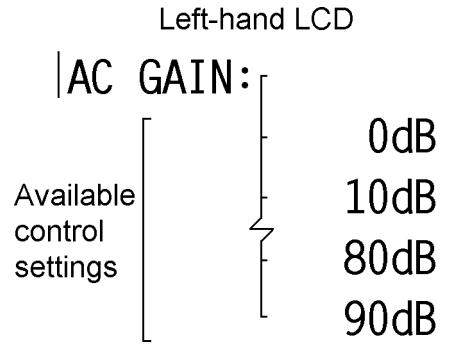


Figure 5-18, AC Gain Control

Time Constant

The time constant of the output filters is set using this control. The settings between 10 μ s and 640 μ s are in a binary sequence and apply only to outputs at the rear panel **FAST X** and **FAST Y** connectors. Settings between 5 ms and 5 ks are in a 1-2-5 sequence and apply only to all the other instrument outputs.

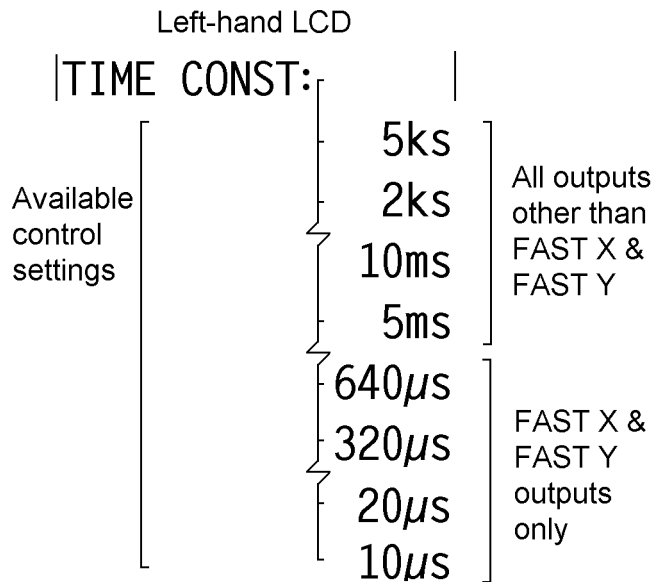


Figure 5-19, Time Constant Control

Slope

The roll-off of the output filters is set, using this control, to any value from 6 dB to 24 dB/octave, in 6 dB steps. Note this control does not affect the roll-off of outputs at the **FAST X** and **FAST Y** connectors which are fixed at 6 dB/octave.

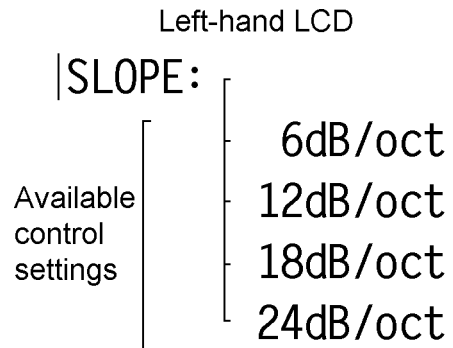


Figure 5-20, Output Filter Slope Control

Oscillator Frequency

The frequency of the instrument's internal oscillator may be set, using this control, to any value between 1 mHz and 120 kHz with a 1 mHz resolution. Adjustment is faster if use is made of the Active Cursor control - see section 4.1.04

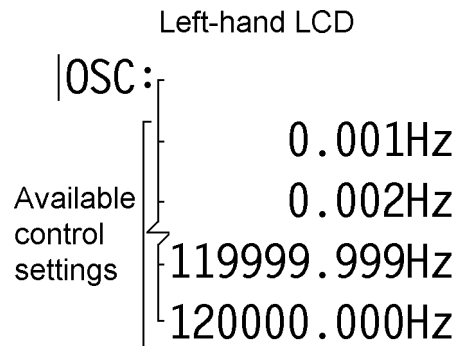


Figure 5-21, Internal Oscillator Frequency Control

Oscillator Amplitude

The amplitude of the instrument's internal oscillator may be set, using this control, to any value between 1 mV and 5 V rms with a 1 mV resolution. Adjustment is faster if use is made of the Active Cursor control - see section 4.1.04.

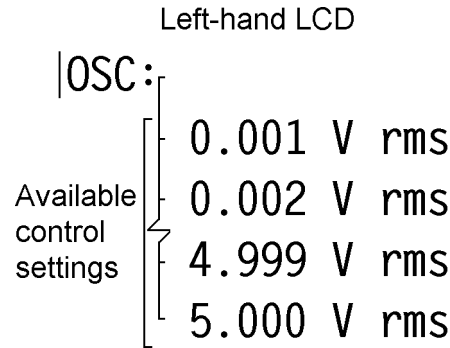


Figure 5-22, Internal Oscillator Amplitude Control

DAC 1

This control sets the voltage appearing at the rear panel **DAC1** output connector to any value between +10 V and -10 V with a resolution of 1 mV. Adjustment is faster if use is made of the Active Cursor control - see section 4.1.04.

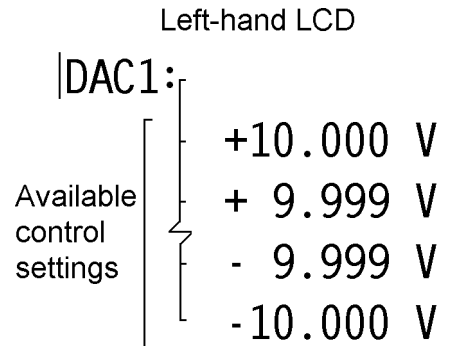


Figure 5-23, DAC 1 Output Control

DAC 2

This control sets the voltage appearing at the rear panel **DAC2** output connector to any value between +10 V and -10 V with a resolution of 1 mV. Adjustment is faster if use is made of the Active Cursor control - see section 4.1.04.

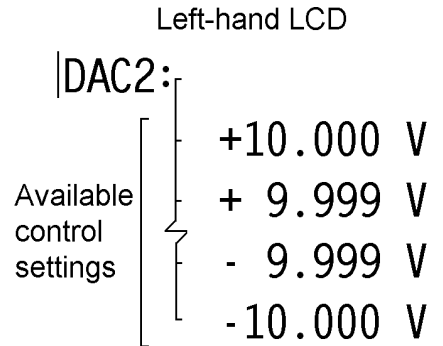


Figure 5-24, DAC 2 Output Control

Offset

This control allows an output offset to be added to the X output, Y output, neither or both outputs. The actual value of offset applied, which may range from -300 % to +300 % of the selected full-scale sensitivity setting, is set using the right-hand LCD panel, or automatically by the Auto-Offset function. Note that the Auto-Offset function automatically switches both X and Y output offsets on.

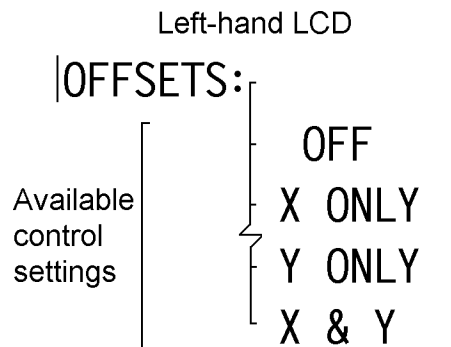


Figure 5-25, Output Offset Status Control

Reference Phase

This control allows the reference phase to be adjusted over the range -360° to $+360^\circ$ in $10m^\circ$ steps, although readers will appreciate that a setting of -180° is equivalent to $+180^\circ$, and that $\pm 360^\circ$ is equivalent to 0° .

The Auto-Phase function also affects the value displayed here.

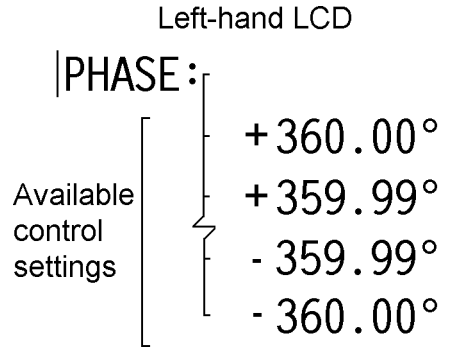


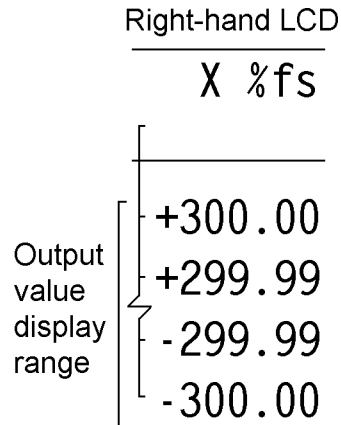
Figure 5-26, Reference Phase Control

5.5 Main Display Mode - Right-hand LCD

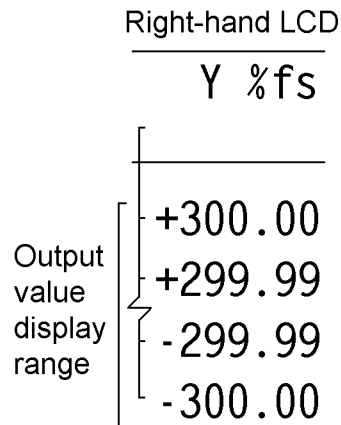
The right-hand display, in Main Display Mode, is used to display two out of the possible fourteen instrument outputs. In addition, it is used to set the levels of the X and Y output offsets.

