

Model 6512
Programmable Electrometer
Instruction Manual

Contains Operating and Servicing Information

KEITHLEY

WARRANTY

Keithley Instruments, Inc. warrants this product to be free from defects in material and workmanship for a period of 1 year from date of shipment.

Keithley Instruments, Inc. warrants the following items for 90 days from the date of shipment: probes, cables, rechargeable batteries, diskettes, and documentation.

During the warranty period, we will, at our option, either repair or replace any product that proves to be defective.

To exercise this warranty, write or call your local Keithley representative, or contact Keithley headquarters in Cleveland, Ohio. You will be given prompt assistance and return instructions. Send the product, transportation prepaid, to the indicated service facility. Repairs will be made and the product returned, transportation prepaid. Repaired or replaced products are warranted for the balance of the original warranty period, or at least 90 days.

LIMITATION OF WARRANTY

This warranty does not apply to defects resulting from product modification without Keithley's express written consent, or misuse of any product or part. This warranty also does not apply to fuses, software, non-rechargeable batteries, damage from battery leakage, or problems arising from normal wear or failure to follow instructions.

THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR USE. THE REMEDIES PROVIDED HEREIN ARE BUYER'S SOLE AND EXCLUSIVE REMEDIES.

NEITHER KEITHLEY INSTRUMENTS, INC. NOR ANY OF ITS EMPLOYEES SHALL BE LIABLE FOR ANY DIRECT, INDIRECT, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OF ITS INSTRUMENTS AND SOFTWARE EVEN IF KEITHLEY INSTRUMENTS, INC., HAS BEEN ADVISED IN ADVANCE OF THE POSSIBILITY OF SUCH DAMAGES. SUCH EXCLUDED DAMAGES SHALL INCLUDE, BUT ARE NOT LIMITED TO: COSTS OF REMOVAL AND INSTALLATION, LOSSES SUSTAINED AS THE RESULT OF INJURY TO ANY PERSON, OR DAMAGE TO PROPERTY.



Keithley Instruments, Inc. • 28775 Aurora Road • Cleveland, OH 44139 • 440-248-0400 • Fax: 440-248-6168 • <http://www.keithley.com>

BELGIUM:	Keithley Instruments B.V.	Bergensesteenweg 709 • B-1600 Sint-Pieters-Leeuw • 02/363 00 40 • Fax: 02/363 00 64
CHINA:	Keithley Instruments China	Yuan Chen Xin Building, Room 705 • 12 Yumin Road, Dewai, Madian • Beijing 100029 • 8610-62022886 • Fax: 8610-62022892
FRANCE:	Keithley Instruments Sarl	B.P. 60 • 3, allée des Garays • 91122 Palaiseau Cédex • 01 64 53 20 20 • Fax: 01 60 11 77 26
GERMANY:	Keithley Instruments GmbH	Landsberger Strasse 65 • D-82110 Germering • 089/84 93 07-40 • Fax: 089/84 93 07-34
GREAT BRITAIN:	Keithley Instruments Ltd	The Minster • 58 Portman Road • Reading, Berkshire RG30 1EA • 0118-9 57 56 66 • Fax: 0118-9 59 64 69
INDIA:	Keithley Instruments GmbH	Flat 2B, WILOCRISSA • 14, Rest House Crescent • Bangalore 560 001 • 91-80-509-1320/21 • Fax: 91-80-509-1322
ITALY:	Keithley Instruments s.r.l.	Viale S. Gimignano, 38 • 20146 Milano • 02/48 30 30 08 • Fax: 02/48 30 22 74
NETHERLANDS:	Keithley Instruments B.V.	Postbus 559 • 4200 AN Gorinchem • 0183-635333 • Fax: 0183-630821
SWITZERLAND:	Keithley Instruments SA	Kriesbachstrasse 4 • 8600 Dübendorf • 01-821 94 44 • Fax: 01-820 30 81
TAIWAN:	Keithley Instruments Taiwan	1 Fl. 85 Po Ai Street • Hsinchu, Taiwan, R.O.C. • 886-3572-9077 • Fax: 886-3572-903

Model 6512 Programmable Electrometer Instruction Manual

©1994, Keithley Instruments, Inc.
All rights reserved.
Cleveland, Ohio, U.S.A.
First Printing February 1994
Document Number: 6512-901-01 Rev. A

Manual Print History

The print history shown below lists the printing dates of all Revisions and Addenda created for this manual. The Revision Level letter increases alphabetically as the manual undergoes subsequent updates. Addenda, which are released between Revisions, contain important change information that the user should incorporate immediately into the manual. Addenda are numbered sequentially. When a new Revision is created, all Addenda associated with the previous Revision of the manual are incorporated into the new Revision of the manual. Each new Revision includes a revised copy of this print history page.

Revision A (Document Number 6512-901-01)..... February 1994

Safety Precautions

The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with non-hazardous voltages, there are situations where hazardous conditions may be present.

This product is intended for use by qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read the operating information carefully before using the product.

The types of product users are:

Responsible body is the individual or group responsible for the use and maintenance of equipment, for ensuring that the equipment is operated within its specifications and operating limits, and for ensuring that operators are adequately trained.

Operators use the product for its intended function. They must be trained in electrical safety procedures and proper use of the instrument. They must be protected from electric shock and contact with hazardous live circuits.

Maintenance personnel perform routine procedures on the product to keep it operating, for example, setting the line voltage or replacing consumable materials. Maintenance procedures are described in the manual. The procedures explicitly state if the operator may perform them. Otherwise, they should be performed only by service personnel.

Service personnel are trained to work on live circuits, and perform safe installations and repairs of products. Only properly trained service personnel may perform installation and service procedures.

Exercise extreme caution when a shock hazard is present. Lethal voltage may be present on cable connector jacks or test fixtures. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30V RMS, 42.4V peak, or 60VDC are present. **A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.**

Users of this product must be protected from electric shock at all times. The responsible body must ensure that users are prevented access and/or insulated from every connection point. In some cases, connections must be exposed to potential human contact. Product users in these circumstances must be trained to protect themselves from the risk of electric shock. If the circuit is capable of operating at or above 1000 volts, **no conductive part of the circuit may be exposed.**

As described in the International Electrotechnical Commission (IEC) Standard IEC 664, digital multimeter measuring circuits (e.g., Keithley Models 175A, 199, 2000, 2001, 2002, and 2010) are Installation Category II. All other instruments' signal terminals are Installation Category I and must not be connected to mains.

Do not connect switching cards directly to unlimited power circuits. They are intended to be used with impedance limited sources. NEVER connect switching cards directly to AC mains. When connecting sources to switching cards, install protective devices to limit fault current and voltage to the card.

Before operating an instrument, make sure the line cord is connected to a properly grounded power receptacle. Inspect the connecting cables, test leads, and jumpers for possible wear, cracks, or breaks before each use.

For maximum safety, do not touch the product, test cables, or any other instruments while power is applied to the circuit under test. ALWAYS remove power from the entire test system and discharge any capacitors before: connecting or disconnecting cables or jumpers, installing or removing switching cards, or making internal changes, such as installing or removing jumpers.

Do not touch any object that could provide a current path to the common side of the circuit under test or power line (earth) ground. Always make measurements with dry hands while standing on a dry, insulated surface capable of withstanding the voltage being measured.

The instrument and accessories must be used in accordance with its specifications and operating instructions or the safety of the equipment may be impaired.

Do not exceed the maximum signal levels of the instruments and accessories, as defined in the specifications and operating information, and as shown on the instrument or test fixture panels, or switching card.

When fuses are used in a product, replace with same type and rating for continued protection against fire hazard.

Chassis connections must only be used as shield connections for measuring circuits, NOT as safety earth ground connections.

If you are using a test fixture, keep the lid closed while power is applied to the device under test. Safe operation requires the use of a lid interlock.

If a  screw is present, connect it to safety earth ground using the wire recommended in the user documentation.

The  symbol on an instrument indicates that the user should refer to the operating instructions located in the manual.

The  symbol on an instrument shows that it can source or measure 1000 volts or more, including the combined effect of normal and common mode voltages. Use standard safety precautions to avoid personal contact with these voltages.

The **WARNING** heading in a manual explains dangers that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading in a manual explains hazards that could damage the instrument. Such damage may invalidate the warranty.

Instrumentation and accessories shall not be connected to humans.

Before performing any maintenance, disconnect the line cord and all test cables.

To maintain protection from electric shock and fire, replacement components in mains circuits, including the power transformer, test leads, and input jacks, must be purchased from Keithley Instruments. Standard fuses, with applicable national safety approvals, may be used if the rating and type are the same. Other components that are not safety related may be purchased from other suppliers as long as they are equivalent to the original component. (Note that selected parts should be purchased only through Keithley Instruments to maintain accuracy and functionality of the product.) If you are unsure about the applicability of a replacement component, call a Keithley Instruments office for information.

To clean an instrument, use a damp cloth or mild, water based cleaner. Clean the exterior of the instrument only. Do not apply cleaner directly to the instrument or allow liquids to enter or spill on the instrument. Products that consist of a circuit board with no case or chassis (e.g., data acquisition board for installation into a computer) should never require cleaning if handled according to instructions. If the board becomes contaminated and operation is affected, the board should be returned to the factory for proper cleaning/servicing.

Table of Contents

1 General Information

1.1	Introduction	1-1
1.2	Features	1-1
1.3	Warranty information	1-1
1.4	Manual addenda	1-2
1.5	Safety symbols and terms	1-2
1.6	Specifications	1-2
1.7	Unpacking and inspection	1-2
1.7.1	Shipment contents	1-2
1.7.2	Instruction manual	1-2
1.7.3	Repacking for shipment	1-2
1.8	Getting started	1-2
1.8.1	Preparation for use	1-2
1.8.2	Quick start procedure	1-3
1.9	Accessories	1-3

2 Operation

2.1	Introduction	2-1
2.2	Power-up procedure	2-1
2.3	Power-up self-test and display messages	2-2
2.3.1	RAM memory test	2-2
2.3.2	Self-test and firmware revision level	2-2
2.4	Front panel familiarization	2-2
2.4.1	Controls	2-2
2.4.2	Display and indicators	2-5
2.4.3	Tilt bail	2-5
2.5	Front panel programs	2-5
2.5.1	IEEE-488 address	2-6
2.5.2	Exponent mode (alpha or numeric)	2-6
2.5.3	Calibration	2-6
2.6	Rear panel familiarization	2-6
2.7	Basic measurement techniques	2-8
2.7.1	Warm-up period	2-8
2.7.2	Input connections	2-8
2.7.3	Making voltage measurements	2-9
2.7.4	Guarded operation	2-11
2.7.5	Making current measurements	2-12
2.7.6	Making charge measurements	2-14
2.7.7	Resistance measurements	2-16
2.7.8	Using the ohms function as a current source	2-17

2.8	Analog outputs	2-18
2.8.1	2V analog output	2-18
2.8.2	Preamp out	2-19
2.9	Using external feedback	2-21
2.9.1	Electrometer input circuitry	2-21
2.9.2	Shielded fixture construction	2-22
2.9.3	External feedback procedure	2-22
2.9.4	Non-standard coulombs ranges	2-23
2.9.5	Logarithmic currents	2-23
2.9.6	Non-decade current gains	2-24
2.10	Using zero correct and baseline suppression	2-25
2.10.1	Zero correct and zero check	2-25
2.10.2	Using suppression	2-25
2.11	Data storage	2-26
2.12	External triggering	2-28
2.12.1	External trigger input	2-28
2.12.2	Meter complete output	2-29
2.12.3	Triggering example	2-29
2.13	Measurement considerations	2-30
2.13.1	Ground loops	2-30
2.13.2	Electrostatic interference	2-31
2.13.3	Thermal EMFs	2-31
2.13.4	Electromagnetic interference (EMI)	2-31
2.13.5	Leakage resistance effects	2-32
2.13.6	Input capacitance effects	2-32
2.13.7	Source resistance	2-33
2.13.8	Source capacitance	2-34
2.14	Engineering units conversion	2-34

3 IEEE-488 Programming

3.1	Introduction	3-1
3.2	Device-dependent command programming	3-1
3.2.1	Calibration value (A)	3-5
3.2.2	Reading mode (B)	3-5
3.2.3	Zero check (C)	3-6
3.2.4	Function (F)	3-6
3.2.5	Data format (G)	3-7
3.2.6	EOI and bus hold-off modes (K)	3-8
3.2.7	Non-volatile memory storage (L)	3-9
3.2.8	SRQ mask (M) and status byte format	3-9
3.2.9	Baseline suppression (N)	3-12
3.2.10	Data store mode (Q)	3-13
3.2.11	Range (R)	3-14
3.2.12	Trigger mode (T)	3-15
3.2.13	Status (U)	3-16
3.2.14	Terminator (Y)	3-20
3.2.15	Execute (X)	3-20
3.2.16	Zero correct (Z)	3-21
3.3	Bus connections	3-22
3.4	Primary address	3-22
3.5	Talk-only mode	3-23
3.6	Front panel messages	3-23

3.6.1	Bus error	3-24
3.6.2	Number error	3-24
3.6.3	Trigger overrun error	3-24
3.7	Bus data transmission times	3-24

4 Applications

4.1	Introduction	4-1
4.2	Low-level leakage current measurements	4-1
4.3	Diode characterization	4-3
4.4	Capacitor leakage measurements	4-4
4.5	Capacitance measurement	4-5
4.6	Insulation resistance measurements	4-5
4.6.1	Unguarded resistance measurements	4-5
4.6.2	Guarded resistance measurements	4-6
4.6.3	V/I resistance measurements with external voltage source	4-6
4.7	High-impedance voltmeter	4-9
4.8	Voltage coefficients of high-megohm resistors	4-9
4.9	Static charge detection	4-11

5 Performance Verification

5.1	Introduction	5-1
5.2	Environmental conditions	5-1
5.3	Initial conditions	5-1
5.4	Recommended test equipment	5-1
5.5	Verification procedures	5-2
5.5.1	Input current verification	5-2
5.5.2	Amps verification	5-2
5.5.3	Coulombs verification	5-3
5.5.4	Volts verification	5-3
5.5.5	Ohms verification	5-4
5.5.6	Input impedance verification	5-6

6 Theory of Operation

6.1	Introduction	6-1
6.2	Overall functional description	6-1
6.3	Input preamplifier	6-2
6.3.1	Input stage	6-3
6.3.2	Gain stage	6-4
6.3.3	Output stage	6-4
6.3.4	Ohms voltage source	6-5
6.3.5	Zero check	6-5
6.4	Additional signal conditioning	6-6
6.4.1	Ranging amplifier	6-6
6.4.2	Multiplexer and buffer amplifier	6-6
6.4.3	-2V reference source	6-7
6.5	A/D converter	6-7
6.6	Digital circuitry	6-9
6.6.1	Microcomputer	6-9

6.6.2	Memory elements	6-9
6.6.3	Device selection	6-9
6.6.4	IEEE-488 bus	6-9
6.6.5	Input/output circuitry	6-10
6.6.6	Display circuitry	6-10
6.7	Power supplies	6-11

7 Maintenance

7.1	Introduction	7-1
7.2	Line voltage selection	7-1
7.3	Line fuse replacement	7-2
7.4	Calibration	7-2
7.4.1	Calibration cycle	7-2
7.4.2	GUARD switch	7-2
7.4.3	Calibration jumper	7-2
7.4.4	Required calibration equipment	7-3
7.4.5	Environmental conditions	7-3
7.4.6	Calibration sequence	7-3
7.4.7	Input offset adjustment	7-3
7.4.8	Input current adjustment	7-4
7.4.9	Calibration program	7-4
7.4.10	Amps calibration	7-4
7.4.11	Coulombs calibration	7-5
7.4.12	Volts calibration	7-6
7.4.13	Ohms calibration	7-7
7.4.14	Permanent storage of calibration constants	7-7
7.4.15	IEEE-488 bus digital calibration	7-7
7.4.16	Additional calibration points	7-8
7.5	Special handling of static-sensitive devices	7-8
7.6	Disassembly instructions	7-9
7.7	Troubleshooting	7-11
7.7.1	Recommended test equipment	7-11
7.7.2	Power-up self-test	7-11
7.7.3	Self-diagnostic program	7-11
7.7.4	Power supply checks	7-13
7.7.5	Relay configuration	7-13
7.7.6	Ranging amplifier gain configuration	7-14
7.7.7	A/D converter and display	7-14
7.7.8	Input and ranging amplifiers	7-14
7.7.9	Digital circuitry	7-14
7.7.10	Display board	7-14
7.8	Input stage balancing procedure	7-17
7.9	Handling and cleaning precautions	7-17

8 Replaceable Parts

8.1	Introduction	8-1
8.2	Parts list	8-1
8.3	Ordering information	8-1
8.4	Factory service	8-1
8.5	Component layout drawings and schematic diagrams	8-1

Appendices

A	IEE-488 Bus Overview	A-1
B	General Bus Commands.....	B-1
C	Interface Function Codes	C-1
D	Example Programs	D-1
E	Model 617/6512 Software Compatibility	E-1

List of Illustrations

2	Operation	
Figure 2-1	Model 6512 front panel	2-3
Figure 2-2	Model 6512 rear panel	2-7
Figure 2-3	Input connector configuration	2-9
Figure 2-4	Connections for voltage measurements	2-10
Figure 2-5	Meter loading considerations	2-10
Figure 2-6	Unguarded circuit.....	2-11
Figure 2-7	Guarded circuit.....	2-11
Figure 2-8	Guarded input connections	2-12
Figure 2-9	Current measurements.....	2-13
Figure 2-10	Voltage burden considerations	2-14
Figure 2-11	Coulombs connections	2-15
Figure 2-12	Resistance measurement connections	2-17
Figure 2-13	Typical 2V analog output connections.....	2-19
Figure 2-14	Typical preamp out connections	2-20
Figure 2-15	Electrometer input circuitry (external feedback mode)	2-21
Figure 2-16	Shielded fixture construction	2-22
Figure 2-17	“Transdiode” logarithmic current configuration	2-24
Figure 2-18	Non-decade current gains.....	2-24
Figure 2-19	Equivalent input impedance with zero check enabled	2-25
Figure 2-20	External trigger pulse specifications	2-28
Figure 2-21	Meter complete pulse specifications	2-29
Figure 2-22	External triggering example.....	2-30
Figure 2-23	Multiple ground points create a ground loop	2-30
Figure 2-24	Eliminating ground loops.....	2-30
Figure 2-25	Leakage resistance effects.....	2-32
Figure 2-26	Input capacitance effects	2-32
Figure 2-27	Simplified model for source resistance and source capacitance	2-33
3	IEEE-488 Programming	
Figure 3-1	General data format.....	3-7
Figure 3-2	SRQ mask and status byte format	3-10
Figure 3-3	U0 status word and default values	3-17
Figure 3-4	U1 status (error condition) format.....	3-18
Figure 3-5	U2 status (data condition) format.....	3-19
Figure 3-6	IEEE-488 connector	3-22
Figure 3-7	IEEE-488 connections.....	3-22
Figure 3-8	Model 6512 rear panel IEEE-488 connector.....	3-22

4	Applications	
Figure 4-1	Leakage current measurement	4-2
Figure 4-2	Diode characterization	4-3
Figure 4-3	Diode curves	4-4
Figure 4-4	Capacitor leakage tests	4-4
Figure 4-5	Capacitor measurement	4-5
Figure 4-6	Insulation resistance measurement (unguarded).....	4-6
Figure 4-7	Insulation resistance measurement (guarded).....	4-7
Figure 4-8	Insulation resistance measurement using external voltage source	4-8
Figure 4-9	Measuring high-impedance gate-source voltage	4-9
Figure 4-10	Configuration for voltage coefficient studies	4-10
Figure 4-11	Faraday cup construction.....	4-11

5	Performance Verification	
Figure 5-1	Connections for amps and coulombs verification	5-3
Figure 5-2	Connections for volts verification	5-4
Figure 5-3	Connections for ohms verification.....	5-5
Figure 5-4	Connections for input impedance verification.....	5-6

6	Theory of Operation	
Figure 6-1	Overall block diagram	6-2
Figure 6-2	Basic configuration of electrometer preamplifier.....	6-2
Figure 6-3	Electrometer preamplifier configuration	6-3
Figure 6-4	Simplified schematic of input stage.....	6-4
Figure 6-5	Gain stage	6-4
Figure 6-6	Output stage configuration in volts and ohms	6-4
Figure 6-7	Output stage configuration in amps and coulombs.....	6-5
Figure 6-8	Ohms voltage source simplified schematic	6-5
Figure 6-9	Zero check configuration in volts and ohms.....	6-6
Figure 6-10	Zero check configuration in amps and coulombs	6-6
Figure 6-11	Simplified schematic of ranging amplifier	6-6
Figure 6-12	Multiplexer and buffer	6-7
Figure 6-13	Multiplexer phases.....	6-7
Figure 6-14	-2V reference source.....	6-7
Figure 6-15	A/D converter	6-8

7	Maintenance	
Figure 7-1	Calibration jumper location	7-3
Figure 7-2	Input offset and current adjustment locations.....	7-4
Figure 7-3	Connections for Model 6512 calibration	7-5
Figure 7-4	Connections for external voltage source.....	7-6
Figure 7-5	Exploded view	7-10

A	IEEE-488 Bus Overview	
Figure A-1	IEEE-488 bus configuration	A-1
Figure A-2	IEEE-488 handshake sequence.....	A-3
Figure A-3	Command groups.....	A-6

List of Tables

2	Operation	
Table 2-1	Front panel power-up default conditions	2-1
Table 2-2	Display error messages	2-5
Table 2-3	Front panel program messages	2-5
Table 2-4	Typical display exponent values	2-6
Table 2-5	Ohms function current output values	2-18
Table 2-6	Typical 2V analog output values	2-18
Table 2-7	Full-range PREAMP OUT values	2-21
Table 2-8	Data store reading rates	2-27
Table 2-9	Voltage and percent error for various time constants	2-33
Table 2-10	Minimum source resistance	2-33
Table 2-11	Equivalent voltage sensitivity of Model 6512 amps ranges	2-34
Table 2-12	Engineering units conversion	2-34
3	IEEE-488 Programming	
Table 3-1	Default conditions	3-2
Table 3-2	Device-dependent command summary	3-3
Table 3-3	Bus hold-off times	3-8
Table 3-4	Trigger to reading-ready times	3-24
4	Applications	
Table 4-1	Diode currents and voltages	4-3
5	Performance Verification	
Table 5-1	Limits for amps verification	5-3
Table 5-2	Limits for volts verification	5-4
Table 5-3	Limits for ohms verification	5-5
6	Theory of Operation	
Table 6-1	Memory mapping	6-9

7 Maintenance

Table 7-1	Line voltage selection (50-60Hz)	7-1
Table 7-2	Line fuse selection	7-2
Table 7-3	Model 6512 amps calibration summary	7-5
Table 7-4	Model 6512 volts calibration	7-6
Table 7-5	Model 6512 ohms calibration	7-7
Table 7-6	Recommended troubleshooting equipment	7-11
Table 7-7	Diagnostic program phases	7-12
Table 7-8	Power supply checks	7-13
Table 7-9	Relay configuration	7-13
Table 7-10	Ranging amplifier gains	7-14
Table 7-11	A/D converter checks	7-15
Table 7-12	Preamplifier checks	7-15
Table 7-13	Ranging amplifier checks	7-16
Table 7-14	Digital circuitry checks	7-16
Table 7-15	Display board checks	7-16
Table 7-16	Input stage balancing	7-17

A IEEE-488 Bus Overview

Table A-1	IEEE-488 bus command summary	A-4
-----------	------------------------------------	-----

B General Bus Commands

Table B-1	General bus commands	B-1
Table B-2	Default conditions	B-2

C Interface Function Codes

Table C-1	Model 6512 interface function codes	C-1
-----------	---	-----

E Model 617/6512 Software Compatibility

Table E-1	Model 617 commands not used by Model 6512	E-1
-----------	---	-----

General Information

1.1 Introduction

The Keithley Model 6512 Programmable Electrometer is a highly sensitive instrument designed to measure voltage, current, charge, and resistance. The measuring range of the Model 6512 is between 10 μ V and 200V for voltage measurements, from 0.1fA and 20mA for current measurements, between 0.1 Ω and 200G Ω for resistance measurements, and in the range of 10fC and 20nC in the coulombs mode. Very high input impedance and extremely low input offset current allow accurate measurement in situations where many other instruments would have detrimental effects on the circuit being measured. A 4½ -digit display and standard IEEE-488 interface allow easy access to instrument data.

1.2 Features

Some important Model 6512 features include:

- Ideal for low-current measurements—Current resolution of 0.1fA makes the Model 6512 ideal for very low-current measurements.
- 4½ -Digit Display—An easy-to-read front panel LED display includes a 4½ -digit mantissa plus a two-digit alpha or numeric exponent.
- Auto-ranging—Included for all functions and ranges.
- Digital Calibration—The instrument may be digitally calibrated from the front panel or over the IEEE-488 bus.
- Zero Correct—A front panel zero correct control allows you to cancel internal voltage offsets, optimizing accuracy.

- Baseline Suppression—One-button suppression of a baseline reading is available from the front panel or over the IEEE-488 bus.
- One-shot Triggering—A front panel control for triggering one-shot readings from the front panel is included.
- Selectable Guarding—A selectable driven cable guard is included to minimize the effects of leakage resistance and stray capacitance.
- Standard IEEE-488 Interface—The IEEE-488 interface allows full bus programmable operation of the Model 6512.
- Analog Outputs—Both preamp and 2V full-range analog outputs are included on the rear panel.
- 100-Point Data Store—An internal buffer that can store up to 100 readings is accessible from either the front panel or over the IEEE-488 bus.
- Minimum and maximum data points can be stored and are accessible from the front panel or over the IEEE-488 bus.

1.3 Warranty information

Warranty information for your Model 6512 may be found inside the front cover of this manual. Should you need to use the warranty, contact your Keithley representative or the factory for information on obtaining warranty service.

1.4 Manual addenda

Information concerning improvements or changes to the instrument that occur after the printing of this manual will be found on an addendum sheet included with this manual. Please be sure that you read this information before attempting to operate or service your instrument.

1.5 Safety symbols and terms

The following safety symbols and terms are used in this manual and found on the instrument:

The  symbol on the instrument indicates that you should refer to the operating instructions in this manual for further details.

The **WARNING** heading as used in this manual explains dangers that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading used in this manual explains hazards that could damage the instrument. Such damage may invalidate the warranty.

1.6 Specifications

Detailed Model 6512 specifications are located at the front of this manual. Note that accuracy specifications assume that the instrument has been properly zero corrected, as discussed in Section 2.

1.7 Unpacking and inspection

The Model 6512 Programmable Electrometer was carefully inspected before shipment. Upon receiving the instrument, carefully unpack all items from the shipping carton and check for any obvious signs of physical damage that might have occurred during shipment. Report any damage to the shipping agent at once. Retain the original packing material in case shipment becomes necessary.

1.7.1 Shipment contents

The following items are included with every Model 6512 shipment:

- Model 6512 Programmable Electrometer
- Model 237-ALG-2 Triax Cable
- Model 6512 Instruction Manual
- Additional accessories as ordered

1.7.2 Instruction manual

If an additional instruction manual is required, order the manual package (Keithley Part Number 6512-901-00). The manual package includes an instruction manual and all pertinent addenda.

1.7.3 Repacking for shipment

Before shipping, the instrument should be carefully packed in its original packing material or the equivalent.

If the instrument is to be returned to Keithley Instruments for repair or calibration, include the following:

- Write **ATTENTION REPAIR DEPARTMENT** on the shipping label.
- Include the warranty status of the instrument.
- Complete the service form at the back of this manual.

1.8 Getting started

1.8.1 Preparation for use

Once the instrument is unpacked, it must be connected to an appropriate power source as described below.

Line power

The Model 6512 is designed to operate from 105-125V or 210-250V power sources. (A factory configuration is available for 90-110V and 195-235V ranges. Contact applications department for details.) The factory set range is marked on the rear panel of the instrument. Note that the line plug is designed to mate with the supplied 3-wire power cord.

CAUTION

Do not attempt to operate the instrument on a supply voltage outside the indicated range, or instrument damage might occur.

Line voltage selection

The operating voltage of the instrument is internally selectable. Refer to Section 7 for the procedure to change or verify the line voltage setting.

Line frequency

The Model 6512 may be operated from either 50 or 60Hz power sources.

IEEE-488 primary address

If the Model 6512 is to be programmed over the IEEE-488 bus, it must be set to the correct primary address. The primary address is set to 27 at the factory, but it may be programmed from the front panel, as described in Section 3.

1.8.2 Quick start procedure

The Model 6512 Programmable Electrometer is a highly sophisticated instrument with many capabilities. Although there are a number of complex aspects about the instrument, you can use the following basic procedure to get your instrument up and running quickly. For more detailed information, you should consult the appropriate section of the manual. Complete, detailed operation concerning Model 6512 front panel operation may be found in Section 2. If you wish to control these functions over the IEEE-488 bus, consult Section 3.

1. Carefully unpack your instrument, as described in paragraph 1.7.
2. Locate the power cord, and plug it into the rear panel power jack. Plug the other end of the line cord into an appropriate power source that uses a grounded outlet. See Section 2 for more complete information.
3. Connect a suitable triaxial cable to the rear panel INPUT jack. (See paragraph 1.9 below for recommended triaxial cables.) Make sure the rear panel V, Ω /GUARD switch is in the OFF position.
4. Press in on the front panel POWER switch to turn on the power. The instrument will power up the auto-range volts mode with zero check enabled.
5. Connect the input cable to the signal source to be measured. Remember that the Model 6512 measures DC voltages up to 200V.

6. Disable zero check to make a measurement.
7. Take the reading from the display.
8. To change to a different measuring function, simply press the desired function button. For example, to measure current, simply press the AMPS button.

1.9 Accessories

The following accessories are available for use with the Model 6512.

INPUT cables

The triaxial cables listed below are recommended for making connections to the Model 6512 INPUT jack.

Model 237-ALG-2 Triax Cable—2m (6 ft.) of low-noise triax cable (SC-22) terminated with a 3-slot male triax connector on one end, and three alligator clips on the other end. (This cable is supplied with the Model 6512.)

Model 7078-TRX-3 Triax Cable—A low-noise triax cable 0.9m (3 ft.) in length, terminated at both ends with 3-slot male triax connectors. Also available in 3m (10 ft.) and 6m (20 ft.) versions (Models 7078-TRX-10 and 7078-TRX-20 respectively).

SC-22 Triax Cable—Unterminated triax cable available in custom lengths. Use with appropriate triax connector (such as CS-631 described below) to construct complete cables.

IEEE-488 cables

Model 7007 IEEE-488 Cables—The Model 7007 cables are shielded cables designed to connect the Model 6512 to the IEEE-488 bus and are available in two similar versions. The Model 7007-1 is 1m (3.3 ft.) in length, while the Model 7007-2 is 2m (6.6 ft.) long. Each cable is terminated with a shielded IEEE-488 connector on each end, and each connector has two metric screws.

Model 7008 IEEE-488 Cables—The Model 7008 cables are similar IEEE-488 cables available in three lengths. The Model 7003-3 is 0.9m (3 ft.) in length, while the Models 7008-6 and Model 7008-13 are 1.8m (6 ft.) and 4m (13 ft.) in length respectively. Each cable is terminated with an IEEE-488 connector on each end, and each connector has two metric screws.

Trigger cables

The following cables are recommended for connecting the Model 6512 METER COMPLETE OUTPUT and EXTERNAL TRIGGER INPUT jacks to other instruments for external triggering:

Model 7051-2 BNC Cable—A 0.6m (2 ft.) BNC to BNC cable (RG-58C) with a 50Ω characteristic impedance. Also available in 1.5m (5 ft.) and 3.0m (10 ft.) lengths (Models 7051-5 and 7051-10 respectively).

Connectors and adapters

The following connectors and adapters are recommended for use with the Model 6512:

- Model 237-TRX-T—3-slot male to dual female triax tee adapter for use with Model 7078-TRX or other similar 3-slot triax cables.
- Model 6171—3-slot male to 2-lug female triax adapter. Useful for connecting 2-slot triax cables to the Model 6512 INPUT jack.
- Model 7078-TRX-BNC—3-slot male triax to BNC adapter. Allows connecting BNC cables to the Model 6512 INPUT jack.
- Model 7078-TRX-TBC—3-lug female triax bulkhead connector with cap for assembly of custom panels and interface connections.
- Model CAP-31—Protective cap/shield for the Model 6512 INPUT connector.
- Model CS-631—3-slot male triax cable mount connector for use with SC-22 low-noise triax cable. Useful for making custom cables for connections to the Model 6512 INPUT jack.

Test fixtures

Models 6105 and 8008 Resistivity Chambers—The Models 6105 and 8008 are guarded test fixtures for measuring volume and surface resistivities. The units assure good electrostatic shielding and high insulation resistance. The complete system requires the use of an external voltage source such as the Model 230 as well as the Model 6512. Volume resistivity up to $10^9\Omega\text{-cm}$ and surface resistivity up to $10^{18}\Omega$ can be measured in accordance with ASTM test procedures. Sheet samples 64 to 102mm ($2\frac{1}{2} \times 4$ ") in diameter and up to 6.4mm ($\frac{1}{4}$ ") thickness can be accommodated. Excitation voltages up to 1000V may be used.

Model 8006 Component Test Fixture—The Model 8006 is specifically designed for making sensitive measurements on standard package devices. Individual devices may be connected to one of eight device sockets, including axial, 4-, 8-, 10-, and 12-lead TO, and 28-pin DIPs. Instruments may be connected using rear panel binding posts, BNC, or triax connectors.

Rack mount kits

Model 1019 Rack Mounting Kits—The Model 1019A kits are fixed or stationary rack mounting kits intended for mounting instruments in standard 19-inch racks. The Model 1019A-1 mounts a single Model 6512 or other similar instrument, while the Model 1019A-2 mounts two Model 6512s or similar instruments in a side-by-side configuration. The Models 1019S-1 and 1019S-2 are similar rack mounting kits with a sliding mount configuration.

2

Operation

2.1 Introduction

Operation of the Model 6512 may be divided into two general categories: front panel operation and IEEE-488 bus operation. This section contains information necessary to use the instrument on a front-panel basis. Note that most of these functions can also be programmed over the IEEE-488 bus, as described in Section 3.

The following paragraphs contain a complete description of Model 6512 front panel operation. First a complete description of each front and rear panel function is presented. Next the complete procedure for each of the measuring functions is presented. Finally, the analog output and guard functions are described along with a method to apply external feedback.

2.2 Power-up procedure

Use the procedure below to connect the Model 6512 to line power and power up the instrument.

1. Connect the female end of the power cord to the AC receptacle on the rear panel of the instrument. Connect the other end of the cord to a grounded AC outlet.

WARNING

The Model 6512 is equipped with 3-wire power cord that contains a separate ground wire and is designed to be used with grounded outlets. When proper connections are made, instrument chassis is connected to power line ground.

Failure to use a grounded outlet may result in personal injury or death because of electric shock.

CAUTION

Be sure that the power line voltage agrees with the indicated range on the rear panel of the instrument. Failure to observe this precaution may result in instrument damage. If necessary, the line voltage may be changed, as described in Section 7.

2. Turn on the power by pressing in the front panel POWER switch. The switch will be at the inner most position when the instrument is turned on.
3. The instrument will power up in the volts function, in the auto-range mode and with zero check enabled, as indicated by the associated front panel LEDs. All other LEDs will be off when the instrument is first turned on. Table 2-1 summarizes front panel power-up default conditions.

Table 2-1

Front panel power-up default conditions

Mode	Power-up status
Function	Volts
Range	Auto-range
Zero Check	Enabled
Suppression	Disabled
Trigger	Continuous, External
Data Store	Disabled

2.3 Power-up self-test and display messages

2.3.1 RAM memory test

RAM memory is automatically tested as part of the power-up procedure. If a RAM memory error occurs, the “rr” message will remain on the display. If the instrument was not able to read the stored calibration constants and configuration, the decimal points in the two exponent digits will flash.

If such errors occur, the instrument may be partially or completely inoperative. Refer to Section 7 for more complete details.

2.3.2 Self-test and firmware revision level

A power-up self-test may be run, and the firmware revision level may be displayed by pressing and holding the TRIG button when the unit is first turned on. During the test, all front panel LEDs and the display segments will turn on as in the example below:

--1.8.8.8.8.*.*.

