Model 181

Low-Noise Current Preamplifier

Instruction Manual

215345-A-MNL-E

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.

Company Names

SIGNAL RECOVERY is part of Advanced Measurement Technology, Inc, a division of AMETEK, Inc. It includes the businesses formerly trading as EG&G Princeton Applied Research, EG&G Instruments (Signal Recovery), EG&G Signal Recovery and PerkinElmer Instruments (Signal Recovery)

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)

Table of Contents

Chapter One, Description

Chapter Two, Initial Checks

Chapter Three, Operating Instructions

Chapter Four, Technical Description

Appendix A, Specifications

Description

Chapter 1

1.1 Description

The Model 181 Current Sensitive Preamplifier is a high-sensitivity low-noise device ideally suited to processing the extremely small current signals provided by photodetectors and similar sources. The preamplifier features a virtual-ground input and sensitivity selectable by means of a front-panel switch from 10^{-4} A/V to 10^{-9} A/V. A built-in output attenuator allows the output signal to be reduced by a factor of ten. A front-panel **OVERLOAD** lamp provides warning when output voltage excursions exceed normal operating levels. There is even provision for biasing an external detector by applying an internally derived DC voltage to the **INPUT** connector.

The model 181 takes advantage of the accessory power outputs provided on ***SIGNAL RECOVERY*** lock-in amplifiers by taking its power from the lock-in amplifier via a rear-panel connector, but it can also be used with a separate line power source, available as an optional extra, or with any suitable regulated power source.

With its small size, high performance, and ease of operation, the instrument should prove of significant value in any application involving low-noise processing of small current signals.

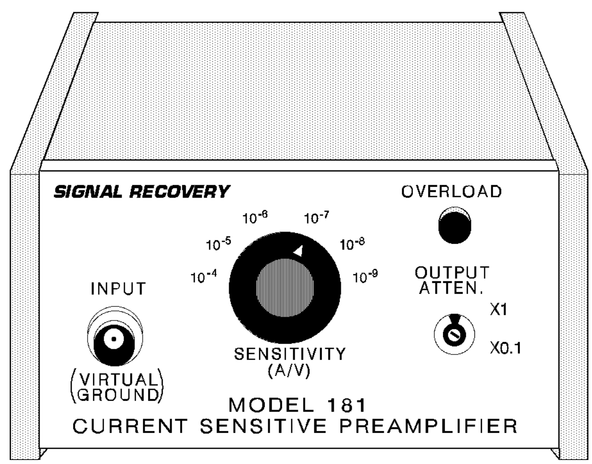

Figure 1-1, Model 181 Low-Noise Current Preamplifier

1.2 Options

The following accessories are available for the model 181.

Model PS0055 Remote Line Power Supply for the model 181, 110 V AC input

Model PS0056 Remote Line Power Supply for the model 181, 220 V AC input

Model C0099 Power cable. This cable allows the user to power the model 181 from any one of the following ***SIGNAL RECOVERY*** (formerly EG&G/PerkinElmer) Lock-in Amplifiers:
Model 124A, 5101, 5203 or 5204

Model C0145 Power cable. This cable allows the user to power the model 181 from any one of the following ***SIGNAL RECOVERY*** (formerly EG&G/PerkinElmer) Lock-in Amplifiers:
Model 5102, 5104, 5109, 5110, 5205, 5206, 5207, 5208, 5209, 5210, 5302, 7220, 7225, 7260, 7265 or 7280.

Initial Checks

Chapter 2

2.1 Introduction

The following procedure is provided to facilitate initial performance checking of the model 181. In general, the procedure should be performed after inspecting the instrument for shipping damage (any noted to be reported to the carrier and to ***SIGNAL RECOVERY***), but before using it experimentally. Should any difficulty be encountered in carrying out these checks, contact the factory or one of its representatives.

2.2 Equipment Needed

1) ±15 V to ±24 V DC regulated power supply.
   Note: If the preamplifier is to be operated in conjunction with a lock-in amplifier, and if that lock-in amplifier is available, then it can serve as the power source by interconnecting it and the preamplifier using the supplied interconnecting cable.

2) General purpose laboratory oscilloscope.

3) Signal generator capable of providing a 1 V and 0.5 V pk-pk sine wave at 1 kHz.