The panel is divided vertically into two halves, with the output description on the upper line and the output value on the lower line. Selection of the required output type is made using the upper **SELECT** keys on each side of the right-hand display. Each press of the key advances the display to the next output choice, with the display “wrapping” so that repeated presses cycle through those available. Note that it is not possible to set both displayed outputs to the same type, i.e. both sides of the display cannot, for example, be set to “X%”.

The fourteen possible outputs and two controls are now discussed in sequence. Note that in the following figures the horizontal lines below the heading “Right-hand LCD” depict the vertical limits of the display to indicate how information is shown. The user may choose to display this information in either the left or the right half of the display so no horizontal limits are depicted (see figure 4-9).

X %fs**Figure 5-27, X Output as % Full-Scale**

Shows the X output as a percentage of the selected full-scale sensitivity setting. Hence if the sensitivity setting were 100 mV and a 50 mV signal were applied, with the instrument's reference phase adjusted for maximum X output, the display would read 50.00 %

Y %fs**Figure 5-28, Y Output as % Full-Scale**

Shows the Y output as a percentage of the selected full-scale sensitivity setting. Hence if the sensitivity setting were 100 mV and a 50 mV signal were applied, with the instrument's reference phase adjusted for maximum Y output, the display would read 50.00 %

MAG %fs

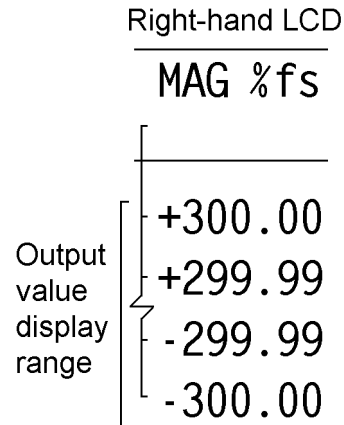


Figure 5-29, Magnitude Output as % Full-Scale

Shows the signal magnitude, where magnitude = $\sqrt{((X \text{ output})^2 + Y \text{ output})^2}$, as a percentage of the selected full-scale sensitivity setting. Hence if the sensitivity setting were 100 mV and a 50 mV signal were applied, regardless of the setting of the instrument's reference phase, the display would read 50.00 %

Noise %fs

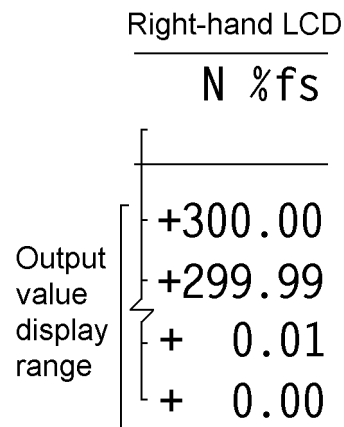
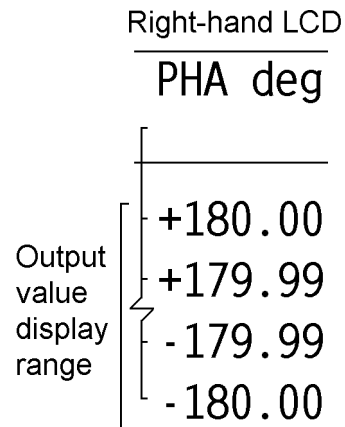
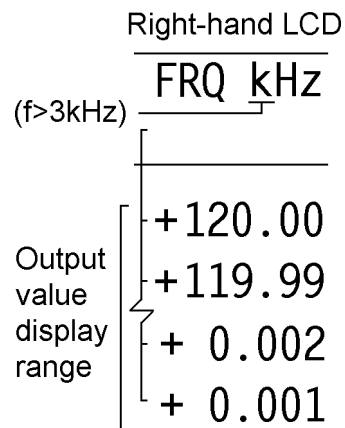


Figure 5-30, Noise Output as % Full-Scale

Shows the noise accompanying the signal, in a bandwidth defined by the setting of the output filter time constant, where it is assumed that the noise is Gaussian. The value is given as a percentage of the instrument's selected full-scale sensitivity setting. Note that the displayed value will change as the time constant control is adjusted. The instrument offers a second Noise output (discussed later in this section), expressed directly in terms of volts or amps per root Hertz, which takes this effect into account.

Phase in Degrees**Figure 5-31, Phase Output in Degrees**

Shows the relative phase, where phase = \tan^{-1} (Y output/X output), in degrees.

Reference Frequency**Figure 5-32, Reference Frequency Display**

Shows the reference frequency at which the lock-in amplifier is operating. Note that the display shows values in kHz only when the frequency is greater than 3 kHz. At all other values the units are Hz.

X Volts (or Amps)

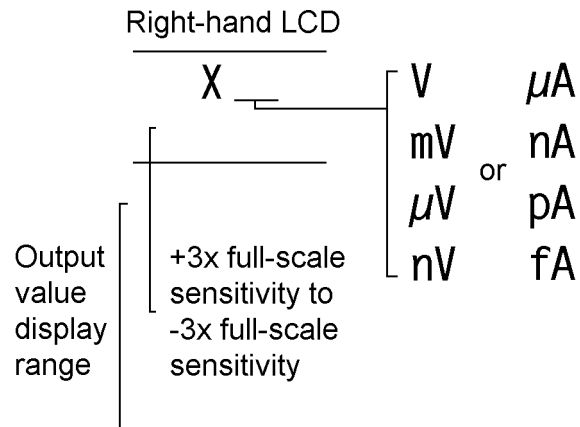


Figure 5-33, X Output in Volts or Amps

Shows the X output directly in terms of volts or amps (depending on whether voltage or current input mode is selected). Hence if the sensitivity setting were 100 mV and a 50 mV signal were applied, with the instrument's reference phase adjusted for maximum X output, the display would read 50.00 mV

Y Volts (or Amps)

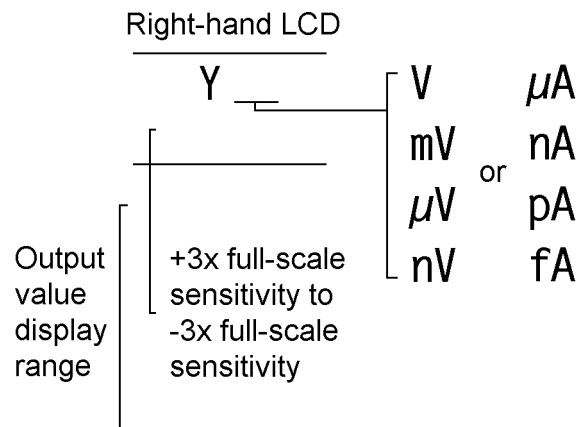
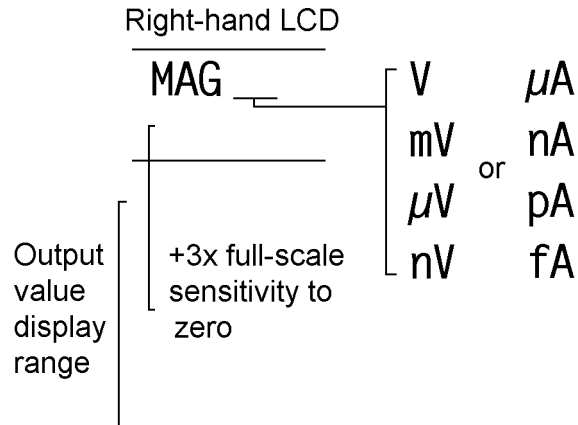
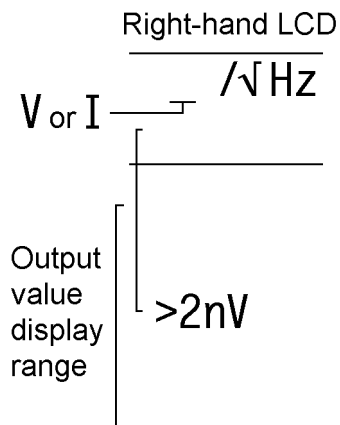


Figure 5-34, Y Output in Volts or Amps

Shows the Y output directly in terms of volts or amps (depending on whether voltage or current input mode is selected). Hence if the sensitivity setting were 100 mV and a 50 mV signal were applied, with the instrument's reference phase adjusted for maximum Y output, the display would read 50.00 mV

MAG Volts (or Amps)**Figure 5-35, Magnitude Output in Volts or Amps**

Shows the signal magnitude, where magnitude = $\sqrt{((X \text{ output})^2 + (Y \text{ output})^2)}$, directly in terms of volts or amps (depending on whether voltage or current input mode is selected). Hence if the sensitivity setting were 100 mV and a 50 mV signal were applied, regardless of the setting of the instrument's reference phase, the display would read 50.00 mV

Noise in Volts or Amps per Root Hertz**Figure 5-36, Noise Output in Volts or Amps per Root Hertz**

Shows the noise accompanying the signal, in a noise bandwidth defined by the setting of the output filter time constant, where it is assumed that the noise is Gaussian. Note that the noise floor of the instrument is 2 nV and so the output value will always be greater than this.