The instrument will then display the software revision level when TRIG is released, for example:

A.1

(The revision level of your unit may be different.)

The instrument will then enter the diagnostic mode, which is used as an aid in troubleshooting problems within the instrument. See Section 7 for details. Note that the power must be turned off to remove the instrument from the diagnostic mode.

NOTE

If the instrument is still under warranty (less than one year from the date of ship-

ment), and problems develop, it should be returned to Keithley Instruments for repair. See paragraph 1.7 for details on returning the instrument.

2.4 Front panel familiarization

The front panel layout of the Model 6512 is shown in Figure 2-1. The front panel may be divided into two sections: controls and display indicators. The following paragraphs describe each of these items in detail.

2.4.1 Controls

All front panel controls except POWER are momentary contact switches. Many control buttons include an annunciator light to indicate the selected mode. Some buttons have a secondary function that is entered by pressing the SHIFT button before pressing the desired button. All such buttons (except ADJUST) are marked in yellow. The controls are color coded into functional groups for ease of operation.

① POWER

The POWER switch controls AC power to the instrument. Pressing and releasing the switch once turns the power on. Pressing and releasing the switch a second time turns the power off. The correct positions for on or off are marked on the front panel immediately above the POWER switch.

② SHIFT

The SHIFT button adds a secondary function to some of the other front panel controls, including VOLTS, TRIG, RECALL, and PROGRAM SELECT. Note that the shift function is entered by pressing SHIFT before the second button rather than pressing the two simultaneously.

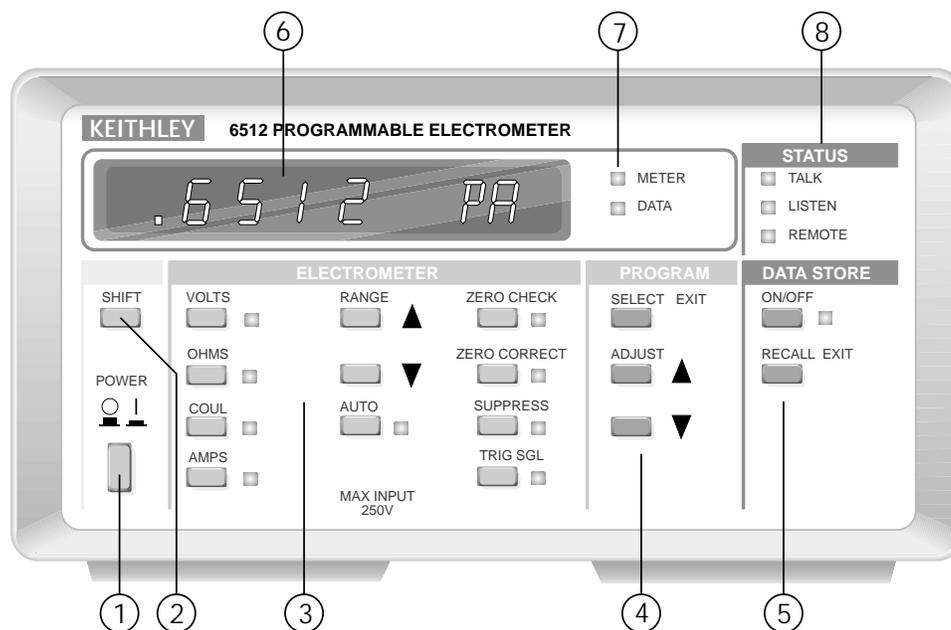


Figure 2-1
Model 6512 front panel

3 ELECTROMETER

The ELECTROMETER buttons control the measuring functions, selection of instrument ranges, and such items as zero check, zero and suppression, and front panel triggering.

VOLTS—The VOLTS button places the instrument in the DC volts measuring mode. When VOLTS is pressed, the indicator next to the button turns on, showing that the instrument is set for that mode. Note that the Model 6512 will be in this mode when it is first turned on. Pressing SHIFT/VOLTS will place the instrument in the external feedback mode, as described in paragraph 2.9.

OHMS—Pressing OHMS places the unit in the resistance measuring function. The indicator next to the OHMS button will be illuminated when the instrument is in this mode. Note that the instrument measures resistance using the constant-current method.

COUL—The Model 6512 may be set up to measure charge by pressing the COUL button. The indicator next to the COUL button will illuminate when the instrument is set for this mode.

AMPS—Pressing AMPS switches the instrument to the current-measuring function. The AMPS indicator will turn on when the instrument is in this mode.

RANGE—These two buttons allow you to increment or decrement the range the instrument uses. Pressing the ▲ button will move the instrument up one range each time it is operated, while the ▼ button will move the instrument down range one increment each time it is pressed. Note that pressing either of these buttons will cancel auto-range if that mode was previously selected. The display mantissa will remain blank until the first reading is ready to be displayed.

AUTO—The AUTO button places the instrument in the auto-range mode. While in this mode, the Model 6512 will switch to the best range to measure the applied signal. Note that the instrument will be in the auto-range mode when it is first turned on. Auto-ranging is available for all functions and ranges. Auto-ranging may be cancelled either by pressing the AUTO button or one of the two RANGE buttons.

ZERO CHECK—The zero check mode is used in conjunction with the **ZERO CORRECT** control to cancel any offsets within the instrument and is also used as a standby mode. Pressing **ZERO CHECK** once will enable this mode, as shown by the associated indicator light. When zero check is enabled, the electrometer input circuit configuration changes (see paragraph 2.10). No readings can be taken with zero check enabled. Pressing **ZERO CHECK** a second time will disable this mode. Zero check should be enabled when making connections (except for coulombs) or when changing functions.

ZERO CORRECT—The zero correct mode works with zero check to cancel electrometer offsets. If zero check is enabled, pressing **ZERO CORRECT** will store a new offset value that will be used to cancel any offset. If the range is changed while zero correct is enabled, the stored value will be scaled accordingly. Zero correct may be cancelled by pressing the **ZERO CORRECT** button a second time. More information on using zero correct may be found in paragraph 2.10.

SUPPRESS—The suppress mode allows you to cancel external offsets or to store a baseline value to be subtracted from subsequent readings. For example, if you applied 10V to the instrument and enabled suppress, that value would then be subtracted from subsequent readings. Once suppress is enabled, the value is scaled when the range is changed. Suppress may be disabled by pressing the **SUPPRESS** button a second time and is cancelled if the function is changed.

TRIG—The **TRIG** button allows you to enter the one-shot trigger mode and trigger single readings from the front panel. To enter the one-shot mode, press **SHIFT** then **TRIG**. The **SGL** indicator light will show that the instrument is in the one-shot mode. Each time the **TRIG** button is pressed, a single reading will be processed and displayed. The displayed reading will flash when the **TRIG** button is pressed. The one-shot trigger mode can be cancelled by pressing **SHIFT** then **TRIG** a second time. Additional information on triggering may be found in paragraphs 2.12 and 3.2.12 in Sections 2 and 3.

④ PROGRAM

These keys allow access to Model 6512 front panel programs, which control the IEEE-488 primary address, set alpha or numeric exponent, and perform instrument calibration. Front panel programs are described in paragraph 2.5.

SELECT/EXIT—This button enters the program mode to allow access to parameters described above. Pressing **SELECT** repeatedly causes the instrument to scroll through a program menu. To cancel the program mode, press **SHIFT** and then **SELECT/EXIT** in that order. Note that the program mode is also cancelled by pressing **SELECT/EXIT** after a program parameter change is made.

ADJUST—These two buttons set program parameters, as described in paragraph 2.5.

⑤ DATA STORE

The two **DATA STORE** buttons control the internal 100-reading data store mode of the instrument. Through these two buttons, data storage may be enabled or disabled, the storage rate may be selected, and readings may be recalled to the front panel display. Paragraph 2.11 contains a complete description of data store operation.

ON/OFF—This control enables or disables data store operation. In addition, reading rates can be selected by holding the button in when first enabling data store. When data store is enabled, the indicator light next to the **ON/OFF** button will be on. Minimum and maximum values are stored and up-dated as long as the **ON/OFF LED** is on.

RECALL/EXIT—This single button serves to recall readings previously stored by data store. Pressing and holding this button causes the instrument to scroll through data store locations as indicated on the display. Once the desired reading number is displayed, releasing the button causes the actual reading to be displayed. To exit the recall mode, press **SHIFT** then **EXIT**.

2.4.2 Display and indicators

The operation of the 4½ digit display and various indicators is described below. The display updates at about three readings per second in the continuous trigger mode.

⑥ Display

The Model 6512 has a display made up of a 4½ digit signed mantissa as well as a two-digit signed exponent. The exponent can be represented either in scientific notation, or with an alphanumeric subscript such as nA. The exponent display mode can be changed with a front panel program, as described in paragraph 2.5. When scientific notation is used, the decimal point remains fixed as in 1.9999, and the range is indicated by the exponent. In addition, the display has a number of front panel error messages that may occur during operation; see Table 2-2.

Table 2-2
Display error messages

Message	Description
OL	Over-range input applied (- for negative value).
b Err	Bus Error: Instrument programmed while not in remote, or illegal command or option sent.
n Err	Number Error: Calibration value out of limits.
t Err	Trigger Error: Instrument triggered while processing reading from previous trigger.

⑦ METER and DATA indicators

The METER indicator identifies when the display is showing a normal reading. The DATA LED indicates when the instrument is displaying DATA STORE information; a data store reading is displayed when the DATA LED is turned on. Usually, the display will show normal readings (METER on), but the RECALL button will switch the display to the data store mode.

⑧ STATUS indicators

These three indicators apply to operation of the Model 6512 over the IEEE-488 bus. The REMOTE indicator shows when the instrument is in the IEEE-488 remote state, while the TALK and LISTEN indicators show when the instrument is in the talk and listen states respectively. See Section 3 for more information on using the Model 6512 over the IEEE-488 bus.

2.4.3 Tilt bail

The tilt bail, which is located on the bottom of the instrument, allows the front panel to be elevated to a convenient viewing height. To extend the bail, rotate it out 90° from the bottom cover and latch it into place. To retract the bail, pull out until it unlatches, and rotate it against the bottom cover.

2.5 Front panel programs

The Model 6512 has three front panel programs that can be used to set the primary address, set the display exponent mode (alpha or numeric), or calibrate the instrument from the front panel. To select a program, press PROGRAM SELECT button repeatedly while observing the display. The instrument will scroll through the available programs with identifying messages, as shown in Table 2-3. When in the program mode, the DATA STORE RECALL button is inoperative; the data store mode may be turned off, but not on. The operation of the various programs is described in the following paragraphs. To exit a program, press SHIFT EXIT. If a change was made, pressing SELECT alone will exit the program.

Table 2-3
Front panel program messages

Message	Program description
IEEE	Displays/sets IEEE-488 primary address.
dISP	Sets numeric or alpha exponent.
CAL*	Allows instrument calibration.

* Not normally accessible unless enabled. See paragraph 7.4.9.

2.5.1 IEEE-488 address

Selection of the IEEE-488 address program is indicated by the following message:

IEEE 27

Along with the message, the presently programmed IEEE-488 address (the factory default value of 27 in this example) will be displayed. To select a new address, use the ADJUST keys. When the desired value is shown in the display, press SHIFT then SELECT EXIT to return to normal operation (or if a change was made, simply press SELECT). For complete information on using the Model 6512 over the IEEE-488 bus, refer to Section 3.

2.5.2 Exponent mode (alpha or numeric)

The display exponent of the Model 6512 can be operated in either the alpha mode or the numeric mode. In the alpha mode, the exponent is given in actual units such as mA. In the numeric mode, the exponent is given in scientific notation. Table 2-4 gives typical examples, including units.

To select the exponent program, scroll through the program menu until the following message is displayed:

dISP

Use either of the ADJUST buttons to set the exponent to the desired mode. In the numeric mode, the display might show:

dISP -3

The display in the alpha mode appears as:

dISPm

Once the desired exponent mode is selected, press SHIFT then SELECT EXIT to return to normal operation (or simply PROGRAM SELECT if a change was made).

Table 2-4

Typical display exponent values

Display	Engineering units	Scientific notation	Value
PA	pA	$10^{-12}A$	Picoamperes
nC	nC	$10^{-9}C$	Nanocoulombs
μA	μA	$10^{-6}A$	Microamperes
mV	mV	$10^{-3}V$	Millivolts
k Ω	k Ω	$10^3\Omega$	Kilo-ohms
M Ω	M Ω	$10^6\Omega$	Mega-ohms
G Ω	G Ω	$10^9\Omega$	Giga-ohms

2.5.3 Calibration

An advanced feature of the Model 6512 is its digital calibration program. The instrument can be calibrated from the front panel or over the IEEE-488 bus. To use the front panel calibration program, refer to the calibration procedures outlined in Section 7, paragraph 7.4.9.

2.6 Rear panel familiarization

The rear panel of the Model 6512 is shown in Figure 2-2.

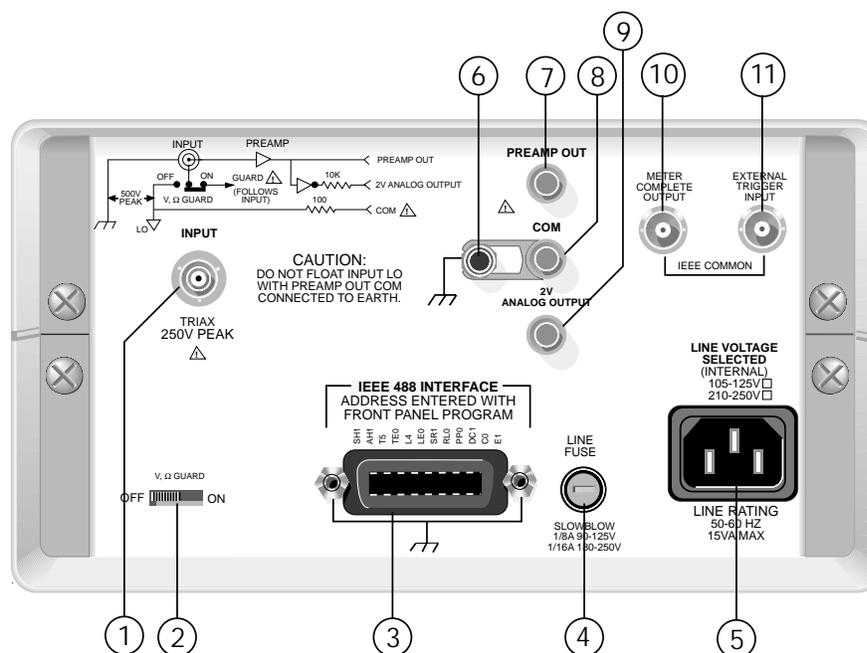


Figure 2-2
Model 6512 rear panel

① INPUT

The INPUT connector is a 3-lug female triax connector to be used for all electrometer signal inputs. Note that you should not confuse a triaxial connector with the BNC type that is used for the EXTERNAL TRIGGER and ELECTROMETER COMPLETE connections. Also, do not attempt to force 2-lug triaxial connector onto the INPUT connector. (See paragraph 1.9 for details on 2-lug to 3-slot triax adapters.)

CAUTION

Do not float INPUT LO with preamp out COM connected to earth (chassis ground).

② V, Ω GUARD Switch

The V, Ω GUARD switch adds capabilities for connecting a guard voltage to the inner shield of the input cable. Guarding is useful in the volts and ohms modes to speed up response time and minimize the effects of leakage resistance and stray capacitance. Note that guarded operation is not recommended in amps or coulombs modes. See paragraph 2.7.4 for more information on guarded operation.

③ IEEE-488 Connector

This connector is used to connect the instrument to the IEEE-488 bus. IEEE-488 function codes are marked above the connector.

④ LINE FUSE

The LINE FUSE, which is accessible on the rear panel, provides protection for the AC power line output. For information on replacing this fuse, refer to Section 7.

⑤ AC Receptacle

Power is applied through the supplied power cord to the AC receptacle. Note that the supply voltage is marked adjacent to the receptacle.

⑥ Chassis Ground

This jack is a 5-way binding post that is connected to instrument chassis ground. It is intended for use in situations requiring an accessible chassis ground terminal. A shorting link is supplied and connected between the chassis ground and COM terminals.

⑦ PREAMP OUT

The PREAMP OUT jack provides a guard output for voltage and resistance measurements. This output can also be used as an inverting output or with external feedback when measuring current or charge. The PREAMP OUT has a maximum output value of $\pm 300V$ and uses a standard 5-way binding post.

WARNING

Hazardous voltage may be present at the PREAMP OUT, depending on the input signal.

⑧ COM Terminal

The COM terminal is a 5-way binding post that provides a low connection for both the 2V ANALOG OUTPUT and the PREAMP OUT. This terminal is also used for input low connection when in guarded mode; COM is internally connected to input low through a 100Ω resistor.

CAUTION

Do not connect PREAMP OUT, COM, or 2V ANALOG OUTPUT to earth ground when floating the input.

⑨ 2V ANALOG OUTPUT

The 2V ANALOG OUTPUT provides a scaled 0-2V output from the electrometer (2V output for full range input). The output uses a standard 5-way binding post and is inverting in the volts and ohms modes.

⑩ METER COMPLETE OUTPUT

This BNC connector provides an output pulse when the Model 6512 has completed a reading; it is useful for triggering other instrumentation.

⑪ EXTERNAL TRIGGER INPUT

This BNC connector can be used to apply external trigger pulses to the Model 6512 to trigger the instrument to take one or more readings, depending on the selected trigger mode.

2.7 Basic measurement techniques

The paragraphs below describe the basic procedures for using the Model 6512 to make voltage, resistance, charge, and current measurements.

2.7.1 Warm-up period

The Model 6512 is usable immediately when it is first turned on. However, the instrument must be allowed to warm up for at least two hours to achieve rated accuracy.

NOTE

While rated accuracy is achieved after the two-hour warm up period, input bias current may require additional time to be reduced to its optimum level. Allow two more hours for input bias current to settle to less than $10fA$ and eight hours for settling to less than $5fA$. In sensitive applications, it is preferable for the unit to be left on continuously.

2.7.2 Input connections

The rear panel INPUT connector is a Teflon-insulated, 3-lug female triax connector intended for all input signals to the Model 6512. As shown in Figure 2-3, the center terminal is high, the inner ring or shield is low, and the outer shield is connected to instrument chassis ground. In the guarded mode, the inner shield is driven at guard potential, while the outer shield is chassis ground.

NOTE

The INPUT connector must be kept clean to maintain high input impedance. Place the supplied rubber dust cap on the INPUT connector when the instrument is not in use.

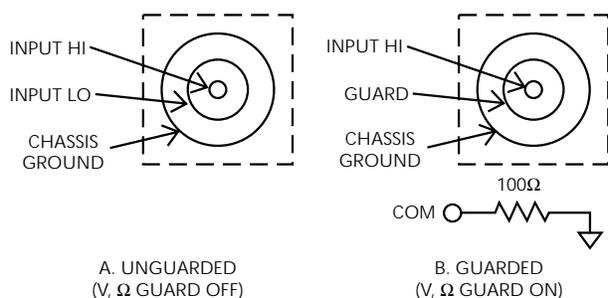


Figure 2-3
Input connector configuration

The supplied Model 237-ALG-2 cable is designed to mate with the INPUT connector. The other end of the Model 237-ALG-2 is terminated with three alligator clips. Input high is color coded in red, input low is colored black, and chassis ground is color coded in green. Keep in mind that these connections are for the unguarded mode. In the guarded mode, red is high, black is guard, and green is chassis ground. The COM binding post provides a connection to input low through 100Ω for use in the guarded mode.

NOTE

It is recommended that zero check be enabled when connecting or disconnecting input signals.

WARNING

The maximum common-mode input voltage (the voltage between input low and chassis ground) is 500V peak. Exceeding this value may create a shock hazard.

CAUTION

Connecting PREAMP OUT, COM, or 2V ANALOG OUTPUT to earth while floating the input may damage the instrument.

CAUTION

The maximum voltage between input high and input low is 250V RMS, DC to

60Hz sine wave (10 seconds maximum in mA ranges). Exceeding this value may cause damage to the instrument.

2.7.3 Making voltage measurements

The Model 6512 can be used to measure voltages in the range of $\pm 10\mu\text{V}$ to $\pm 200\text{V}$. In principle, the instrument operates much like an ordinary DMM, but its special characteristics allow it to make measurements in cases where an ordinary DMM would be unable to perform well. In particular, the very high input resistance of $200\text{T}\Omega$ ($2 \times 10^{14}\Omega$) allows it to accurately measure voltage sources with high internal resistances. In contrast, an ordinary DMM may have an input resistance of only $10\text{M}\Omega$, resulting in inaccurate measurements because of instrument loading.

Use the following procedure to make voltage measurements:

1. Turn on instrument power, and allow the unit to warm up for two hours to reach rated accuracy.
2. Check to see that the voltage function is selected by pressing the VOLTS button. Use the auto-range mode, or select the desired range with the ranging pushbuttons.
3. To achieve specified accuracy, especially on the lower ranges, it is recommended that you zero the instrument. To do so, first enable zero check, and then press the ZERO CORRECT button. Correcting zero on the lowest range of any function will correct all ranges because of internal scaling.

NOTE

The input circuit configuration changes with zero check enabled. See paragraph 2.10.1 for details.

4. Connect the supplied Model 237-ALG-2 triaxial input cable or other suitable triax cable to the rear panel INPUT jack. For sources with high output resistance, the cable should be kept as short as possible to minimize cable capacitance.
5. If response time and leakage resistance are considerations, place the instrument in the guarded mode as described in paragraph 2.7.4.
6. Connect the other end of the cable to the voltage to be measured, as shown in Figure 2-4. Disable zero check.

- Take the reading directly from the display. The exponent can be placed either in the alpha or numeric mode, as described in paragraph 2.5.

Voltage measurement considerations

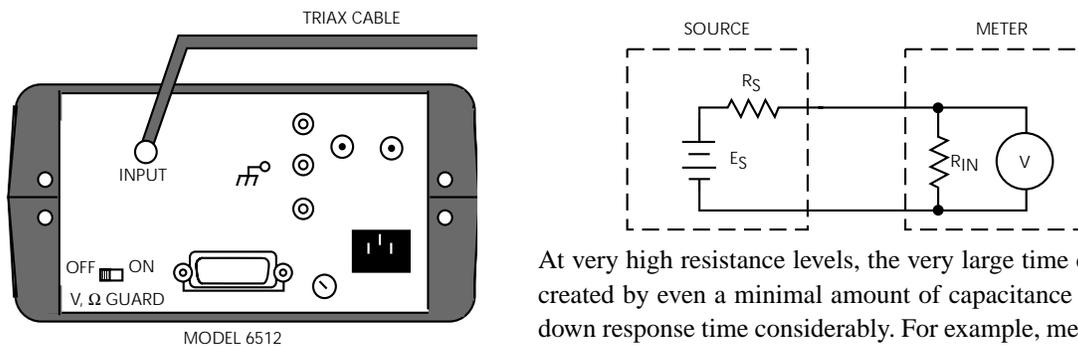
Two factors are of concern when making voltage measurements, especially for voltage sources with high output (source) resistances. For one thing, the loading effects of the measuring instrument come into play at the high resistance levels involved. Secondly, the distributed capacitance of the source, the input cable, and the input circuit of the instrument itself are a factor when making these measurements.

Figure 2-5 demonstrates how meter loading can affect measurement accuracy. Here, a voltage source with a value E_S and a source resistance R_S is connected to the input of the electrometer. The input resistance of the electrometer is R_{IN} . The percent error due to loading can be calculated as follows:

$$\% \text{ ERROR} = \frac{100R_S}{R_S + R_{IN}}$$

Thus, to keep the error under 0.1%, the input resistance must be about 1000 times the value of the source resistance, R_S . Note that the Model 6512 input resistance is $\geq 200G\Omega$, but the cable resistance appears in parallel.

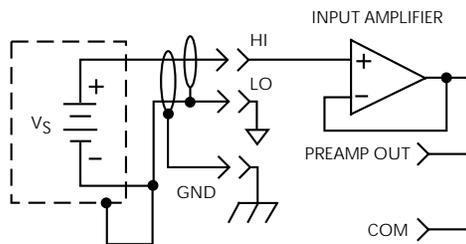
Figure 2-5
Meter loading considerations



At very high resistance levels, the very large time constants created by even a minimal amount of capacitance can slow down response time considerably. For example, measuring a source with an internal resistance of $100G\Omega$ would result in an RC time constant of one second when measured through a cable with a nominal capacitance of $10pF$. If 1% accuracy is required, a single measurement would require at least five seconds. Note that typical input cables have unguarded capacitance (high to inner shield) of 120 to $150pF$ per meter.

Basically, there are two ways to minimize this problem: (1) keep the input cable as short as possible, and (2) use guarding. With the first method, there is a limit as to how short the cable can be. Using guarding can reduce these effects and decrease settling times by up to a factor of 1,000. The Model 6512 rear

Figure 2-4
Connections for voltage measurements



panel V, Ω GUARD switch allows guarding to be easily applied to the input circuit; see paragraph 2.7.4 for details.

At low signal levels, noise may affect accuracy. Shielding of the unknown voltage can reduce noise effects substantially. When using shielding, the shield should normally be connected to input low, although connecting the shield to chassis ground may yield better results in some cases.

2.7.4 Guarded operation

Guarding consists of using a conductor driven by a low-impedance source to totally surround the leads carrying a high-impedance signal. The output of this low-impedance source is kept at the same potential as the signal itself, resulting in drastically reduced leakage currents.

To approach the concept of guarding, let us first review the unguarded circuit shown in Figure 2-6. The measured signal is represented by the voltage source E_S and the source resistance R_S . Cable leakage impedance is represented by Z_L . The source resistance and leakage impedance form a voltage divider that attenuates the source voltage as follows:

$$E_O = \frac{Z_L E_S}{Z_L + R_S}$$

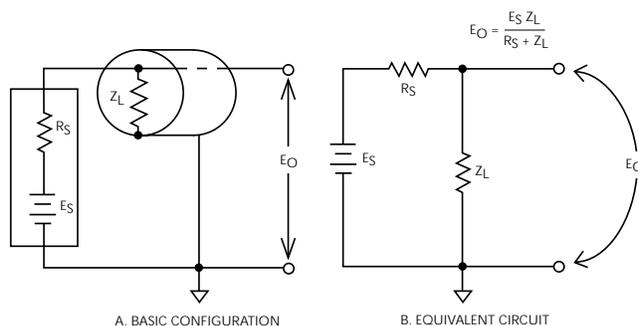


Figure 2-6
Unguarded circuit

Thus, to keep the error due to leakage resistance under 0.1%, the leakage resistance must be at least 1,000 times the source resistance value.

Guarding the circuit minimizes these effects by driving the shield at signal potential, as shown in Figure 2-7. Here, a uni-

ty-gain amplifier with a high input impedance and low output impedance is used. The input of the amplifier is connected to the signal, while the output is used to drive the shield. Since the amplifier has unity gain, the potential across Z_L is typically $<1\text{mV}$, so no leakage current flows. Leakage between the cable shield and ground may be considerable, but it is of no consequence since that current is supplied by the low-impedance source, rather than by the signal itself.

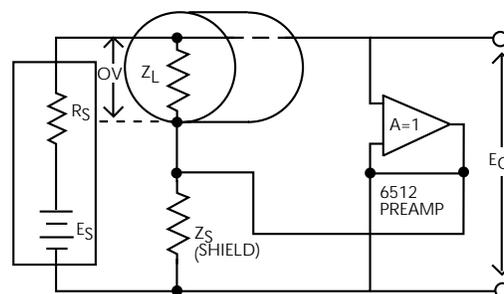


Figure 2-7
Guarded circuit

When the rear panel V, Ω/ GUARD switch is placed in the ON position, guard potential is placed on the inner shield of the triaxial cable. The outer shield remains at chassis ground. Thus, it is necessary to use the COM terminal for low signal connections, as shown in Figure 2-8. For very critical measurements, a shielded, guarded enclosure should be used.

WARNING

Hazardous voltage (up to 300V) may be present on the inner shield when V, Ω/ GUARD is on, depending on the input signal. A safety shield, connected to chassis ground is recommended when making voltage measurements over 30V or for guarded resistance measurements.

NOTE

The use of guarding is not recommended for the amps or coulombs functions.

The PREAMP OUT terminal may be used for guarding in the volts and ohms modes in a similar manner. In this mode,

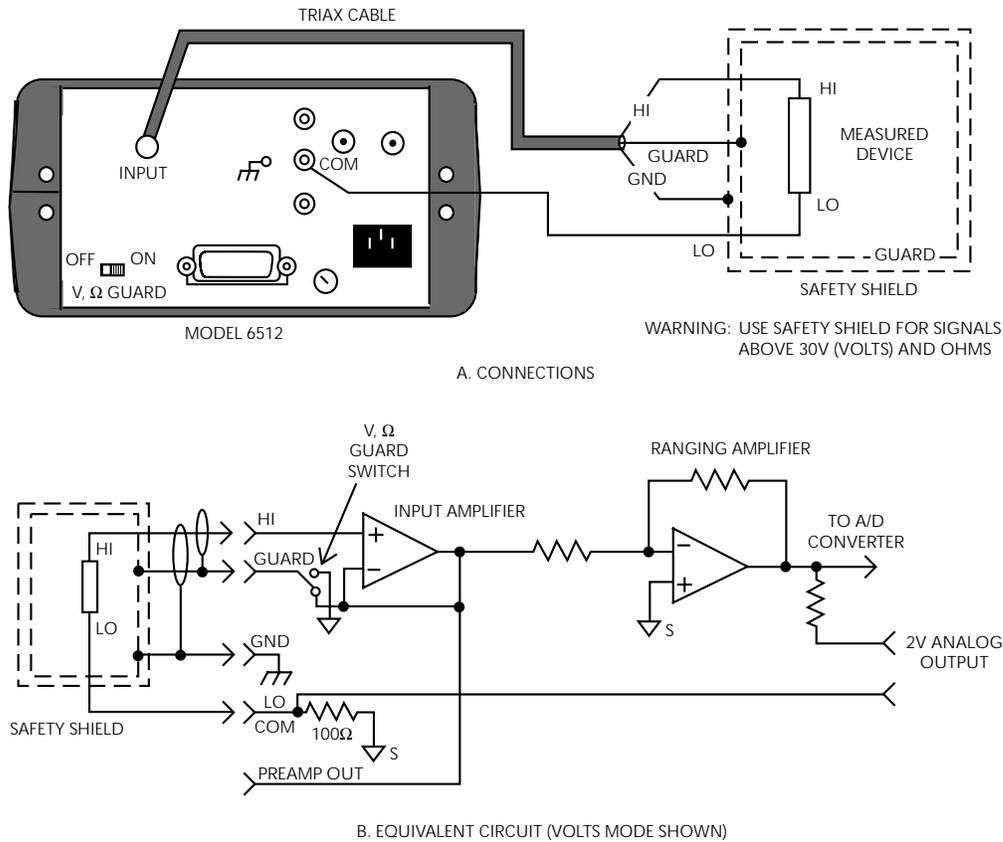


Figure 2-8
Guarded input connections

the preamplifier acts as a unity-gain amplifier with low output impedance.

WARNING

Hazardous voltage (up to 300V) may be present at the PREAMP OUT terminal, depending on the input signal.

CAUTION

Safe operation and good measurement practice dictates the use of an external resistor when necessary to limit currents to less than 30mA.

2.7.5 Making current measurements

The Model 6512 can resolve currents as low as 0.1fA (10^{-16} A), and measure as high as 20mA in 11 ranges. The Model 6512 exhibits low input voltage burden and extremely low input offset current. The low voltage burden is achieved because the Model 6512 measures current as a feedback type picoammeter, rather than the shunt method used by many DMMs.

NOTE

After measuring high voltage in volts, or following an overload condition in ohms, it may take a number of minutes for input current to drop to within specified limits. Input current can be verified by placing a shielded cap on the INPUT jack and then connecting a jumper between the COM and chassis ground terminals. With the instrument on the 2pA range and zero check disabled, allow the reading to settle until the instrument is within specifications.

To measure current with the Model 6512, use the following procedure:

1. Turn on the power, and allow the instrument to warm up for at least two hours to obtain rated accuracy.
2. Select the current mode by pressing the AMPS button on the front panel. Set the V, Ω / GUARD switch to OFF.
3. To achieve rated accuracy, select the 2pA range, zero the instrument by enabling zero check and then pressing the ZERO CORRECT button. After zero correction, select the desired range, or use auto-ranging if desired.
4. Connect a suitable triax cable to the rear panel INPUT jack. Connect the other end of the circuit to be measured as shown in Figure 2-9. Shielding will be required for low-level measurements. Connect the shield to input low.
5. Disable zero check, and allow the reading to settle.
6. Read the current value directly from the display. The exponent may be placed either in the alpha or numeric modes, as described in paragraph 2.5.

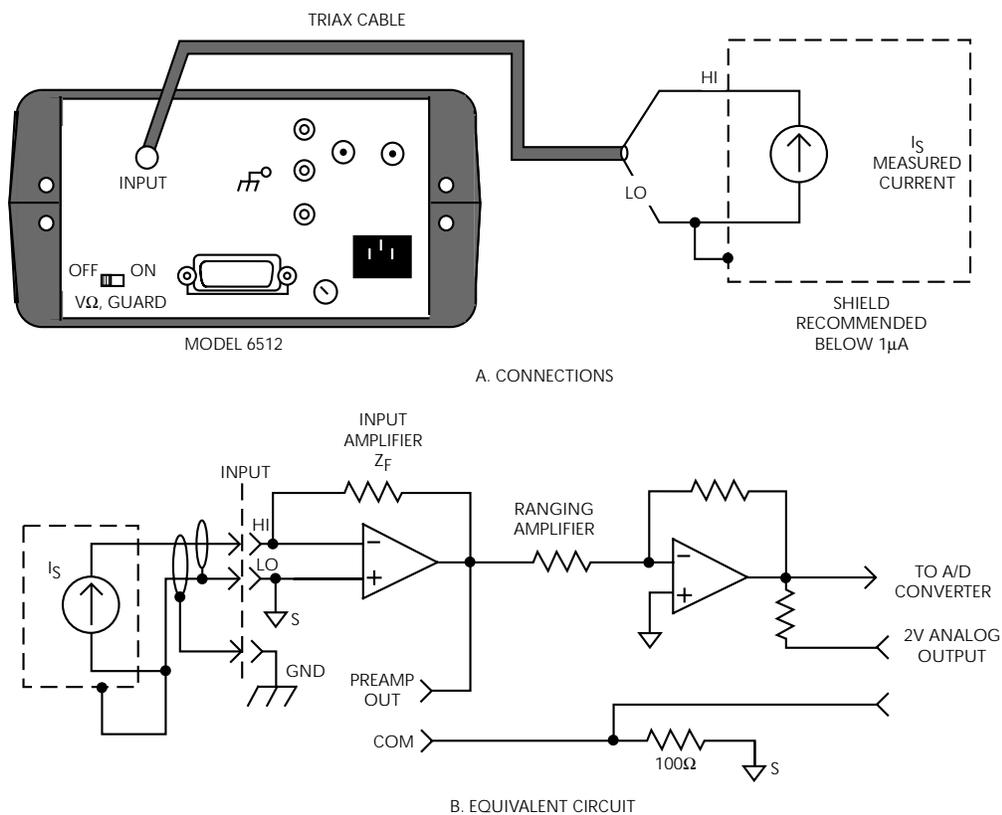


Figure 2-9
Current measurements

Current measurement considerations

At very low levels (in the picoampere range or below), noise currents generated in the cable or from other sources can affect measurements. Currents generated by triboelectric effects are a primary cause of noise currents generated in connecting cables. These currents are generated by charges created at the junction between a conductor and an insulator because of friction. Coaxial and triaxial cables are especially prone to such noise currents, which are generated by cable flexing. To minimize these effects, the cable should be tied down firmly to minimize any flexing. Also, special low-noise cable, constructed with graphite between the shield and insulator, is available to minimize these effects (see paragraph 1.9). However, even with low-noise cables, several tens of femtoamps of noise currents can be generated by cable movement.