4) A 1 MΩ resistor mounted inside a screened enclosure and connected between the inner connecting pins of male and female BNC connectors. The outer shield, or ground, terminals of these connectors should be connected together.

5) A BNC shorting plug or 50 Ω attenuator.

5) Assorted BNC cables and clip leads.

2.3 Procedure

Using a Lock-in Amplifier as the Source of Preamplifier Power

1) If the preamplifier is to be powered from a lock-in amplifier using the cable provided, interconnect it and the lock-in amplifier with the cable. Then establish a common ground by connecting a clip lead from the outer shell of the model 181's **MONITOR** connector to the outer shell of the lock-in amplifier's **OUTPUT** or **CH1** connector. In actual operation, ground is established by other means as explained in chapter 3.

Using an External Power Supply

2) If the preamplifier is to be powered form an external supply, proceed as follows.

   a) Remove the two screws that secure the top cover. Then slide the cover off to the rear.

b) Connect a jumper from pin A (inside) of the rear-panel connector to the ground lug immediately behind the connector. If the preamplifier is to be powered from an external supply in laboratory operation, solder the jumper in permanently. If the power supply is purely a temporary measure for the purpose of doing these initial checks then simply use a clip lead.

c) Return the top cover to its proper position, securing it with the screws removed in step a).

d) Make the power supply connections to the model 181 as follows. Connect ground to pin A, +15V to +24 V to pin B, and -15 to -24 V to pin C.

3) Turn on the power (power supply or lock-in amplifier, as appropriate) and allow a few minutes for the circuitry in the model 181 to stabilize. If a lock-in amplifier is being used as the power source, there is no need to be concerned about its control settings, since in this procedure it is simply acting as a power supply.

4) Plug the 1 MΩ module onto the model 181's **INPUT** connector and then plug the BNC short or 50 Ω terminator onto the input module.

5) Set the **SENSITIVITY** switch to 10^{-6} A/V and set the **OUTPUT ATTEN** switch to ×1.

6) Turn the preamplifier on its side to gain access to the two controls accessible through the bottom panel. Then rotate the **BIAS** control to the fully clockwise (zero bias) position.

7) Monitor the preamplifier's rear-panel **OUT** connector using the oscilloscope (DC coupled and zeroed). Then adjust the 181's **DC ZERO** control, also accessible through the bottom panel, for DC zero at the output.

8) Remove the BNC short or 50 Ω terminator from the input module and return the preamplifier to its normal operating position.

9) Set the signal generator to supply a 1 V rms (2.8 V pk-pk) signal at 1 kHz. Then connect its output to the 1 MΩ input module.

10) Monitor the signal at the preamplifier's rear-panel **OUT** connector; it should be a 1 V rms (2.8 V pk-pk) sine wave at 1 kHz.

11) Set the front-panel **OUTPUT ATTEN** switch to ×0.1. The amplitude of the observed signal should decrease to 0.1 V rms (280 mV pk-pk). Set the switch back to ×1.

12) Decrease the amplitude of the input signal to 0.5 V rms (1.4 V pk-pk). Then set the **SENSITIVITY** switch to 10^{-7} A/V. The amplitude of the output signal should increase to 14 V pk-pk.

13) Set the **SENSITIVITY** switch to 10^{-8} A/V. The **OVERLOAD** lamp should glow

and the observed output waveform should be increased in amplitude and clipped.

14) Set the **SENSITIVITY** switch back to 10^{-7} A/V. The **OVERLOAD** lamp should extinguish and the output waveform should be undistorted with an amplitude of 14 V pk-pk.

15) Transfer the oscilloscope from the **OUT** connector to the **MONITOR** connector. The observed signal should be the same as at the **OUT** connector, that is, a 14 V pk-pk sine wave at 1kHz.

This completes the initial checks. If the indicated behavior was observed, one can be reasonably sure that the instrument is operating properly. If the internal connection to pin A was made in step 2 to facilitate performing the initial checks, remove it at this time if further operation with a power supply is not expected.

Operating Instructions

Chapter 3

3.1 Introduction

The model 181 is primarily designed for operation in conjunction with lock-in amplifiers manufactured by ***SIGNAL RECOVERY***. In particular, standard power cables are available for each of the lock-in amplifiers with which the unit might be used so that the necessary power requirements are automatically satisfied when the system is assembled.