Ratio

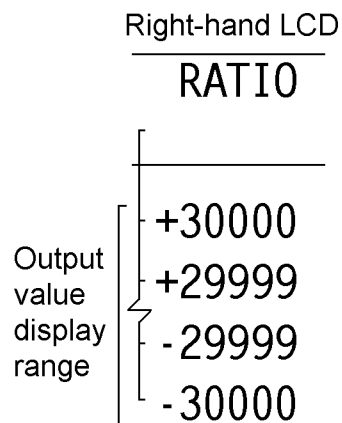


Figure 5-37, Ratio Output

Shows the ratio, where ratio = (X output / ADC1 Input), usually used to compensate for source intensity fluctuations in optical experiments.

Log Ratio

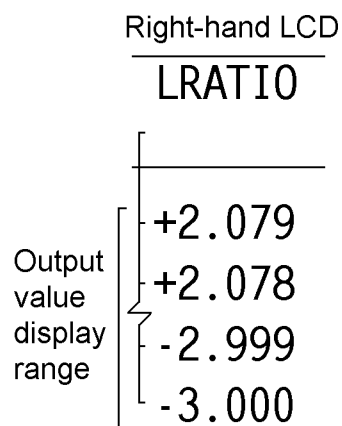
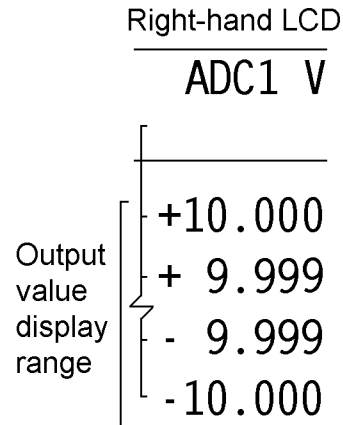
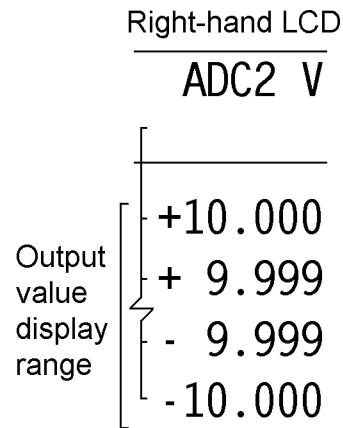


Figure 5-38, Log Ratio Output

Shows the logarithm to base 10 of the ratio, where ratio = (X output / ADC1 Input), usually used to compensate for source intensity fluctuations in optical experiments.

ADC1 Volts**Figure 5-39, ADC 1 Input**

Shows the voltage applied to the rear panel **ADC1** auxiliary input.

ADC2 Volts**Figure 5-40, ADC 2 Input**

Shows the voltage applied to the rear panel **ADC2** auxiliary input.

X Offset

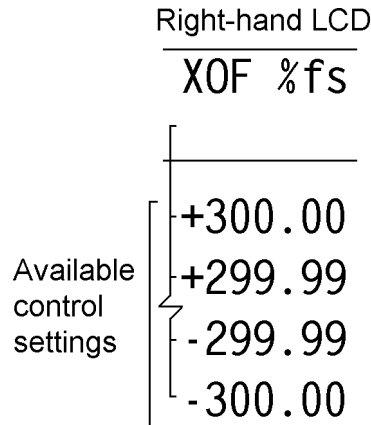


Figure 5-41, X Output Offset Control

This control allows the X output offset to be adjusted, using the lower **ADJUST** keys adjacent to the displayed value. Note that although this control adjusts the level of the offset, it is only applied if the **OFFSET** control on the left-hand LCD is set to **X** or **BOTH**. If the X offset is **ON** then the description on the LCD display of all outputs which would be affected, such as **X% fs**, or **MAG % fs**, is alternated with the warning message **OFFSET!**

Y Offset

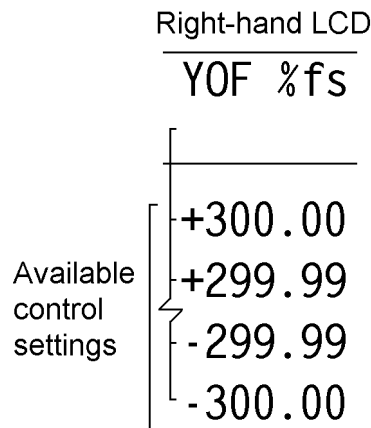


Figure 5-42, Y Output Offset Control

This control allows the Y output offset to be adjusted, using the lower **ADJUST** keys adjacent to the displayed value. Note that although this control adjusts the level of the offset, it is only applied if the **OFFSET** control on the left-hand LCD is set to **Y** or **BOTH**. If the Y offset is **ON** then the description on the LCD display of all outputs which would be affected, such as **Y% fs**, or **MAG % fs**, is alternated with the

warning message OFFSET!

The instrument provides a quick way to switch between the following pairs of outputs, by simply pressing simultaneously both ends of the **SELECT** keys adjacent to their description:-

X % fs	↔	X volts or amps
Y % fs	↔	Y volts or amps
Mag % fs	↔	Mag volts or amps
Noise % fs	↔	Noise volts/ $\sqrt{\text{Hz}}$ or amps/ $\sqrt{\text{Hz}}$

5.6 Typical Lock-in Amplifier Experiment

Having discussed how the instrument's controls may be adjusted and outputs displayed, readers may find the following basic checklist helpful in setting up the instrument for manual operation.

Auto-Default

Use the Auto-Default function on the Control Setup menu to set the instrument to a known state.

Selection of Signal Input

Use the Input Setup menu to select voltage (single-ended or differential) or current input mode, and connect your signal source to the relevant **A** and/or **B/I** input connector(s).

Selection of Reference Mode

The default setting function will have set the reference mode to internal, which assumes that the internal oscillator will be used as a source of excitation to your experiment. Use the Internal Oscillator amplitude and frequency controls to set the required oscillator output, and connect the output signal from the **OSC OUT** connector to your experiment.

If using external reference mode, use the Reference Setup menu to select one of the two External modes, and connect your reference signal to the specified connector.

Auto-Measure

Use the Auto-Measure function to set the instrument so that it is correctly displaying your signal.

Other Adjustments

You may now adjust the other controls as required, and choose the outputs you wish to display. In particular, if you want to use the analog outputs of the instrument, use the Output Setup menu to specify what the output signals at the **CH1** and **CH2** connectors should represent.

6.1 Introduction

The model 7220 includes both RS232 and IEEE-488 (also known as GPIB for General Purpose Interface Bus) interface ports, designed to allow the lock-in amplifier to be completely controlled from a remote computer. All the instrument's controls may be operated, and all the outputs read, via these interfaces. In addition, there are some functions, such as curve storage and oscillator frequency sweeps which may only be accessed remotely.

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

6.2 Capabilities

6.2.01 General

All instrument controls which may be set using the front panel may also be set remotely. In addition, the current setting of each control may be determined by the computer. All instrument outputs which may be displayed on the front panel may also be read remotely.

When operated via the interfaces, the following features are also available:-

6.2.02 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.

6.2.03 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.

6.2.04 Internal Oscillator Frequency Sweep Generator

The instrument's internal oscillator may be swept in frequency both linearly and logarithmically over a specified range. This facility allows the instrument to function as a simple swept-frequency oscillator, or, in conjunction with the curve storage capability, allows frequency response curves to be recorded.

6.3 RS232 and GPIB Operation

6.3.01 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 versions 3.1 and 3.11 include a program called Terminal, 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).

6.3.02 RS232 Interface - General Features

The RS232 interface in the model 7220 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, for example Microsoft's GWBASIC, QBASIC or Windows Terminal mode.

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 7220 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 using the three front-panel RS232 SETUP menus, discussed in chapter 4. They may also be adjusted by means of the RS command.

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.

6.3.03 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.

6.3.04 Choice of Number of Data Bits

The model 7220 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.

6.3.05 Choice of Parity Check Option

Parity checks are not required at the baud rates available in the model 7220, 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 7220 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 7220 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.