Voltage burden is frequently a consideration when making current measurements. Ideally, the input voltage burden should be zero for the instrument to have absolutely no effect on the circuit it is measuring. If the voltage burden is too high, its effects can degrade measurement accuracy considerably.

To see how voltage burden can upset measurement accuracy, refer to Figure 2-10. A source, represented by E_S with an output resistance R_S , is shown connected to the input of a picoammeter. The voltage burden is represented by a constant voltage source at the input as E_{IN} . If E_{IN} were zero, the current as seen by the meter would simply be:

$$I = \frac{E_S}{R_S}$$

However, if E_{IN} has a non-zero value, the current now becomes:

$$I = \frac{E_S - E_{IN}}{R_S}$$

Note that the Model 6512 voltage burden is typically 1mV or less. Additional considerations include source resistance and capacitance, as discussed in paragraph 2.13.

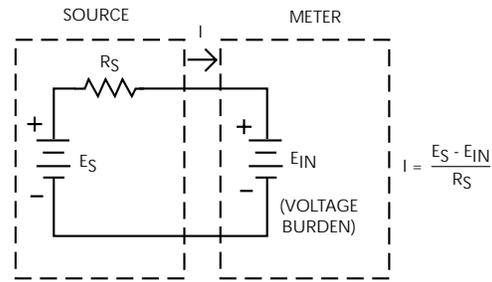


Figure 2-10
Voltage burden considerations

2.7.6 Making charge measurements

The Model 6512 is equipped with three coulombs ranges to resolve charges as low as 10fC (10^{-14} C) and measure as high as 20nC (20×10^{-9} C). When the instrument is placed in one of the coulombs ranges, an accurately known capacitor is placed in the feedback loop of the amplifier so that the voltage developed is proportional to the integral of the input current in accordance with the formula:

$$V = \frac{1}{C} \int i \, dt = \frac{Q_S}{C}$$

The voltage is scaled and displayed as charge.

NOTE

After measuring high voltages in volts, or following an overload condition in ohms, it may take a number of minutes for the input current to drop to within specified limits. Input current can be verified by placing a shielded cap on the INPUT jack and then connecting a jumper between the COM and chassis ground terminals. With the instrument on the 2pA range and zero check disabled, allow the reading to settle until the instrument is within specifications.

Normal charge measurements

Use the following procedure to measure charge with the Model 6512:

1. Turn on the power, and allow a two-hour warm up period for rated accuracy.
2. Place the instrument in the coulombs mode by pressing the COUL button. Set V, Ω / GUARD to OFF.
3. To achieve rated accuracy, place the instrument on the 200pC range, and zero the instrument by enabling zero check and then pressing the ZERO CORRECT button.
4. Select the desired range, or use auto-ranging, if desired.
5. Disable zero check. A small amount of zero check hop (sudden change in the reading) may be observed when

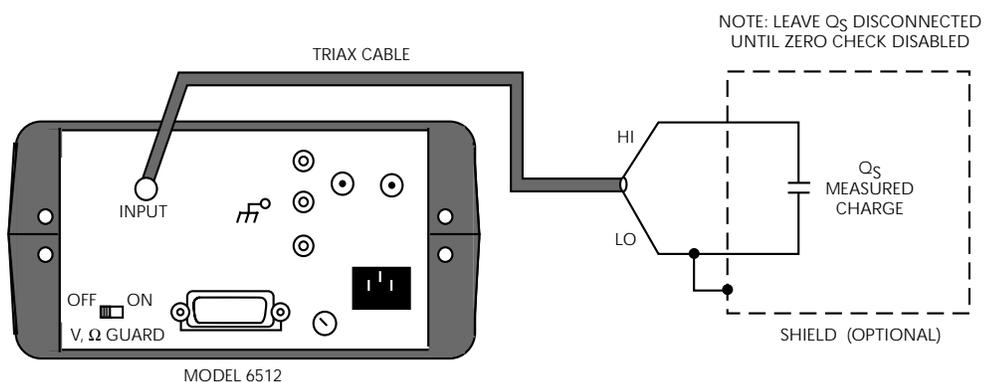
zero check is disabled. If desired, enable suppress to null out any zero check hop, which typically will be in the 10-25 count range.

6. Connect the triax cable to the INPUT jack. Connect the other end of the cable to the circuit being measured, as shown in Figure 2-11. For low-level measurements, shielding may be required.

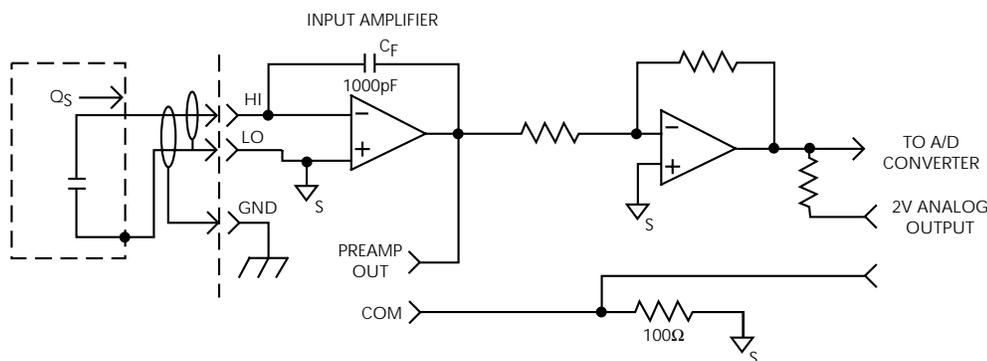
NOTE

Do not connect the circuit to the instrument with zero check enabled.

7. Read the charge value from the display. The exponent may be placed either in the alpha or numeric modes as described in paragraph 2.5.



A. CONNECTIONS



B. EQUIVALENT CIRCUIT

Figure 2-11
Coulombs connections

Using the coulombs function to measure current

Note that the coulombs function can also be used to measure current. The advantage of doing so is that noise in the measurement is substantially reduced because of the integrating process. To measure current using the coulombs function, proceed as follows:

1. Place the instrument in the coulombs function, and select the desired range, or use auto-ranging, if desired.
2. Enable zero check, and connect the current to be measured to the INPUT jack (see Figure 2-9).
3. Disable zero check, and note the charge measurement at the end of a specific interval of time (for example, 10 seconds).
4. To determine the current, simply divide the measured charge by the time in seconds. For example, if a charge of 12nC is seen after a 10-second interval, the current is $12\text{nC}/10 = 1.2\text{nA}$. (Using Data Store at a 10-second rate can simplify the process.)
5. As an alternative to the above procedure, connect a chart recorder to the 2V ANALOG OUTPUT (paragraph 2.9), and graph the measured charge. Since the current is given by $I=dQ/dt$, the current at any point is equal to the slope of the graph at that point, after applying the appropriate scaling factor (100pC/V, 200pC range; 1nC/V, 2nC range; 10nC/V, 20nC range).

CAUTION

Connecting PREAMP OUT, COM, or 2V ANALOG OUTPUT to earth while floating input may damage the instrument.

Charge measurement considerations

A primary consideration when making charge measurements is the input offset current of the integrating amplifier. Any such current is integrated along with the input signal and reflected in the final reading. The Model 6512 has a maximum

input offset current of $5 \times 10^{-15}\text{A}$ at 23°C. This value doubles every 10°C. This input offset current translates into a charge of $5 \times 10^{-15}\text{C}$ per second at a temperature of 23°C. This value must be subtracted from the final reading to obtain the correct value.

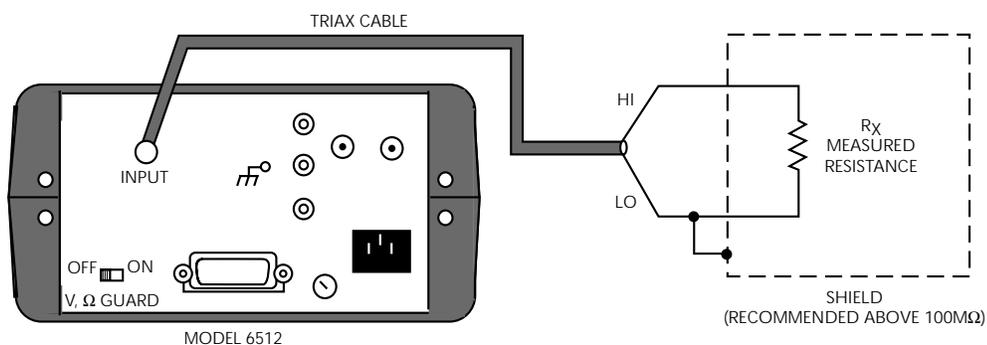
When using an external voltage source, the input current should be limited to less than 1mA by placing a resistor in series with the high input lead. The value of this resistor should be at least: $R=1000 \times V_S$ (in ohms) where V is the voltage source value, or the compliance of the current being integrated.

2.7.7 Resistance measurements

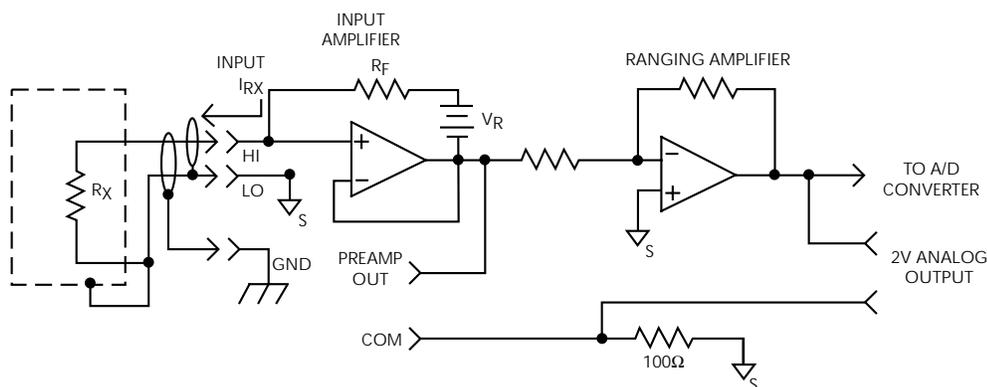
The Model 6512 makes resistance measurements using the constant-current method. (A current is forced through the DUT, and the voltage across the DUT is measured.) The instrument can resolve resistances as low as 0.1Ω and measure as high as $200\text{G}\Omega$.

To measure resistance with the Model 6512, use the following procedure:

1. Turn on the power, and allow a two-hour warm-up period for rated accuracy.
2. Press the OHMS button to select the ohms mode.
3. For maximum accuracy, place the instrument on the $2\text{k}\Omega$ range, and zero the instrument by enabling zero check and then pressing the ZERO CORRECT button.
4. Select the desired range, or use auto-ranging, if desired.
5. Connect the triax cable to the INPUT jack. Keep the cable as short as possible to minimize the effects of cable capacitance. Connect the other end of the cable to the resistance to be measured, as shown in Figure 2-12. For measurements above $1\text{G}\Omega$, it is recommended that you use guarded connections, as described in paragraph 2.7.4.
6. Disable zero check, and allow the reading to settle.
7. Take the reading from the display. The exponent may be placed in either the alpha or numeric modes, as described in paragraph 2.5.



A. CONNECTIONS



B. EQUIVALENT CIRCUIT

Figure 2-12

Resistance measurement connections

Resistance measurement considerations

When measuring high resistance values, there are two primary factors that can affect measurement accuracy and speed. Any leakage resistance in the connecting cable or test fixture can decrease the actual resistance seen by the instrument. Also, capacitance of the cable or input circuit can slow down the response time considerably.

These two problems can be minimized by using guarding, especially when measuring resistances above $1\text{G}\Omega$. Guarding is further discussed in paragraph 2.7.4. Noise pickup can also be a problem, in which case the resistor must be shielded. Connect the shield to input low.

At low resistances, lead resistance can be a consideration. Cancel the effects of lead resistance by shorting the ends of the input leads and enabling suppress with zero check disabled. Leave suppress enabled for subsequent measurements.

2.7.8 Using the ohms function as a current source

The Model 6512 ohms function may also be used to generate currents in decade values between 1nA and $100\mu\text{A}$. To use the instrument in this manner, simply connect the triax cable to the INPUT jack, and connect the other end of the cable to the circuit under test. Select the resistance range in accordance with the desired current (see Table 2-5). Note that current flows out from input high into input low. The test voltage is less than 2V for all ranges $2\text{G}\Omega$ and less, except when an overload occurs, in which case the compliance voltage is 300V.

Table 2-5*Ohms function current output values*

Ranges	Output current ($\pm 1.5\%$)
2k Ω , 20k Ω	100 μ A
200k Ω	10 μ A
2M Ω	1 μ A
20M Ω	100nA
200M Ω	10nA
2G Ω , 20G Ω , 200G Ω	1nA

2.8 Analog outputs

The Model 6512 has two analog outputs on the rear panel. The 2V ANALOG OUTPUT provides a scaled 0-2V output with a value of 2V corresponding to full-range input. The PREAMP OUT is especially useful in situations requiring buffering. These two analog outputs are discussed in the following paragraphs.

WARNING

When floating Input Low above 30V RMS from earth ground, hazardous voltage will be present at the analog outputs. Hazardous voltage may also be present when measuring in ohms, or when the input voltage exceeds 30V RMS in the volts mode.

CAUTION

Connecting PREAMP OUT, COM, or 2V ANALOG OUTPUT to earth while floating the input may damage the instrument.

2.8.1 2V analog output

The 2V ANALOG OUTPUT provides a scaled 0-2V output that is inverting in the volts and ohms modes. Connections for using this output are shown in Figure 2-13. For a full-range input, the output will be 2V; typical examples are listed in Table 2-6. The 2V ANALOG OUTPUT signal is not corrected during calibration. Gain errors of up to 3% may appear at this output, depending on function and range selection.

Note that the output impedance is 10k Ω ; to minimize the effects of loading, the input impedance of the device connected to the 2V ANALOG OUTPUT should be as high as possible. For example, with a device with an input impedance of 10M Ω , the error due to loading will be approximately 0.1%.

Table 2-6*Typical 2V analog output values*

Range	Applied signal	Nominal 2V analog output value*
20pA	10.4pA	1.04V
2 μ A	1.65 μ A	1.65V
200mV	140mV	1.4V
200V	35V	0.35V
200k Ω	175k Ω	1.75V
20G Ω	9.5G Ω	0.95V
200pC	125pC	1.25V
20nC	19nC	1.9V

*Output values within $\pm 3\%$ of nominal value.

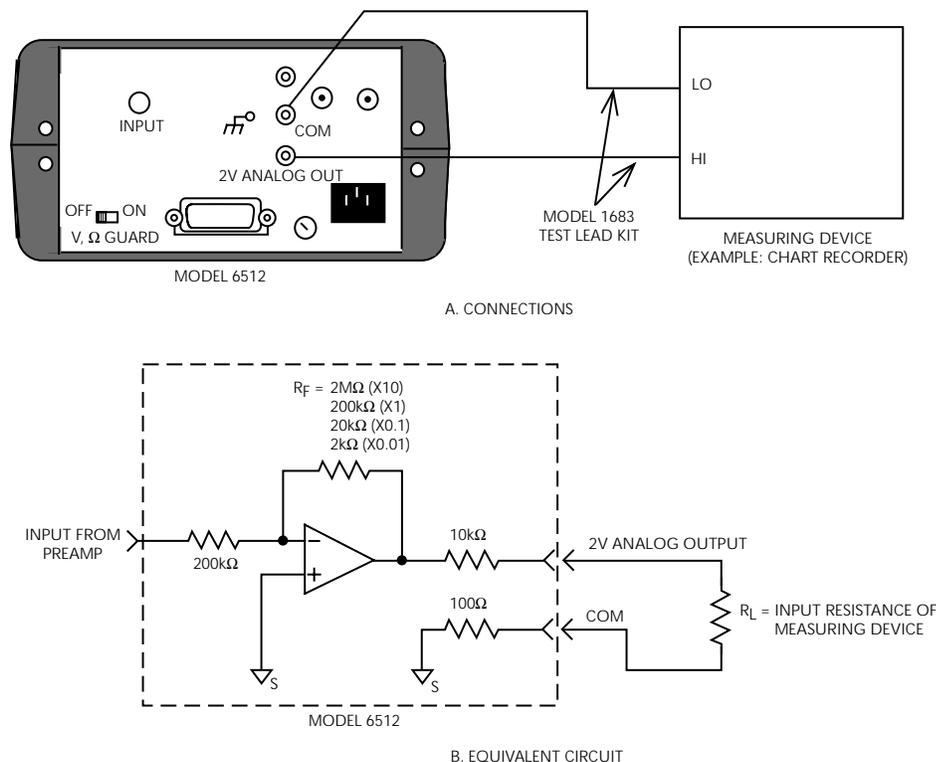


Figure 2-13
Typical 2V analog output connections

2.8.2 Preamp out

The PREAMP OUT of the Model 6512 follows the signal amplitude applied to the INPUT terminal. Some possible uses for PREAMP OUT include buffering of the input signal, as well as for guarding in the volts and ohms modes. Connections and equivalent circuits for the preamp output are shown in Figure 2-14. Full-range outputs for various functions and ranges are listed in Table 2-7. Since the PREAMP OUT signal is not corrected during calibration, gain errors of up to 3% may appear at this output, depending on function and range selection. For all volts ranges, PREAMP OUTPUT accuracy is typically 5ppm.

WARNING

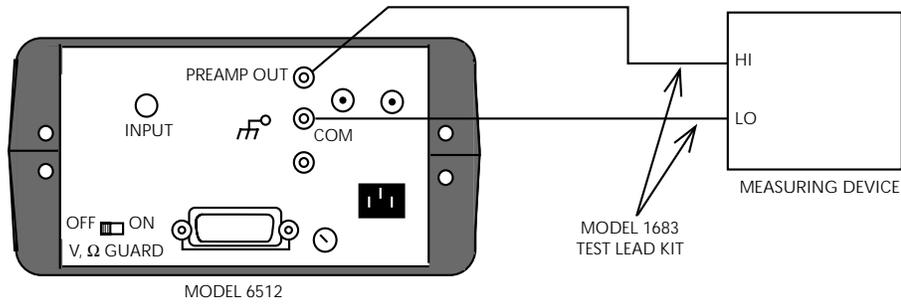
High voltage may be present between the PREAMP OUT and COM terminals depending on the input signal (see Table 2-

7). Open-circuit voltage of 300V is present at PREAMP OUT in the ohms function.

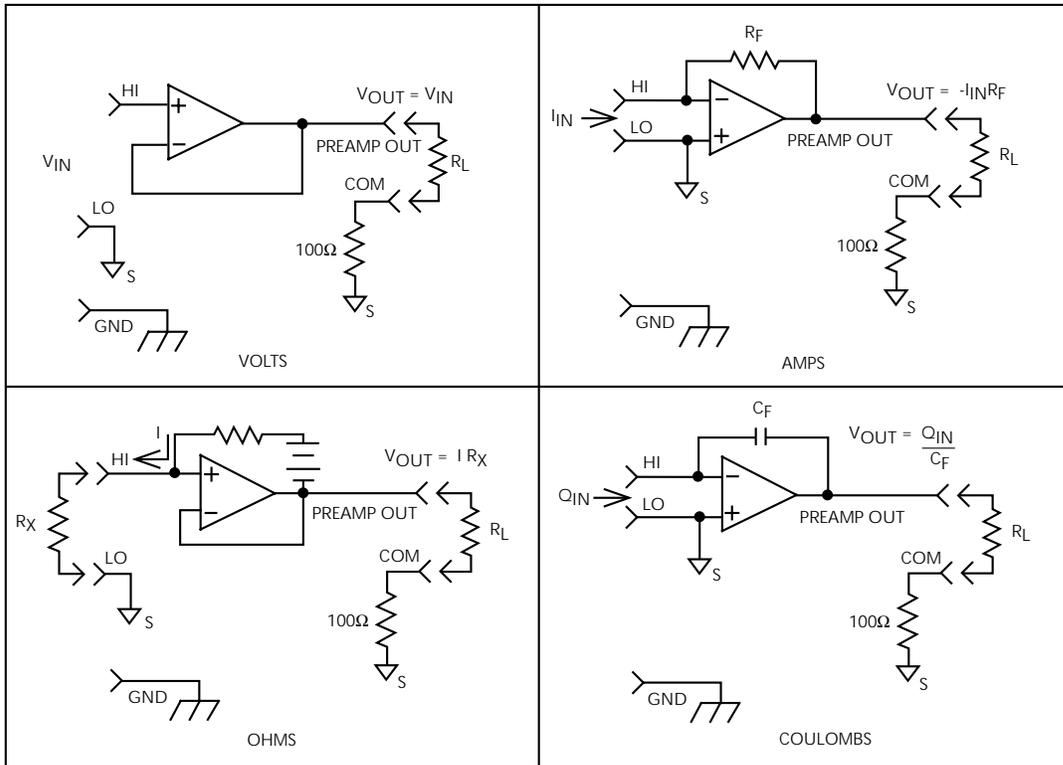
CAUTION

Connecting PREAMP OUT, COM, or 2V ANALOG OUTPUT to earth while floating input may damage the instrument.

Note that the PREAMP OUT output resistance is 100Ω. The output resistance appears between Input Low and Analog Output Low to keep the resistor out of the loop when using external feedback elements. To keep loading errors under 0.1%, the device connected to the PREAMP OUT should have a minimum input impedance of 100kΩ.



A. CONNECTIONS



B. EQUIVALENT CIRCUITS

Figure 2-14
 Typical preamp out connections

Table 2-7
Full-range PREAMP OUT values

Function	Range	Full-range value
Volts	200mV	200mV
	2V	2V
	20V	20V
	200V	200V
Amps	2pA, 2nA, 2μA, 2mA	200mV
	20pA, 20nA, 20μA, 20mA	2V
	200pA, 200nA, 200μA	20V
Ohms*	2kΩ	200mV
	20kΩ-2GΩ	2V
	20G	20V
	200GΩ	200V
Coulombs	200pC	200mV
	2nC	2V
	20nC	20V

*WARNING: Open-circuit voltage of 300V present at PREAMP OUT in ohms.

2.9 Using external feedback

The external feedback function provides a means to extend the capabilities of the Model 6512 Electrometer to such uses as logarithmic currents, non-decade current ranges, as well as non-standard coulombs ranges. The following paragraphs discuss the basic electrometer input circuitry and methods to implement these functions.

2.9.1 Electrometer input circuitry

A simplified diagram of the electrometer input in the external feedback mode is shown in Figure 2-15. An input current applied to the inverting (-) input of the op amp is nulled by a current fed back through the internal feedback network made up of R_{FB} and C_{FB} . Because the output of the op amp appears at the PREAMP OUT, this internal network can be replaced by an external network connected between the preamp output and Input HI connections. When using external feedback, the following factors must be taken into account:

1. The maximum current value that can be supplied by the preamp output is 20mA in amps (1mA in volts and

ohms). The maximum voltage span in external feedback is $\pm 20V$.

2. The input impedance in the external feedback mode is given by the relationship $Z_{IN} = Z_{FB}/A_V$, where: Z_{FB} is the impedance of the external feedback network, and A_V is the open-loop gain of the electrometer (typically greater than 10^6). Note that the input impedance is $Z_{IN} = 10M\Omega \parallel Z_{FB}$ when zero check is enabled.
3. The voltage at the PREAMP OUT terminal is given by the formula:

$$V = -IZ_{FB}$$

where Z_{FB} is the value of the feedback impedance.

4. Any feedback elements should be housed in a suitable shielded enclosure (see paragraph 2.9.2 below). Insulators connected to Input HI should be made of Teflon or other high-quality insulating material and should be thoroughly cleaned to maintain the high input impedance and low input current of the Model 6512. If these insulators become contaminated, they can be cleaned with methanol and then dried with clean, pressurized air.

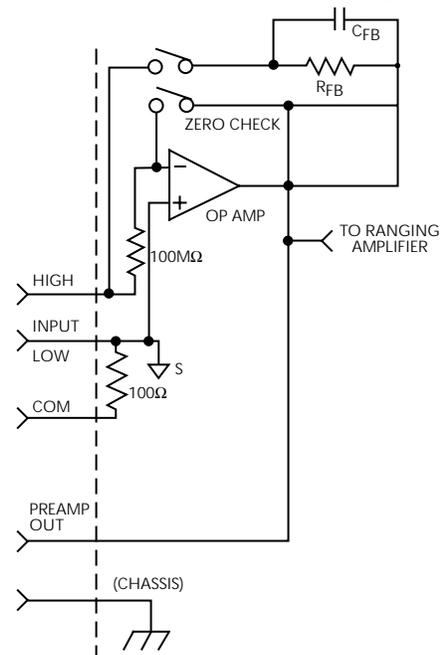


Figure 2-15
Electrometer input circuitry (external feedback mode)

2.9.2 Shielded fixture construction

Since shielding is so critical for proper operation of external feedback, it is recommended that a shielded fixture similar to the one shown in Figure 2-16 be used to house the feedback element. The fixture is constructed of a commercially available shielded fixture modified with the standard BNC connectors replaced with triaxial female connectors. For convenience, a banana jack can be mounted on the box to make the necessary PREAMP OUT connection. Alternately, a wire could be run through a rubber grommet mounted in a hole in the side of the box. Note that input low is connected to chassis ground within the shielded box. This connection can be made by using a small solder lug secured with a screw.

1. Connect the feedback element between the PREAMP OUT terminal and the Input High terminal.
2. Place the instrument in the external feedback mode by pressing the SHIFT then VOLTS buttons in that order. The AMPS and VOLTS indicators will illuminate simultaneously in the external feedback mode.
3. The display will show the voltage measured at the output of the input preamplifier (PREAMP OUT). However, the "V" exponent will not appear as in the volts mode. For example, with a 150mV output the display will show:

150.00 m

(External feedback may be temporarily digitally calibrated as outlined in paragraph 7.4.16.)

2.9.3 External feedback procedure

Use the following procedure to operate the Model 6512 in the external feedback mode.

4. The external feedback mode may be cancelled by pressing one of the four functions keys (VOLTS, OHMS, COUL, or AMPS).

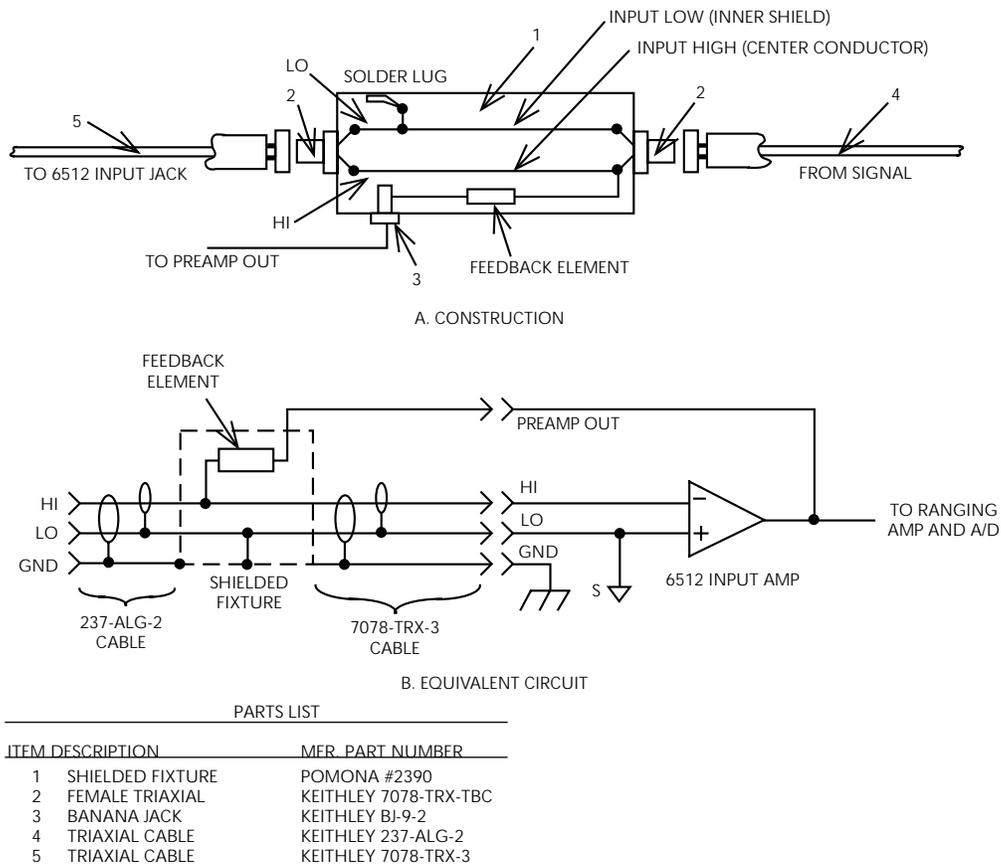


Figure 2-16
Shielded fixture construction

2.9.4 Non-standard coulombs ranges

In its standard form, the Model 6512 has three coulombs ranges allowing it to measure charge between 10fC and 20nC. Different charge measurement ranges can be used by placing an external feedback capacitor between the PREAMP OUT and Input HI and then placing the instrument in the external feedback mode.

Charge is related to capacitance and voltage by the formula: $Q = CV$, where Q is the charge in coulombs, C is the capacitance in farads, and V is the voltage in volts. The Model 6512 display will read charge directly in units determined by the value of C . For example, a 1 μ F capacitor will result in a displayed reading of 1 μ C/V.

In practice, the feedback capacitor should be greater than 100pF for feedback stability and of suitable dielectric material to ensure low leakage and low dielectric absorption. Polystyrene, polypropylene, and Teflon dielectric capacitors are examples of capacitor types with these desirable characteristics. The capacitor should be mounted in a shielded fixture like the one in Figure 2-16.

To discharge the external feedback capacitor, enable zero check. The discharge time constant will be given by: $\tau = (10M\Omega)(C_{FB})$. Allow five time constants for discharge to within 1% of final value.

2.9.5 Logarithmic currents

The use of a diode junction in the external feedback path permits a logarithmic current-to-voltage conversion. This relationship for a junction diode is given by the equation:

$$V = mkT/q \ln(I/I_O) + IR_B$$

where: q = unit of charge (1.6022×10^{-19})
 k = Boltzmann's constant (1.3806×10^{-23})
 T = temperature (K).

The limitations in this equation center on the factors I_O , m , and R_B . I_O is the extrapolated current for V_O . An empirical proportional constant, m , accounts for the different character current conduction (recombination and diffusion mechanisms) within the junction, typically varying between 1 and 2. Finally, R_B constitutes the ohmic bulk resistance of the di-

ode junction material. I_O and R_B limit the usefulness of the junction diode at low and high currents respectively. The factor m introduces non-linearities between those two extremes. Because of these limitations, most diodes have a limited range of logarithmic behavior.

A solution to these constraints is to use a transistor configured as a "transdiode" in the feedback path, as shown in Figure 2-17. Analyzing the transistor in this configuration leads to the relationship:

$$V = kT/q[\ln(I/I_O) - \ln(h_{FE}/(1 + h_{FE}))]$$

where h_{FE} is the current gain of the transistor.

From this equation, proper selection of Q_1 would require a device with high current gain (h_{FE}), which is maintained over a wide range of emitter currents. Suitable devices for this application include Analog Devices AD812 and Precision Monolithics MAT-01. Use the enclosure in Figure 2-16 to shield the device.

Frequency compensation/stabilization is accomplished by adding a feedback capacitor, C_{FB} . The value of this capacitor depends on the particular transistor being used and the maximum current level expected. Compensation at maximum current is required because the dynamic impedance will be minimum at this point. It should be noted that the response speed at lower currents will be compromised due to the increasing dynamic impedance, which is given by the following formula:

$$Z = \frac{dV}{dI} = kT/qI = 0.026/I \text{ (@ } 25^\circ\text{C)}$$

Using the above transistors, a minimum RC time constant of 100 μ sec at maximum input current would be used. At I_{IN} (max) of 100 μ A, this value would correspond to 0.4 μ F. Note that at 100nA, this value would increase the RC response time constant to 100msec. A minimum capacitance of 100pF is recommended.

Although the input signal to this particular circuit is assumed to be a current, conversion to voltage input could be performed by placing a shunt resistor across the input. However, the nominal voltage burden of 1mV must be considered as an error signal that must be taken into account.

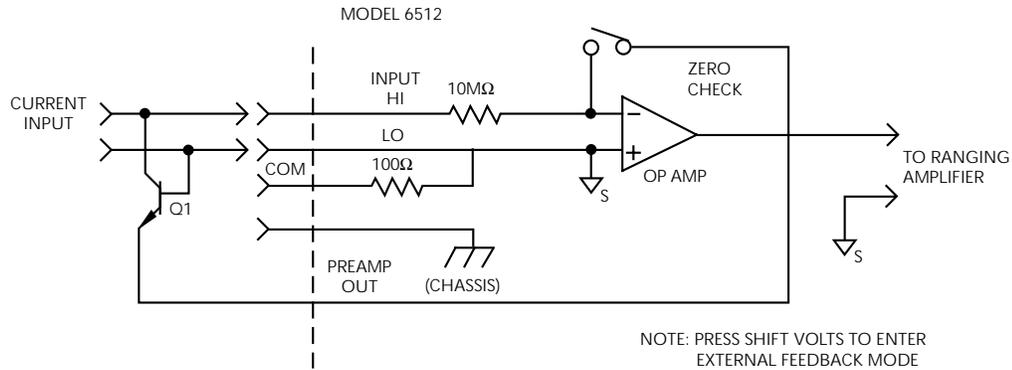


Figure 2-17
“Transdiode” logarithmic current configuration

Further processing of the current response can be achieved by using the suppress feature. For example, suppress could be enabled with a reference input current applied. For all subsequent currents, the natural logarithm of the ratio of the measured current to the suppressed current would then be displayed:

$$V_{DISP} = V_{SUPPRESS} \frac{kT}{q} (\ln(I_{READ}/I_O) - \ln(I_{SUPPRESS}/I_O))$$

$$= \frac{kT}{q} (\ln(I_{READ}/I_{SUPPRESS}))$$

$$= 0.26/I (\ln(I_{READ}/I_{SUPPRESS})) @ 25^\circ C$$

NOTE

The circuit topology of Figure 2-17 works for positive input currents only. For bipolar input signals, an external offset bias must be applied, or use a PNP transistor for Q₁.

2.9.6 Non-decade current gains

The Model 6512 electrometer input uses internal decade resistance feedback networks for the current ranges. In some applications, non-decade current gains may be desirable. As shown in Figure 2-18, an external feedback resistor, R_{FB}, can be used to serve this purpose. Limitations on the magnitude of the feedback current require that the value of R_{FB} be greater than 10²Ω.

Note that external feedback can be temporarily calibrated over a range of ±12% using the calibration program with the calibration jumper in the disable position. See paragraph 7.4.16 in Section 7.

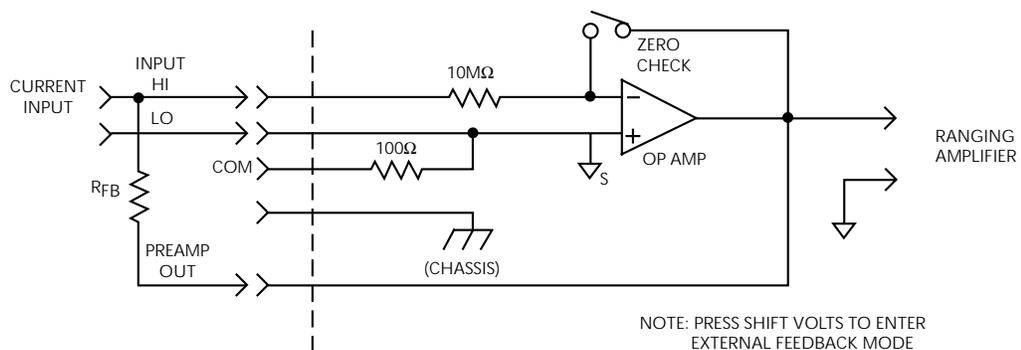


Figure 2-18
Non-decade current gains

2.10 Using zero correct and baseline suppression

The Model 6512 has zero correction and baseline suppression modes that allow the cancellation of any internal offsets, or the storage of a baseline value that can be subtracted from subsequent readings.

2.10.1 Zero correct and zero check

The ZERO CORRECT and ZERO CHECK buttons work together to cancel any internal offsets that might reduce accuracy. Note that the specifications listed for the instrument at the front of this manual assume that the instrument has been zeroed; use the following procedure to zero the instrument. Note that the instrument should be zero corrected on the range to be used, or on the lowest range of the function being used.