Although the instructions that follow are written primarily in terms of operating the model 181 with a lock-in amplifier, operation in conjunction with other equipment is feasible and straightforward, the only additional requirements being to see that the unit is properly powered and that a ground to it is established as explained in section 3.2

3.2 Power

Power is applied through a rear-panel power connector. The amplifier circuits require a minimum of ±15 V of regulated power at nominally 20 mA, but will operate properly with supply voltages as high as ±25 V. The overload circuit ideally requires a minimum of -24 V, which need not be regulated, but will, however, still operate with reduced supply voltages to -15 V although the overload lamp, when lit, will not be as bright.

The pin allocations on the power connector are as follows:

Pin A	Ground (but see note below)
Pin B	Amplifier positive power supply: +15 V to +24 V @ 20 mA
Pin C	Amplifier negative power supply: -15 V to -24 V @ 20 mA
Pin D	Not connected
Pin E	Overload lamp power supply: -24 V @ 10 mA when lit

Note that if pin E is not connected the overload lamp will automatically take its supply from the amplifier negative power supply input (pin C) instead.

The ground connection between the external supply and the preamplifier is normally made to pin A of the interface connector. However, because the instrument is primarily designed for operation with lock-in amplifiers, in which case the ground connection is made differently as explained below, a slight internal modification is necessary to make the pin A ground "good". It is necessary to slide back the top cover (secured by two screws), and solder a jumper from pin A of the connector (inside) to the ground lug mounted on the circuit board immediately behind the power connector.

When the model 181 is operated in conjunction with a ***SIGNAL RECOVERY*** lock-in amplifier, the power connections are made automatically by using the correct power cable, although the ground connection is not normally made via this cable. It is instead made through the braid of the coaxial cable connecting the model 181's **OUT** connector to the signal channel input connector of the lock-in amplifier. It is necessary therefore that this connection be made in order for the preamplifier to work.

3.3 Operating Frequency

The frequency response of the model 181 is shown in Figure A-1 on page A-2. A brief check of these curves will show whether the intended operating frequency and the frequency response of the model 181 are compatible. It is worth noting that the noise performance of the instrument will be poorer at the higher frequencies (Figure A-3).

3.4 Sensitivity

When working from a current source, optimum noise performance is achieved when the load resistor is as large as possible. This is because the signal amplitude varies directly with the load resistance while the noise varies with the square root of the resistance. In terms of the model 181, this means that for optimum noise performance, one should operate with the maximum possible sensitivity, that is, with the **SENSITIVITY** switch as far clockwise as possible. The best procedure for setting the **SENSITIVITY** switch is to first set it to 10^{-4} A/V. When the input signal is connected, begin rotating the switch clockwise until the **OVERLOAD** lamp glows. Then back off one step on the **SENSITIVITY** switch so that the lamp extinguishes. If the resulting output signal is too large for use with the lock-in amplifier, set the **OUTPUT ATTEN** switch to ×0.1 to reduce the amplitude of the output signal by a factor of ten. If any further reduction is required, the only solution is to operate with less preamplifier sensitivity. It is generally advisable to operate with the **OUTPUT ATTEN** switch set to ×0.1 whenever noise is a consideration, since by so doing, a higher input sensitivity and hence better noise performance can be obtained.

The lock-in amplifier should be operated exactly as described in its instruction manual. The overall system sensitivity will then be determined by multiplying the sensitivity of the model 181 by the lock-in amplifier's sensitivity, e.g., with a lock-in amplifier sensitivity of 1 mV and a model 181 sensitivity of 10^{-8} A/V, the overall system sensitivity would be $10^{-3} \times 10^{-8} = 10^{-11}$ A full scale. If the model 181's attenuator were set to ×0.1, then the overall sensitivity would be reduced to 10^{-10} A full scale.

3.5 Overload

When operated from ±15 V amplifier supply levels (the case when operating in conjunction with the majority of ***SIGNAL RECOVERY*** lock-in amplifiers), the maximum output from the model 181 is nominally ±9 V and the overload sensing circuit is preset to activate the **OVERLOAD** light at these levels. With higher supply voltages, maximum output capability increases, with the increase being proportional to the increased supply voltage. At the maximum allowable supply voltage levels of ±25 V, the maximum output levels (and the overload detection levels) are nominally ±14 V. Thus the dynamic reserve of the instrument varies as a function of the supply levels. In most instances, this characteristic will be of little consequence. However, circumstances could conceivable arise where operation from the higher supply voltage might be justified by the need for the extra reserve.