6.3.06 Auxiliary RS232 Interface

The auxiliary RS232 interface allows up to sixteen model 7220s 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 from the front panel 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 `\\`.

6.3.07 GPIB Interface - General Features

The GPIB is a parallel digital interface with 8 bidirectional 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 7220 the address is set using the GPIB SETUP 1 setup menu or by means of 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.

6.3.08 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 7220 on a byte-by-byte basis and are not connected in the model 7220 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 adaptor 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.

6.3.09 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 7220 there are three input termination options for GPIB communications, selected from the front panel under the GPIB SETUP 1 menu or 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.

6.3.10 Command Format

The simple commands listed in section 6.4 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 6.3.09.

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 6.3.11).

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.

$\pm 1.234E\pm 01$

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

6.3.11 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 via the RS232 SETUP 2 setup screen or by the use of the DD command.

6.3.12 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.

6.3.13 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 7220, 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

6.3.14 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 7220 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.

6.4 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 E gives the same list of commands but in alphabetical order.

6.4.01 Signal Channel

IMODE [n] Controls whether the instrument input is connected to a current or a voltage preamplifier

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

<i>n</i>	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:

<i>n</i>	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:

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

FLOAT [n] Input connector shield float / ground control

The value of *n* sets the input shield switch according to the following table:

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

CP [n] Input coupling control

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

n	Coupling mode
0	AC
1	DC

SEN[.] [n] 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
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	n/a
8	500 nV	500 fA	n/a
9	1 μ V	1 pA	n/a
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
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 output and minimize the Y 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, either using the front panel or the ACGAIN command
1	Automatic AC Gain control is activated, with the gain being adjusted according to the full-scale sensitivity setting

LF [n] Signal channel line frequency rejection filter control

In instruments manufactured prior to June 1996, the value of n sets the mode of the line frequency notch filter according to the following table:

n	Selection
0	Off
1	On (i.e. reject 50/60 Hz and 100/120 Hz)

In instruments manufactured after June 1996, the value of n sets the mode of the line frequency notch filter according to the following table:

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

Users may identify which version of the instrument they have by sending the command LF 3; if this is accepted by the instrument, it was made after June 1996, but if it generates a command error, it was made prior to this date.

Units made after June 1996 respond in addition to a new command, LINE50, which sets the notch filter centre frequency.

LINE50 [n] Signal channel line frequency rejection filter centre frequency control

The value of n sets the line frequency notch filter centre frequency according to the following table:

- n Notch filter mode
- 0 60 Hz (and/or 120 Hz)
- 1 50 Hz (and/or 100 Hz)

Units made prior to June 1996 generate an Invalid Command (bit 1 of the serial poll status byte is asserted) to the LINE50 command.

SAMPLE [n] Main analog to digital converter sample rate control

The sampling rate 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, 2 or 3, corresponding to four different sampling rates (not specified) near 166 kHz.

6.4.02 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 TTL input)
- 2 EXT (external front panel analog input)

FNF [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 F mode according to the following table:

- n Mode selected
- 1 The lock-in amplifier measures signals at the reference frequency F
- 2 The lock-in amplifier measures at 2F
- 3 The lock-in amplifier measures at 3F

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 output and minimize the Y output signals.

FRQ[.] Reference frequency meter

If the lock-in amplifier is in the EXT or EXT LOGIC 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 INT 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.

6.4.03 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

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

6.4.04 Signal Channel Output Amplifiers

XOF [n₁ [n₂]] X output offset control

The value of n₁ sets the status of the X offset facility according to the following table:

n ₁	Selection
0	Disables offset facility
1	Enables offset facility

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

YOF [n₁ [n₂]] Y output offset control

The value of n₁ sets the status of the Y offset facility according to the following table:

n ₁	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 output offsets are turned on and set to levels giving zero X and Y 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 outputs by a factor of 10. Changes meter, **CH1** and **CH2** outputs full-scale to $\pm 10\%$ 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 n_1 [n₂] Analog output control

Defines what outputs appear on the rear panel **CH1** and **CH2** connectors 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

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

6.4.05 Instrument Outputs

X[.] X 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 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 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 $X / \text{ADC } 1$.

LR[.] Log Ratio output

In integer mode, the LR command reports a number equivalent to $1000 \log (X / \text{ADC1})$ 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 $\log (X / \text{ADC } 1)$. 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 output, expressed in $\text{volt}/\sqrt{\text{Hz}}$ or $\text{amp}/\sqrt{\text{Hz}}$ referred to the input. This measurement assumes that the Y output is Gaussian with zero mean. (Section 3.10). The command is only available in floating point mode.

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.

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 output in the range 0 to 12000, full-scale being 10000. If the mean value of the Y 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 listed above. 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 7220 to get into the high speed transfer mode. When in this mode, the front panel controls are inactive and display is frozen.

The mode is terminated 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.

*Caution: 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.*

6.4.06 Internal Oscillator

OA[.] [n] Oscillator amplitude control

In fixed point mode n sets the oscillator amplitude in mV. 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.

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 fixed point mode, n is in millihertz.

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 fixed point mode, n is in millihertz.

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

SRATE[.] [n] Oscillator frequency 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 sweep start/stop

Starts/stops the internal oscillator frequency sweep depending on the value of n according to the following table:

n	Frequency sweep status
0	Stop/Pause
1	Run

When a frequency sweep has been defined, applying SWEEP 1 will start it. The sweep will continue until the stop frequency 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 and stops, the next SWEEP 1 command will reset the frequency to the start frequency and restart the sweep.

6.4.07 Auxiliary Outputs

DAC[.] n₁ [n₂] Auxiliary DAC output controls

Sets the voltage appearing at the rear panel **DAC1** and **DAC2** outputs.

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 -12.000 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.

6.4.08 Auxiliary Inputs

ADC[.] n Read auxiliary analog to digital inputs

Reads the voltage appearing at the rear panel **ADC1** (n = 1) and **ADC2** (n = 2) inputs.

In fixed point mode the response 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 (rear panel TRIG input)
2	Burst mode, fixed rate, triggered by command (ADC1 only)
3	Burst mode, fixed rate, 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, fixed rate, External trigger (rear panel TRIG input) (ADC1 only)
7	Burst mode, fixed rate, External trigger (rear panel TRIG input) (ADC1 and ADC2)
8	Burst mode, variable rate, External trigger (rear panel TRIG input) (ADC1 only)
9	Burst mode, variable rate, External trigger (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 whether the sampling is timed or simply runs as fast as possible. In the modes above described as Fixed Rate, sampling runs at the maximum possible rate, nominally 20 kHz when sampling both ADC1 and ADC2 or 40 kHz when sampling ADC1 only. In the Variable Rate modes, the sampling speed is set by the BURSTRATE command.

BURSTRATE [n] Sets the burst mode sampling rate for ADC1 and ADC2

n sets the sample rate for the Variable Rate burst modes according to the following equations:

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

$$\text{Sample Rate} = \frac{16,000,000}{(25 \times n) + 157} \text{ Hz}$$

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

$$\text{Sample Rate} = \frac{16,000,000}{(25 \times n) + 1031} \text{ Hz}$$

Note that these equations apply only to units manufactured after December 1995. Earlier instruments used a 16.384 MHz instead of a 16.0 MHz crystal, so the above equations should be modified accordingly by replacing the 16,000,000 figure with 16,384,000.

For example when n = 20, the sample rate will be 24,353 Hz for ADC1 for an instrument with a 16.0 MHz crystal, and 24,937 Hz for a unit with a 16.384 MHz crystal.

6.4.09 Output Data Curve Buffer

CBD [n] Curve buffer define

Defines which data outputs are stored in the curve buffer when subsequent TD (take data) or TDC (take data continuously) commands are issued. Up to 16 curves, or outputs, may be acquired, as specified by the CBD parameter.

The CBD is an integer between 0 and 65,535, being the decimal equivalent of a 16-bit binary word. When a given bit in the word 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 (± 10000 FS)
3	8	Phase ($\pm 18000 = \pm 180^\circ$)
4	16	Sensitivity setting (4 to 27) + IMODE (0, 1, 2 = 0, 32, 64)
5	32	ADC1 ($\pm 10000 = \pm 10.0$ V)
6	64	ADC2 ($\pm 10000 = 10.0$ V)
7	128	Unassigned
8	256	DAC1 ($\pm 10000 = 10.0$ V)
9	512	DAC2 ($\pm 10000 = 10.0$ V)
10	1024	Noise (± 10000 FS)
11	2048	Ratio (± 10000 FS)
12	4096	Log ratio (-3000 to +2000)
13	8192	Last value given to EVENT command
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 all 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 is needed, which stores both the sensitivity and the IMODE setting, 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 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.

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 800 Hz. However this only allows storage of the X and Y 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 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.

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 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 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.

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.