Proceed as follows to zero correct the instrument:

1. With the zero correct mode off, press the ZERO CHECK button. Be sure the ZERO CHECK light is on. In this mode, the input signal is disconnected from the input amplifier, and the input circuit is configured, as shown in Figure 2-19. The internal preamplifier is configured to measure its own offset when zero check is enabled.
2. Press the ZERO CORRECT button to zero the instrument. Note that if zero check is not enabled, the zeroing process will not take place. The previously stored zero parameter will be used instead.
3. To take readings, press ZERO CHECK to disable the zero check mode.
4. Readings can now be taken in the normal manner. Note that the instrument will remain zeroed even if the instrument is moved uprange.
5. For maximum accuracy, the zero correction process should be repeated every 24 hours when the ambient temperature changes by more than 1°C, or when the function is changed.

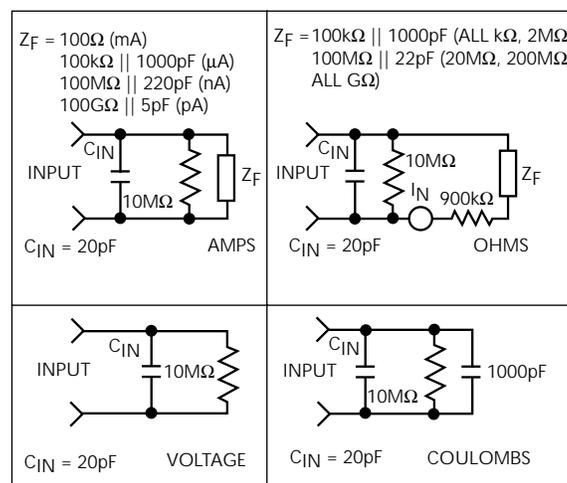


Figure 2-19

Equivalent input impedance with zero check enabled

NOTES:

1. Leave zero check enabled when connecting or disconnecting input signals (except for the coulombs function), or when changing functions.
2. Zero will automatically be scaled when the instrument is moved uprange.
3. Do not move the instrument down range after zero correction. Re-zero the instrument after moving down range.

2.10.2 Using suppression

The suppression mode allows a stored offset value to be subtracted from subsequent readings. When the SUPPRESS button is pressed, the instrument will trigger a conversion and internally store the displayed value as a baseline. The SUPPRESS LED will illuminate to indicate that the suppression mode is enabled. All subsequent readings will be the difference between the suppressed value and the actual signal level.

The baseline maintains its absolute value regardless of range. For example, if a 1V signal is suppressed on the 2V range, it will remain at 1V on the 20V and 200V ranges. Only one reading for the presently selected function can be suppressed; the value will be lost if the function is changed.

The suppressed readings can be as small as the resolution of the instrument will allow, or as large as full range. Some typical examples include:

Suppressed Reading	Applied Signal	Displayed Value
+10.500V	+18.600V	+8.100V
+2.556nA	+1.8000nA	-0.7560nA
-12.600mA	+4.500mA	+17.100mA

To use suppression, perform the following steps:

1. Cancel suppress if presently enabled.
2. Select a range and function that is consistent with the anticipated measurement.
3. Connect the signal to be suppressed to the instrument input.

WARNING

With suppress enabled, the voltage on the input terminals may be significantly larger than the displayed value. For example, if a 150VDC baseline is stored, an applied voltage of +175V will result in a displayed value of only +25V.

4. Press the SUPPRESS button. The triggered reading will be stored at that point.
5. Disconnect the suppressed signal from the input, and connect the signal to be measured in its place. Subsequent readings will be the difference between the suppressed value and the applied signal.
6. To return the instrument to the normal mode, press the SUPPRESS button. The SUPPRESS light will go off, and the instrument will be taken out of the suppression mode. The previously stored suppressed value will be cancelled.

NOTES:

1. Using suppress reduces the dynamic range of the measurement. For example, if the suppressed value is 100mV on the 200mV range, an input voltage of 100mV or more will over-range the instrument even though input voltages up to 199.99mV are normally within the capabilities of the 200mV range. If the instrument is in the auto-range mode, it will move up range, if necessary.
2. Setting the range lower than the suppressed value will over-range the display; the instrument will display the "OL" message under these conditions.
3. To store a new baseline, suppress must first be disabled and then enabled once again. The new value will be stored with the first triggered conversion.
4. Do not move the instrument down range when using suppress.

2.11 Data storage

The Model 6512 has an internal 100-point data store mode that can be used to log a series of readings. The fill rate of the data store buffer can be set to specific intervals by a parameter that is entered when the storage mode is first enabled. Alternatively, a special one-shot trigger mode can be used to control the fill rate from the front panel. Once data is stored, readings can be easily recalled from the front panel.

Minimum and maximum values can also be retained for future recall. As long as data store is enabled, maximum and minimum values are updated with each reading conversion.

Enter the data storage mode as follows:

1. Press and hold the DATA STORE ON/OFF button. The instrument will then scroll through the various reading rates that are listed in Table 2-8. In addition to the continuous rate, which stores readings at the conversion rate (about three readings per second), five additional intervals from one reading per second to one reading per hour are available. A special trigger mode allows you to control the interval with the TRIG button. During the rate selection process, the display will appear as follows:

r=3

In this example, the rate parameter is 3, indicating a 1 rdg/min interval.

Table 2-8
Data store reading rates

r Value	Rate
0	Conversion Rate (every 360msec)
1	One Reading Per Second
2	One Reading Every 10 seconds
3	One Reading Per Minute
4	One Reading Every 10 Minutes
5	One Reading Per Hour
6	One reading Per Front Panel Trigger

- To select the desired interval, simply release the ON/OFF button when the desired rate appears in the display. The Model 6512 will then begin storing readings at the selected rate. If you selected the triggered mode, one reading will be stored in memory each time the front panel TRIG button is pushed.
(For rapid starts, the rate can be pre-selected by pressing ON/OFF, releasing the button when the selected rate is displayed, and then turning off data store. Storage will then begin at the pre-selected rate the next time the ON/OFF button is pressed.)

- When data store memory is full (after all 100 readings have been stored), the instrument will stop logging data, and the DATA LED will flash to indicate that memory is full.

- Readings can be recalled any time (even if the instrument is still logging) by pressing and holding the RECALL button. Holding the RECALL button in causes the reading memory location number to be displayed. Releasing the RECALL button causes the reading at that location to be displayed. The first data point to be displayed will be the last reading stored. For example, if reading #65 was the last point, the display will show:

n=65

- The second and third points will be the high and low data points. For example, for the high value, the display will show:

n=HI

Similarly, the display will show the following for the low data point:

n=Lo

- Following these three points, the remaining data points will be displayed, beginning with the first one stored. The memory location will increment from 1 to the maximum point stored. For example, the tenth reading appears as:

n=10

- To continue recalling readings, use the RECALL button to scroll reading memory locations. Scrolling becomes more rapid if the RECALL button is held in. Release the button when the desired data point is displayed.
- The recall mode can be cancelled simply by pressing SHIFT RECALL. The instrument will then return to the normal display mode. As long as data store is not disabled and then re-enabled, readings are retained within memory. You can return to the recall mode at any time to review data.
- To cancel data store operation, press the ON/OFF button. The ON/OFF LED will turn off, indicating that data store is disabled. Data is retained until data store is enabled once again. Thus, you can still recall data even after data store is turned off.

Data Store Operating Notes:

- Data logging continues at the selected rate during recall until all 100 locations have been filled. Logging stops when all 100 locations are full, as indicated by the flashing DATA indicator.
- The data store trigger mode should not be confused with the front panel trigger mode. The data store trigger mode is enabled by entering the special trigger parameter (r=6) at the beginning of the data storage process, while the front panel trigger mode is entered by pressing SHIFT TRIG.
- If the instrument is placed in the front panel one-shot trigger mode, display readings will be triggered at the data store rate interval except when r=0. For example, if the instrument is set up for 10 minute intervals, one reading will be triggered and displayed every 10 minutes. When r=0, a single reading is stored each time an appropriate trigger is received (for example, GET in the T3 trigger mode, as described in Section 3).
- The data store rate can be used to control the data output rate in the IEEE-488 talk-only mode. To use the Model 6512 in this manner, place the instrument in the talk-only mode (see Section 3). Now enter the data storage mode, and select the desired interval as described above.

The instrument will then output readings over the IEEE-488 bus at the selected rate.

5. The storage rate in $r=0$ and $r=1$ may be affected if the instrument is in auto-range and a range change occurs. Typically, it takes about 350msec per range change.

Minimum/maximum operation

Minimum/Maximum operation is essentially separate from data store except for the fact that both are enabled or disabled by the ON/OFF button. Thus, the minimum and maximum data points are continuously updated with each triggered conversion as long as the ON/OFF LED is on. Note that only range, not function, is indicated when reading maximum and minimum values. Maximum and minimum values can be obtained during the recall process, as indicated in step 4 above.

2.12 External triggering

The Model 6512 has two BNC connectors on the rear panel associated with instrument triggering. The EXTERNAL TRIGGER INPUT allows the instrument to be triggered by other devices, while the METER COMPLETE OUTPUT allows the instrument to trigger other devices.

2.12.1 External trigger input

The Model 6512 may be triggered on a continuous or one-shot basis. For each of these modes, the trigger stimulus will depend on the selected trigger mode, which is further described in Section 3. In a continuous trigger mode, the instrument takes a continuous series of readings. A trigger stimulus in continuous aborts a reading in progress and triggers a new series of readings. In a one-shot mode, only a single reading is taken each time the instrument is triggered.

The EXTERNAL TRIGGER INPUT requires a falling-edge pulse at TTL logic levels, as shown in Figure 2-20. The low logic level should be between 0-0.8V, and the high level should be 2-5V. The minimum pulse width for reliable triggering is approximately 10µsec. Connections to the rear panel EXTERNAL TRIGGER INPUT jack should be made with a standard BNC coaxial cable. If the instrument is in the ex-

ternal trigger mode, it will be triggered to take readings while in either a continuous or one-shot mode when the negative-going edge of the external trigger pulse occurs.

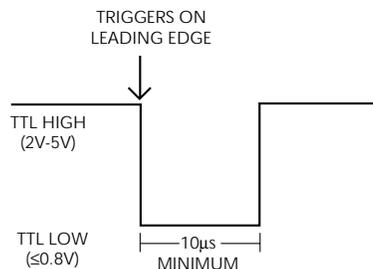


Figure 2-20
External trigger pulse specifications

To use the external triggering, proceed as follows:

1. Connect the external trigger source to the rear panel BNC EXTERNAL TRIGGER INPUT connector. The shield (outer) part of the connector is connected to digital common. Since an internal pull-up resistor is included, a mechanical switch may be used. Note, however, that de-bouncing circuitry will probably be required to avoid improper triggering.
2. Place the instrument in the one-shot trigger mode by pressing SHIFT and then TRIG in that order. The instrument will indicate that it is in the one-shot mode by illuminating the SGL indicator.
3. To trigger the instrument, apply a pulse to the EXTERNAL TRIGGER INPUT. The instrument will process a single reading each time the pulse is applied. Note that the instrument may also be triggered by pressing TRIG.
4. To return the instrument to the continuous mode, press the SHIFT and TRIG buttons in sequence.

NOTES:

1. External triggering can be used to control the fill rate in the data store mode. See paragraph 2.11 for details.
2. The Model 6512 must be in the appropriate trigger mode to respond to external triggering (the unit will be in this mode upon power-up). See Section 3 for details on programming trigger modes.

- If a trigger overrun occurs (the instrument is triggered while processing a reading from a previous trigger), it will ignore the trigger and display the following:

t Err

2.12.2 Meter complete output

The Model 6512 has an available output pulse that can be used to trigger other instrumentation. A single TTL-compatible negative-going pulse with a minimum duration of 10 μ sec (see Figure 2-21) will appear at the METER COMPLETE OUTPUT jack each time the instrument completes a reading. To use the METER COMPLETE OUTPUT, proceed as follows:

- Connect the Model 6512 to the instrument to be triggered with a suitable shielded cable. Use a standard BNC coaxial cable to make the connection to the Model 6512.

CAUTION

Do not exceed 30V RMS between the METER COMPLETE common (outer ring) and chassis ground, or instrument damage may occur.

- Select the desired function, range, trigger mode, and other operating parameters, as desired.
- In a continuous trigger mode, the instrument will output pulses at the conversion rate; each pulse will occur after the Model 6512 has completed a conversion (about every 360msec).
- In a one-shot trigger mode, the Model 6512 will output a pulse once each time it is triggered after it completes the reading conversion.

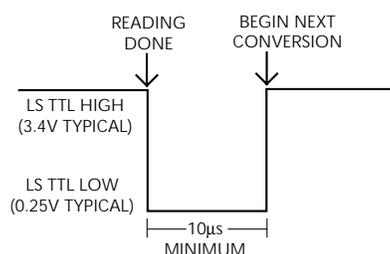


Figure 2-21
Meter complete pulse specifications

2.12.3 Triggering example

As an example of using both the external trigger input and the meter complete output, assume that the Model 6512 is to be used in conjunction with a Keithley Model 7001 Switch System to allow the Model 6512 to measure a number of different signals, which are to be switched by the scanner. Using appropriate scanner cards, the Model 7001 can switch up to 80 2-pole channels.

By connecting the triggering inputs of the two instruments together, a complete automatic measurement sequence could be performed. Data obtained from each measurement point could be stored by the data store mode of the Model 6512. Alternatively, the Model 6512 could be connected through the IEEE-488 bus to a printer, which would print out the data for each point as it is measured.

Once the Model 7001 is programmed for its scan sequence, the measurement procedure is set to begin. When the Model 7001 closes the selected channel, it triggers the Model 6512 to take a reading. When the Model 6512 finishes the reading, it triggers the Model 7001 to scan to the next channel. The process repeats until all channels have been scanned.

To use the Model 6512 with the Model 7001, proceed as follows:

- Connect the Model 6512 to the Model 7001 as shown in Figure 2-22. Use shielded cables with BNC connectors. The Model 6512 METER COMPLETE OUTPUT jack should be connected to the Model 7001 EXTERNAL TRIGGER input jack. The Model 6512 EXTERNAL TRIGGER INPUT should be connected to the Model 7001 CHANNEL READY output. Additional connections, which are not shown on the diagram, will also be necessary to apply signal inputs to the scanner cards, as well as for the signal lines between the scanner and the Model 6512.
- Place the Model 6512 in the one-shot trigger mode by pressing the SHIFT and TRIG buttons, in that order.
- Install the desired scanner cards and make the required input and output signal connections.
- Program the Model 7001 scan list and trigger modes as required. See the Model 7001 Instruction Manual for details.
- If data storage is required, enter the data storage mode as described in paragraph 2.11.

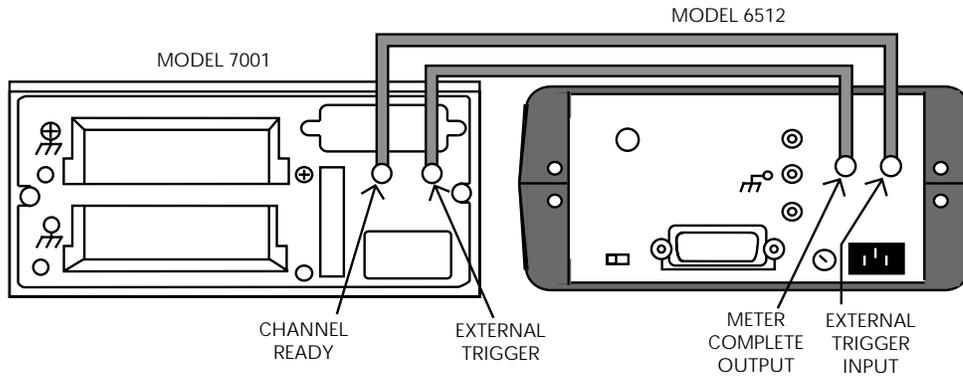


Figure 2-22
External triggering example

- Begin the measurement sequence by pressing the Model 7001 STEP button. The Model 7001 will close the first channel and trigger the Model 6512 to take a reading. When the Model 6512 completes the reading, it will trigger the Model 7001 to go to the next channel. The process repeats until all programmed channels have been scanned.

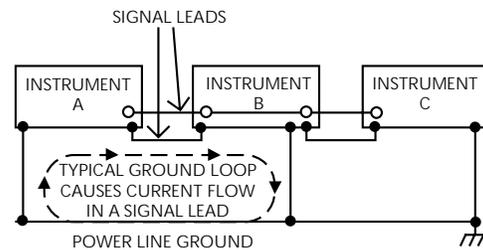


Figure 2-23
Multiple ground points create a ground loop

2.13 Measurement considerations

The Model 6512 is a highly sensitive instrument that can measure extremely low signal levels. At these low signal levels, a number of factors can affect a measurement. Some considerations when making measurements with the Model 6512 are discussed in the following paragraphs.

2.13.1 Ground loops

Ground loops that occur in multiple-instrument test set-ups can create error signals that cause erratic or erroneous measurements. The configuration shown in Figure 2-23 introduces errors in two ways. Large ground currents flowing in one of the wires will encounter small resistances, either in the wires, or at the connecting points. This small resistance results in voltage drops that can affect the measurement. Even if the ground loop currents are small, magnetic flux cutting across the large loops formed by the ground leads can induce sufficient voltages to disturb sensitive measurements.

To prevent ground loops, instruments should be connected to ground at only a single point, as shown in Figure 2-24. Note that only a single instrument is connected directly to power line ground. Experimentation is the best way to determine an acceptable arrangement. For this purpose, measuring instruments should be placed on their lowest ranges. The configuration that results in the lowest noise signal is the one that should be used.

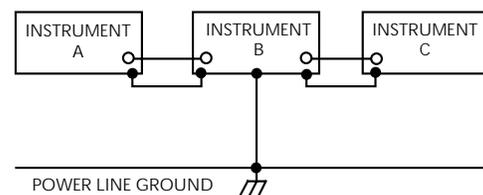


Figure 2-24
Eliminating ground loops

2.13.2 Electrostatic interference

Electrostatic interference occurs when an electrically charged object is brought near an uncharged object, thus inducing a charge on the previously uncharged object. Usually, effects of such electrostatic action are not noticeable because low impedance levels allow the induced charge to dissipate quickly. However, the high impedance levels of many Model 6512 Electrometer measurements do not allow these charges to decay rapidly, and erroneous or unstable readings may result. These erroneous or unstable readings may be caused in the following ways:

1. DC electrostatic field can cause undetected errors or noise in the reading.
2. AC electrostatic fields can cause errors by driving the input preamplifier into saturation, or through rectification that produces DC errors.

Electrostatic interference is first recognizable when hand or body movements near the experiment cause fluctuations in the reading. Pick-up from AC fields can also be detected by observing the electrometer preamp output on an oscilloscope. Line frequency signals on the output are an indication that electrostatic interference is present.

Means of minimizing electrostatic interference include:

1. Shielding. Possibilities include: a shielded room, a shielded booth, shielding the sensitive circuit, and using shielded cable. The shield should always be connected to a solid connector that is connected to signal low. If circuit low is floated above ground, observe safety precautions, and avoid touching the shield. Meshed screen or loosely braided cable could be inadequate for high impedances, or in strong fields. Note, however, that shielding can increase capacitance in the measuring circuit, possibly slowing down response time.
2. Reduction of electrostatic fields. Moving power lines or other sources away from the experiment reduces the amount of electrostatic interference seen in the measurement.

2.13.3 Thermal EMFs

Thermal EMFs are small electric potentials generated by differences in temperature at the junction of two dissimilar metals. Although thermal EMFs are most troublesome with low-voltage signals, they can also affect measurements made at higher levels in extreme cases.

Low-thermal connections should be used whenever thermal EMFs are known to be a problem. Crimped copper-to-copper

connections should be used to minimize these effects. Make certain that all connecting surfaces are kept clean and free of oxides, since copper-to-copper oxide junctions generate much higher thermal EMFs than do pure copper-to-copper connections.

2.13.4 Electromagnetic interference (EMI)

The electromagnetic interference characteristics of the Model 6512 Electrometer comply with the electromagnetic compatibility (EMC) requirements of the European Union as denoted by the CE mark. However, it is still possible for sensitive measurements to be affected by external sources. In these instances, special precautions may be required in the measurement setup.

Sources of EMI include:

- radio and television broadcast transmitters
- communications transmitters, including cellular phones and handheld radios
- devices incorporating microprocessors and high speed digital circuits
- impulse sources as in the case of arcing in high-voltage environments

The effect on instrument performance can be considerable if enough of the unwanted signal is present. The effects of EMI can be seen as an unusually large offset, or, in the case of impulse sources, erratic variations in the displayed reading.

The instrument and experiment should be kept as far away as possible from any EMI sources. Additional shielding of the instrument, experiment, and test leads will often reduce EMI to an acceptable level. In extreme cases, a specially constructed screen room may be required to sufficiently attenuate the troublesome signal.

External filtering of the input signal path may be required. In some cases, a simple one-pole filter may be sufficient. In more difficult situations, multiple notch or band-stop filters, tuned to the offending frequency range, may be required. Connecting multiple capacitors of widely different values in parallel will maintain a low impedance across a wide frequency range. Such filtering, however, may have detrimental effects (such as increased response time) on the measurement.

2.13.5 Leakage resistance effects

At normal resistance levels, the effects of leakage resistance are seldom seen because any leakage resistance present is generally much higher than the resistance levels encountered

in the circuit under test. At the high resistance levels of many Model 6512 measurements, however, leakage resistance can have a detrimental effect on the measurement. Such leakage resistance can occur in the circuit under test (on PC boards, for example), in the connecting cable, or even at the electrometer input itself, especially if the input connector is not kept clean.

To see how leakage resistance can affect measurement accuracy, let us review the equivalent circuit in Figure 2-25. E_S and R_S are the source voltage and source resistance respectively. The leakage resistance is represented by R_L , while the voltage, as seen by the electrometer, is V_M .

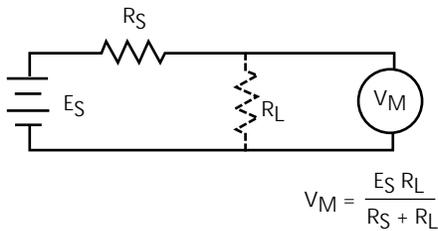


Figure 2-25
Leakage resistance effects

R_S and R_L form a voltage divider that attenuates the input signal in accordance with the formula:

$$V_M = \frac{E_S R_L}{R_S + R_L}$$

Thus, if R_L has a value of $100G\Omega$, and R_S is $10G\Omega$, the actual voltage measured by the electrometer with a 10V source would be:

$$V_M = \frac{10 \times 100G\Omega}{10G\Omega + 100G\Omega}$$

$$V_M = 9.09V$$

Thus, we see that the effects of leakage resistance can be substantial, resulting in an error of more than 9% in this case.

Certain steps can be taken to ensure that the effects of leakage resistance are minimal. The most obvious remedy to ensure that the leakage resistance itself is as high as possible. Use only good quality triaxial cable for signal connections,

and make sure that the circuit under test and connectors are kept free of contamination.

Even with these steps, however, there is a limit as to how high the leakage resistance can be. In those cases, guarded input connections should be used, as described in paragraph 2.7.4.

2.13.6 Input capacitance effects

Virtually any circuit has at least some small amount of distributed capacitance that can slow down the response time of high-impedance measurements. Even if the circuit itself has minimal capacitance, cable or instrument input capacitance effects can be noticeable.

As an example, assume that the Model 6512 is being used to measure the value of a high-impedance voltage source, as shown in Figure 2-26. The source and source resistance are represented by E_S and R_S , the input capacitance is C_{IN} , and the voltage measured by the electrometer is V_M .

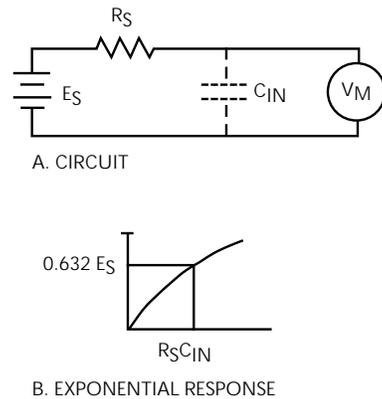


Figure 2-26
Input capacitance effects

When E_S is first applied, the voltage across the capacitance (and thus, at the electrometer input) does not instantaneously rise to its final value. Instead, the capacitance charges exponentially in accordance with the following formula:

$$V_M = E_S \left(1 - e^{-\frac{t}{RC}} \right)$$

Note that R_S is given in megohms, C is in microfarads, while t is in seconds.

Because of the charging of C_{IN} , the electrometer follows the exponential curve shown in Figure 2-26B. At the end of one time constant ($R_S C_{IN}$), the voltage will reach approximately 63% of its final value. At the end of two time constants ($2R_S C_{IN}$), the voltage will reach about 86% of its final value, and so on. Generally, at least five time constants should be allowed for better than 1% accuracy.

The amount of time that must be allowed will, of course, depend on the relative values of R_S and C_{IN} . For example, when measuring a voltage with a source resistance of $10G\Omega$ with an input capacitance of $100pF$, a time constant of one second results. Thus, at least five seconds must be allowed to achieve a better than 1% accuracy figure. Table 2-9 summarizes voltage values and percentage error values for ten different time constants ($\tau = R_S C_{IN}$).

Table 2-9
Voltage and percent error for various time constants

Time constant*	V_M	%Error
τ	$0.632E_S$	37%
2τ	$0.86E_S$	14%
3τ	$0.95E_S$	5%
4τ	$0.982E_S$	1.8%
5τ	$0.993E_S$	0.674%
6τ	$0.9975E_S$	0.25%
7τ	$0.999E_S$	0.09%

* $\tau = R_S C_{IN}$

The most obvious method to minimize the slowing effects of input capacitance is to minimize the amount of capacitance in the circuit. Using low-capacitance cable and keeping the cable as short as possible are two ways to do so. However, there is a limit to the amount of capacitance reduction that can be achieved. In those cases, especially where high impedance levels are involved, guarded operation (see paragraph 2.7.4) may be necessary.

While input capacitance does increase rise-time, it can help to filter out some noise present at the input by effectively reducing electrometer bandwidth. If we assume that all input capacitance is lumped into a single element, the half-power (-3dB) point of the circuit in Figure 2-26A will be:

$$f_{-3dB} = \frac{1}{2\pi R_S C_{IN}}$$

Thus, if R_S has a value of $10M\Omega$, and C_{IN} has a value of $100pF$, the half-power point will be $159Hz$.

2.13.7 Source resistance

As shown in Table 2-10, a minimum value of source resistance is recommended for each AMPS range. The reason for this limitation can be understood by examining Figure 2-27. C_S and C_F do not affect low-frequency noise and drift and can be ignored for the purposes of this discussion.

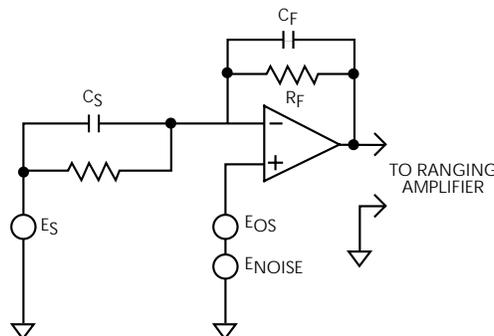


Figure 2-27
Simplified model for source resistance and source capacitance

Table 2-10
Minimum source resistance

Range	Minimum source resistance
All pA	$100G\Omega$
All nA	$100M\Omega$
All μA	$100k\Omega$
All mA	100Ω

Input amplifier noise (E_{NOISE}) and offset (E_{OS}) appearing at the output can be calculated as follows:

$$\text{Output } E_{NOISE} = \text{Input } E_{NOISE} \times \left(1 + \frac{R_F}{R_S} \right)$$

Thus, it is clear that, as long as $R_S \gg R_F$, Output $E_{NOISE} = \text{Input } E_{NOISE}$. However, as R_S decreases in value relative to R_F , Output E_{NOISE} increases. When $R_F = R_S$, Output $E_{NOISE} = 2 \times \text{Input } E_{NOISE}$, and the same relationship applies for E_{OS} .

The Model 6512 will typically show insignificant degradation in displayed performance with the noise gain of 2 resulting from allowing $R_S = R_F$. Typical amplifier Input E_{NOISE} is about 9 μ V p-p over a bandwidth of 0.1-10Hz. Amplifier E_{OS} can be nulled by using suppress. The temperature coefficient of E_{OS} is <30 μ V/ $^{\circ}$ C, and these values can be used with the above equation to determine expected displayed noise/drift given any source resistance. Note also that the values given in Table 2-10 for minimum source resistance also represent the value of R_F on that range.

2.13.8 Source capacitance

In amps, the Model 6512 is designed to accommodate up to 10,000pF input capacitance (C_S in Figure 2-27). This limit will preclude problems in most test setups and allow extremely long input cable lengths without inducing instability or oscillations.

Increasing source capacitance beyond this level may increase noise and induce instrument instability. Again referring to Figure 2-27, the noise gain of the measurement circuit can be found as follows:

$$\text{Output}E_{NOISE} = \text{Input}E_{NOISE} \times \left(1 + \frac{Z_F}{Z_S} \right)$$

where,

$$Z_F = \frac{R_F}{\sqrt{(2\pi f R_F C_F)^2 + 1}}$$

$$Z_S = \frac{R_S}{\sqrt{(2\pi f R_S C_S)^2 + 1}}$$

Note that as $f \rightarrow 0$, the above equation reduces to the low-frequency equation discussed in paragraph 2.13.7.

The frequency range of interest is from 0.1 to 10Hz, which is the noise bandwidth of the A/D converter. The value of C_F is 5pF for pA ranges, 22pF for nA ranges, and 1,000pF for μ A ranges. Also, since the noise factor is given in volts, current must be converted to volts. Table 2-11 summarizes equivalent voltage sensitivity of Model 6512 amps ranges.

Table 2-11

Equivalent voltage sensitivity of Model 6512 amps ranges

Range	Equivalent voltage sensitivity (μ V/count)
2pA, 2nA, 2 μ A, 2mA	10 μ V
20pA, 20nA, 20 μ A, 20mA	100 μ V
200pA, 200nA, 200 μ A	1mV

In general, as C_S becomes larger, the noise gain increases. An application where C_S may be greater than 10,000pF is leakage measurement of capacitors. In this case, Input E_{NOISE} must include the effects of the voltage source (E_S) used to bias the capacitor (any noise in the source voltage will increase the input noise).

When measuring leakage currents on capacitors larger than 10,000pF, stability and noise performance can be maintained by connecting a resistor in series with the capacitor under test. The value of this resistor should be about 1M Ω . For large capacitor values (>1 μ F), the value of the series limiting resistor can be made lower in order to improve settling times; however, values below 10k Ω are not generally recommended.

This resistor is not critical in terms of tolerance or stability. Any carbon composition resistor will prove adequate.

2.14 Engineering units conversion

The Model 6512 is a highly sensitive instrument with wide-ranging measurement capabilities. In the amps mode, for example, the unit can detect currents as low as 0.1fA (10^{-16} A). At the other extreme, resistances up to 200G Ω can be measured. The instrument can display its reading either in engineering units (such a mA) or in scientific notation (such as 10^{-3} A). Table 2-12 lists engineering units and their equivalent scientific notation values.

Table 2-12
Engineering units conversion

Symbol	Prefix	Exponent
f	femto-	10^{-15}
p	pico-	10^{-12}
n	nano-	10^{-9}
μ	micro-	10^{-6}
m	milli-	10^{-3}
k	kilo-	10^3
M	mega-	10^6
G	giga-	10^9

3

IEEE-488 Programming

3.1 Introduction

This section contains detailed information on programming Model 6512 operating modes over the IEEE-488 bus. For additional bus information, refer to the following sections of the Appendix:

- IEEE-488 bus overview: Appendix A
- General bus commands: Appendix B
- Interface function codes: Appendix C
- Example computer programs: Appendix D
- Compatibility with Model 617 Electrometer: Appendix E

3.2 Device-dependent command programming

IEEE-488 device-dependent commands are used with the Model 6512 to control various operating modes such as function, range, trigger mode, and data format. Each command is made up of a single ASCII letter followed by a number representing an option of that command. For example, a command to control the measuring function (Volts, Ohms, Amps, Coul) is programmed by sending an ASCII “F” followed by a number representing the function option.

Multiple commands

A number of commands may be grouped together in one string. A command string is usually terminated with an ASCII “X” character, which tells the instrument to execute

the command string. Commands sent without the execute character will not be executed at that time, but they will be retained within an internal command buffer for execution at the time the X character is received. If any errors occur, the instrument will display appropriate front panel error messages and generate an SRQ if programmed to do so.

Electrometer commands

Commands that directly affect the electrometer section (F, R, C, Z, N, T, and A) will trigger a reading when the command is executed. These bus commands affect the Model 6512 much like the front panel controls.

Order of command execution

Note that commands are not necessarily executed in the order received; instead, they will be executed in the same order as they appear in the status word:

Function (F); Range (R); Zero Check (C); Zero Correct (Z); Suppress (N); Trigger (T); Reading Mode (B); Data Storage (Q); SRQ Mode (M); EOI and Bus Hold-off (K); and Terminator (Y).

Thus to force a particular command sequence, you would follow each command with the execute character, as in the example string, C1XZ1XC0X, which can be used to zero correct the instrument.

Valid command strings

Device-dependent commands can be sent either one at a time, or in groups of several commands within a single string. Some examples of valid command strings include:

F0X Single command string.
 F0K1R0X Multiple command string.
 T6 X Spaces are ignored.

Typical invalid command strings include:

H1X Invalid command, as H is not one of the instrument commands.
 F9X Invalid command option because 9 is not an option of the F command.

If an illegal command (IDDC), illegal command option (IDDCO), is sent, or if a command string is sent with REN false, the string will be ignored, and an appropriate error message will be displayed.

Default conditions

Command default conditions are summarized in Table 3-1.

Device-dependent command summary

Device-dependent commands that control the Model 6512 are listed in Table 3-2. These commands are covered in detail in the following paragraphs.

NOTE

REN must be true when sending device-dependent commands to the instrument, or it will ignore the command and display a bus error message.

Controller programs

Refer to Appendix D for example programs that can be used to send commands to the Model 6512.

Table 3-1
Default conditions

Mode	Default value	Status*
Function	F0	Volts
Range	R0	Auto-range
Zero check	C1	Enabled
Zero correct	Z0	Disabled
Suppression	N0	Disabled
Trigger	T6	Continuous, external
Data format	G0	Prefix, no suffix
Data store	Q7	Disabled
SRQ mode	M00	Disabled
EOI and bus hold-off	K0	Both disabled
Terminator	Y<CR><LF>	<CR><LF>

* Instrument status on power-up or after receiving DCL or SDC.