3.6 DC Offset and Bias Controls

In addition to the front-panel controls, there are two controls than can be adjusted via openings in the bottom of the instrument. One sets the DC zero of the preamplifier, while the other allows a bias voltage in the range of 0 V to -5 V to be made available at the **INPUT** connector.

The **DC ZERO** adjustment is normally made with the signal disconnected and with the **BIAS** adjustment fully clockwise (zero bias). The output is monitored with a DC voltmeter or oscilloscope and the adjustment set to give zero volts out.. Once this adjustment has been made, the signal can be connected and the **BIAS** adjustment set as appropriate. This adjustment provides a variable potential bias of 0 V to -5 V at the **INPUT** connector. Because full-scale output in terms of the selected sensitivity is 1 V, the range of the **BIAS** adjustment is five times full scale. This potential can be used to bias an external detector, or to cancel the effects of offset accompanying the input signal. The source impedance of the bias is 10^{-5}/S ohms, where S is the selected sensitivity.

As an example of the utility of this feature, suppose one were operating on the 10 A/V sensitivity range with a photomultiplier tube detector. Further, suppose the dark current of the photomultiplier to be 4 µA. This dark current would introduce a +4 V offset at the output of the model 181. The **BIAS** adjustment could be used to cancel the effect of this offset by adjusting for 0 V at the **MONITOR** connector.

The input bias can also act as a current source. The source impedance varies with sensitivity ($Z_{in} = 10^{-5}$/S ohms) such that the range is always five times the selected current sensitivity. For example, with the **SENSITIVITY** switch set to 10^{-9} A/V, the model 181's **INPUT** connector can supply as much as -5×10^{-9} A into a short circuit.

3.7 Ground Loop Considerations

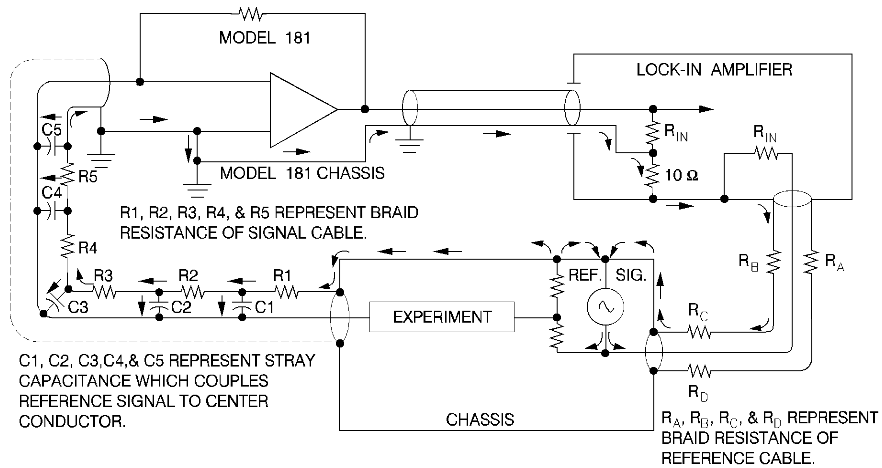

Figure 3-1, Reference Ground Loop In Typical Model 181 Application

Figure 3-1 is a block diagram of a model 181 operated in conjunction with a lock-in amplifier in a typical application. The experiment involves measuring the output of some kind of current source. The current source output is cabled to the input of the model 181, with its output being in turn connected to the input of the lock-in amplifier. In addition, the reference signal, presumed to originate in the experimental apparatus, is cabled to the reference input of the lock-in amplifier. There are therefore three cables in all, and all have their braids in common, that is, at ground.

The reference signal source is shown as a voltage signal generator within the experimental apparatus. This reference signal drives the reference input of the lock-in amplifier, and also a "load" shown as two series resistors, also within the experimental apparatus. The reference frequency excitation of the signal to be measured is presumed to be performed by the flow of reference signal current through the load. Note that there are two parallel paths for returning the reference load current to the reference signal source. The first is the very short "direct" path through the chassis of the apparatus. Most of the reference load current will be returned by this path. However, a small part of this current will be returned by the parallel path consisting of the three chassis, the braids of the three cables, and the ten ohm ground-isolation resistor of the lock-in amplifier. This current causes reference frequency voltage drops in the cable braids, and these drops can constitute a serious source of interfering signal.