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 (± 10000 FS)
3	8	Phase ($\pm 18000 = \pm 180^\circ$)
4	16	Sensitivity setting (4 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 (± 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 output curve and the Magnitude curve simultaneously. A typical output data sequence would be:

<X output value₁><delim><Magnitude value₁><term>
 <X output value₂><delim><Magnitude value₂><term>
 <X output value₃><delim><Magnitude value₃><term>
 <X output value₄><delim><Magnitude value₄><term>
 <X 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.

6.4.10 Computer Interfaces (RS232 and GPIB)

RS [n₁ [n₂]] Set/read RS232 interface parameters

The values of n₁ set 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 n₂ 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	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

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 7220 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 set from the front panel the instrument will switch into addressed mode. If n does not match the address set from the front panel the instrument will switch into unaddressed mode.

Note: The \N n command does not change the address of an instrument but which instrument is addressed.

Warning: All instruments must have a unique address.

DD [n] Define delimiter control

The value of n, which can be set to 13 or 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.

Note: this command is not normally used in GPIB communications, where the status

byte is accessed by performing a serial poll.

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

N Report overload byte

Causes the lock-in amplifier to respond with the overload byte.

Bit 0	not used
Bit 1	CH1 output overload ($> \pm 120\% \text{FS}$)
Bit 2	CH2 output overload ($> \pm 120\% \text{FS}$)
Bit 3	Y output overload ($> \pm 300\% \text{FS}$)
Bit 4	X output overload ($> \pm 300\% \text{FS}$)
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

REMOTE [n] Remote only (front panel lock-out) control

Allowed values of n are 0 and 1. When n is equal to 1, the lock-in amplifier enters remote only mode in which the front panel control functions are inoperative and the instrument can only be controlled with the RS232 or the GPIB interfaces. When n is equal to 0, the front panel control functions normally.

6.4.11 Instrument Identification

ID Identification

Causes the lock-in amplifier to respond with the number 7220.

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.

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 front-panel RS232 SETUP 3 screen.

6.4.12 Front Panel

LTS [n] Lights on/off control

The value of n controls the front panel LEDs and LCD backlights according to the following table:

n	Selection
0	All lights off
1	Normal operation

6.4.13 Default Setting

ADF Default Setting command

This command will automatically set all the instrument controls and displays to the factory set default values. However, if the command is used when the interface parameters are at values other than their default settings, then communication will be lost.

6.5 Programming Examples

6.5.01 Introduction

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

6.5.02 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 front panel 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	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.

6.5.03 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	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.

6.5.04 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 front panel 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	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.

6.5.05 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.

6.5.06 Frequency Response Measurement using Curve Storage and Frequency Sweep

In this example, a more sophisticated version of that given in section 6.5.03, 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	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

Appendix A

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		2F or 3F
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	20 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	20 fA to 10 nA in a 1-2-5 sequence
Wide Bandwidth	20 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	≤ 0.6 % typ
Wide Bandwidth	≤ 0.6 % typ
Line Filter	attenuates 50, 60, 100, 120 Hz
Grounding	BNC shields can be grounded or floated via 1 k Ω to ground

Reference Channel

TTL Input (rear panel)	
Frequency Range	1 mHz to 120 kHz
Analog Input (front panel)	
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	$< 0.01^\circ/\text{C}$ below 10 kHz $< 0.1^\circ/\text{C}$ 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/ $^\circ\text{C}$
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 < 20 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

ADC 1 and 2	
Maximum Input	±10 V
Resolution	1 mV
Accuracy	±0.2 %
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 Output	
Time Constant	≤ 640 μs
Amplitude	±10 V
Update Rate	170 kHz
Output Impedance	1 kΩ
Fast Y Output	
Time Constant	≤ 640 μs
Amplitude	±10 V
Update Rate	170 kHz
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	±0.1 %
Output Impedance	1 kΩ
8-bit Digital Output	8 TTL compatible lines that can be independently set high or low to activate external equipment
Reference Output	
Waveform	0 to 5 V square wave
Impedance	TTL compatible
Power - Low Voltage	±15 V at 100 mA rear panel DIN connector for powering EG&G 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)

Pinouts

B.1 RS232 Connector Pinout

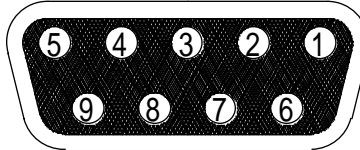


Figure B-1, RS232 and AUX RS232 Connector (Female)

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 Preampifier Power Connector Pinout

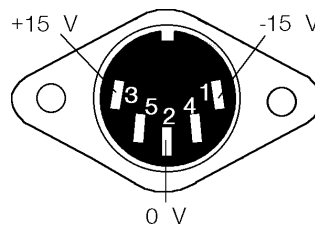


Figure B-2, Preamplifier Power Connector

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

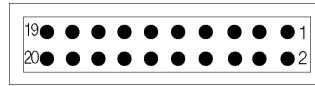


Figure B-3, Digital Output Port Connector

8-bit TTL-compatible output set from the front panel or 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 Program with Handshakes

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$
110 GOSUB 180
120 GOSUB 310: PRINT Z$;
130 IF A$="?" THEN GOSUB 410: GOSUB 470
140
150 WEND
160 '
170 '
180 '...output the string B$.....
190 ON ERROR GOTO 510
200 IF LOC(1)>0 THEN A$=INPUT$(LOC(1),#1)
210 ON ERROR GOTO 0
220 FOR J1%=1 TO LEN(B$)
230 C$=MID$(B$,J1%,1): PRINT#1,C$;
240 WHILE LOC(1)=0: WEND
250 A$=INPUT$(1,#1)
260 IF A$<>C$ THEN PRINT"handshake error"
270 NEXT J1%
280 RETURN
290 '
300 '
310 '....read response.....
320 A$="": Z$=""
330 WHILE (A$<>"*" AND A$<>"?")
340 Z$=Z$+A$
350 WHILE LOC(1)=0: WEND
360 A$=INPUT$(1,#1)
370 WEND
380 RETURN
390 '
400 '
410 '....fetch status byte.....
420 B$="ST"+CR$
430 GOSUB 180
440 GOSUB 310
450 STATUS%=VAL(Z$)
460 RETURN
470 '....instrument error message.....
480 PRINT"Error prompt, status byte = ";STATUS%
490 PRINT
500 RETURN
510 '....I/O error routine.....
520 RESUME

```

```

' append a carriage return
' output the command B$
' read and display response
' if "?" prompt fetch STATUS%
' and display message
' return to start of loop

' enable error trapping
' clear input buffer
' disable error trapping
' LEN(B$) is number of bytes
' send byte
' wait for byte in input buffer
' read input buffer
' input byte should be echo
' next byte to be sent or
' return if no more bytes

' read until prompt received
' append next byte to string
' wait for byte in input buffer
' read byte from buffer
' next byte to be read
' return if it is a prompt

' "ST" is the status command
' output the command
' read response into Z$
' convert to integer