Table 3-2
Device-dependent command summary

Mode	Command	Description	Paragraph
Calibration Value	A+nnn.nn or An.nnnE+n	Calibrate Function and Range	3.2.1
Reading Mode	B0 B1 B2 B3	Electrometer Buffer Reading Maximum Reading Minimum Reading	3.2.2
Zero Check	C0 C1	Zero Check Off Zero Check On	3.2.3
Function	F0 F1 F2 F3 F4	Volts Amps Ohms Coulombs External Feedback	3.2.4
Data Format	G0 G1 G2	Reading with Prefix (NDCV-1.23456E+00) Reading without Prefix (-1.23456E+00) Reading with Prefix and Buffer Suffix (if in B1) (NDCV-1.234556E+00,012)	3.2.5
EOI and Bus Hold-off	K0 K1 K2 K3	Enable both EOI and Bus Hold-off on X Disable EOI, Enable Bus Hold-off on X Enable EOI, Disable Bus Hold-off on X Disable both EOI and Bus Hold-off on X	3.2.6
Store Calibration	L1	Store Calibration Constants in NVRAM	3.2.7
SRQ	M0 M1 M2 M8 M16 M32	Disable SRQ Reading Overflow Buffer Full Reading Done Ready Error	3.2.8
Baseline Suppression	N0 N1	Suppression Disabled Suppression Enabled	3.2.9
Data Store	Q0 Q1 Q2 Q3 Q4 Q5 Q6 Q7	Conversion Rate One Reading Per Second One Reading Every 10 Seconds One Reading Per Minute One Reading Every 10 Minutes One Reading Per Hour Trigger Mode Disabled	3.2.10

Table 3-2*Device-dependent command summary (cont.)*

Mode	Command	Description	Paragraph																																																																														
Range		<table border="0"> <tr> <td></td> <td>Volts</td> <td>Amps</td> <td>Ohms</td> <td>Coul.</td> <td>External Feedback</td> </tr> <tr> <td>R0</td> <td>Auto</td> <td>Auto</td> <td>Auto</td> <td>Auto</td> <td>Auto</td> </tr> <tr> <td>R1</td> <td>200mV</td> <td>2pA</td> <td>2kΩ</td> <td>200pC</td> <td>200mV</td> </tr> <tr> <td>R2</td> <td>2V</td> <td>20pA</td> <td>20kΩ</td> <td>2nC</td> <td>2V</td> </tr> <tr> <td>R3</td> <td>20V</td> <td>200pA</td> <td>200kΩ</td> <td>20nC</td> <td>20V</td> </tr> <tr> <td>R4</td> <td>200V</td> <td>2nA</td> <td>2MΩ</td> <td>20nC</td> <td>20V</td> </tr> <tr> <td>R5</td> <td>200V</td> <td>20nA</td> <td>20MΩ</td> <td>20nC</td> <td>20V</td> </tr> <tr> <td>R6</td> <td>200V</td> <td>200nA</td> <td>200MΩ</td> <td>20nC</td> <td>20V</td> </tr> <tr> <td>R7</td> <td>200V</td> <td>2μA</td> <td>2GΩ</td> <td>20nC</td> <td>20V</td> </tr> <tr> <td>R8</td> <td>200V</td> <td>20μA</td> <td>20GΩ</td> <td>20nC</td> <td>20V</td> </tr> <tr> <td>R9</td> <td>200V</td> <td>200μA</td> <td>200GΩ</td> <td>20nC</td> <td>20V</td> </tr> <tr> <td>R10</td> <td>200V</td> <td>2mA</td> <td>200GΩ</td> <td>20nC</td> <td>20V</td> </tr> <tr> <td>R11</td> <td>200V</td> <td>20mA</td> <td>200GΩ</td> <td>20nC</td> <td>20V</td> </tr> </table>		Volts	Amps	Ohms	Coul.	External Feedback	R0	Auto	Auto	Auto	Auto	Auto	R1	200mV	2pA	2k Ω	200pC	200mV	R2	2V	20pA	20k Ω	2nC	2V	R3	20V	200pA	200k Ω	20nC	20V	R4	200V	2nA	2M Ω	20nC	20V	R5	200V	20nA	20M Ω	20nC	20V	R6	200V	200nA	200M Ω	20nC	20V	R7	200V	2 μ A	2G Ω	20nC	20V	R8	200V	20 μ A	20G Ω	20nC	20V	R9	200V	200 μ A	200G Ω	20nC	20V	R10	200V	2mA	200G Ω	20nC	20V	R11	200V	20mA	200G Ω	20nC	20V	3.2.11
		Volts	Amps	Ohms	Coul.	External Feedback																																																																											
	R0	Auto	Auto	Auto	Auto	Auto																																																																											
	R1	200mV	2pA	2k Ω	200pC	200mV																																																																											
	R2	2V	20pA	20k Ω	2nC	2V																																																																											
	R3	20V	200pA	200k Ω	20nC	20V																																																																											
	R4	200V	2nA	2M Ω	20nC	20V																																																																											
	R5	200V	20nA	20M Ω	20nC	20V																																																																											
	R6	200V	200nA	200M Ω	20nC	20V																																																																											
	R7	200V	2 μ A	2G Ω	20nC	20V																																																																											
	R8	200V	20 μ A	20G Ω	20nC	20V																																																																											
	R9	200V	200 μ A	200G Ω	20nC	20V																																																																											
	R10	200V	2mA	200G Ω	20nC	20V																																																																											
R11	200V	20mA	200G Ω	20nC	20V																																																																												
	R12	Cancel auto-ranging for all functions.																																																																															
Trigger Mode	T0	Continuous, Triggered by Talk	3.2.12																																																																														
	T1	One-shot, Triggered by Talk																																																																															
	T2	Continuous, Triggered by GET																																																																															
	T3	One-shot, Triggered by GET																																																																															
	T4	Continuous, Triggered by X																																																																															
	T5	One-shot, Triggered by X																																																																															
	T6	Continuous, Triggered by External Trigger																																																																															
	T7	One-shot, Triggered by External Trigger																																																																															
Status Word	U0	Send Status Word: 6512FRRCZNT0BG0QMMKYY	3.2.13																																																																														
	U1	Send Error Conditions																																																																															
	U2	Send Data Conditions																																																																															
Execute	X	Execute other device-dependent commands	3.2.14																																																																														
Terminator	Y<LF CR>	Terminator = <LF> <CR>	3.2.15																																																																														
	Y<CR LF>	Terminator = <CR> <LF>																																																																															
	Y<ASCII>	Terminator = ASCII character (except A-Z)																																																																															
	YX	No terminator																																																																															
Zero Correct	Z0	Zero Correct Disabled	3.2.16																																																																														
	Z1	Zero Correct Enabled																																																																															

3.2.1 Calibration value (A)

Purpose	To send calibration values to the instrument when digitally calibrating the unit.
Format	Ann.nnn An.nnnE+n
Description	<p>One advanced feature of the Model 6512 is its digital calibration capabilities. Instead of the more difficult method of adjusting a number of potentiometers, the user need only apply an appropriate calibration signal and send the calibration value over the bus.</p> <p>If the calibration value is outside the allowed range ($\pm 6\%$ of nominal value), a number error will occur, as indicated by the following message:</p> <p style="text-align: center;">n Err</p> <p>Once all functions and ranges have been calibrated, permanent storage of calibration parameters must be performed, as described in paragraph 3.2.7.</p>
Programming Note	The proper calibration signal must be connected to the instrument before attempting calibration. See Section 7 for complete details on calibrating the instrument, either from the front panel or over the bus.
Examples	A1.9X Value = 1.9. A1.9E-3X Value = 0.0019

3.2.2 Reading mode (B)

Purpose	To control the source of the data sent over the IEEE-488 bus.
Format	B0 Electrometer reading B1 Data store reading B2 Maximum reading B3 Minimum reading
Default	Upon power-up, or after a DCL or SDC command, the instrument will be in the B0 (electrometer) mode.
Description	<p>The reading mode command parameters allow the selection of the source of data that is transmitted over the IEEE-488 bus. Through this command, you have a choice of data from the electrometer, data store reading, or minimum and maximum values. Note that the commands associated with data store are always available; however the suffix of the reading string will show 000 if data store is disabled, as in NDCV+1.2345E+00,000. Minimum/maximum values returned will be the last values stored, unless these parameters are requested after a DCL, in which case unusable readings will be returned.</p> <p>When in B0, normal electrometer readings will be sent. In a continuous trigger mode, readings will be updated at the conversion rate (one reading every 360msec). In B1, readings will be taken from consecutive data store locations, beginning with the oldest reading and progressing to the newest reading until all readings currently stored have been read. Once all readings have been requested, the unit will cycle back and begin again. These readings may be accessed even if data store is still taking place.</p>

While data store is enabled, the maximum (most positive) and minimum (most negative) readings may also be requested by sending the B2 or B3 commands. Note that the maximum and minimum values are updated at the maximum reading rate while data store is enabled.

Programming Note

See paragraph 3.2.10 for a complete description of data storage.

Examples

B1X Select data store reading.
B3X Select minimum reading.
B0X Choose electrometer reading.

3.2.3 Zero check (C)

Purpose

To zero check the instrument as an aid in nulling offsets.

Format

C0 Zero check off
C1 Zero check on

Default

Upon power-up, or after receiving a DCL or SDC command, zero check will be enabled (C1).

Description

The zero check command works together with the zero correct command to cancel any internal offsets that might upset accuracy. See paragraph 3.2.16 for a complete description of the zero correction process.

Programming Notes

1. In general, zero check should be enabled when changing input connections (except for the coulombs function).
2. After sending a zero correct command, the instrument will be ready for a new command on reading done.

Examples

C0X Disable zero check.
C1X Enable zero check.

3.2.4 Function (F)

Purpose

To program the operating function of the instrument.

Format

F0 Volts
F1 Amps
F2 Ohms
F3 Coulombs
F4 External Feedback

Default

Upon power-up, or after receiving a DCL or SDC command, the instrument will be in the F0 (volts) function.

Description

The function command and its options allow you to select the type of measurement made by the Model 6512, and they perform essentially the same operations as the front panel function keys. The parameter options associated with the function command set the instrument to measure voltage, current, resistance, charge, or external feedback.

Programming Note

When the instrument responds to a function command, it will be ready to take a reading once the input circuitry is properly configured.

Examples

F1X Select amps function.
F3X Switch to coulombs function.

3.2.5 Data format (G)

Purpose	To control the format of the data the instrument sends over the IEEE-488 bus.
Format	G0 Reading with prefix (NDCV-1.23456E+00) G1 Reading without prefix (-1.23456E+00) G2 Reading with prefix and suffix (NDCV-1.23456E+00,001)
Default	Upon power-up, or after a DCL or SDC command, the instrument will be in the G0 (reading with prefix) mode.
Description	Through the use of the G command, the format of the data the instrument sends over the bus may be controlled. Figure 3-1 further clarifies the general data format. Note that the prefix identifies a normal or overflow reading as well as the measuring function. The mantissa is always 5½ digits, although the most significant digit will assume a value of 2 under overload conditions.
Programming Notes	<ol style="list-style-type: none"> The B command affects the source of the data. See paragraph 3.2.2 for complete details. In the G2 mode, the suffix will always return 000 if the instrument is in the electrometer reading mode (B0).
Examples	G2X Prefix and suffix mode. G0X Prefix only mode.

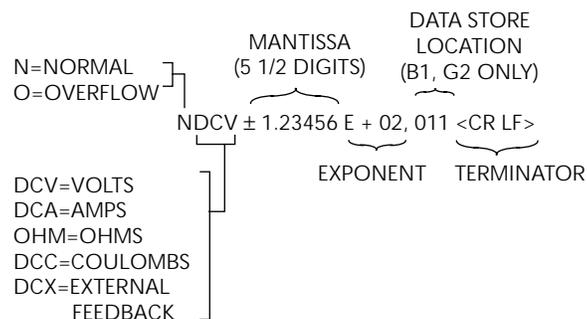


Figure 3-1
General data format

3.2.6 EOI and bus hold-off modes (K)

Purpose	To program EOI and bus hold-off modes.								
Format	<table border="0"> <tr> <td style="padding-right: 20px;">K0</td> <td>Send EOI with last byte; hold off bus until commands processed on X</td> </tr> <tr> <td>K1</td> <td>Do not send EOI with last byte; hold off bus until commands processed on X</td> </tr> <tr> <td>K2</td> <td>Send EOI with last byte; do not hold off bus on X</td> </tr> <tr> <td>K3</td> <td>Send no EOI with last byte; do not hold off bus on X</td> </tr> </table>	K0	Send EOI with last byte; hold off bus until commands processed on X	K1	Do not send EOI with last byte; hold off bus until commands processed on X	K2	Send EOI with last byte; do not hold off bus on X	K3	Send no EOI with last byte; do not hold off bus on X
K0	Send EOI with last byte; hold off bus until commands processed on X								
K1	Do not send EOI with last byte; hold off bus until commands processed on X								
K2	Send EOI with last byte; do not hold off bus on X								
K3	Send no EOI with last byte; do not hold off bus on X								
Default	Upon power-up, or after receiving a DCL or SDC command, the K0 mode will be enabled (both EOI and bus hold-off enabled).								
Description	The K command allows control over whether or not the instrument sends the EOI command at the end of its data string, and whether or not bus activity is held off (through the NRFD line) until all commands sent to the instrument are internally processed once the instrument receives the X character.								

The EOI line on the IEEE-488 bus provides a method to positively identify the last byte in a multi-byte transfer sequence. Keep in mind that some controllers rely on EOI to terminate their input sequences. In this case, suppressing EOI with the K command may cause the controller input sequence to hang up unless other terminator sequences are used.

The bus hold-off mode allows the instrument to temporarily hold up bus operation when it receives the X character until it processes all commands sent in the command string. The purpose of the hold-off is to ensure that the front end FETs and relays are properly configured before taking a reading. Keep in mind that all bus operation will cease—not just activity associated with the Model 6512. The advantage of this mode is that no bus commands will be missed while the instrument is processing commands previously received.

The hold-off period depends on the commands being processed. Table 3-3 lists hold-off times for a number of different commands. Since NRFD hold-off is employed, the handshake sequence for the X character is completed.

Table 3-3
Bus hold-off times

Commands	Bus held off on X until:
L	NVRAM storage completed (13msec)
F, R, C	6512 front end configured (20msec)
Z, N	Value taken (360msec)
All others	When X is recognized

NOTE: NRFD will be held off until each byte is recognized (1-60msec in continuous trigger mode; 1msec in one-shot trigger mode).

Examples	K1X	EOI disabled, hold-off enabled.
	K3X	Both EOI and hold-off disabled.

3.2.7 Non-volatile memory storage (L)

Purpose	To store calibration constants in NVRAM.	
Format	L1	
Description	The Model 6512 uses non-volatile (NV) RAM to store calibration parameters. Once the instrument has been calibrated, as described in the last paragraph, the NVRAM storage command should be sent to permanently store these parameters. This procedure is performed by sending the following sequence: L1X. NVRAM storage will take place when the instrument receives this command over the bus. Note that NVRAM storage may be disabled by changing the position of a calibration jumper, as described in Section 7. If the jumper is in the enabled position, all calibration must be properly done, or calibration of all functions and ranges will be affected.	
Programming Note	Do not perform the programming example below unless actual NVRAM storage is desired. Unless proper calibrating parameters have been previously programmed, inadvertent use of this command could affect instrument accuracy.	
Example	L1X	Perform non-volatile RAM storage.

3.2.8 SRQ mask (M) and status byte format

Purpose	To control which instrument conditions will cause the unit to generate an SRQ (Service Request).	
Format	M0	SRQ disabled
	M1	Reading overflow
	M2	Data store memory full (100 readings)
	M8	Reading done
	M16	Ready to accept bus commands
	M32	Error
Default	Upon power-up, or after receiving a DCL or SDC command, SRQ will be disabled (M0).	
Description	The SRQ command controls which of a number of conditions within the Model 6512 will cause the instrument to request service from the controller by asserting SRQ. Once an SRQ is generated, the status byte can be checked to determine if the Model 6512 was the instrument that asserted SRQ, and, if so, what conditions caused it to do so. Note that additional data and error conditions can be checked by using the U1 and U2 commands, as described in paragraph 3.2.13.	
SRQ Mask	The Model 6512 uses an internal mask to determine which conditions will cause an SRQ to be generated. Figure 3-2 shows the general format of this mask, which is made up of eight bits. The SRQ mask has the same general format as the status byte (described below) except for the fact that bit 6 is not used in the SRQ mask.	

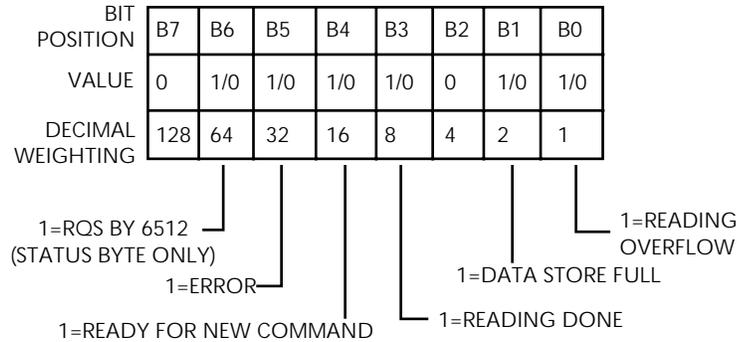


Figure 3-2
SRQ mask and status byte format

SRQ can be programmed by sending the ASCII letter “M” followed by a decimal number to set the appropriate bit in the SRQ mask. Note that the instrument may be programmed for more than one set of conditions simultaneously. To do so, simply add up the decimal bit values for the required SRQ conditions. For example, to enable SRQ under reading overflow and buffer full conditions, send M3X.

Status Byte

The status byte contains information relating to data and error conditions within the instrument. The general format of the status byte (which is obtained by using serial polling) is also shown in Figure 3-2. Note that the various bits correspond to the bits in the SRQ mask as described above.

The bits in the status (serial poll) byte have the following meanings:

Reading Overflow (Bit 0)—Set when an over-range input is applied to the instrument. Cleared when a non-overflowed reading is available.

Data Store Full (Bit 1)—Set when all 100 readings in the data store buffer have been stored. Cleared by reading a stored reading over the bus (B1X).

Reading Done (Bit 3)—Set when the Model 6512 has completed the present reading conversion. Cleared by requesting a reading over the bus.

Ready (Bit 4)—Set when the instrument has processed all previously received commands and is ready to accept additional commands over the bus. Cleared when processing commands.

Error (Bit 5)—Set when an error condition occurs, as described above. Cleared by reading the error word with the U1 command.

RQS (Bit 6)—Set if the Model 6512 has asserted SRQ. Cleared by serial polling the instrument.

Bits 2 and 7 are not used, and are always set to 0.

Bit 6 provides a means for you to determine if SRQ was asserted by the Model 6512. If this bit is set, service was requested by the instrument. Bit 5 flags a Model 6512 error condition, which can be further checked with the U1 command. If this bit is set, one of the following errors has occurred:

1. An illegal device dependent command (IDDC) or illegal device dependent command option (IDDCO) was transmitted.
2. The instrument was programmed when not in remote.
3. A trigger overrun has occurred (the instrument was triggered while processing a reading from a previous trigger).
4. A number error has occurred (a calibration value was out of limits).

Keep in mind that you can program the instrument to assert SRQ under any of these conditions simply by setting bit 5 in the SRQ mask (M32X). Paragraph 3.2.13 describes how to use the U1 command to obtain information on the type of error from the instrument. The U1 command is used to clear the error bit and restore operation of SRQ on error after the error byte is read.

Programming Notes

1. Note that the status byte should be read to clear the SRQ line once the instrument has generated an SRQ. All bits in the status byte will be latched when the SRQ is generated. Bit 6 (RQS) will be cleared when the status byte is read.
2. Even with SRQ disabled, the status byte can be read to determine appropriate instrument conditions. In this case, bits 0, 1, 3, and 4 will be continuously updated to reflect current instrument status; however, bit 5 (the error bit) will latch and remain so until the U1 status word (paragraph 3.2.13) is read, even if no SRQ occurs.
3. See Appendix D for an example program that demonstrates SRQ and serial polling.

Examples

M3X	SRQ on reading overflow and data store full.
M40X	SRQ on reading done and on error.
M32X	SRQ on error only.

3.2.9 Baseline suppression (N)

Purpose	To enable or disable baseline suppression.	
Format	N0	Disable suppression
	N1	Enable suppression
Default	Upon power-up, or after receiving a DCL or SDC command, suppression will be disabled (N0).	

Description The baseline suppression mode allows a stored offset value to be subtracted from subsequent readings. When the suppression mode is enabled with the appropriate command, the instrument will internally store the baseline value with the next triggered conversion. All subsequent readings will be the difference between the stored baseline value and the actual signal level. For example, if 100mV is stored as a baseline, that value will be subtracted from the following readings. See paragraph 2.10.2 for a complete description.

To use baseline suppression, perform the following steps:

1. Cancel baseline suppression by sending N0X if already enabled.
2. Select a range and function consistent with the expected measurement.
3. Connect the signal to be used as a baseline to the instrument input.

WARNING

The voltage present on the input terminals may be larger than the displayed value. For example, if a 150VDC baseline is stored, an applied voltage of +175V will result in a displayed reading of only +25V.

4. Enable baseline suppression by sending N1X over the bus. The baseline will be stored when the command is executed.
5. Disconnect the baseline signal from the instrument, and connect the signal to be measured in its place. Subsequent readings will be the difference between the baseline and the applied signal.

Programming Notes

1. Baseline suppression reduces the dynamic range of the measurement. For example, if the stored baseline value is 100mV on the 200mV range, an input voltage of 100mV or more would over-range the instrument even though voltages up to 199.99mV are normally within the capabilities of the 200mV range. If the instrument is in the auto-range mode, it will move up range if necessary.
2. Setting the range lower than the stored baseline value will over-range the instrument.
3. Accurate control over when the baseline is actually stored may be achieved by placing the instrument in a one-shot trigger mode. Once the desired baseline value is connected to the instrument, the baseline can be stored by sending N1X.
4. Function changes cancel baseline suppress. Refer to paragraph 2.10.2 for details concerning suppress.

Examples	N1X	Enable suppress.
	N0X	Disable suppress.

3.2.10 Data store mode (Q)

Purpose	To control the data store rates and trigger mode.																
Format	<table border="0"> <tr><td>Q0</td><td>Conversion rate (one reading every 360msec)</td></tr> <tr><td>Q1</td><td>One reading per second</td></tr> <tr><td>Q2</td><td>One reading every 10 seconds</td></tr> <tr><td>Q3</td><td>One reading per minute</td></tr> <tr><td>Q4</td><td>One reading every 10 minutes</td></tr> <tr><td>Q5</td><td>One reading per hour</td></tr> <tr><td>Q6</td><td>Trigger mode (TRIG button)</td></tr> <tr><td>Q7</td><td>Data store disabled</td></tr> </table>	Q0	Conversion rate (one reading every 360msec)	Q1	One reading per second	Q2	One reading every 10 seconds	Q3	One reading per minute	Q4	One reading every 10 minutes	Q5	One reading per hour	Q6	Trigger mode (TRIG button)	Q7	Data store disabled
Q0	Conversion rate (one reading every 360msec)																
Q1	One reading per second																
Q2	One reading every 10 seconds																
Q3	One reading per minute																
Q4	One reading every 10 minutes																
Q5	One reading per hour																
Q6	Trigger mode (TRIG button)																
Q7	Data store disabled																
Default	Upon power-up, or after receiving a DCL or SDC, data store is disabled (Q7).																
Description	<p>The data store commands enter the data storage mode and allow you to store up to 100 readings within the internal memory of the Model 6512. By entering an appropriate parameter, readings may be stored at one of six intervals between the conversion rate and one reading per hour. Either during or after the storage process, readings, including maximum and minimum values, may be recalled by using the B command as described in paragraph 3.2.2.</p> <p>Once the unit has stored all 100 readings, it will stop data storage until another Q command is sent to enable data store once again. Note that the instrument may be programmed to generate an SRQ when memory is full, as described in paragraph 3.2.8.</p> <p>In addition to the various rates, data store can be used at a rate determined by the TRIG button (Q6 mode). When in this mode, one reading will be stored in memory each time TRIG button is operated.</p>																
Programming Notes	<ol style="list-style-type: none"> 1. To use data store on a one-shot basis with other trigger sources, place the instrument in the Q0 mode, and select the desired one-shot trigger mode (paragraph 3.2.12). 2. In Q0 and Q1, the storage rate may be decreased if the instrument is in auto-range and a range change occurs. 3. See Appendix D for an example program that demonstrates data store operation. 																
Examples	<table border="0"> <tr><td>Q1X</td><td>Enable data store, one per second rate.</td></tr> <tr><td>Q7X</td><td>Disable data store.</td></tr> </table>	Q1X	Enable data store, one per second rate.	Q7X	Disable data store.												
Q1X	Enable data store, one per second rate.																
Q7X	Disable data store.																

3.2.11 Range (R)

Purpose	To select the measurement range.				
Format	Volts	Amps	Ohms	Coul.	External Feedback
	<hr/>				
R0	Auto	Auto	Auto	Auto	Auto
R1	200mV	2pA	2k Ω	200pC	200mV
R2	2V	20pA	20k Ω	2nC	2V
R3	20V	200pA	200k Ω	20nC	20V
R4	200V	2nA	2M Ω	20nC	20V
R5	200V	20nA	20M Ω	20nC	20V
R6	200V	200nA	200M Ω	20nC	20V
R7	200V	2 μ A	2G Ω	20nC	20V
R8	200V	20 μ A	20G Ω	20nC	20V
R9	200V	200 μ A	200G Ω	20nC	20V
R10	200V	2mA	200G Ω	20nC	20V
R11	200V	20mA	200G Ω	20nC	20V
R12	Cancel auto-ranging for all functions.				
Default	Upon power up, or after receiving a DCL or SDC command, the instrument will be in the R0 (auto-range) mode.				
Description	The range command gives you control over the measurement sensitivity of the instrument. This command, and its options, perform essentially the same functions as the front panel AUTO and \blacktriangle and \blacktriangledown range buttons.				
Programming Notes	<ol style="list-style-type: none"> 1. The instrument will be ready to take a reading after the range is set up when responding to a range command. 2. When auto-range is disabled (R12), the instrument will stay on its present range. 				
Examples	R12X	Disable auto-range.			
	R3X	Choose 200pA range (in amps).			
	R0X	Enable auto-range.			

3.2.12 Trigger mode (T)

Purpose	To control the source that triggers readings as well as whether the instrument operates in the continuous or one-shot trigger mode.																
Format	<table border="0"> <tr><td>T0</td><td>Continuous Mode, Triggered by Talk</td></tr> <tr><td>T1</td><td>One-shot Mode, Triggered by Talk</td></tr> <tr><td>T2</td><td>Continuous Mode, Triggered by GET</td></tr> <tr><td>T3</td><td>One-shot Mode, Triggered by GET</td></tr> <tr><td>T4</td><td>Continuous Mode, Triggered by X</td></tr> <tr><td>T5</td><td>One-shot Mode, Triggered by X</td></tr> <tr><td>T6</td><td>Continuous Mode, Triggered with External Trigger</td></tr> <tr><td>T7</td><td>One-shot Mode, Triggered with External Trigger</td></tr> </table>	T0	Continuous Mode, Triggered by Talk	T1	One-shot Mode, Triggered by Talk	T2	Continuous Mode, Triggered by GET	T3	One-shot Mode, Triggered by GET	T4	Continuous Mode, Triggered by X	T5	One-shot Mode, Triggered by X	T6	Continuous Mode, Triggered with External Trigger	T7	One-shot Mode, Triggered with External Trigger
T0	Continuous Mode, Triggered by Talk																
T1	One-shot Mode, Triggered by Talk																
T2	Continuous Mode, Triggered by GET																
T3	One-shot Mode, Triggered by GET																
T4	Continuous Mode, Triggered by X																
T5	One-shot Mode, Triggered by X																
T6	Continuous Mode, Triggered with External Trigger																
T7	One-shot Mode, Triggered with External Trigger																
Default	Upon power-up, or after the instrument receives a DCL or SDC command, the T6 (continuous mode, external trigger) mode will be enabled.																
Description	<p>Triggering provides a stimulus to begin a reading conversion within the instrument. Triggering may be done in two basic ways: in a continuous trigger mode, a single trigger stimulus is used to restart a continuous series of readings. In a one-shot mode, a single reading will be processed each time the appropriate trigger stimulus is given.</p> <p>The trigger modes are paired according to the type of stimulus that is used to trigger the instrument. In the T0 and T1 modes, triggering is performed by addressing the Model 6512 to talk. In the T2 and T3 modes, the IEEE-488 multiline GET command performs the trigger function. The instrument execute (X) character provides the trigger stimulus in the T4 and T5 modes, while a trigger pulse applied to the rear panel EXTERNAL TRIGGER INPUT, triggers the instrument in the T6 and T7 modes.</p>																
Programming Notes	<ol style="list-style-type: none"> 1. A trigger stimulus will abort the present reading conversion and immediately begin another. 2. The front panel TRIG button will trigger the instrument regardless of the selected trigger mode, unless LLO is in effect. 3. Serial polling addresses the instrument to talk. This talk command will trigger the instrument in the T0 and T1 modes. 																

3.2.13 Status (U)

Purpose To request status, error, and data conditions from the instrument.

Format

U0	Send status word
U1	Send instrument error conditions
U2	Send instrument data conditions

Description The status commands allow access to information concerning instrument operating modes that are controlled by other device-dependent commands such as F (function) and R (range). Additional parameters of the status command allow data and error conditions to be accessed.

Status Word When the command sequence U0X is transmitted, the instrument will transmit the status word instead of its normal data string the next time it is addressed to talk. The status word will be transmitted only once each time the U0 command is given. To make sure that correct status is transmitted, the status word should be requested as soon as possible after the command is transmitted.

The format of U0 status is shown in Figure 3-3. Note that the letters correspond to modes programmed by the respective device-dependent commands. The default values in the status word (upon power up or after a DCL or SDC command) are also shown in Figure 3-3.

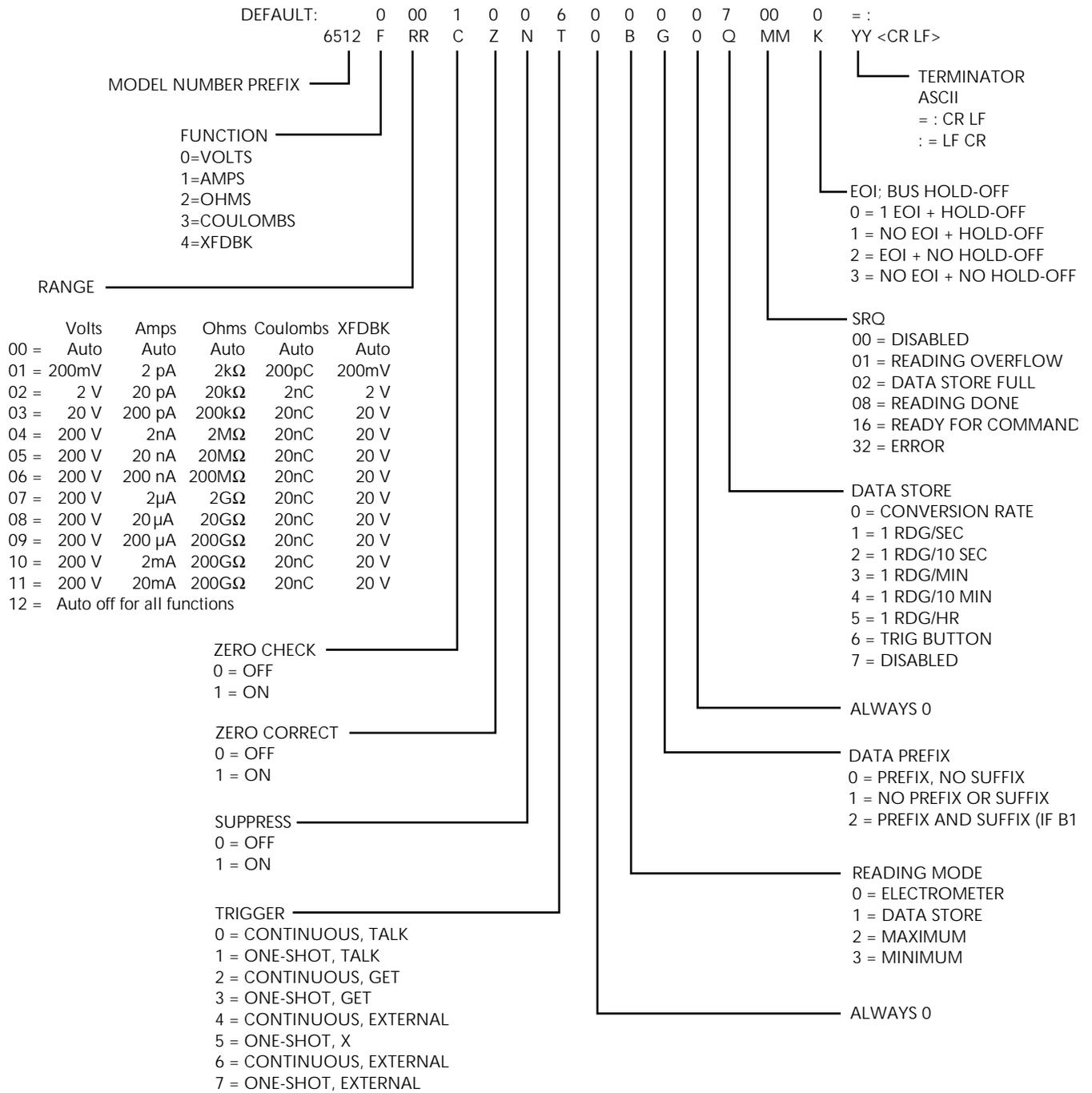


Figure 3-3
U0 status word and default values

Note that all returned values except for those associated with the terminator correspond to the programmed numeric values. For example, if the instrument is presently on the R3 range, the R bytes in the status word will correspond to an ASCII 03. The returned terminator characters are derived by ORing the actual terminator byte values with 30_H. For example, a <CR> character has a decimal value of 13, which equals 0D_H. ORing this value with 30_H yields 3D_H, or 61₁₀, which prints out as an ASCII equal sign (=). This terminator conversion step is necessary to convert the standard terminators into displayable form, as they will not normally print out on a computer CRT.

Error Conditions

The U1 command allows access to Model 6512 error conditions in a similar manner. Once the sequence U1X is sent, the instrument will transmit the error conditions with the format shown in Figure 3-4 the next time it is addressed to talk in the normal manner. The error condition word will be sent only once each time the U1 command is transmitted. Note that the error condition word is actually a string of ASCII characters representing binary bit positions. An error condition is also flagged in the status (serial poll) byte, and the instrument can be programmed to generate an SRQ when an error condition occurs. (See paragraph 3.2.8). Note that all bits in the error condition (U1) word and the status byte error bit will be cleared when the U1 word is read. In addition, SRQ operation will be restored after an error condition by reading U1.

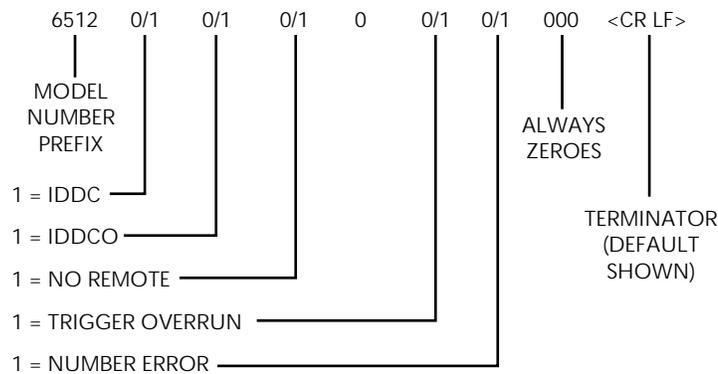


Figure 3-4
U1 status (error condition) format

The various bits in the error condition word are described as follows:

IDDC—Set when an illegal device dependent command (IDDC) such as H1X is received (“H” is illegal).

IDDCO—Set when an illegal device-dependent command option (IDDCO) such as T9X is received (“9” is illegal).

No Remote—Set when a programming command is received when REN is false.

NOTE

The complete command string will be ignored if an IDDC, IDDCO or No Remote error occurs.

Trigger Overrun—Set when a trigger is received when the instrument is still processing a reading from a previous trigger.

Number Error—Set when an out-of-range calibration value is received.

Data Conditions

In a similar manner, the U2X sequence allows access to instrument data conditions. When this command is transmitted, the instrument will transmit the data condition word shown in Figure 3-5 the next time it is addressed to talk. This information will be transmitted only once each time the command is received. As with the U1 error word, the U2 word is made up of ASCII characters representing binary values. Unlike the U1 error word, however, the U2 data condition word will not be cleared when read; thus, instrument status in the U2 word is always current.

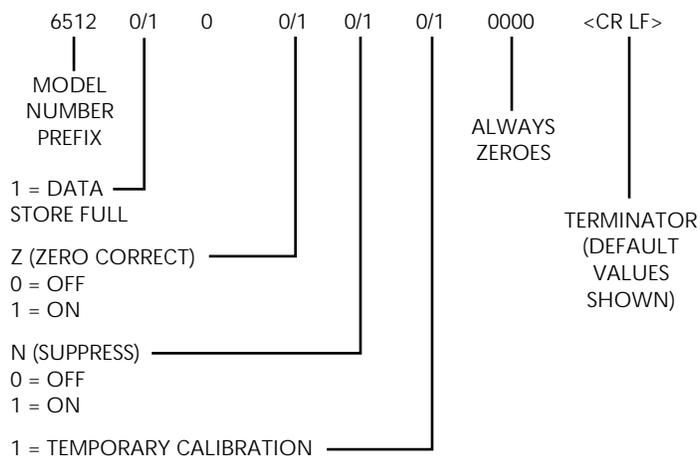


Figure 3-5
U2 status (data condition) format

The various bits in the data condition word include:

Data Store Full—Set when all 100 readings have been stored in the data store memory. Cleared by requesting a data store reading over the bus.