The drop across the braid of the cable interconnecting the experiment and the input of the model 181 is capacitatively coupled onto the center conductor of the cable by stray capacitance of the cable and thereby acts as an input signal. The drop across the braid of the cable that connects the model 181 with the lock-in amplifier adds directly to the signal at the output of the model 181 and thereby additionally degrades the input to the lock-in amplifier. The potential seriousness of the problem becomes apparent when one realizes that these interference signals are synchronous with the signal of interest and at the same frequency. There is no way for the lock-in amplifier to distinguish between the signal of interest and reference signal interference. In most instances this will be a small effect, and will pose a problem on the higher sensitivity ranges only. Where it is a problem, it can be solved by breaking the loop so that reference signal current cannot flow through the braids of the cables going to and from the model 181. This is most easily done by grounding the braid of the cable interconnecting the experiment and the model 181 at the model 181 end of the cable only, as depicted in Figure 3-2. When this is done, both the model 181 and the experimental apparatus will assume the ground of the lock-in amplifier without ground-loop current contamination.

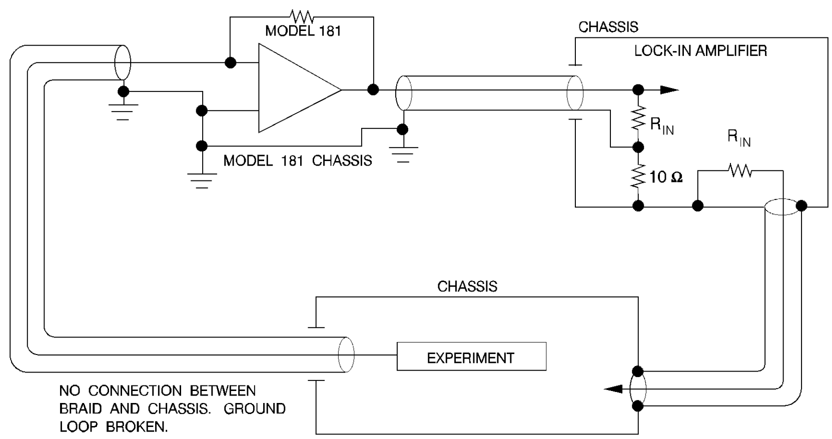

Figure 3-2. Typical Model 181 Application With Ground Loop Broken

Breaking the loop in this manner to prevent reference signal current interference will also prevent analogous interference from developing as a consequence of magnetic fields "cutting the loop", particularly those at the power frequency and its lower order harmonics.

Technical Description

4.1 Overview

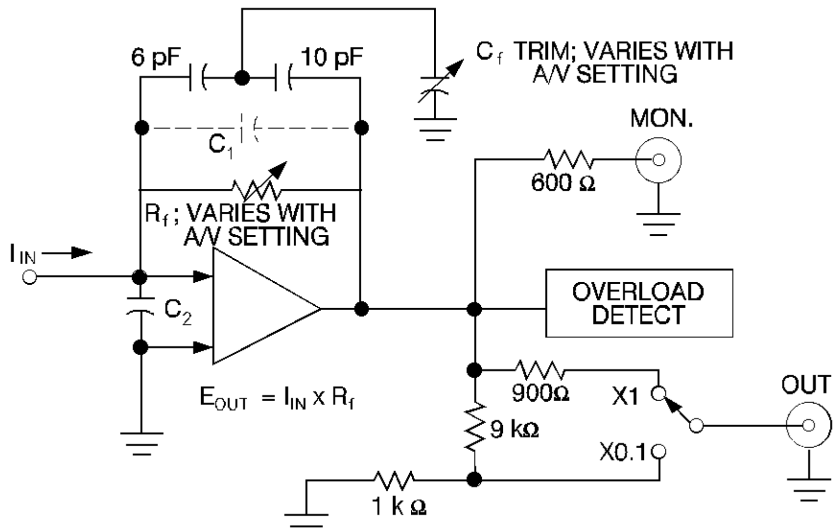

Figure 4-1, Model 181 Preamplifier - Block Diagram

As can be seen from figure 4-1, the model 181 preamplifier is a low-noise, inverting, operational amplifier whose summing junction is connected to the **INPUT** connector. The value of feedback resistance is set by the front-panel **SENSITIVITY** switch as required to obtain the desired sensitivity. The **SENSITIVITY** switch also trims the value of capacitance in parallel with the feedback resistance to optimize the frequency response as a function of sensitivity.