' bits are defined in manual

```


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 BDNAMES$="GPIB0"
110 CALL IBFIND(BDNAMES$,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%)
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 7220 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.

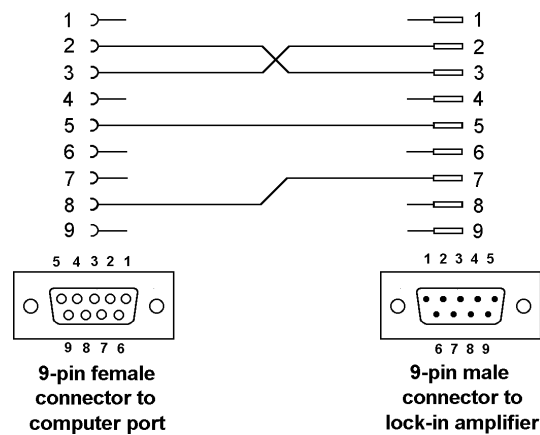


Figure D-1, Interconnecting RS232 Cable Wiring Diagram

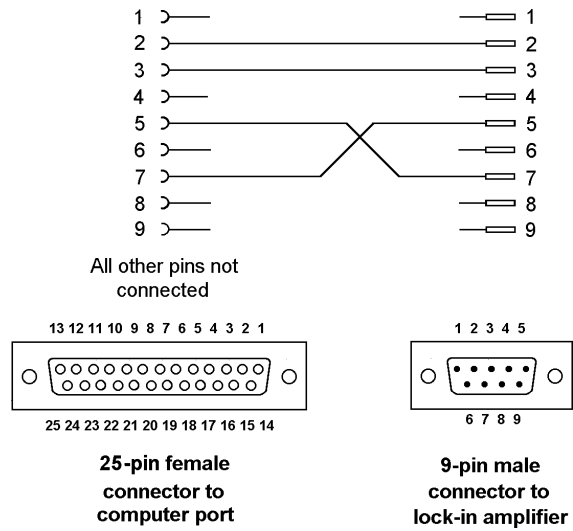


Figure D-2, Interconnecting RS232 Cable Wiring Diagram

Alphabetical Listing of Commands

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

Reads the voltage appearing at the rear panel **ADC1** (n = 1) and **ADC2** (n = 2) inputs.

In fixed point mode the response 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 Default setting command

This command will automatically set all the instrument controls and displays to the factory set default values. However, if the command is used when the interface parameters are at values other than their default settings, then communication will be lost.

AQN Auto-Phase (auto-quadrature null)

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

AS Perform an Auto-Sensitivity operation

The instrument adjusts its full-scale sensitivity so that the X 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 output and minimize the Y output

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, either using the front panel or 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

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

BURSTRATE [n] Sets the burst mode sampling rate for ADC1 and ADC2

n sets the sample rate for the Variable Rate burst modes according to the following equations:

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

$$\text{Sample Rate} = \frac{16,000,000}{((25 \times n) + 157)} \text{ Hz}$$

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

$$\text{Sample Rate} = \frac{16,000,000}{((25 \times n) + 1031)} \text{ Hz}$$

Note that these equations apply only to units manufactured after December 1995. Earlier instruments used a 16.384 MHz instead of a 16.0 MHz crystal, so the above equations should be modified accordingly by replacing the 16,000,000 figure with 16,384,000.

For example when n = 20, the sample rate will be 24,353 Hz for ADC1 for an instrument with a 16.0 MHz crystal, and 24,937 Hz for a unit with a 16.384 MHz crystal.

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) or TDC (take data continuously) commands are issued. Up to 16 curves, or outputs, may be acquired, as specified by the CBD parameter.

The CBD is an integer between 0 and 65,535, being the decimal equivalent of a 16-bit binary word. When a given bit in the word 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 (± 10000 FS)
3	8	Phase ($\pm 18000 = \pm 180^\circ$)
4	16	Sensitivity setting (4 to 27) + IMODE (0, 1, 2 = 0, 32, 64)
5	32	ADC1 ($\pm 10000 = \pm 10.0$ V)
6	64	ADC2 ($\pm 10000 = 10.0$ V)
7	128	Unassigned
8	256	DAC1 ($\pm 10000 = 10.0$ V)
9	512	DAC2 ($\pm 10000 = 10.0$ V)
10	1024	Noise (± 10000 FS)
11	2048	Ratio (± 10000 FS)
12	4096	Log ratio (-3000 to +2000)
13	8192	Last value given to EVENT command
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 all 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 is needed, which stores both the sensitivity and the IMODE setting, 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 rear panel **CH1** and **CH2** connectors 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: $(1000 \times X)/\text{ADC } 1$

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

CP [n] Input coupling control

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

n	Coupling mode
0	AC
1	DC

DAC[.] n_1 [n_2] Auxiliary DAC output controls

Sets the voltage appearing at the rear panel **DAC1** and **DAC2** outputs.

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.

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 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.

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.

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 (± 10000 FS)
3	8	Phase ($\pm 18000 = \pm 180^\circ$)
4	16	Sensitivity setting (4 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 (± 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 output curve and the Magnitude curve simultaneously. A typical output data sequence would be:

<X output value₁><delim><Magnitude value₁><term>
<X output value₂><delim><Magnitude value₂><term>
<X output value₃><delim><Magnitude value₃><term>
<X output value₄><delim><Magnitude value₄><term>
<X 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.

DD [n] Define delimiter control

The value of n, which can be set to 13 or 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.

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

Expands X and/or Y outputs by a factor of 10. Changes meter, **CH1** and **CH2** outputs full-scale to $\pm 10\%$ 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

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
- 1 FET, 10 M Ω input impedance, 5 nV/ $\sqrt{\text{Hz}}$ voltage noise

FLOAT [n] Input connector shield float / ground control

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

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

FNF [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 F mode according to the following table:

- n Mode selected
- 1 The lock-in amplifier measures signals at the reference frequency F
- 2 The lock-in amplifier measures at 2F
- 3 The lock-in amplifier measures at 3F

FRQ[.] Reference frequency meter

If the lock-in amplifier is in the EXT or EXT LOGIC 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 INT 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 fixed point mode, n is in millihertz.

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 fixed point mode, n is in millihertz.

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

n	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

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.

- 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 or TDC command, as appropriate.
- ID** Identification
- Causes the lock-in amplifier to respond with the number 7220.
- 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 TTL input) |
| 2 | EXT (external front panel analog input) |
- IMODE [n]** Controls whether the instrument input is connected to a current or a voltage preamplifier
- 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.
- 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 [n] Signal channel line frequency rejection filter control

In instruments manufactured prior to June 1996, the value of n sets the mode of the line frequency notch filter according to the following table:

- n Selection
- 0 Off
- 1 On (i.e. reject 50/60 Hz and 100/120 Hz)

In instruments manufactured after June 1996, the value of n sets the mode of the line frequency notch filter according to the following table:

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

Users may identify which version of the instrument they have by sending the command LF 3; if this is accepted by the instrument, it was made after June 1996, but if it generates a command error, it was made prior to this date.

Units made after June 1996 respond in addition to the command, LINE50, which sets the notch filter centre frequency.

LINE50 [n] Signal channel line frequency rejection filter centre frequency control

The value of n sets the line frequency notch filter centre frequency according to the following table:

- n Notch filter mode
- 0 60 Hz (and/or 120 Hz)
- 1 50 Hz (and/or 100 Hz)

Units made prior to June 1996 generate an Invalid Command (bit 1 of the serial poll status byte is asserted) to the LINE50 command.

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 $1000 \log (X / \text{ADC1})$ 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 $\log (X / \text{ADC } 1)$. The response range is -3.000 to +2.079.

LTS [n] Lights on/off control

The value of n controls the front panel LEDs and LCD backlights according to the following table:

n	Selection
0	All lights off
1	Normal operation

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 7220 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 set from the front panel the instrument will switch into addressed mode. If n does not match the address set from the front panel the instrument will switch into unaddressed mode.

Note: The \N n command does not change the address of an instrument but which instrument is addressed.

Warning: All instruments must have a unique address.

N Report overload byte

Causes the lock-in amplifier to respond with the overload byte.

Bit 0	not used
Bit 1	CH1 output overload (> ±120 %FS)
Bit 2	CH2 output overload (> ±120 %FS)
Bit 3	Y output overload (> ±300 %FS)
Bit 4	X output overload (> ±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 output, expressed in volt/√Hz or amp/√Hz referred to the input. This measurement assumes that the Y output is Gaussian with zero mean. (Section 3.10). The command is only available in floating point mode.

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 output in the range 0 to 12000, full-scale being 10000. If the mean value of the Y 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 mV. 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.

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.