Z and N—Represents the same information as the corresponding zero correct (Z) and suppress (N) bytes in the U0 status word.

Temporary Calibration—Set when new calibration parameters not yet stored in NVRAM have been received, or if power-up recall of NVRAM data was in error. Cleared when NVRAM storage is performed.

Programming Note

See Appendix D for an example program that can be used to request the status, error, and data conditions words from the instrument.

Examples

U0X Request status word.
U1X Request error word.

3.2.14 Terminator (Y)

Purpose	To program the terminator character(s) the Model 6512 adds to the end of its reading and status strings.
Format	Y<LF> <CR> <LF> <CR> (two terminator characters) Y<CR> <LF> <CR> <LF> (two terminator characters) Y<ASCII> ASCII character (except A-Z) YX No terminator
Default	Upon power-up, or after a DCL or SDC command, the terminator sequence is <CR> <LF>.
Description	The terminator sequence that marks the end of the instrument's data string or status word can be programmed by sending the Y command followed by an appropriate ASCII character. The default terminator sequence is the commonly used carriage return, line feed (<CR> <LF>) sequence (<CR>=ASCII 13; <LF>=ASCII 10).
Programming Notes	<ol style="list-style-type: none">1. Capital letters A through Z cannot be used as terminator characters.2. Programming non-standard terminators may cause the controller input sequence to hang up.
Examples	Y@X Program @ character as terminator. YX Disable terminator.

3.2.15 Execute (X)

Purpose	To instruct the Model 6512 to execute device-dependent commands.
Format	X
Description	The execute command is implemented by sending an ASCII "X" over the bus. Its purpose is to direct the Model 6512 to execute other device-dependent commands such as F (function) or R (range). Usually, the execute character is the last byte in the command string (a number of commands may be grouped together into one string); however, there may be certain circumstances where it is desirable to send a command string at one time, and then send the execute character later on.
Programming Note	Command strings sent without the execute character will be stored within an internal command buffer for later execution. When the X character is finally transmitted, the stored commands will be executed, assuming that all commands in the previous string were valid.
Examples	F0X Select DC volts function. X Execute previous commands.

3.2.16 Zero correct (Z)

Purpose	To zero correct the instrument, nulling any internal offsets that might affect accuracy.
Format	Z0 Zero correct off Z1 Zero correct on
Default	Upon power-up, or after receiving a DCL or SDC command, zero correct will be disabled (Z0).
Description	The zero correct and zero check commands work together to cancel any internal offsets that might upset accuracy. If the instrument is placed in the zero correct mode with zero check enabled, it will store a new offset value to be used for subsequent readings. If the instrument is zero corrected with zero check disabled, the previously stored zero value will be used instead. Note that the specifications at the front of this manual assume that the instrument has been properly zeroed. Use the following procedure to zero the instrument: <ol style="list-style-type: none"> 1. With zero correct off, place the instrument in zero check by sending C1X. 2. Zero correct the instrument by sending Z1X. 3. Disable zero check by sending C0X. Readings can then be taken in the usual manner.
Programming Note	After sending a zero check command, the instrument will be ready for a new command when the front end is set up.
Examples	Z1X Zero correct instrument. Z0X Disable zero correct. C1XZ1C0X Perform complete correction.

3.3 Bus connections

The Model 6512 is to be connected to the IEEE-488 bus through a cable equipped with standard IEEE-488 connectors, an example of which is shown in Figure 3-6. The connector is designed to be stacked to allow a number of parallel connections. Two metric screws are located on each connector to ensure that connections remain secure.

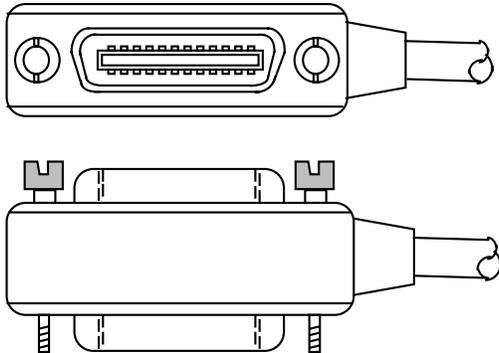


Figure 3-6
IEEE-488 connector

A typical connecting scheme for the bus is shown in Figure 3-7. Each cable normally has the standard connector on each end. These connectors are designed to be stacked to allow a number of parallel connections on one instrument.

NOTE

To avoid possible damage, it is recommended that you stack no more than three connectors on any one instrument.

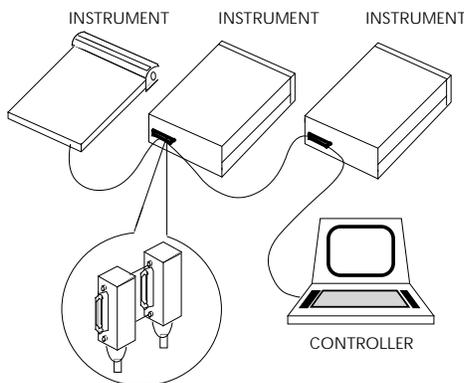


Figure 3-7
IEEE-488 connections

Connect the Model 6512 to the cable as follows:

1. With the power off, line up the connector on the cable with the connector on the rear panel of the instrument. See Figure 3-8 for connector location.
2. Tighten the screws securely, but do not overtighten them.
3. Add additional connectors from other instruments, as required.
4. Make sure the other end of the cable is properly connected to the controller.

NOTE

The IEEE-488 bus is limited to a maximum of 15 devices, including the controller. Also, the maximum cable length is limited to 20 meters, or 2 meters times the number of devices, whichever is less. Failure to heed these limits may result in erratic bus operation.

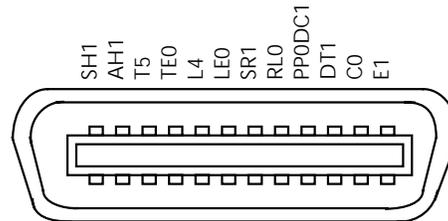


Figure 3-8
Model 6512 rear panel IEEE-488 connector

3.4 Primary address

The Model 6512 must receive a listen command before it will respond to addressed commands. Similarly, the unit must receive a talk command before it will transmit its data. The Model 6512 is shipped from the factory with a programmed primary address of 27. Until you become more familiar with your instrument, it is recommended that you leave the address at this value because the example programs included in Appendix D of this manual assume that address.

The primary address may be set to any value between 0 and 30 as long as address conflicts with other instruments are avoided. Note that controllers are also given a primary address, so you must be careful not to use that address either. Most frequently, controller addresses are set to 0 or 21, but you should consult the controller's instruction manual for de-

tails. Whatever primary address you choose, you must make certain that it corresponds with the value specified as part of the controller's programming language.

To check the present primary address, or to change to a new one, use the following sequence:

1. Press the PROGRAM SELECT button, and note that the following message is displayed:

IEEE 27

2. This message indicates that the IEEE address program is selected, along with the presently programmed value (in this case, the default value of 27 is being displayed).
3. Using one of the ADJUST buttons, scroll the displayed address to the desired value from 0 to 30 (the display will show special values for the talk-only mode, as described in the next paragraph).
4. Exit the program by pressing SHIFT then SELECT EXIT. The new address is now in effect, and it will remain programmed even if the power is turned off.

NOTE

Each device on the bus must have a unique primary address. Failure to observe this precaution will result in improper bus operation.

3.5 Talk-only mode

The Model 6512 may be placed into the talk-only mode and be used with a listen-only device such as a printer. When in this mode, the instrument will ignore commands given over the bus and merely output data as requested by the listening device. When the instrument is in the talk-only mode, the front panel TALK LED will turn on.

The instrument can be placed in the talk-only mode by entering one of the following parameters in the primary address program:

- | | |
|----|---|
| 40 | Talk-only mode with prefix on data string
(Example: NDCV-1.2345E-01) |
| 41 | Talk-only mode without prefix on data string
(Example: -1.2345E-01) |

To place the instrument in the talk-only mode, perform the following steps:

1. Press the PROGRAM SELECT button so that the following message is displayed:

IEEE 27

2. Press the up arrow ADJUST button repeatedly until the desired talk-only parameter (40 or 41) is shown.
3. To exit the program, press SHIFT then SELECT EXIT. The unit is now programmed for the talk-only mode, and it will remain programmed in this manner even if the power is turned off.

Selecting the data output rate

The data output rate in the talk-only mode can be selected as follows:

1. Press and hold the DATA STORE ON/OFF button until the desired rate is displayed, as indicated below.

Displayed r Value/data output rate

r=0	Conversion Rate (Every 360msec)
r=1	One reading per second
r=2	One reading every 10 seconds
r=3	One reading per minute
r=4	One reading every 10 minutes
r=5	One reading per hour
r=6	One reading each time TRIG is pressed

2. Press the PROGRAM SELECT button until the IEEE program message is displayed, and then release the button. Select the desired IEEE-488 talk-only parameter (40 or 41) using an ADJUST button.
3. Press SELECT EXIT to return to normal operation. The instrument will then enter the talk-only mode and output readings over the IEEE-488 bus at the selected interval.

3.6 Front panel messages

The Model 6512 has a number of front panel messages associated with IEEE-488 programming. These messages are intended to inform you of certain conditions that occur when sending device-dependent commands to the instrument.

The following paragraphs describe the front panel error messages associated with IEEE-488 programming.

3.6.1 Bus error

A bus error will occur if the instrument receives a device-dependent command when it is not in remote, or if an illegal device-dependent command (IDDC) or illegal device-dependent command option (IDDCO) is sent to the instrument. Under these conditions, the complete command string will be rejected, and the following message will be displayed:

b Err

In addition, the error bit and pertinent bits in the U1 word will be set (paragraphs 3.2.13 and 3.2.16), and the instrument can be programmed to generate an SRQ under these conditions (paragraph 3.2.13).

No Remote error

A no remote error can occur when a command is sent to the instrument when the REN line is false. Note that the state of REN is only tested when the X character is received.

IDDC error

An IDDC error can occur when an invalid command such as H1X is transmitted (this command is invalid because the instrument has no command associated with that letter).

IDDCO error

Similarly, an IDDCO error occurs when an invalid option is sent with a valid command. For example, the command T9X has an invalid option because instrument has no such trigger mode.

3.6.2 Number error

A number error occurs when an out of range calibration command (A) value is sent to the instrument. Under these conditions, the instrument will display the following error message:

n Err

The command string will be accepted, but the calibration value will remain unchanged.

3.6.3 Trigger overrun error

A trigger overrun error occurs when the instrument receives a trigger while it is still processing a reading from a previous trigger. Note that only the overrun triggers are ignored and will have no effect on the instrument except to generate the message below. When a trigger overrun occurs, the following front panel message will be displayed for approximately one second:

t Err

3.7 Bus data transmission times

A primary consideration is the length of time it takes to obtain a reading once the instrument is triggered to make a conversion. The length of time will vary somewhat depending on the selected function and trigger mode. Table 3-4 gives typical times.

Table 3-4

Trigger to reading-ready times

Configuration	Time (msec)	Error (1% of step input)
2V, 20V, 200V	365	0.01
200mV	780	0.1
20nA, 200nA, 20 μ A,		
200 μ A, 20mA	365	0.01
20pA, 200pA	365	55 ²
2nA, 2 μ A, 2mA	780	0.1
2pA	780	25 ²
2nC, 20nC	365	0.01
200pC	780	0.1
20k Ω -200G Ω	365	0.01
2k Ω	780	0.1

NOTES:

1. Conditions: Input is on range, and times may depend on controller used.
2. Preamp settling time (to 12%) is 2 seconds on preamp ranges (2, 20, 200pA), and must be taken into account by the user.
3. Volt time/error also applies to external feedback.

4

Applications

4.1 Introduction

Applications for the Model 6512 are many and varied and will depend on your needs. Basically, the Model 6512 can be used to make many of the same measurements in the range of ordinary DMMs; however, special characteristics such as high input resistance and high sensitivity give the instrument much better capabilities than those of the ordinary DMM.

For example, the typical input resistance for an ordinary DMM is on the order of $10\text{M}\Omega$. In contrast, the Model 6512 has an input resistance of greater than $200\text{T}\Omega$ ($2 \times 10^{14}\Omega$). The Model 6512 can detect currents as low as 0.1fA (10^{-16}A), while a typical DMM might be limited to current measurements in the μA range.

In this section, we will discuss some possible applications for the Model 6512 Electrometer. Keep in mind that these examples are only representative of what is possible with this highly sophisticated instrument, and by no means exhaust the possible uses for the unit.

4.2 Low-level leakage current measurements

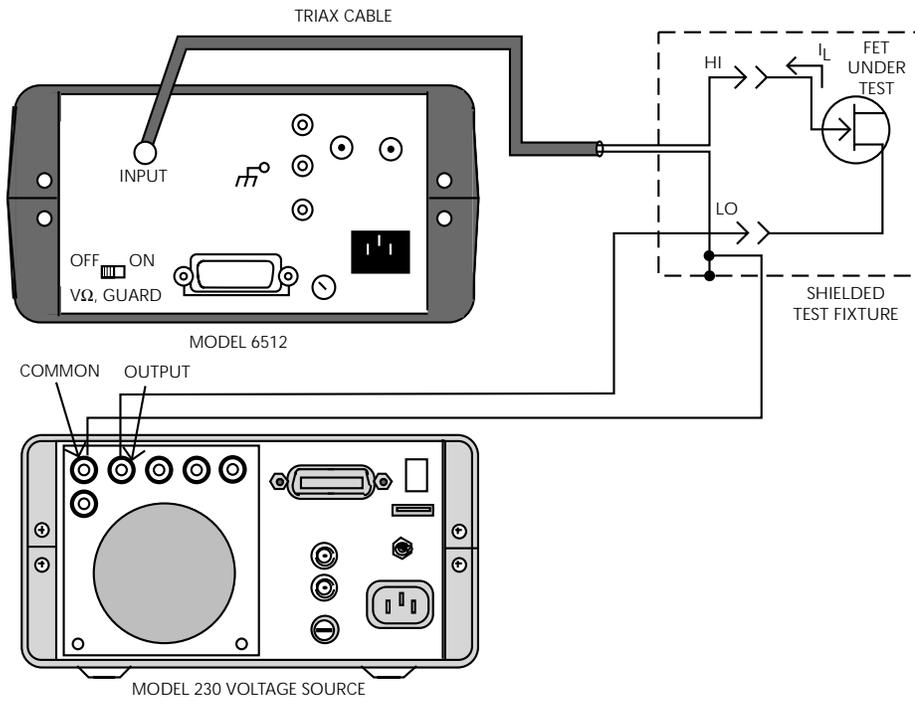
Many devices exhibit low-level leakage currents that may require measurement. Typically, such leakage currents might lie in the nA (10^{-9}A), pA (10^{-12}A) or even the fA (10^{-15}A) range. The Model 6512 is an ideal instrument for such current measurements because it can detect currents as low as 0.1fA .

An example of a situation requiring low current measurement is shown in Figure 4-1. In this example, the gate leakage current of a JFET is to be measured. Although the device manufacturer may specify the current value, it is often desirable to verify the specification for a particular sample of the device. Also, the specified leakage current might be at a higher voltage than required. For example, the specified leakage current might be 1nA with an applied voltage of 25V , while that figure might be much less at an operating value of 10V .

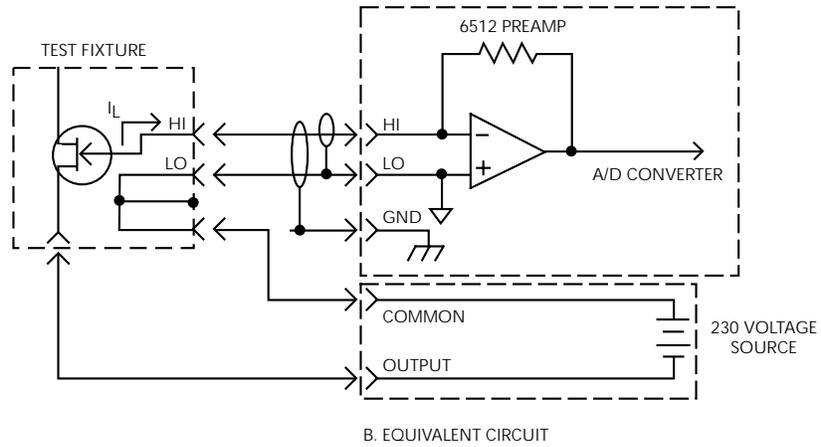
This application requires the use of an external voltage source such as the Model 230 shown in the figure. The voltage source can be programmed to the desired value or values, and the leakage current could be measured for each voltage. In this manner, leakage current characterization studies could be performed with a minimum of effort.

As shown in Figure 4-1, a shielded test fixture should be used to keep the measurement quiet and stable. A good quality low-noise triax cable should be used to connect the current input to the instrument.

Forward and reverse diode currents could be measured in a similar manner. The forward leakage current (measured with the voltage source set to less than 0.6V) can be measured using the Model 6512 without regard to input voltage burden. High-capacitance diodes such as zener devices will present no problem, since the Model 6512 is unaffected by stray capacitance up to $0.01\mu\text{F}$.



A. CONNECTIONS



B. EQUIVALENT CIRCUIT

Figure 4-1
Leakage current measurement

4.3 Diode characterization

When the Model 6512 is placed in the ohms mode, constant current values between 1nA and 100µA are available at the INPUT jack high and low terminals, as shown in Table 4-1. (Input high sources the current.) These currents can be used to plot the I-V (current-voltage) characteristics over a substantial range.

Table 4-1
Diode currents and voltages

Range	Diode current	Diode voltage (V)*
2kΩ, 20kΩ	100µA	$V = (100 \times 10^{-6}) (R)$
200kΩ	10µA	$V = (10 \times 10^{-6}) (R)$
2MΩ	1µA	$V = (1 \times 10^{-6}) (R)$
20MΩ	100nA	$V = (100 \times 10^{-9}) (R)$
200MΩ	10nA	$V = (10 \times 10^{-9}) (R)$
2GΩ, 20GΩ, 200GΩ	1nA	$V = (1 \times 10^{-9}) (R)$

*R = displayed resistance.

Figure 4-2 shows the basic circuit configuration for using the Model 6512 in this manner. A decade current, I, is forced through the diode under test. The current will develop a forward voltage drop, V_F , across the diode. The voltage across the diode can be calculated by multiplying the displayed resistance by the test current (see Table 4-1). For example, assume that a resistance reading of 50kΩ is measured with the instrument on the 200kΩ range. The voltage across the diode is:

$$V_F = 10\mu\text{A} \times 50\text{k}\Omega = 0.5\text{V}$$

Figure 4-3 shows several examples for typical diodes. The curves were drawn from data obtained in the manner described.

WARNING

Up to 300V may be present between the high and low terminals in ohms.

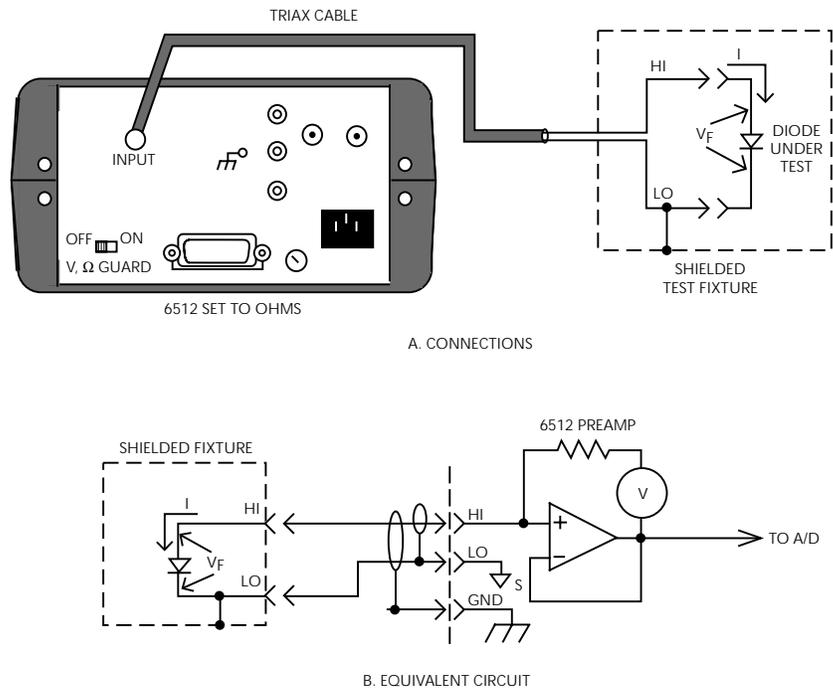


Figure 4-1
Diode characterization

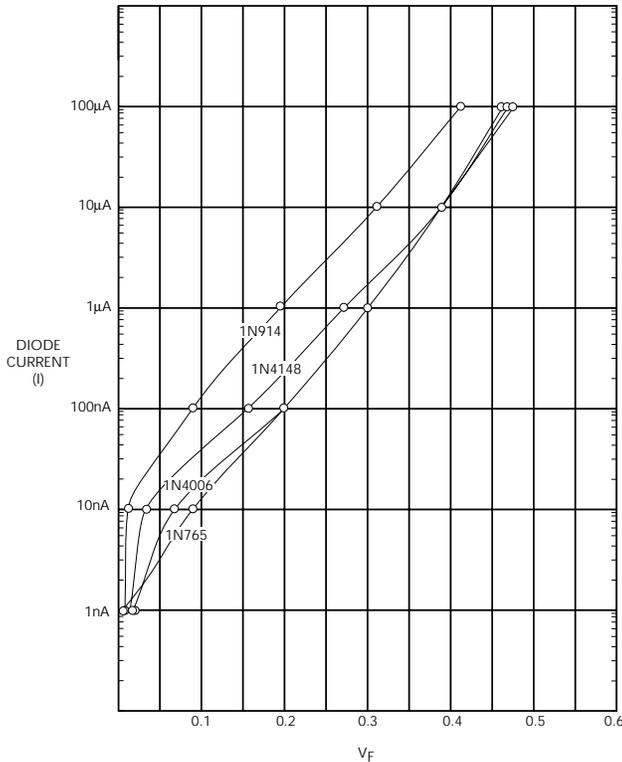


Figure 4-2
Diode curves

4.4 Capacitor leakage measurements

An important parameter associated with capacitors is their leakage currents. Once the leakage current is known, the insulation resistance can be calculated. Ideally, a capacitor should have no leakage current, and thus infinite leakage resistance. However, capacitors, like all practical devices, are not ideal, so these parameters can become important, especially to circuit design and component engineers. The amount of leakage current in a given capacitor depends on its dielectric as well as the applied voltage. Ceramic dielectric capacitors typically have leakage currents in the nA to pA range, while polystyrene and polyester dielectric devices exhibit much lower leakage currents—generally in the fA range. (These values are for test voltages in the 100V range).

The basic configuration for this test is shown in Figure 4-4. A Model 230 Voltage Source is used to impress a voltage across the capacitor, C. The resulting leakage current is then measured by the Model 6512.

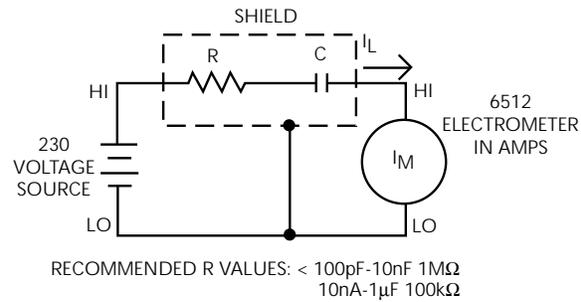


Figure 4-3
Capacitor leakage tests

The resistor R is necessary to limit current to a safe value in case the capacitor is shorted, and it also helps to reduce noise. Typically a value of about 1MΩ should be used, although that value can be decreased for larger capacitor values. However, values under 10kΩ are not recommended. (Refer to paragraph 2.13.8.)

At the start of the test, the Model 6512 should be placed in the amps mode and on the 20mA range. The Model 230 Voltage Source is then programmed to the desired voltage, and its output is turned on. Once the required soak time has passed, the Model 6512 can be placed on the proper current range to make the current measurement. (The soak time is the period necessary to fully charge the capacitor; typically 10RC.) Once the test is completed, the voltage source should be turned off to allow the capacitor to discharge.

The leakage current can be directly read from the Model 6512 display during the test procedure. If the leakage resistance value is required instead, the value can be calculated from the source voltage and the measured current.

This basic procedure could be used to test a number of capacitors on an automated basis. A test fixture that holds a number of capacitors could be constructed, and a Keithley Model 7001 or Model 7002 Switch System, equipped with appropriate scanner cards, could be used to select among the various devices to be tested. For a higher degree of automation, the switch system, voltage source, and Model 6512 could be controlled from a computer via the IEEE-488 bus. In this way, measurements that would otherwise be tedious and time consuming could be conducted on a more routine basis.

4.5 Capacitance measurement

The coulombs function of the Model 6512 provides a quick and easy method of measuring capacitance values of capacitors, cables, and connectors. It is especially useful in cases of cables and connectors because of the very small values of charge that can be measured.

The basic method involves using a Model 230 voltage source to apply a step voltage across the capacitor, as shown in Figure 4-5. Since charge is to be measured, the Model 6512 should be in the coulombs function to make the measurement. Just prior to turning on the voltage source, zero check should be disabled and the charge suppressed. Then, turn on the voltage source and note the final charge value.

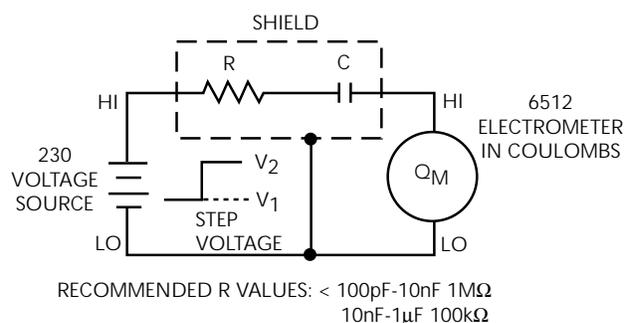


Figure 4-4
Capacitor measurement

The capacitance can then be computed as follows:

$$C = \frac{\Delta Q}{\Delta V}$$

where:

$\Delta Q = Q_2$ (final charge) - Q_1 (initial charge, assumed to be 0)

$\Delta V = V_2$ (step voltage) - V_1 (initial voltage, assumed to be 0)

As an example of the above procedure, assume that an unknown capacitor is to be measured. If the step voltage is 100V, and a Q value of 2nC is obtained, the capacitance value is:

$$C = \frac{2\text{nC}}{100\text{V}} = 20\text{pF}$$

4.6 Insulation resistance measurements

At the moderate impedance levels of many circuits, insulation resistance is seldom a consideration, as it is generally many orders of magnitude above the highest impedance encountered in the remainder of the circuit. At very high impedance levels, however, insulation resistance can be a consideration, since it can lower effective circuit impedance considerably. Since typical insulation resistances run in the range of 10^{10} - $10^{16}\Omega$, their values lie above the measurement range of ordinary instruments. The high resistance measurement range of the Model 6512, however, gives it capabilities to measure such high resistances.

4.6.1 Unguarded resistance measurements

A typical test configuration for making unguarded insulation resistance measurements is shown in Figure 4-6. The constant-current method is used, and insulation resistances up to $200\text{G}\Omega$ can be measured using the Model 6512 ohms function. As the term implies, the test current through the unknown resistance is kept constant, while the voltage developed across the test resistance will, of course, depend on the value of the insulation resistance. The Model 6512 measures the generated voltage and calculates the resistance value accordingly. The low compliance voltage of the Model 6512 (<2V on $2\text{G}\Omega$ range and lower, except <300V during overload) keeps error due to voltage coefficient small.

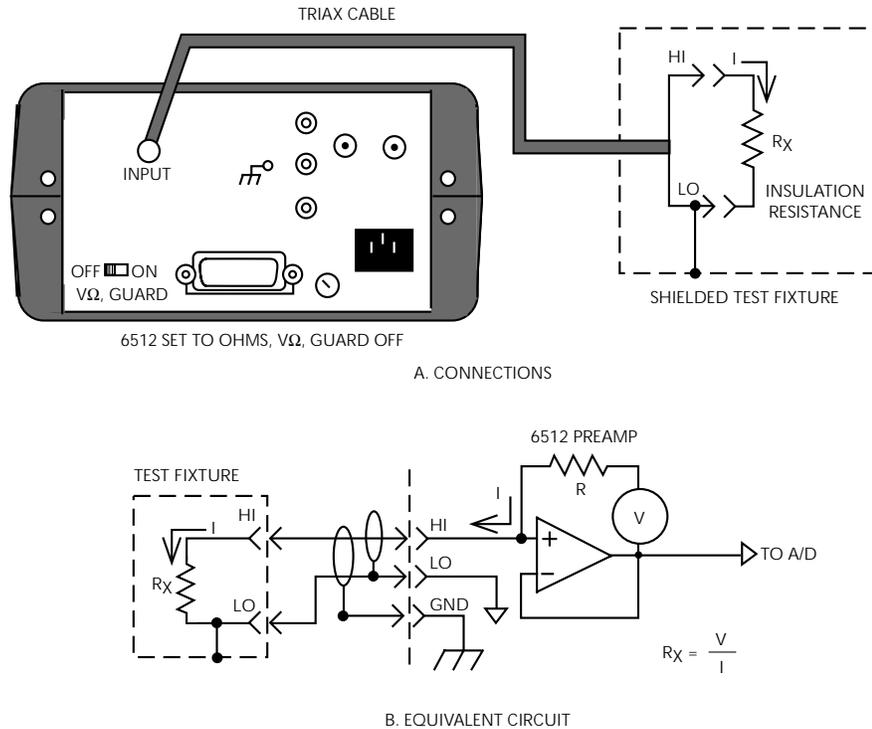


Figure 4-5
Insulation resistance measurement (unguarded)

Since the inner shield carries the guard signal, the COM terminal acts as circuit LO.

4.6.2 Guarded resistance measurements

For resistance measurements above $10^8\Omega$, or for cables longer than three feet, guarded measurements are recommended, as shown in Figure 4-7. In this case, the rear panel V, Ω GUARD switch is used to apply a guard signal to the inner shield of the connecting triax cable. The guard is carried through to the inner shield of the test fixture. The inner shield must be insulated from the outer shield, which is a safety shield. Incidentally, a shielded fixture is recommended for both unguarded and guarded resistance measurements above $10^7\Omega$ if stable readings are to be expected (in the unguarded mode, the shield should be connected to input low).

4.6.3 V/I resistance measurements with external voltage source

With the constant-current method discussed above, the Model 6512 can make measurements as high as $200G\Omega$. However, the insulation resistance of such materials as polyethylene may lie above this range. By using the Model 6512 along with an external voltage source to make resistance measurements in the constant-voltage mode, measurement range can be extended up to $10^{16}\Omega$. Also, for a given resistance, the constant-voltage method will be faster.

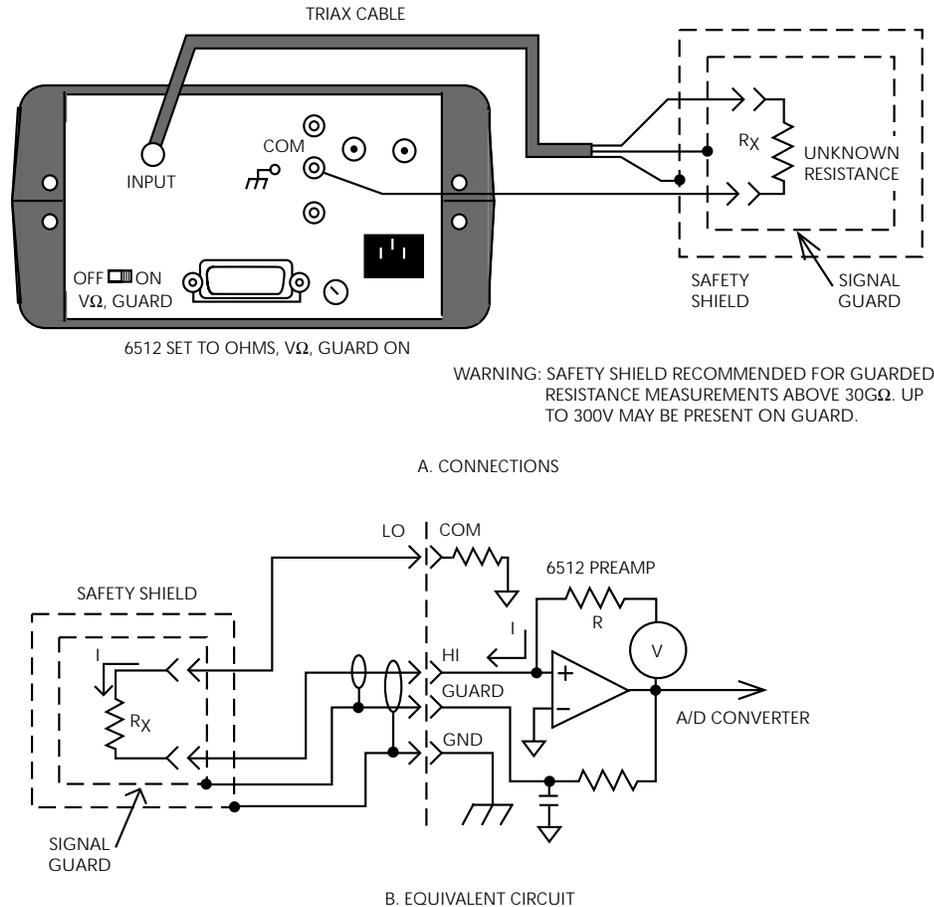


Figure 4-6
Insulation resistance measurement (guarded)

A typical configuration for using the Model 6512 to make V/I resistance measurements is shown in Figure 4-8. Here, an external Model 230 Voltage Source is used to force a current, I, through the unknown resistance, R. The insulation resistance can then be calculated as follows:

$$R = \frac{V}{I}$$

I is the current through the resistance as measured by the Model 6512, and V is the programmed Model 230 voltage. For example, assume that the applied voltage is 100V, and the measured current is 1pA. The resistance is calculated as follows:

$$R = \frac{100V}{1pA} = 10^{14} \Omega$$

Since the Model 230 voltage source can be adjusted over a wide range of values (up to ±101V), this configuration can be used for voltage coefficient studies, as described later in this section.

Note that COM is connected to input LO through 100Ω and appears in series with the resistor under test. This resistance is below the resolution of the instrument for measurements above 2MΩ.

In addition to the measurement of insulation resistances, this basic method can be used to measure unwanted leakage resistances. For example, leakage resistance between PC board traces and connectors can be made with either of the two methods described above, depending on the resistance values involved.