Note from figure 4-1 that the feedback capacitance can be represented as a single capacitor (C_1). This capacitor can be construed as consisting of the stray capacitance around the feedback resistor paralleled by a 6 pF fixed capacitor in series with the parallel combination of a 10 pF capacitor and a variable capacitor to ground. Also, there is by necessity a small amount of input shunt capacitance, represented in figure 4-1 as C_2.

The amplifier is followed by an overload detector circuit which acts as a bipolar level detector biased at nominally ±9 V (±15 V supply levels assumed). There is provision for "slowing" the turn-off characteristic of the lamp drive circuit. The result is that even very brief overloads will maintain the lamp glow long enough to be noticed.

In addition to being applied to the overload detector circuit, the amplifier output is brought out to two rear-panel BNC connectors. The **MONITOR** output is a 600 Ω output unaffected by the output attenuator. The **OUT** connector is either the same as the **MONITOR** signal or one tenth of its amplitude, according to the position of the front-panel **OUTPUT ATTEN** switch.

4.2 Input Impedance

When an amplifier is operated in the conventional current-to-voltage configuration, it is common practice to assume the amplifier has zero input impedance. However, such a generality cannot be made when dealing with real-world amplifiers with their finite capabilities. Zero input impedance implies infinite open-loop gain. The open-loop gain of the model 181, although very high as shown in figure 4-2, is finite, with the result that the input impedance is finite as well.

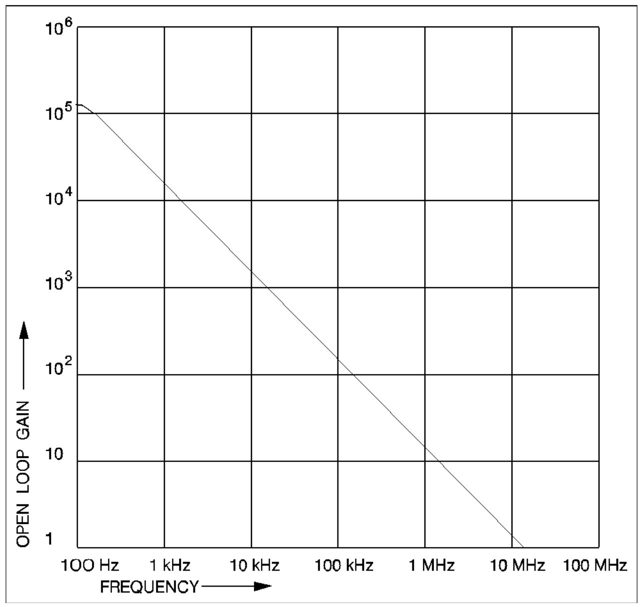

Figure 4-2, Open Loop Frequency Response

At DC, the input impedance is simply the feedback resistance divided by the open loop gain. At higher frequencies, the input shunt capacitance, the decreasing reactance of the feedback capacitance, and the decreasing open loop gain all interact to give the input impedance characteristics depicted in figure A-1. Note that the input appears inductive over a wide range of frequencies, with the result that the input impedance rises with frequency. At the upper end of the frequency range, the input shunt capacitance dominates and the input impedance drops again.