REMOTE [n] Remote only (front panel lock-out) control

Allowed values of n are 0 and 1. When n is equal to 1, the lock-in amplifier enters remote only mode in which the front panel control functions are inoperative and the instrument can only be controlled with the RS232 or the GPIB interfaces. When n is equal to 0, the front panel control functions normally.

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

The values of n_1 set 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

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 $X / \text{ADC 1}$.

SAMPLE [n] Main analog to digital converter sample rate control

The sampling rate 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, 2 or 3, corresponding to four different sampling rates (not specified) near 166 kHz.

SEN[.] [n] 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
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	n/a
8	500 nV	500 fA	n/a
9	1 μ V	1 pA	n/a
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
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.

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

SRATE[.] [n] Oscillator frequency 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.

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

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

STAR [n] Star mode setup command

The star mode allows faster access to instrument outputs than is possible using the conventional commands listed above. 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 7220 to get into the high speed transfer mode. When in this mode, the front panel controls are inactive and display is frozen.

The mode is terminated 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.

Caution: 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 about one point in 12 days.

In addition, n may be set to 0, which sets the rate of data storage to the curve buffer to 800 Hz. However this only allows storage of the X and Y 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 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 sweep start/Stop

Starts/stops the internal oscillator frequency sweep depending on the value of n according to the following table:

n	Frequency sweep status
0	Stop/Pause
1	Run

When a frequency sweep has been defined, applying SWEEP 1 will start it. The sweep will continue until the stop frequency 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 and stops, the next SWEEP 1 command will reset the frequency to the start frequency and restart the sweep.

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

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.

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 (rear panel **TRIG** input)
- 2 Burst mode, fixed rate, triggered by command (ADC1 only)
- 3 Burst mode, fixed rate, 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, fixed rate, External trigger (rear panel **TRIG** input) (ADC1 only)
- 7 Burst mode, fixed rate, External trigger (rear panel **TRIG** input) (ADC1 and ADC2)
- 8 Burst mode, variable rate, External trigger (rear panel **TRIG** input) (ADC1 only)
- 9 Burst mode, variable rate, External trigger (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 whether the sampling is timed or simply runs as fast as possible. In the modes above described as Fixed Rate, sampling runs at the maximum possible rate, nominally 20 kHz when sampling both ADC1 and ADC2 or 40 kHz when sampling ADC1 only. In the Variable Rate modes, the sampling speed is set by the BURSTRATE command.

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

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. 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

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, current data overwrites earlier points.

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 front panel RS232 SETUP 3 setup screen.

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.

X[.] X 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 output offset control

The value of n₁ sets the status of the X offset facility according to the following table:

n ₁	Selection
0	Disables offset facility
1	Enables offset facility

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

XY[.] X, Y outputs

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

Y[.] Y 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 [n_1 [n_2]] Y output offset control

The value of n_1 sets the status of the Y offset facility according to the following table:

n_1	Selection
0	Disables offset facility
1	Enables offset facility

The range of n_2 is ± 30000 corresponding to ± 300 % full-scale.

Default Settings

Default Setting Function

The default setting function sets the model 7220's controls and output displays as follows:-

Left-hand LCD

Displays the AC Gain control on the upper line and the full-scale sensitivity control on the lower line.

Right-hand LCD

Displays the magnitude as a percentage of full-scale output on the left-hand side and the phase angle in degrees output on the right-hand side.

The ten controls accessed via the left-hand LCD are set to the following values:-

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°

The two output offset controls accessed via the right-hand LCD are set as follows:-

X channel output offset	0.00 %
Y channel output offset	0.00 %

The remaining instrument controls, accessed via the setup menus, are set as follows:-

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
Display contrast	0
RS232 interface settings	
Baud rate	9600
Data bits	7
Stop bits	1
Parity	Even
Prompt character	On
Character echo	On
Delimiter	, (044)
Address	1
GPIB interface settings	
Address	12
Terminator	CR,LF
SRQ mask byte	0
Test Echo	Disabled
Digital outputs	0 (i.e. D0 - D7 are at logic zero)
Sample rate adjustment	0

Index

Index

- * command 6-18, E-16
- \N n command 6-28, E-12
- 2F reference mode 3-7, 5-4
- 8-bit programmable output port 3-8
- 90° Key 4-5
- Absolute accuracy 3-8
- AC Gain
 - and full-scale sensitivity 3-9
 - and input overload 3-4
 - control 5-8, 5-22
 - description of 3-4
- AC GAIN [n] command 6-12, E-1
- AC/DC input coupling 3-2
- Accuracy 3-8
- Active cursor 4-3
- ADC
 - sample rate control 5-17
 - sampling frequency 3-4
 - trigger control 5-10
- ADC[.] n command 6-21, E-1
- ADC1
 - auxiliary input 3-8
 - connector 4-8
 - display 5-33
- ADC2
 - auxiliary input 3-8
 - connector 4-8
 - display 5-33
- ADF command 6-30, E-1
- ADJUST keys 4-2
- Analog meter 3-9, 4-1, 4-6
- Analog to digital converter (ADC) 3-4
- Anti-aliasing filter 3-4
- AQN command 6-13, E-1
- AS command 6-11, E-1
- ASM command 6-12, E-1
- Auto functions
 - Auto-Measure 3-9, 3-16, 5-19
 - Auto-Offset 3-15, 5-19
 - Auto-Phase 3-11, 3-15, 5-18
 - Auto-Sensitivity 3-9, 3-15, 5-18
 - introduction 3-14
 - menu 5-18
- AUTO key 4-4
- AUTO menu 4-4
- Auto repeat 4-3
- AUTOMATIC [n] command 6-12, E-1
- AUX RS232 connector 4-7
- Auxiliary ADCs 3-8
- Auxiliary RS232 interface 6-4
- AXO command 6-16, E-2
- Baseband reference mode 3-6
- Baud rate control 5-11
- Bipolar input device 3-2, 5-3
- Burst mode acquisition 6-1
- BURSTRATE [n] command 6-22, E-2
- BYTE [n] command 6-21, E-2
- CBD [n] command 6-23, E-2
- CH n1 [n2] command 6-16, E-4
- CH1
 - connector 4-8
 - output 3-8
 - output connector 5-6
 - output control 5-6
- CH2
 - connector 4-8
 - output 3-8
 - output connector 5-6
 - output control 5-6
- Commands
 - alphabetical listing of E-1 – E-21
 - compound 6-7
 - descriptions of 6-10
 - for auxiliary inputs 6-21
 - for auxiliary outputs 6-20
 - for computer interfaces 6-27
 - for default setting 6-30
 - for front panel 6-30
 - for instrument identification 6-29
 - for instrument outputs 6-16
 - for internal oscillator 6-19
 - for output data curve buffer 6-23
 - for reference channel 6-13
 - for signal channel 6-10
 - for signal channel output amplifiers 6-15
 - for signal channel output filters 6-14
 - format 6-6
- Common mode rejection ratio (CMRR) 3-2

- Computer control, sample programs 6-30
- Contrast control 5-10
- Control options menu 5-8
- Control setup menu 5-17
- CP [n] command 6-11, E-4
- Current input mode 3-2, 5-2
- Current to voltage converter 5-2
- Current/voltage input mode selection 3-3
- Curve storage 6-1

- DAC[.] n1 [n2] command 6-20, E-4
- DAC1
 - auxiliary output 3-8
 - connector 4-8
 - control 5-24
- DAC2
 - auxiliary output 3-8
 - connector 4-8
 - control 5-25
- DC[.] n command 6-25, E-4
- DCT n command 6-26, E-5
- DD [n] command 6-7, 6-28, E-6
- Default setting 3-16
- Default setting control 5-17
- Default settings, list of F-1 – F-2
- Delimiters 6-7
- Demodulator
 - DSP 3-7
 - gain 3-9
 - monitor 3-7, 5-4
- Differential voltage input mode 3-2, 4-1, 5-2
- Digital displays 3-9
- Digital low-pass filter 3-7
- Digital output port 3-8
- DIGITAL OUTPUTS connector 4-7
- Digital outputs setup menu 5-16
- Digital phase locked loop 3-6
- Digital phase shifter 3-6
- Direct digital synthesizer (DDS) 3-6
- Direct mode 6-2
- Display contrast control 5-10
- Dynamic range 3-4
- Dynamic reserve 3-9

- ENBW[.] command 6-18, E-6
- Equivalent noise bandwidth 3-14
- EVENT [n] command 6-24, E-6
- EX [n] command 6-16, E-7
- External reference 5-4
- External reference mode 3-6

- FAST X
 - connector 4-8
 - output 3-7
- FAST Y
 - connector 4-8
 - output 3-7
- FET [n] command 6-10, E-7
- FET input device 3-2, 5-3