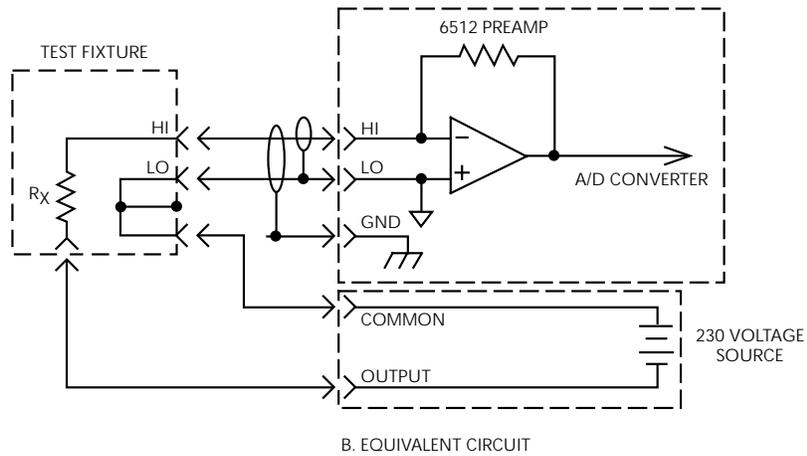
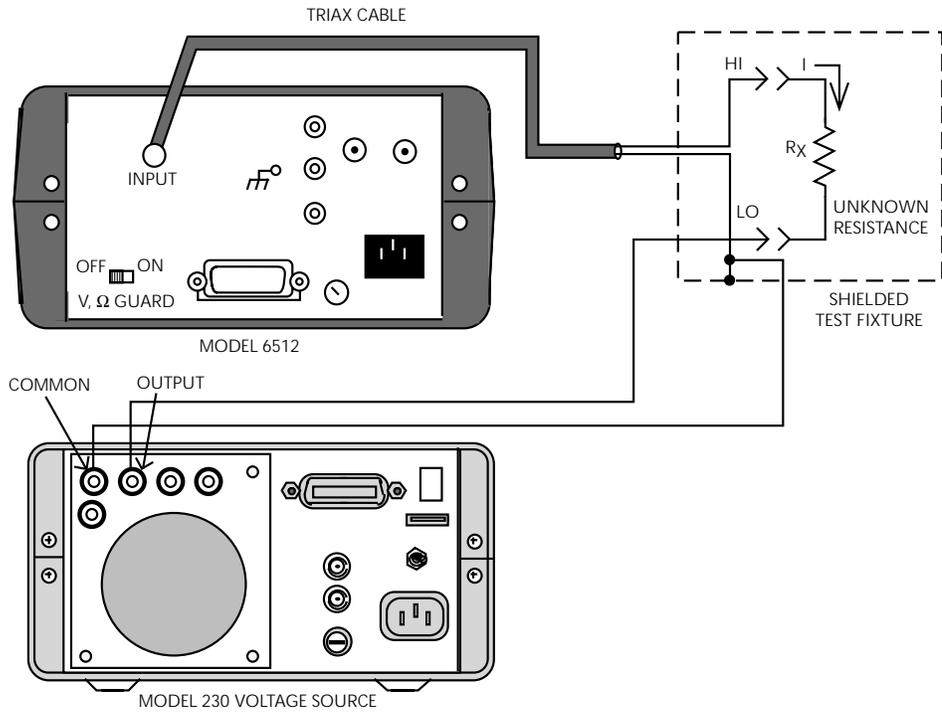


Figure 4-7
 Insulation resistance measurement using external voltage source

4.7 High-impedance voltmeter

The input resistance of the Model 6512 in the volts mode is greater than $200\text{T}\Omega$. Because of this high value, the Model 6512 can be used to make voltage measurements in high-impedance circuits with a minimum of loading effects on the circuit.

Consider the situation where a circuit designer must measure the gate-to-source voltage of a precision JFET amplifier that has a gate impedance of $100\text{M}\Omega$. Further assume that the required accuracy of this measurement is 1%.

The setup for this measurement is shown in Figure 4-9. The gate-source voltage is represented by V_{GS} , while the effective gate impedance is represented as R_{S} . The input resistance of the voltmeter is given as R_{IN} .

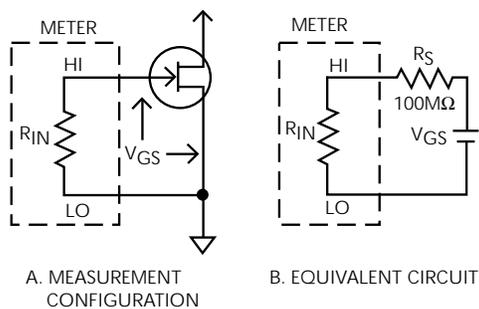


Figure 4-8
Measuring high-impedance gate-source voltage

The percent error due to voltmeter loading in this circuit can be given as:

$$\% \text{ ERROR} = \frac{R_{\text{S}}}{R_{\text{S}} + R_{\text{IN}}} \times 100 \%$$

Suppose, for example, a typical DMM with a $10\text{M}\Omega$ input resistance were used to make this measurement. The error because of meter loading would be:

$$\% \text{ ERROR} = \frac{100\text{M}\Omega}{100\text{M}\Omega + 10\text{M}\Omega} \times 100 \% = 91\% \text{ error}$$

Even if a DMM with an input resistance of $1\text{G}\Omega$ ($10^9\Omega$) were used, the error would still be:

$$\% \text{ ERROR} = \frac{100\text{M}\Omega}{100\text{M}\Omega + 1\text{G}\Omega} \times 100 \% = 9.1\% \text{ error}$$

Such a large error would not be tolerable in this case because of the 1% accuracy requirement. However, since the Model 6512 has an input resistance of $200\text{T}\Omega$, its error in this example would be:

$$\% \text{ ERROR} = \frac{100\text{M}\Omega}{100\text{M}\Omega + 200\text{T}\Omega} \times 100 \% = 0.00005\% \text{ error}$$

Note that this error term is so small as to be insignificant as it would be dominated by the instruments' accuracy specification.

Thus, the input impedance of the Model 6512 would be more than adequate for this situation, because the error due to meter loading is substantially better than the required 1% value stated earlier. In addition, the $4\frac{1}{2}$ digit resolution of the instrument allows the designer sufficient precision to make use of the high input impedance.

4.8 Voltage coefficients of high-megohm resistors

High-megohm resistors (above $10^9\Omega$) often exhibit a change in resistance with applied voltage. This resistance change is characterized as the voltage coefficient. The Model 6512 can be used in conjunction with a Model 230 Voltage Source to determine the voltage coefficient of such resistors.

The basic configuration for making voltage coefficient measurements is shown in Figure 4-10. The voltage, V_{S} , is applied to the resistor under test by the voltage source of the instrument. The current is measured by the electrometer input of the Model 6512. The resulting current can then be used to calculate the resistance.

Two resistance readings at two different voltage values will be required to calculate the voltage coefficient. The voltage coefficient in $\%/V$ can then be calculated as follows:

$$\text{Voltage Coefficient } (\%/V) = \frac{100(R_2 - R_1)}{R_1(\Delta V)}$$

where:

R_1 is the resistance with the first applied voltage.

R_2 is the resistance with the second applied voltage.

ΔV is the difference between the two applied voltages.

As an example, assume that the following values are obtained:

$$R_1 = 1.01 \times 10^{10} \Omega$$

$$R_2 = 1 \times 10^{10} \Omega$$

$$\Delta V = 5V$$

The resulting voltage coefficient is:

$$\text{Voltage Coefficient (\%/V)} = \frac{100(1 \times 10^8)}{1 \times 10^{10}(5)}$$

Note that the voltage coefficient of a particular device may apply only across the selected voltage range, and may, in fact, vary with different voltage increments in the same approximate range.

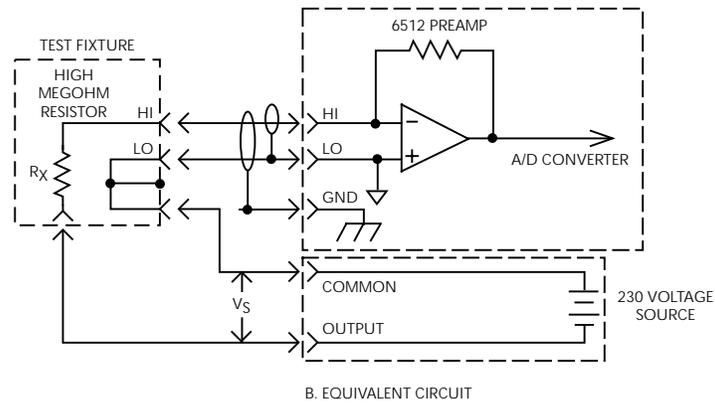
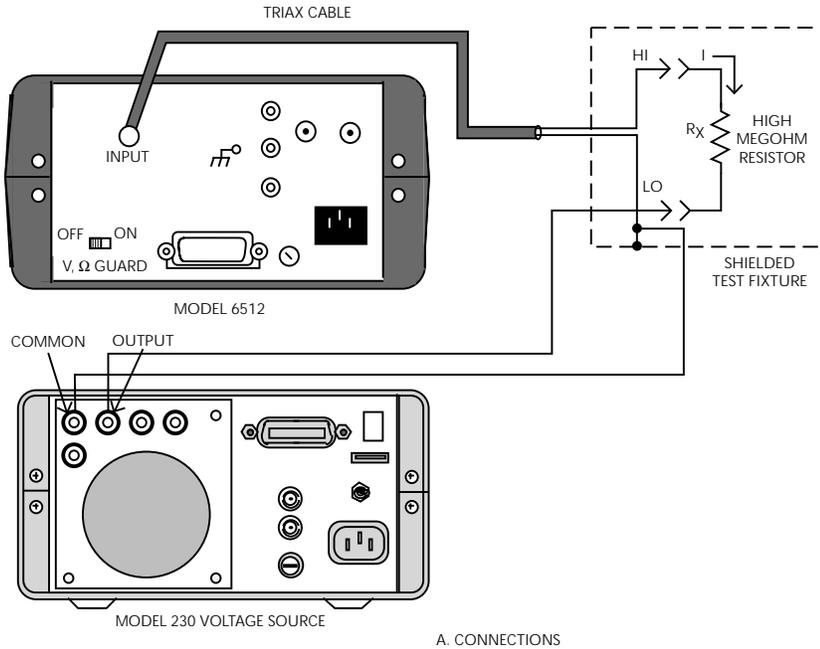


Figure 4-9
Configuration for voltage coefficient studies

4.9 Static charge detection

Electrostatic charge is a deficiency or excess of electrons on an ungrounded surface. Such charges are usually generated on poor conductors of electricity such as plastics, synthetic fibers, and paper during handling or processing of these materials. Once these charges accumulate, they do not dissipate readily because of the excellent insulating characteristics of the materials involved.

Static charge build-up can be a problem with integrated circuits, especially with those of the CMOS variety. While these devices, which operate at high impedance levels, often have static protection built in, it is best to properly protect them during transit or storage. For that reason, such ICs are usually shipped and stored in anti-static tubes.

A primary consideration, then, is the degree of static protection afforded by the anti-static tube. A comparison among various tubes can be set up to test the variations in charge build-up as a particular IC slides the length of the tube. The charge value will, of course, be measured by the Model 6512 being operated in the coulombs function.

To perform this test, a test fixture called a Faraday cup will be necessary. Such a fixture can be easily constructed from two cans, as shown in Figure 4-11. For example, the outer can could be a one-gallon paint can, while the inner cylinder could be one of slightly smaller diameter, such as a quart paint can. The two cans must be insulated from one another. Although the type of insulator is not all that critical, ceramic or Teflon insulators can be used.

For convenience, a BNC connector could be mounted on the outside can. The outer, or shield connection will, of course, be connected to the outer can, while the inner conductor should be connected to the inner can.

To perform the test, connect the Model 6512 to the Faraday cup using a suitable shielded cable, such as Model 4801 BNC cable. A Model 7078-TRX-BNC triax-to-BNC adapter will be required to make the connection. With the instrument in the coulombs mode, place a typical IC in the tube to be tested; allow it to slide the full length of the tube and fall into the Faraday cup. The amount of charge built up during the test will then be registered on the Model 6512.

The test can be repeated with other tubes, as required. In order for the test to be valid, all tubes should be the same length, and the same IC should be used in every case. The tube that generates the smallest static charge as seen on the electrometer is the one with the best anti-static characteristics. The amount of charge seen during this test will depend on many factors, including the type of tube material, tube length, the IC used, as well as the relative humidity. Typical values might be in the 0.5-1nC range for a good anti-static tube, while one without anti-static protection might generate 10 times that amount.

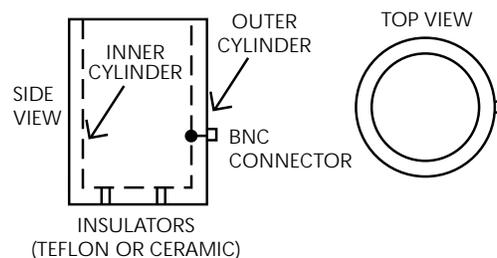


Figure 4-10
Faraday cup construction

5

Performance Verification

5.1 Introduction

The procedures outlined in this section may be used to verify that the instrument is operating within the limits stated in the specifications at the front of this manual. Performance verification may be performed when the instrument is first received to ensure that no damage or misadjustment has occurred during shipment. Verification may also be performed whenever there is a question of instrument accuracy, or following calibration, if desired.

WARNING

The procedures in this section are intended only for qualified service personnel. Some of the procedures may expose you to hazardous voltages. Do not perform these tests unless you are qualified to do so.

NOTE

If the instrument is still under warranty (less than one year from the date of shipment), and its performance falls outside the specified range, contact your Keithley representative or the factory to determine the correct course of action.

5.2 Environmental conditions

All measurements should be made at 18-28°C (65-82°F) and at less than 70% relative humidity unless otherwise noted.

5.3 Initial conditions

The Model 6512 must be turned on and allowed to warm up for at least two hours before beginning the verification procedures. If the instrument has been subjected to extremes of temperature (outside the range specified in paragraph 5.2), additional time should be allowed for internal temperatures to reach normal operating temperature. Typically, it takes one additional hour to stabilize a unit that is 10°C (18°F) outside the specified temperature range.

NOTE

While rated accuracy is achieved after the two-hour warm up period, input bias current may require additional time to settle to its optimum level. Allow two hours for input bias current to settle to less than 10fA and eight hours to less than 5fA. It is preferable in sensitive applications to leave the unit on continuously.

5.4 Recommended test equipment

The following equipment is needed to verify all measuring functions of the Model 6512:

- Keithley Model 263 Calibrator/Source (source volts, ohms, amps, and coulombs).
- Fluke 343A DC Calibrator (190V; $\pm 0.002\%$).
- 2-slot triax cable (supplied with Model 263).

- Keithley Model 6171 3-slot male to 2-lug female triax adapter.
- Single banana cable.
- Keithley Model CAP-31 protective cap/shield for INPUT connector.

5.5 Verification procedures

The following paragraphs contain procedures for verifying instrument accuracy with each of the four measuring functions: volts, ohms, amps and coulombs using a Model 263 Calibrator/Source. Using the Model 263 to verify Model 6512 simplifies the procedure and eliminates tedious characterization procedures and the need to build a special test fixture.

These procedures are intended for use only by qualified personnel using accurate and reliable test equipment. If the instrument is out of specifications, refer to Section 7 for calibration procedures, unless the unit is still under warranty.

WARNING

The maximum common-mode voltage (voltage between input low and chassis ground) is 500V. Exceeding this value may cause a breakdown in insulation, creating a shock hazard. Some of the procedures in this section may expose you to dangerous voltages. Use standard safety precautions when such dangerous voltages are encountered.

CAUTION

The maximum voltage between the high and low input terminals is 250V (10 seconds maximum on the mA ranges). Instrument damage may occur if this value is exceeded.

NOTE

Verify performance in the order listed: input current, amps, coulombs, volts, and ohms. Input current may remain high for several minutes following measurement of

high volts or ohms. Place the V, Ω GUARD switch in the OFF position unless otherwise noted.

5.5.1 Input current verification

Perform input current verification as follows:

NOTE

The following procedure must be performed at an ambient temperature of $23^{\circ}\text{C} \pm 1^{\circ}\text{C}$.

1. Disconnect all cables from the Model 6512 input.
2. Place the CAP-31 input cap on the INPUT connector.
3. Select the amps function, 2pA range, enable zero check, and then enable zero correct.
4. Connect a jumper between the rear panel COM and chassis ground terminals.
5. Disable zero check, and allow one minute for the reading to stabilize.
6. Verify that the reading is 50 counts or less (within 50fA). Enable zero check.
7. Remove the jumper connected between the COM and chassis ground terminals.

5.5.2 Amps verification

Connect the Model 6512 to the Model 263, as shown in Figure 5-1, and perform amps verification as follows:

1. Enable Model 6512 zero check, and select the 20mA range. Do not use auto-range.
2. Check that the display reads 0.000 ± 1 count. If not, enable zero correct.
3. Using the AMPS (active) current source mode, program the Model 263 to output 19.0000mA to the Model 6512.
4. Disable zero check, and verify that the reading on the Model 6512 is within the limits in Table 5-1.
5. Using Table 5-1 as a guide, repeat steps 1 through 4 for the 2mA through 2nA current ranges.
6. Using the AMPS V/R (passive) current source mode of the Model 263, repeat steps 1 through 4 for the 200pA through 2pA ranges.

* Reading limits shown include Model 6512 and Model 263 accuracy specifications.

5.5.3 Coulombs verification

Connect the Model 6512 to the Model 263 as shown in Figure 5-1, and perform coulombs verification as follows:

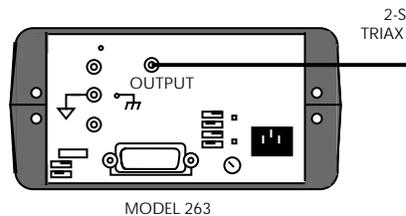


Figure 5-1
Connections for amps and coulombs verification

Table 5-1
Limits for amps verification

6512 range	263 function	263 output	Allowable reading (1 Year, 18°C-28°C)
20mA	AMPS	19.000mA	18.978 - 19.022mA
2mA	AMPS	1.90000mA	1.8973 - 1.9027mA
200µA	AMPS	190.000µA	189.76 - 190.24µA
20µA	AMPS	19.0000µA	18.976 - 19.024µA
2µA	AMPS	1.90000µA	1.8973 - 1.9027µA
200nA	AMPS	190.000nA	189.59 - 190.41nA
20nA	AMPS	19.0000nA	18.965 - 19.035nA
2nA	AMPS	1.90000nA	1.8962 - 1.9038nA
200pA	AMPS V/R	190.000pA	187.45 - 192.55pA
20pA	AMPS V/R	19.0000pA	18.770 - 19.230pA
2pA	AMPS V/R	1.90000pA	1.8811 - 1.9189pA

- Using the COUL (active) charge source of the Model 263, select the 2nC range.
- Place the Model 263 in the coulombs function, and perform zero correction by enabling zero check and zero correct in that order.
- Disable zero check on the Model 6512.

- Program the Model 263 to output 1.90000nC, and press OPERATE to source charge to the Model 6512.
- Verify that the Model 6512 reading is between 1.8943 and 1.9057nC.

5.5.4 Volts verification

NOTE

Current and charge verification must be performed before volts verification.

Connect the Model 6512 and 190V calibration source to the Model 263, as shown in Figure 5-2, and perform volts verification as follows:

- On the Model 6512, enable zero check, and select the 200mV range.
- Check to see that the display reads 000.00 ±1 count. If not, enable zero correct.
- Program the Model 263 to output 190.000mV.
- Disable zero check, and verify that the reading on the Model 6512 is within the limits listed in Table 5-2.
- Using Table 5-2 as a guide, repeat steps 1 through 4 for the 2V and 20V ranges.
- Set the Model 6512 to the 200V range.
- Set the external calibration source to output 190.000V to the Model 263.
- Source 190.000V to the Model 6512 by pressing SHIFT VOLTS on the Model 263.
- Verify that the reading on the Model 6512 is within the limits listed in the table.

10. Enable zero check on the Model 263, and turn off the external calibration (190V) source.

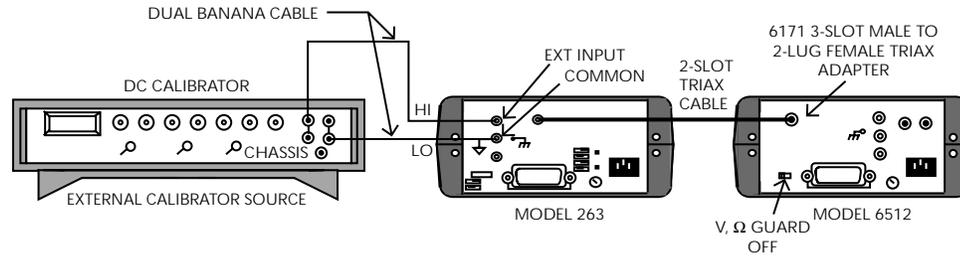


Figure 5-2
Connections for volts verification

Table 5-2
Limits for volts verification

6512 range	263 output	Allowable reading (1 year, 18°-28°C)
200mV	190.000mV	189.91 to 190.09mV
2V	1.90000V	1.8993 to 1.9007V
20V	19.0000V	18.993 to 19.007V
200V	190.000V	189.86 to 190.14V

* The 200mV, 2V, and 20V ranges allowable readings include Model 263 error. The 200V range reading is based solely on Model 6512 accuracy specifications.

5.5.5 Ohms verification

Connect the Model 6512 to the Model 263, as shown in Figure 5-3, and perform ohms verification as follows:

NOTE

Charge and current verification must be performed before resistance verification.

1. Set the Model 6512 to the 2kΩ range.
2. Zero correct the Model 6512 by enabling zero check and zero correct in that order.
3. Set the Model 263 to the 1kΩ range, and while in OPERATE, press ZERO to source zero ohms to the Model 6512.
4. Release zero check on the Model 6512, and allow the reading to settle.
5. On the Model 6512, press SUPPRESS to cancel offset and test lead resistance.
6. On the Model 263, source the 1kΩ resistor to the Model 6512. The actual value of the output resistance is displayed on the Model 263.
7. Record the Model 263 reading in Table 5-3.
8. Calculate the Model 6512 reading limit using the formula in the table.
9. Verify that the reading on the Model 6512 is within the limits calculated in step 8.
10. Referring to Table 5-3, repeat the basic procedure in steps 3 through 9 for the 20kΩ range.

11. For the remaining Model 6512 ranges, repeat steps 6 through 9 by sourcing the appropriate resistance to the electrometer. Note that guard must be enabled on both the Models 6512 and 263 when verifying the $G\Omega$ ranges. Also, note that COM of the Model 6512 must be connected to COMMON of the Model 263 (see Figure 5-3).

Figure 5-3
Connections for ohms verification

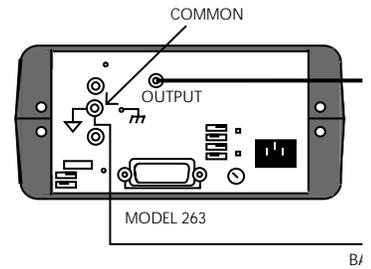


Table 5-3
Limits for ohms verification

6512 range	263 output (nominal)	6512 & 263 guard	Calculated limit			Allowable 6512 reading (1 year, 18°-28°C)
			263 reading	Equipment error*	Limit	
2kΩ	1kΩ	Off	(___ × 0.16%)	+ 0.0004kΩ	= ___	263 Reading ± Limit
20kΩ	10kΩ	Off	(___ × 0.13%)	+ 0.001kΩ	= ___	263 Reading ± Limit
200kΩ	100kΩ	Off	(___ × 0.23%)	+ 0.01kΩ	= ___	263 Reading ± Limit
2MΩ	1MΩ	Off	(___ × 0.225%)	+ 0.0001MΩ	= ___	263 Reading ± Limit
20MΩ	10MΩ	Off	(___ × 0.2125%)	+ 0.001MΩ	= ___	263 Reading ± Limit
200MΩ	100MΩ	Off	(___ × 0.23%)	+ 0.01MΩ	= ___	263 Reading ± Limit
2GΩ	1GΩ	On	(___ × 1.4%)	+ 0.0001GΩ	= ___	263 Reading ± Limit
20GΩ	10GΩ	On	(___ × 1.275%)	+ 0.001GΩ	= ___	263 Reading ± Limit
200GΩ	100GΩ	On	(___ × 1.1%)	+ 0.01GΩ	= ___	263 Reading ± Limit

* Includes Model 263 error.

5.5.6 Input impedance verification

Perform this test to verify that the input impedance of the Model 6512 is greater than $200T\Omega$:

1. Connect the DC calibrator, Model 263, and the Model 6512 together as shown in Figure 5-4.
2. Place the Model 6512 in the volts function, select the 20V range, and enable ZERO CHECK. Verify that the display shows $0.000V \pm 1$ count. If not, enable ZERO CORRECT.
3. Enable GUARD on both the Models 6512 and 263.
4. On the Model 263, select the $200G\Omega$ range, and press ZERO to source zero ohms. Make sure the Model 263 is in OPERATE.
5. Set the DC calibrator to output 19.000V.
6. On the Model 6512, disable ZERO CHECK, and note the reading.
7. Enable ZERO CHECK on the Model 6512, and press ZERO on the Model 263 to select the $100G\Omega$ resistor.
8. Disable ZERO CHECK on the Model 6512. After waiting a few seconds for settling, note the reading on the Model 263.
9. Compare the reading obtained in step 8 with that noted in step 6. The two readings should be within 10 counts (10mV) of one another.

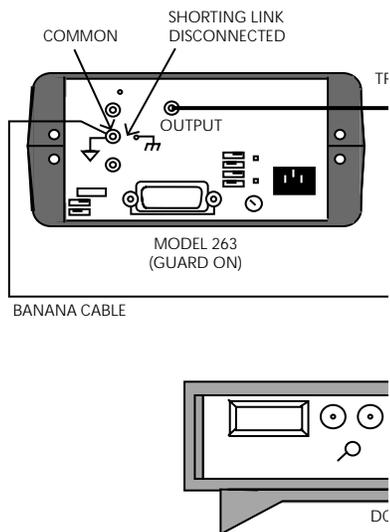


Figure 5-4
Connections for input impedance verification

6

Theory of Operation

6.1 Introduction

This section contains an overall functional description of the Model 6512 in block diagram form, as well as details of the various sections of the instrument. Information concerning the electrometer section, mother board circuitry, IEEE-488 interface, power supplies, and display circuitry is included.

Information is arranged to provide a description of each of the functional blocks within the instrument. Many of these descriptions include simplified schematics and block diagrams. Detailed schematic diagrams and component layout drawings for the various circuit boards are located at the end of Section 8.

6.2 Overall functional description

A simplified block diagram of the Model 6512 is shown in Figure 6-1. The instrument may be divided into three discrete sections: analog, digital, and power supplies. The analog and digital sections are electrically isolated from one another by using opto-isolators for control and communications. Separate power supplies for the various analog and digital sections ensure proper isolation. Because of these isolation techniques, the analog low connection may be floated up to $\pm 500\text{V}$ above chassis ground, while digital common may be floated up to $\pm 30\text{V}$ above ground.

The analog section consists of the input stage, output stage, ranging amplifier, A/D converter, and feedback and switch-

ing elements. The input stage is a proprietary FET amplifier designed for high input impedance ($200\text{T}\Omega$) and low input offset current (less than 5fA). The output stage provides further amplification, thus allowing the preamp output to go as high as $\pm 210\text{V}$, depending on the selected range and function. Further control of the input and output stages is provided by the feedback and switching elements, which set gain and transfer function according to the selected range and measuring function. In addition, zero check and zero correct provide a convenient means to zero the instrument, allowing cancellation of internal offsets.

The ranging amplifier conditions the output stage signal into a $0\text{-}2\text{V}$ signal for the A/D converter. The A/D converter uses both charge balance and single-slope conversion techniques.

The heart of the digital section is the 146805E2 CMOS processor that supervises the entire operation of the instrument. Additional digital circuits include the display made up of a 4 1/2 digit mantissa and a 2-digit alpha or numeric exponent, the IEEE-488 interface, and the front panel switch matrix. The switch matrix decodes front panel switch closure information that controls instrument operation from the front panel.

Because of the diversity of circuitry within the Model 6512, a number of power supply voltages are required. The analog section requires $\pm 5\text{V}$ (input stage) and $\pm 210\text{V}$ and $\pm 24\text{V}$ supplies (output stage). Additional supplies include a separate $+5\text{V}$ and -9.1V supply for A/D circuits, and a separate $+5\text{V}$ supply for digital circuitry.

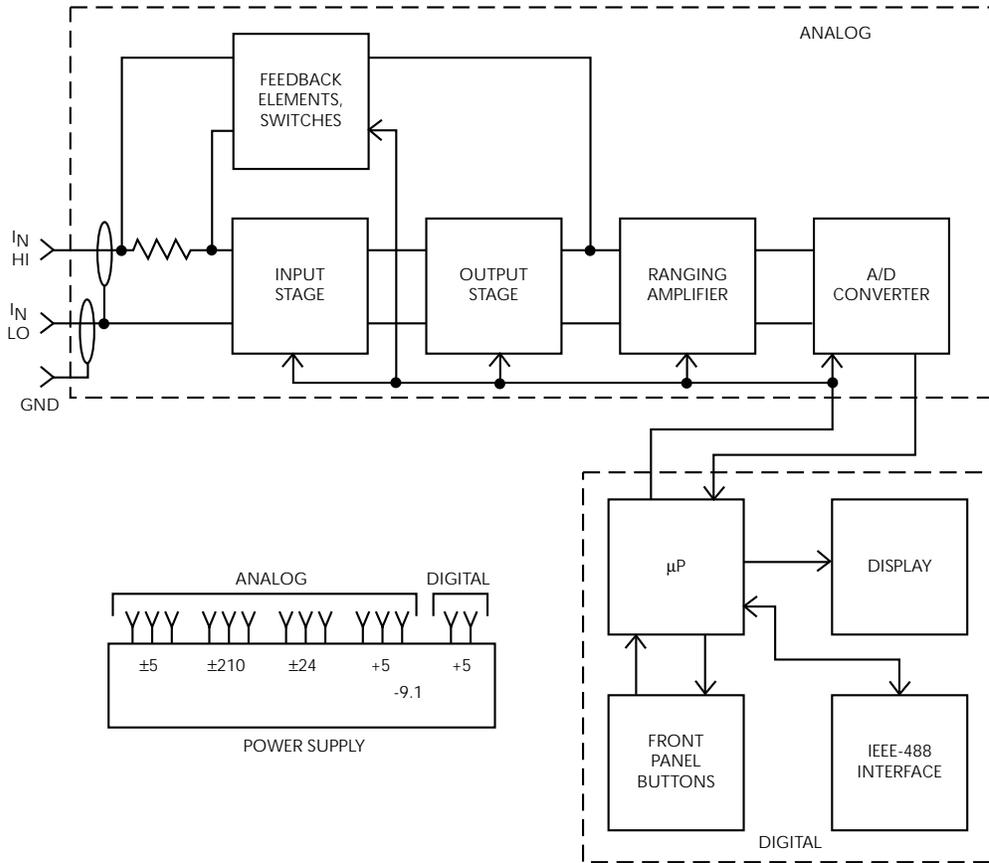


Figure 6-1
Overall block diagram

6.3 Input preamplifier

The input preamplifier provides the high input impedance and high output voltage capability necessary for the volts and ohms functions, and the low input impedance and high current output capability needed for the amps and coulombs functions.

A simplified block diagram of the input preamplifier is shown in Figure 6-2. The circuit is essentially made up of three sections: an input stage, which provides the necessary input impedance functions, a gain stage, which provides the needed amplification, and an output stage, which supplies the required voltage or current drive capability. Additional feedback and switching elements configure the amplifier according to the selected range and measuring function.

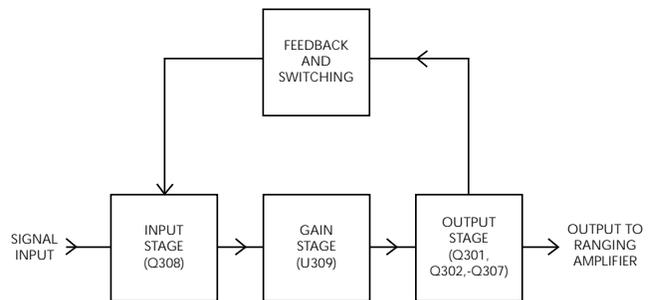


Figure 6-2
Basic configuration of electrometer preamplifier

The exact configuration of the input preamplifier will depend on the measuring function. Figure 6-3 shows circuit configuration for the four measuring functions. In the volts function, the circuit is set up as a high-input impedance ($2 \times 10^{14}\Omega$), unity gain, non-inverting buffer amplifier. In the ohms function, a bootstrapped reference is placed in series with a range resistor (R_F) that drives a constant current through the measured resistance (R_X). The reference has a value of 10V, 1V or 0.1V, depending on the selected range. The voltage developed across the unknown resistance is proportional to its value.

In the amps and coulombs modes, the circuit is configured as a feedback type current-to-voltage converter. In the amps mode, the feedback element is a resistor, with the value dependent on the selected range. In the coulombs mode, the feedback element is a capacitor.

6.3.1 Input stage

A simplified schematic of the input stage is shown in Figure 6-4. The primary purpose of this stage is to provide low leakage characteristics of the input preamplifier.

Stage operation centers around a dual JFET, Q308. Resistors R314, R342, R351 and R352 provide a means to balance the circuit with help of jumper W303. Depending on circuit offset, jumper W303 should be placed in one of three positions: A, B, or C.

Signal input is applied to the gate of the left JFET section through R334. The characteristics of the right JFET section remain constant since its V_{GS} voltage stays constant. Because of the variation in the characteristics of Q308A, the current through R335 varies, developing a proportional output signal that is applied to the next stage.

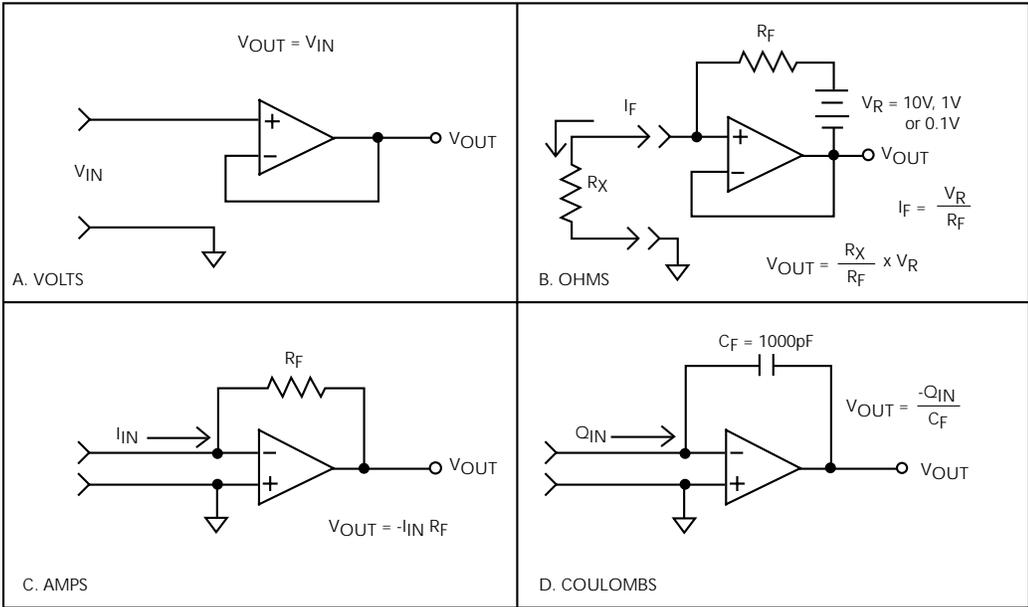


Figure 6-3
Electrometer preamplifier configuration

sistors. This input causes a current, V/R_E , to flow through R309 and R323. This current develops an output voltage: $-V(R_L/R_E)$. R327 and R324 limit power dissipation at high current outputs for Q306 and Q307 respectively. CR306 and CR307 provide protection for the $\pm 24V$ supplies in case a high external voltage is applied to the PREAMP OUT terminal. R305 and R308 provide protection for the output stage in this same situation. Note that the output stage provides an inversion in amps and coulombs, while in volts and ohms it does not.

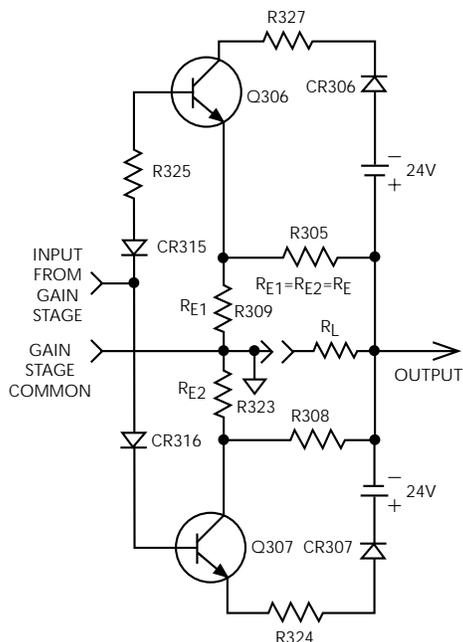


Figure 6-7
Output stage configuration in amps and coulombs

6.3.4 Ohms voltage source

In the ohms function, a bootstrapped voltage source is connected in series with a range resistor to force a constant current through the resistance being measured. A simplified schematic diagram of this source is shown in Figure 6-8.