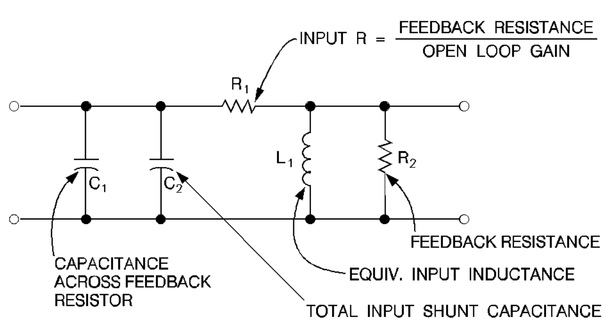

Figure 4-3. Equivalent Input Circuit

Figure 4-3 illustrates the equivalent input circuit of the model 181. The real elements are the feedback capacitance (C_1), the input shunt capacitance (C_2), and the feedback resistance (R_2). As shown in the preceding paragraph, there is also the input resistance (R_1) and an equivalent input inductance (L_1) to be considered. Although C_1 and C_2 can be considered to be in parallel, they are depicted separately because of the different effect they have on noise. C_1 (the feedback capacitance) does not contribute to the input noise other than by its real value. The input shunt capacitance, on the other hand, acts to convert the equivalent noise generator of the amplifier to noise voltage at its output (or, equivalently, to a noise current referred to the input). In other words, for good noise performance, it is imperative that the input shunt capacitance be minimized, and this includes shunt capacitance connected external to the instrument as well.

This condition can best be satisfied by using very short connections from the detector to the preamplifier, using low capacitance coaxial cable.

Specifications

Appendix A

General

DC coupled current to voltage amplifier with adjustable sensitivity and a maximum frequency response extending from DC to 200 kHz. Adjustable negative detector bias. Single-ended virtual ground input and single-ended DC coupled output via BNC connectors.

Powered from external DC power supplies that can be provided by most ***SIGNAL RECOVERY*** lock-in amplifiers or a separate line power supply module.

Input

Sensitivity	10^{-4} A/V to 10^{-9} A/V in six ranges
Overload Indicator	Indicates that instantaneous (DC plus peak AC) current has exceeded amplifier capability - see table A-1
Frequency Response	see table A-1 and Figure A-1

Sensitivity (A/V)	Max DC Input Current at 1 kHz	Frequency Response, DC to
10^{-4}	1 mA	200 kHz
10^{-5}	100 µA	200 kHz
10^{-6}	10 µA	100 kHz
10^{-7}	1 µA	50 kHz
10^{-8}	100 nA	10 kHz
10^{-9}	10 nA	1 kHz