- FIR filters 3-12
- Firmware version display 5-13
- FLOAT [n] command 6-10, E-7
- Floating point command format 6-7
- FNF [n] command 6-13, E-7
- Front panel
 - layout 4-1
 - operation 5-1
- FRQ[.] command 6-14, E-7
- FSTART[.] [n] command 6-19, E-8
- FSTEP[.] [n1 n2] command 6-20, E-8
- FSTOP[.] [n] command 6-19, E-8
- Full-scale sensitivity 3-9
- Fuses, line 2-1, 2-2

- General purpose reference input 3-6
- GP [n1 [n2]] command 6-4, 6-6, 6-28, E-8
- GPIB interface
 - address 6-4
 - address control 5-14
 - connector 4-7
 - general features 6-4
 - handshaking 6-5
 - microprocessor support of 3-8
 - service request 5-15, 6-9
 - service request mask byte 5-15
 - setup 1 menu 5-14
 - setup 2 menu 5-15
 - status byte 5-15
 - terminator control 5-14
 - test echo control 5-15

- Handshaking and echos 6-5
- Harmonic measurement selection 5-4
- Harmonic measurements 3-7
- HC command 6-25, E-9
- Highband reference mode 3-6

- ID command 6-29, E-9
- IE [n] command 6-13, E-9
- IMODE [n] command 6-10, E-9
- Initial checks 2-3

- Input
 - connector ground/float 5-3
 - connector selection 5-2
 - connector shell ground/float 3-2
 - coupling 3-2, 5-3
 - device selection 3-2, 5-3
 - float/ground control 3-2
 - impedance 3-2, 5-3
 - mode 5-2
 - mode selection 3-3
 - overload 3-4
 - overload indicators 4-1
 - selection 3-2
 - setup menu 5-2
- Inspection 2-1
- Installation 2-1
- Internal oscillator 3-7
- Internal oscillator frequency sweep 3-8
- Internal reference 5-4
- Internal reference mode 3-6
- Key specifications 1-3
- LCD contrast control 5-10
- LED indicators 4-1
- Left-hand LCD display panel 4-2
- LEN [n] command 6-24, E-9
- LF [n] command 6-12, E-10
- Lights control 5-10
- Line cord 2-1
- Line frequency rejection filter 3-3, 5-8
- Line fuses 2-1, 2-2
- Line power input assembly 4-6
- Line power switch 4-6
- Line voltage selection 2-1
- LINE50 [n] command 3-3, 6-12, E-10
- LOCK command 3-10, 6-14, E-10
- Log ratio display 5-32
- LR[.] command 6-17, E-10
- LTS [n] command 6-30, E-11
- M command 6-25, E-11
- MAG % output 5-6
- MAG %fs display 5-28
- MAG in volts/amps display 5-31
- MAG[.] command 6-17, E-11
- Main Display mode 5-1, 5-20
- Main display mode 4-4
- Main microprocessor 3-8
- MENU key 4-4
- Microsoft Windows Terminal program 6-2
- Miscellaneous options menu 5-10
- MP[.] command 6-17, E-11
- MSK [n] command 6-9, 6-29, E-11
- N command 6-8, 6-29, E-12
- NC command 6-24, E-12
- nF reference mode 3-7, 5-4
- NHZ. command 6-17, E-12
- NN[.] command 6-18, E-12
- Noise %fs display 5-28
- Noise in volts/amps per root hertz display 5-31
- Noise measurements 3-14
- NOISE output 5-7
- Null modem 6-2, 6-5
- OA[.] [n] command 6-19, E-13
- OF[.] [n] command 6-19, E-13
- Offset status control 5-25
- Operating environment 2-1
- OSC OUT connector 3-7, 4-1
- Oscillator
 - amplitude control 5-24
 - frequency control 5-23
- Output
 - channel filters 3-7, 3-11
 - expand 3-12
 - expand control 5-5
 - offset 3-12
 - offset indicators 5-34
 - processor 3-8
 - setup menu 5-5
- Overload byte 6-7
- PHA[.] command 6-17, E-13
- Phase 3-8
- Phase in degrees display 5-29
- Phase noise 3-6
- Phase sensitive detector 3-7
- Phase shifter 3-10
- Phase values 3-6
- PHASE1 output 5-7
- PHASE2 output 5-7
- Power consumption 2-1
- Power input assembly 2-1
- Power-up defaults 3-14
- PREAMP POWER connector 4-7
- Programming examples 6-30
- Prompt character 6-7
- Rack mounting 2-1
- Ratio calculations 3-8

- Ratio display 5-32
- RATIO output 5-7
- Rear panel layout 4-6
- REF IN connector 3-10, 4-2, 5-4
- REF MON connector 4-7
- REF TTL connector 4-7, 5-4
- Reference channel DSP 3-6
- Reference frequency changes 3-10
- Reference frequency display 5-29
- Reference harmonic 5-4
- Reference harmonic number 3-7
- Reference mode
 - external 3-6
 - internal 3-6
- Reference phase 3-10
- Reference phase control 5-26
- Reference setup menu 5-4
- Reference source control 5-4
- Reference unlock indicator 4-2
- REFP[.] [n] command 3-11, 6-13, E-13
- Relative accuracy 3-8
- REMOTE [n] command 6-29, E-13
- REV command 6-29, E-13
- Right-hand LCD display panel 4-5
- RS [n1 [n2]] command 6-27, E-14
- RS232 interface
 - address 6-4
 - address control 5-13
 - character echo control 5-12
 - choice of baud rate 6-3
 - choice of number of data bits 6-3
 - choice of parity check option 6-3
 - connector 4-7
 - data delimiter control 5-12
 - data format control 5-11
 - data prompt character control 5-12
 - general features 6-2
 - handshaking 6-5
 - input terminator 6-6
 - microprocessor support of 3-8
 - output terminator 6-6
 - setup 1 menu 5-11
 - setup 2 menu 5-12
 - setup 3 menu 5-13
- RT[.] command 6-17, E-14
- SAMPLE [n] command 6-13, E-14
- Sample rate control 5-17
- SELECT keys 4-2, 5-1
- SEN[.] [n] command 6-11, E-15
- Sensitivity control 5-20
- SET key 4-5
- Setup menu mode 4-4, 5-1
- SIG MON connector 3-4, 4-7
- Signal channel inputs 3-2
- Signal channel overload 3-9
- Signal input connectors 4-1
- Single-ended voltage input 5-2
- Single-ended voltage input mode 4-1
- Slope 3-11
- SLOPE [n] command 6-14, E-15
- Slope control 5-23
- Specifications
 - detailed listing of A-1 – A-6
 - 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 6-20, E-15
- ST command 6-8, 6-28, E-16
- STAR [n] command 6-18, E-16
- Status byte 6-7
- STR [n] command 6-24, E-17
- SWEEP [n] command 6-20, E-17
- SYNC [n] command 6-15, E-17
- Synchronous filters 3-12
- Synchronous oscillator 3-7
- SYNCOSC [n] command 6-19, E-18
- System updates 3-10
- TADC [n] command 6-21, E-18
- TC [n] command 6-14, E-19
- TC. command 6-14, E-19
- TD command 6-24, E-19
- TDC command 6-24, E-20
- Technical description 3-1
- Terminal emulator 6-2
- Terminal mode 6-2
- Terminators 6-6
- Time constants 3-12
- Time Constants control 5-22
- Time constants control 5-9
- Transient recorder 3-8
- TRIG connector 4-8
- TTL logic reference input 3-6
- Typical experiment description 5-35

Update program 3-8

Vector magnitude 3-8

Ventilation 2-1

VER command 6-29, E-20

VMODE [n] command 6-10, E-20

Voltage input mode 3-2

What is a lock-in amplifier? 1-2

X % output 5-6

X %fs display 5-27

X & Y demodulation functions 3-7

X in volts/amps display 5-30

X output offset level control 5-34

X[.] command 6-16, E-20

XOF [n1 [n2]] command 6-15, E-20

XY[.] command 6-17, E-20

Y % output 5-6

Y %fs display 5-27

Y in volts/amps display 5-30

Y output offset level control 5-34

Y[.] command 6-16, E-20

YOF [n1 [n2]] command 6-15, E-21

Zero error 3-15

WARRANTY

EG&G Instruments Corporation warrants each instrument of its own manufacture to be free of defects in material and workmanship for a period of ONE year from the date of delivery to the original purchaser. Obligations under this Warranty shall be limited to replacing, repairing or giving credit for the purchase, at our option, of any instruments returned, shipment prepaid, to our Service Department for that purpose, provided prior authorization for such return has been given by an authorized representative of EG&G Instruments Corporation.

This Warranty shall not apply to any instrument, which our inspection shall disclose to our satisfaction, to have become defective or unusable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation, or other causes beyond our control. This Warranty shall not apply to any instrument or component not manufactured by EG&G Instruments Corporation. When products manufactured by others are included in EG&G Instruments Corporation equipment, the original manufacturers Warranty is extended to EG&G Instruments customers.

EG&G Instruments Corporation reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

THERE ARE NO WARRANTIES WHICH EXTEND BEYOND THE DESCRIPTION ON THE FACE HEREOF. THIS WARRANTY IS IN LIEU OF, AND EXCLUDES ANY AND ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESSED, IMPLIED OR STATUTORY, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, AS WELL AS ANY AND ALL OTHER OBLIGATIONS OR LIABILITIES OF EG&G INSTRUMENTS CORPORATION, INCLUDING, BUT NOT LIMITED TO, SPECIAL OR CONSEQUENTIAL DAMAGES. NO PERSON, FIRM OR CORPORATION IS AUTHORIZED TO ASSUME FOR EG&G INSTRUMENTS CORPORATION ANY ADDITIONAL OBLIGATION OR LIABILITY NOT EXPRESSLY PROVIDED FOR HEREIN EXCEPT IN WRITING DULY EXECUTED BY AN OFFICER OF EG&G INSTRUMENTS CORPORATION.

SHOULD YOUR EQUIPMENT REQUIRE SERVICE

- A. Contact your local EG&G Instruments office, agent, representative or distributor to discuss the problem. In many cases it may be possible to expedite servicing by localizing the problem to a particular plug-in circuit board.
- B. We will need the following information, a copy of which should also be attached to any equipment which is returned for service.

- | | |
|---|---|
| 1. Model number and serial number of instrument | 6. Symptoms (in detail, including control settings) |
| 2. Your name (instrument user) | 7. Your purchase order number for repair charges (does not apply to repairs in warranty) |
| 3. Your address | 8. Shipping instructions (if you wish to authorize shipment by any method other than normal surface transportation) |
| 4. Address to which the instrument should be returned | |
| 5. Your telephone number and extension | |

- C. If you experience any difficulties in obtaining service please contact

EG&G Instruments
Signal Recovery
Sorbus House
Mulberry Business Park
WOKINGHAM RG41 2GY
United Kingdom

Phone: +44 (0)118 977 3003
Fax: +44 (0)118 977 3493