Table A-1, Max DC Input and Frequency Response vs. Sensitivity

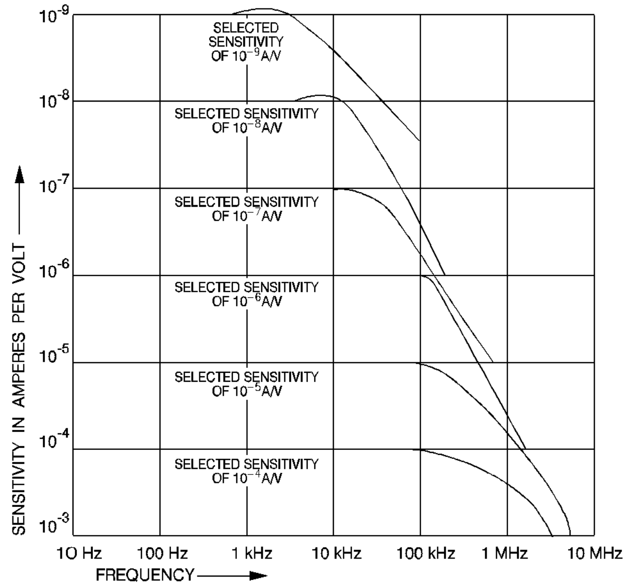

Figure A-1, Frequency Response

Input Impedance	See Figure A-2

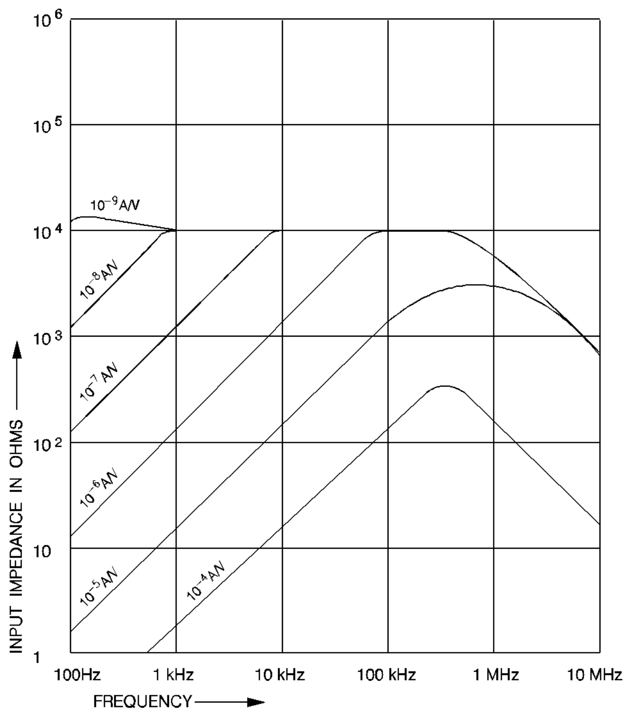

Figure A-2, Input Impedance

Noise Current	See Figure A-3

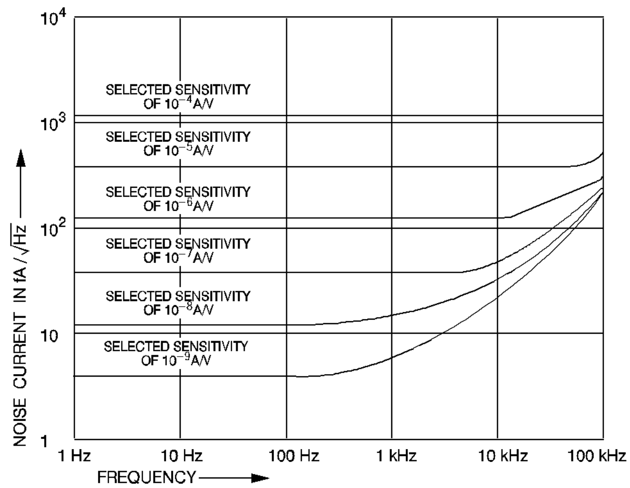

Figure A-3, Noise Current

Outputs

Monitor Output	600 Ω rear-panel BNC connector permits monitoring of the output signal
Main Output	
Level	6.5 V rms maximum
Impedance	1 kΩ nominal
Output Attenuator	Provides optional 1:10 attenuation of output voltage

Power

±15 V or ±24 V at 30 mA

General

Dimensions (excluding connectors)	
	4.5" wide × 6.6" long × 2.7" high (114 mm wide × 168 mm long × 69 mm high)
Shipping Weight	2.2lbs (1 kg)

WARRANTY

AMETEK SIGNAL RECOVERY, a part of AMETEK Advanced Measurement Technology, Inc, 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 AMETEK Advanced Measurement Technology, Inc.

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 AMETEK Advanced Measurement Technology, Inc. When products manufactured by others are included AMETEK Advanced Measurement Technology, Inc equipment, the original manufacturers Warranty is extended to AMETEK Advanced Measurement Technology, Inc customers. AMETEK Advanced Measurement Technology, Inc 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 AMETEK ADVANCED MEASUREMENT TECHNOLOGY, INC, INCLUDING, BUT NOT LIMITED TO, SPECIAL OR CONSEQUENTIAL DAMAGES. NO PERSON, FIRM OR CORPORATION IS AUTHORIZED TOASSUME FOR AMETEK ADVANCED MEASUREMENT TECHNOLOGY, INC ANY ADDITIONAL OBLIGATION OR LIABILITY NOT EXPRESSLY PROVIDED FOR HEREIN EXCEPT IN WRITING DULY EXECUTED BY AN OFFICER OF AMETEK ADVANCED MEASUREMENT TECHNOLOGY, INC.

SHOULD YOUR EQUIPMENT REQUIRE SERVICE

A. Contact your local AMETEK SIGNAL RECOVERY 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 unit or cable.

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

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

SIGNAL RECOVERY Service
AMETEK Advanced Measurement Technology, Inc
801 South Illinois Avenue — Phone: +1 865 483 2121
Oak Ridge — Fax: +1 865 483 0396
TN 37831-2011, USA — E-mail: service@signalrecovery.com

or

SIGNAL RECOVERY Service
AMETEK Advanced Measurement Technology — Phone: +44 (0)1344 477900
Astro House — Fax: +44 (0)1344 477901
Brants Bridge, — E-mail: service@signalrecovery.com
Bracknell
RG12 9HW, UNITED KINGDOM