The source itself is made up of U304 and associated components. VR301 provides the voltage reference, while VR304 is a clamping diode to protect the circuit in case of line over voltage. R347 limits power dissipation in Q302. The current through the reference is produced by the 10V output through R315. R316, R313, and R317 divide the output to provide feedback for U304. R313 and VR301 are selected at the fac-

tory to provide an accurate 10V output. The actual source output is 10V, but this value is divided to 1V and 0.1V by a voltage divider made up of elements of R304. Q302 buffers the output of U304 since R304 will draw 10mA. Only a single voltage source value is used for a given range, with the value being selected by the appropriate relay contacts. For the 2M Ω range, however, all relay contacts are open, and a 1 μ A current is sourced through the precision 900k Ω resistor R303 and feedback element R322.

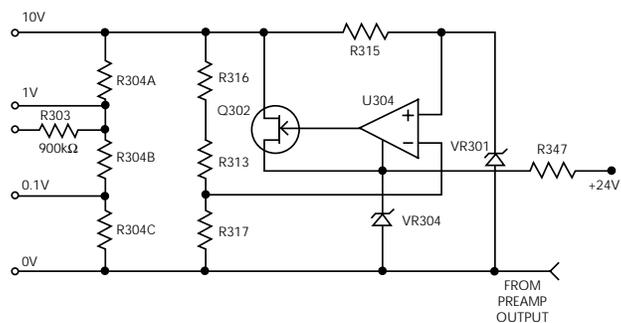


Figure 6-8
Ohms voltage source simplified schematic

6.3.5 Zero check

The zero check mode provides a means for determining and cancelling offsets internal to the instrument. The exact configuration of the zero check circuitry will depend on the selected function.

A simplified schematic of the zero check circuitry for volts and ohms functions is shown in Figure 6-9. When zero check is enabled, K307 is energized, providing a path to signal common through the normally closed contacts of K301. A 10M Ω resistor, R334, is placed across the electrometer input when zero check is enabled, while the preamp input is shorted to input low.

In amps and coulombs, contacts on K301 connect the inverting input and the output of the op amp together. This configuration gives the circuit unity gain, allowing any input offset voltage to appear at the output. Note that when zero check is enabled, the input impedance is the combined impedance of the feedback element in parallel with R334, which has a value of 10M Ω (see Figure 6-10).

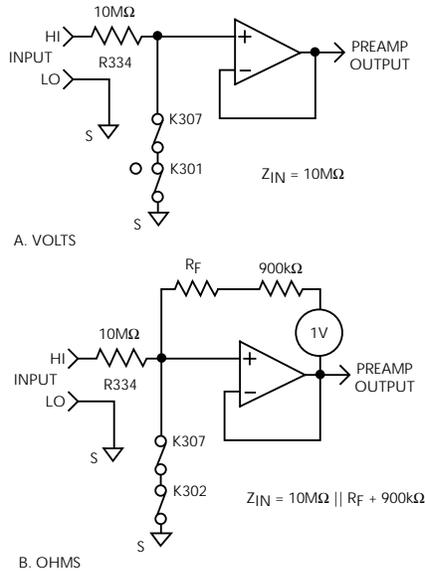


Figure 6-9
Zero check configuration in volts and ohms

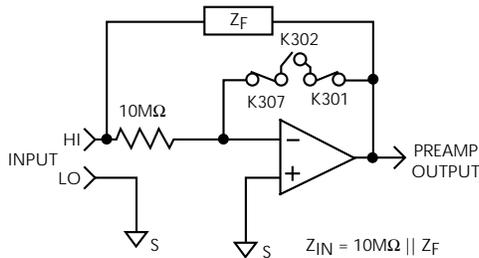


Figure 6-10
Zero check configuration in amps and coulombs

6.4 Additional signal conditioning

Before the signal can be applied to the A/D converter for digitization, it must be further scaled as described in the following paragraphs.

6.4.1 Ranging amplifier

The ranging amplifier provides inverting gain values of X10, X1, X0.1, or X0.01. The actual gain value will depend on the selected range and function.

A simplified schematic of the ranging amplifier is shown in Figure 6-11. The ranging amplifier itself is U130, while gain is set by feedback resistors R142, R143, R144, R145, and input resistor R128. The gain is selected by switching these resistors in and out of the circuit with FETs.

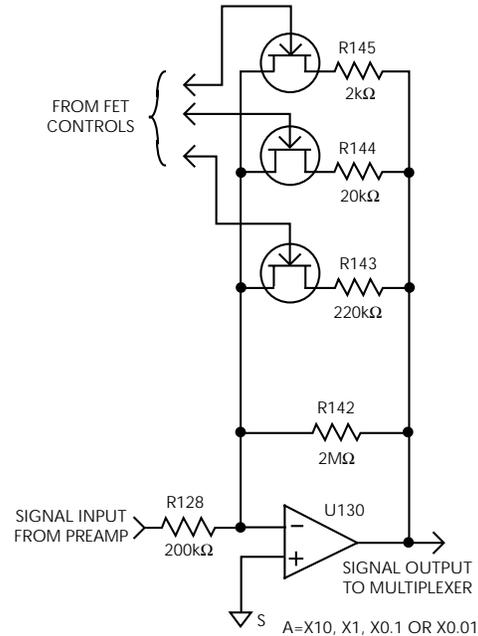


Figure 6-11
Simplified schematic of ranging amplifier

6.4.2 Multiplexer and buffer amplifier

The multiplexer selects among the three signals that are part of the Model 6512 measurement cycle. During the common phase, the multiplexer selects signal common. During the reference phase, the -2V reference voltage is selected, while the signal from the ranging amplifier is selected during the signal phase.

Figure 6-12 shows a simplified schematic of the multiplexer and buffer amplifier. U145 is the multiplexer IC, which contains CMOS devices that act as analog switches to select among the three input signals. The multiplexer IC is controlled by digital signals that are generated by the microprocessor.

Figure 6-13 shows the general signal switching phases for the three signals. During each phase, an integration is performed by the A/D converter, and the resulting data is then used by the microprocessor to calculate the final reading.

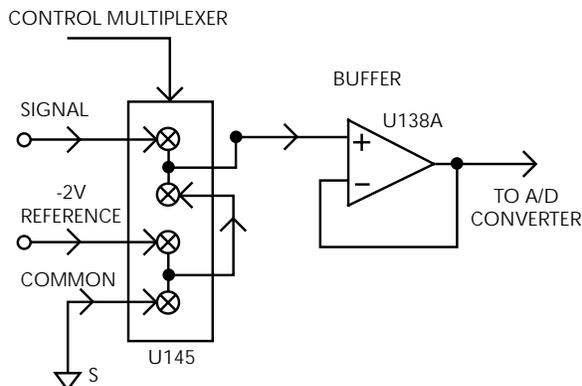


Figure 6-12
Multiplexer and buffer

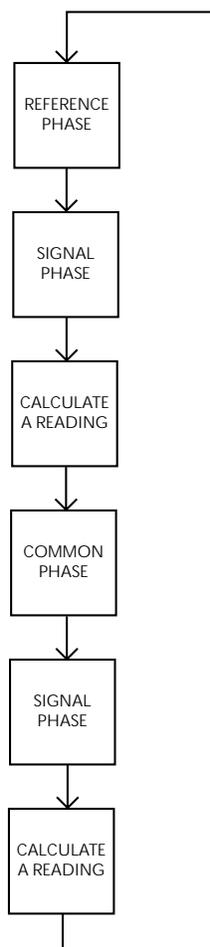


Figure 6-13
Multiplexer phases

6.4.3 -2V reference source

Model 6512 measurements are based on comparing the unknown signal with an internal -2V reference voltage source. During each measurement cycle, the unknown signal is sampled and then compared with signal common and the -2V reference values.

Figure 6-14 shows a simplified diagram of the -2V reference source. VR102 provides a highly stable -6.3V reference, while U139 and elements of R153 provide a constant current to minimize zener voltage variations. R146A and R146B divide down the -6.3V value to the final -2V reference voltage. The output of U139 (-7V) is used as bias for the A/D converter, and as a negative supply for various other components.

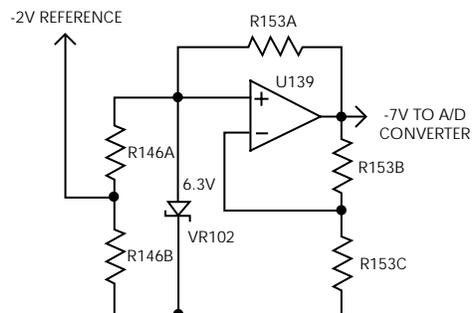


Figure 6-14
-2V reference source

6.5 A/D converter

The Model 6512 uses an A/D converter that utilizes both constant-frequency charge balance and single-slope techniques. This combination gives the instrument both high accuracy and relatively fast conversion times.

A simplified schematic of the A/D converter is shown in Figure 6-15, along with an associated integrator waveform.

The charge balance phase begins when the input ENABLE/DISABLE line is set high. This action occurs at the end of a firmware-generated delay period that allows the signal to settle following signal selection. Once the input is enabled, the signal from the buffer amplifier is added to the level-shift current applied through R153H. In this manner, the $\pm 2V$ bipolar signal from the buffer amplifier is converted to a unipolar signal that can be integrated.

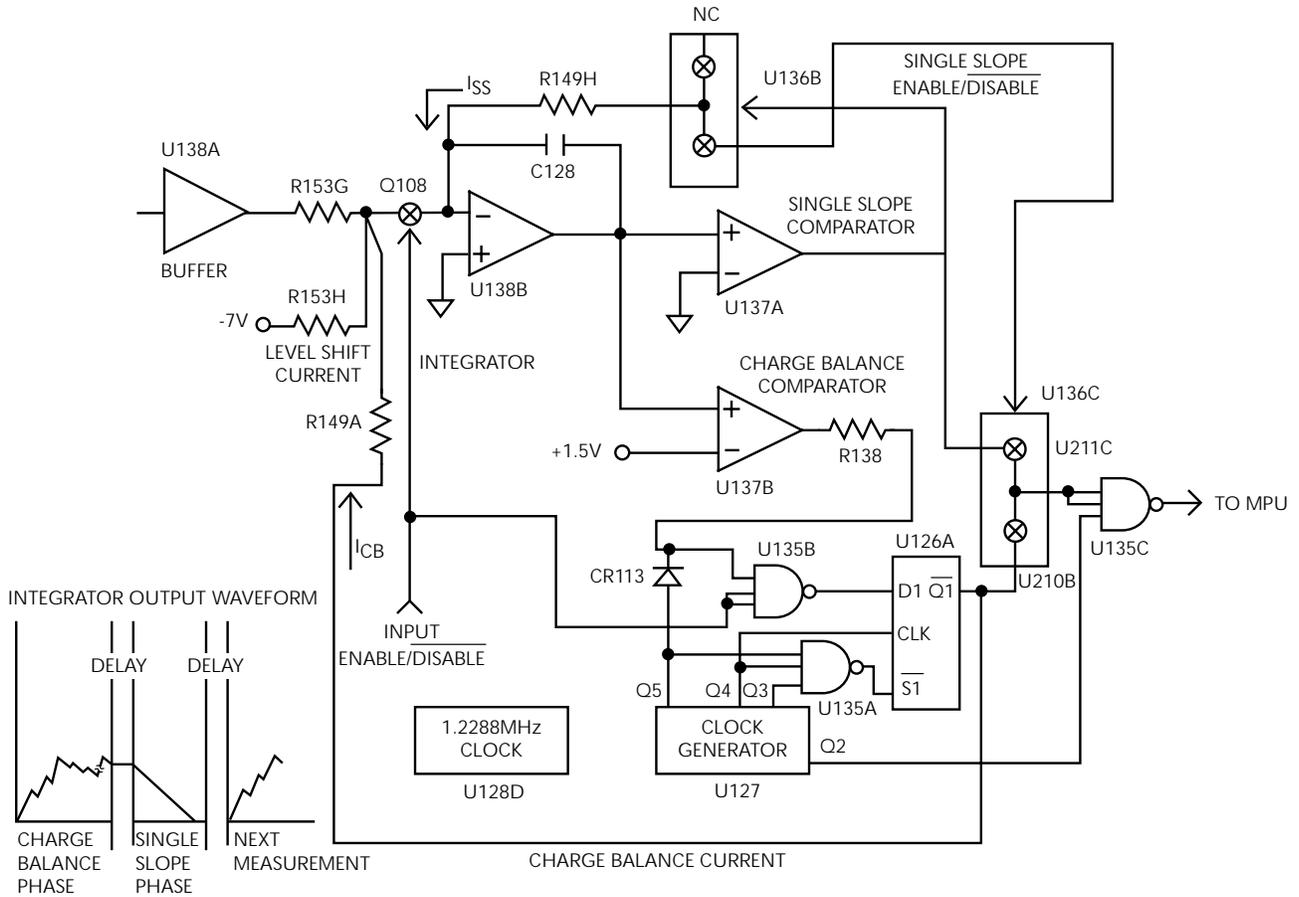


Figure 6-15
A/D converter

The integrator is made up of U138B and C128. When the input to the integrator is applied, the integrator output ramps up until its voltage is slightly higher than the voltage applied to the inverting input of the charge balance comparator (U137B). When the Q4 output of the clock generator (U127) goes high, the output of U135B is low, and the $\overline{Q1}$ output of U126A will go high. This action injects the charge balance current into the integrator input. Since the charge balance current is much larger than the sum of the input and level-shift currents, the integrator output now ramps in the negative direction. The integrator output will continue to ramp in the negative direction until the output of U135A goes low. Note that the Q3, Q4, and Q5 outputs of U127 must all be high for the output of U135A to go low.

The output of U136C is gated with the Q2 output of the clock generator by U135C. Each time Q2 goes high while the U136C output is high, a pulse is fed to the microprocessor. The MPU then counts the total number of pulses that occur during the charge balance phase.

The charge balance phase lasts for 100msec. At the end of this period, the output of the integrator is resting at some positive voltage. Since the integrator output is connected to the non-inverting input of the single-slope comparator (U137A), the single-slope comparator output remains high until the integrator output ramps in the negative direction.

During the single-slope phase, Q108 is turned off to disconnect the input and charge balance currents from the integrator input. In place of these two currents, the single-slope current (I_{SS}) is injected into the integrator input. This current

is developed by connecting one end of R149H to +5V through U136B. As long as the integrator output remains positive, the Q2 pulses from U127 are transmitted to the microprocessor, where they are counted to be used in the final reading. Once the single-slope comparator output goes low, the Q2 pulses are turned off by U135C.

6.6 Digital circuitry

Model 6512 operation is controlled by the internal microcomputer and associated firmware. The following paragraphs briefly describe the various aspects of the digital circuitry. Descriptions are keyed to the digital circuitry schematic (drawing number 6512-106, page 2) located at the end of Section 8.

6.6.1 Microcomputer

Microcomputer operation centers around the 8 bit 146805 CMOS microprocessor, U109. This device utilizes an 8-bit data bus and incorporates a multiplexed data/address bus for the lower eight bits of the 12-bit address bus. The 146805 has 112 bytes of on-chip memory, two 8-bit I/O ports, and is capable of directly addressing 8K bytes of memory. The MPU has direct control over the display, front panel switches, analog-to-digital converter, the IEEE-488 bus, as well as the Meter Complete output and the External Trigger Input.

Microprocessor timing is performed by Y101, a 3.2768MHz crystal. The signal is internally divided by five to obtain a bus operating frequency of 655.36kHz. This signal is present at the AS terminal of the processor and is used as a control signal to strobe the lower ordered eight bits of the address into the address latch, U108. A 655.36kHz signal is also present at the DS terminal to act as a system clock.

6.6.2 Memory elements

Firmware for the Model 6512 is stored in U106, a 27128 16K × 8 PROM. Temporary storage is afforded by U107, a 6116 2K × 8 RAM IC. The MPU uses the RAM for temporary storage, as well as for data store readings. Calibration constants, the display mode, and the IEEE-488 primary address are stored in the NVRAM, U104. During the power-up cycle, NVRAM data is transferred to normal RAM to allow easier access during operation. While data transmission to the ROM and RAM are done in parallel, NVRAM data transmission is performed serially.

6.6.3 Device selection

The 146805 processor can directly address only 8K bytes of memory. The Model 6512 requires greater addressing capability, as 16K of ROM, 2K of RAM, and other memory space requirements are present in the system. To get around this limitation, device selection circuitry is incorporated with the microcomputer.

Device selection is performed by elements of U111, U112, U117, and U118. MPU lines used as part of the selection process include the A10-A12 address lines, the PB6 line, the PB7 line, and the DS line. Signals generated by this circuitry include a line that controls the ROM chip select, a signal line that controls the RAM chip select, and circuitry which enables the display control and IEEE-488 bus circuits. Additional device selection signals include the memory paging signals. Two signals divide the 16K ROM area into 4K pages, while the a third signal divides the 2K RAM area into two 1K pages.

Because of the paging scheme employed, several devices can occupy a given address within the microprocessor's addressing space. Table 6-1 gives the general address range for each device.

Table 6-1
Memory mapping

Device	Address range
RAM (U107)	000 _H -03FF _H
ROM (U106)	0800 _H -1FFF _H
Display Control (U110)	0412 _H
Display Control (U116)	040A _H
IEEE-488 Bus (U113)	0418 _H -041F _H

6.6.4 IEEE-488 bus

The Model 6512 has a standard IEEE-488 interface that allows the instrument to be programmed from a system controller. Commands can be sent over the bus to the instrument, and data can be requested from the instrument as well.

The IEEE-488 interface is made up of U113, U119, and U120. U113 is a 9914 GPIA (General Purpose Interface

Adapter), while U119 and U120 are 75160 and 75161 interface bus drivers.

The 9914 GPIA simplifies MPU interfacing to the IEEE-488 bus because many control sequences take place automatically. For example, when the MPU writes to the GPIA data output register, the handshake sequence is performed automatically. Without the GPIA chip, complex firmware routines would otherwise be required.

On the MPU side of the GPIA, data transmission is handled much like any other data bus transaction. MPU data access is performed through the D0-D7 lines, while the RS0-RS2 lines (which are connected to the three least significant address lines) serve to select among the 14 internal registers (seven read, seven write) of the IC. Chip selection is performed by the CS line.

The output of the 9914 IC is in standard IEEE-488 format; the eight data lines (DIO1-DIO8), the three handshake lines (DAV, NRFD, NDAC), and the five management lines (ATN, REN, IFC, SRQ, and EOI) are all active low with approximately zero volts representing a logic one. The two IEEE-488 bus drivers, U119 and U120, are necessary to bring the drive capability of the interface up to the requirements of the IEEE-488 standard, which includes provisions for up to 15 devices to be connected to the bus at one time. The outputs of the bus drivers are connected to J1010, which is a standard IEEE-488 connector.

6.6.5 Input/output circuitry

Additional MPU functions include the control of the Meter Complete Output and External Trigger Input, and analog-to-digital converter control.

At the end of its conversion cycle, the Model 6512 sends a pulse out the Meter Complete Output jack on the rear panel. This function is performed by the PB2 line of the MPU through U102A configured as a buffer/inverter. Diodes CR104 and CR105 and resistor R102 protect the circuit output.

U102D, U105B, and associated components process the incoming trigger signal. U102D buffers and inverts the signal, while U105B latches the trigger pulse. The pulse is then read by the MPU through PA6. PB1 is used to reset the trigger latch once the pulse is read. Note that PB1 is also used to read the status of the calibration jumper (W101) during the calibration program.

As with the Meter Complete Output, protection of the External Trigger Input is necessary to protect the device from over-voltage inputs. External Trigger protection components include R101, CR102, and CR103.

A/D control information is fed out the PB3 and PB5 terminals through U102B. A pulse-width modulation scheme is used, with 18 and 50 μ sec pulses representing logic 0 and logic 1 respectively. A 200 μ sec pulse is used to strobe data into the A/D and serial-parallel control circuits. Note that this information is used to control the A/D converter as well as to control the input preamplifier (through relays), set the ranging amplifier gain, and to control the three phases of the measurement cycle. Isolation is provided by opto-isolator U122. Because of this isolation scheme, input signal common can be floated up to ± 500 V above chassis ground, while digital common floats within ± 30 V of ground.

In a similar fashion, A/D data is routed in from the A/D converter through opto-isolator U121. The MPU reads this data through the TIMER terminal. As data pulses come in, an internal 8-bit timer is incremented until 256 counts have occurred. When all counts have been taken, an internal interrupt is generated, which causes to MPU to read the timer data. A separate firmware counter is then decremented, and the process repeats. Because of this data input scheme, MPU time necessary to read the A/D converter data is minimized, and the processor can concentrate on other important tasks.

6.6.6 Display circuitry

Display circuitry includes those elements necessary to control the seven- and 14-segment readouts, the front panel annunciator LEDs, and to read the front panel switches. The display circuitry schematic may be found on drawing number 6512-116 located at the end of Section 8.

The display circuitry consists of the LED readouts (DS201-DS206), the LED annunciators (DS207-DS224), the segment drivers (U201 and U202), and the digit select circuitry (U204, U201, and U203). DS202-DS205 are standard 7-segment units, while DS206 is a dual 14-segment display.

The display is updated at 1.56msec intervals. Timing for this process is performed by a 640Hz clock, which controls the segment latches, U110 and U116, located on the mother board. Each time an interrupt is generated, the MPU writes segment data for two digits to the segment latches. The two latch outputs are then enabled in sequence by the 640Hz

clock. When a latch output is enabled, segments in the selected digit are turned on.

Digit selection is performed by data from the PA3, PA4, and PA5 outputs of the MPU to control U203. A single U203 output, corresponding to the selected digit, will go low when the correct data appears on its inputs. For example, if 010₂ appears on the inputs of U203, DS201 will be turned on.

Selection of the display annunciators is performed in a similar manner. The data stored in the corresponding segment latches will then turn on the appropriate annunciator LEDs.

Front panel switches are read in a somewhat similar manner by using a row-column matrix along with U206. To select a particular row, data is transmitted out the MPU PA3, PA4, and PA5 lines to U206. This action selects one of the rows by placing the corresponding output of U206 high. Matrix columns are then read by reading data in through PA0, PA1, and PA2, of the MPU. If a particular switch contact is closed, the data bit will be high; if the switch is open, the data bit will be low.

6.7 Power supplies

The Model 6512 has numerous power supplies, which are used to power the analog and digital circuits. Diagrams of these supplies may be found on drawing numbers 6512-106, page 1 and 6512-166 located at the end of Section 8.

The power supplies are essentially divided into two groups: one group powers the digital circuits, while a second group of supplies is used to power the analog circuits. Each group of supplies has its own transformer secondary. This configuration is used to maintain proper isolation between the digital circuits and sensitive analog circuitry.

AC power is applied to J1011, which is the power connector located on the rear panel of the instrument. S101 is the POWER switch located on the front panel, while S102 is the line voltage selection switch. When S102 is in the 115V position, the primary windings are connected in parallel; when S102 is in the 230V position, the T101 windings are placed in series.

T101 has a secondary winding, which is used to supply the +5V supply used to power the digital circuitry. Rectification is done by elements of CR110, while filtering is performed by C101. The supply voltage is regulated by U101, which is a standard 7805 IC regulator.

Other secondaries of T101 supply power to all the DC supplies that power the analog circuits.

The $\pm 210V$ supplies, which are used to power the preamplifier output circuit, are generated by one secondary winding of T101 and two voltage-doubling circuits. CR301, CR303, C301, and C304 perform the rectifier and filtering functions for the +210V supply, while CR302, CR304, C302, and C303 are similar components in the -210V supply. The $\pm 210V$ supplies are not regulated and are referenced to analog and signal common.

Another secondary winding on T101 feeds power to components that generate the +5V analog and -9V analog supplies. The +5V supply is used to power the ranging amplifier, A/D converter, and other components (such as U301) located in the analog section, while the -9V supply powers the -2V reference source. +5V supply components include CR311, which rectifies AC input, C305 for filtering, and Q309, VR302, and U306 for regulation. Elements of CR311 also provide rectification for the -9V supply, while C306 filters, and VR303 regulates the output voltage. Both of these supplies are referenced to analog and signal common.

The $\pm 5V$ sources supply power to much of the input preamplifier section. These two supplies, which are referenced to bootstrap common, utilize half-wave rectification and IC regulators. CR320, C316, and U308 are associated with the +5V supply, and CR319, C315, and U307 perform similar functions for the -5V supply. R344 and R345 are intended to trim the -5V supply voltage to a precise value.

The $\pm 24V$ sources supply power to the preamp output stage when the circuit is configured for amps or coulombs. Each supply is a simple half-wave rectifier, filter capacitor pair, with CR323 and C317 supplying +24V, and CR322 and C311 performing the same functions in the -24V supply. Both these supplies are referenced to the preamplifier output.

7

Maintenance

7.1 Introduction

This section contains information necessary to maintain, calibrate, and troubleshoot the Model 6512. Fuse replacement and line voltage selection procedures are also included.

WARNING

The procedures included in this section are intended for use only by qualified service personnel. Do not perform these procedures unless qualified to do so. Many of the steps in this section may expose you to potentially lethal voltages that could result in personal injury or death if normal safety precautions are not observed.

7.2 Line voltage selection

The Model 6512 may be operated from either 105-125V or 210-250V, 50 or 60Hz power sources. A special transformer may be installed for 90-110V and 195-235V ranges. The instrument was shipped from the factory set for an operating voltage marked on the rear panel. To change the line voltage, proceed as follows:

WARNING

Disconnect the Model 6512 from the power line and all other sources before removing the top cover.

1. Remove the screws securing the top cover to the rear panel, and carefully lift the cover away from the instrument.
2. Locate the line voltage switch adjacent to the POWER switch on the mother board. Place the switch in the correct position, as outlined in Table 7-1. (Switch positions are marked on the mother board.)
3. Install a fuse consistent with the operating voltage, as described in paragraph 7.3.

CAUTION

The correct fuse type must be used to maintain proper instrument protection.

4. Mark the selected line voltage on the rear panel for future reference (to avoid confusion, erase the old mark).
5. Replace the top cover, and connect the instrument to the power line.

Table 7-1

Line voltage selection (50-60Hz)

Line voltage	Voltage selection switch position
105-125V	115V
210-250V	230V
90-110V*	115V
195-235V*	230V

* Requires special factory configuration. Unit will be appropriately marked when configured for 90-110V or 195-235V operation.

7.3 Line fuse replacement

A rear panel fuse protects the power line input of the instrument. Use the following procedure to replace the line fuse:

WARNING

Disconnect the instrument from the power line and other equipment before replacing the fuse.

1. With the power off, place the end of a flat-blade screwdriver into the slot in the rear panel LINE FUSE holder. Push in gently, and rotate the fuse carrier one-quarter turn counterclockwise. Release pressure on the holder, and its internal spring will push the fuse and carrier out of the holder.
2. Remove the fuse, and replace it with the type recommended in Table 7- 2.

CAUTION

Do not use a fuse with a higher current rating than specified, or instrument damage may occur. If the instrument repeatedly blows fuses, locate and correct the cause of the trouble before replacing the fuse.

3. Install the new fuse and the fuse carrier into the holder by reversing the above procedure.

Table 7-2
Line fuse selection

Line voltage	Fuse type	Keithley part no.
90-125V	A, 250V, 3AG, slow blow	FU-20
195-250V	1/16A, 250V, 3AG, slow blow	FU-21

7.4 Calibration

An advanced feature of the Model 6512 is its digital calibration capabilities. Instead of the more conventional time-consuming method of adjusting numerous calibration potentiometers, the technician need only apply an appropriate calibration signal and digitally calibrate the instrument, either from the front panel, or over the IEEE-488 bus.

7.4.1 Calibration cycle

Calibration should be performed every 12 months, or if the performance verification procedures in Section 5 show that the instrument is out of specification. If any of the calibration procedures cannot be performed properly, refer to the troubleshooting information in this section.

7.4.2 GUARD switch

Place the V, Ω GUARD switch in the OFF position unless otherwise noted.

7.4.3 Calibration jumper

A jumper, located in the mother board, disabled/enables front panel and IEEE- 488 bus calibration. When the jumper is in the disabled position, permanent (NVRAM) storage of calibration constants will not take place. However, temporary calibration values may be entered and used even if NVRAM calibration storage is disabled. Note, however, that calibration parameters will be lost once power is turned off unless they are stored in NVRAM.

The calibration jumper location and the disabled/enabled positions are indicated in Figure 7-1.

WARNING

Turn off the instrument, and disconnect the line cord before removing the top cover to reposition the calibration jumper.

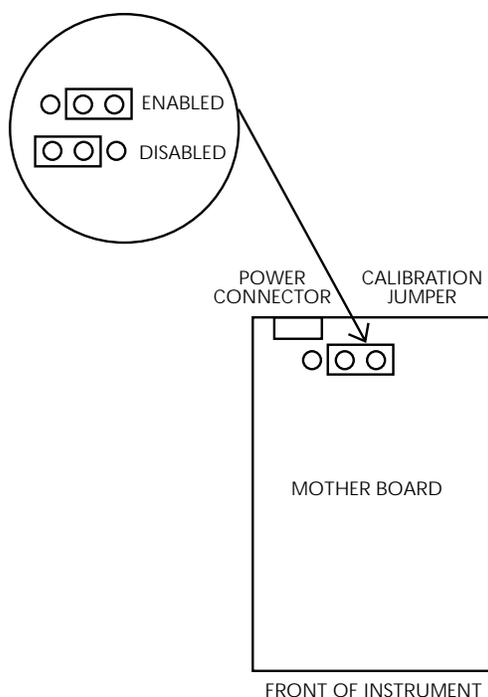


Figure 7-1
Calibration jumper location

7.4.4 Required calibration equipment

The following items (one of each) are necessary to calibrate the Model 6512:

- Keithley Model 263 Calibrator/Source.
- Fluke Model 343A DC Voltage Calibrator (190V; $\pm 0.002\%$ accuracy).
- Triax-to-Triax cable (supplied with 263).
- Keithley Model 6171 3-slot male to 2-lug female triax adapter.
- Keithley Model CA-18-1 Dual Banana-to-Banana cable.
- Keithley Model CAP-31 protective cap/shield for the INPUT connector.

NOTE

If the Model 6512 is to be calibrated over the IEEE-488 bus, computer equipment will also be required. See Appendix D for equipment and calibration program details.

7.4.5 Environmental conditions

Calibration should be performed under laboratory conditions having an ambient temperature of $23^{\circ} \pm 1^{\circ}\text{C}$ and a relative humidity of less than 70%. Both the Models 6512 and 263 should be allowed to warm up for at least two hours before beginning calibration. If either instrument has been subjected to extreme temperature or humidity, allow at least one additional hour for the instrument to stabilize before beginning the calibration procedure.

NOTE

While rated accuracy of the Model 6512 is achieved after the two-hour warm up period, input bias current may require additional time to come to its optimum level. Allow two hours for input bias current to settle to less than 10fA and eight hours to less than 5fA.

7.4.6 Calibration sequence

Model 6512 calibration **must** be performed in the order given in the following paragraphs. The basic sequence is:

Manual adjustments:

1. Input offset adjustment (paragraph 7.4.7)
2. Input current adjustment (paragraph 7.4.8)

Digital calibration (front panel or IEEE-488 bus):

1. Amps calibration (paragraph 7.4.10)
2. Coulombs calibration (paragraph 7.4.11)
3. Volts calibration (paragraph 7.4.12)
4. Ohms calibration (paragraph 7.4.13)

In addition to the above sequence, the ranges for each function must be calibrated in the order given. Note that you should never calibrate a range using a suppress or a zero correct value taken on a different range.

7.4.7 Input offset adjustment

Perform the following steps to null out any small offset in the input amplifier:

1. Disconnect all input signals from the Model 6512.

2. Remove the two screws securing the top cover, and remove the cover from the instrument.
3. Select the amps function, and place the instrument on the 2pA range.
4. Enable zero check, but leave zero correct disabled.
5. Locate the offset adjustment pot (R314) on the electrometer board (see Figure 7-2). The pot is accessible through a small hole in the shield closest to the rear of the instrument.
6. Adjust R314 for a reading of 0.0000 ± 1 count on the display.
7. Replace the top cover unless the following input current adjustment is to be performed.

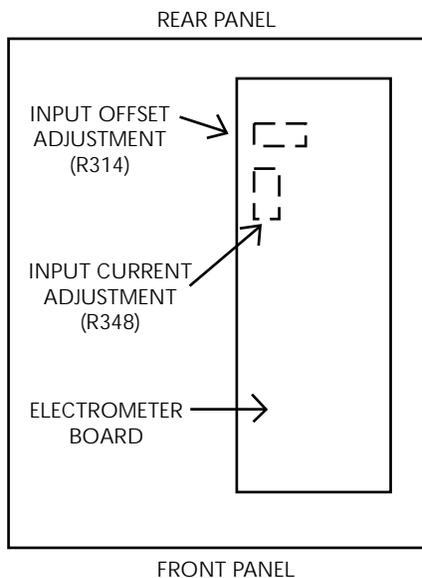


Figure 7-2
Input offset and current adjustment locations

7.4.8 Input current adjustment

Use the following procedure to null out any input current in the input stage:

1. Disconnect all input signals from the Model 6512. Place the optional protection cap (CAP-31) on the INPUT connector.
2. Remove the two screws securing the top cover, and remove it from the instrument.
3. Place the Model 6512 in the amps function, and select the 2pA range.
4. Enable zero check and zero correct in that order.

5. Disconnect floating sources, and connect a ground link between the COM and chassis ground binding posts. Disable zero check, but leave zero correct enabled.
6. Wait several minutes until the reading on the display settles down; about 15 counts (1.5fA) p-p of noise is normal.
7. Locate the input current pot (R348) on the electrometer board. It is accessible through a small hole in the shield (see Figure 7-2).
8. Carefully adjust R348 for a reading of 0.0000 ± 15 counts on the display. Iterative adjustment may be necessary.
9. Replace the top cover, and secure it with the two screws removed earlier.

7.4.9 Calibration program

The Model 6512 must be placed in the calibration program in order to perform the front panel digital calibration procedures. Select the calibration program as follows:

1. Turn off the instrument for at least three seconds if it is presently turned on.
2. Press and hold the PROGRAM SELECT button, and then turn on the power.
3. The instrument powers up as normal, but the CAL program is accessible in the program menu.
4. Select the calibration program by pressing PROGRAM SELECT repeatedly until the following message is displayed briefly:

CAL

5. A normal reading will now be displayed except that the exponent decimal points will be displayed to indicate that the instrument is in the calibration mode.

With the instrument in the calibration mode, perform the following procedures to calibrate the Model 6512 from the front panel.

7.4.10 Amps calibration

Calibration of the amps function should be performed in the following order: 200pA, 20nA, 20μA and 20mA ranges. Once these ranges are calibrated, the remaining ranges are automatically calibrated. Use the AMPS (active) function of the Model 263 to source current.

Proceed as follows:

1. Connect the Model 263 Calibrator/Source to the Model 6512, as shown in Figure 7-3.
2. Place the Model 6512 in the amps function, and select the 200pA range.
3. On the Model 6512, enable zero check and zero correct in that order.
4. Program the Model 263 to output 00.000pA, and release zero check on the Model 6512.
5. After allowing the reading to settle for a few seconds, press SUPPRESS to zero the display of the Model 6512.
6. Program the Model 263 to output 190.000pA.
7. Adjust the display of the Model 6512 to read 190.00pA using the Model 6512 ADJUST buttons.
8. Program the Model 263 to output 00.000pA by pressing ZERO on the Model 263.
9. On the Model 6512, disable zero correct and suppress.
10. Using Table 7-3 as a guide, select the next electrometer range and calibrator range, and repeat the basic procedure in steps 3 through 9. Calibrate all the electrometer ranges listed in the table.

Table 7-3

Model 6512 amps calibration summary

6512 & 263 range	263 output current	6512 reading
200pA	190.000pA	190.00pA
20nA	19.0000nA	19.000nA
20μA	19.000μA	19.000μA
20mA	19.000mA	19.000mA

NOTE: Use AMPS (active) mode of Model 263 to source current.

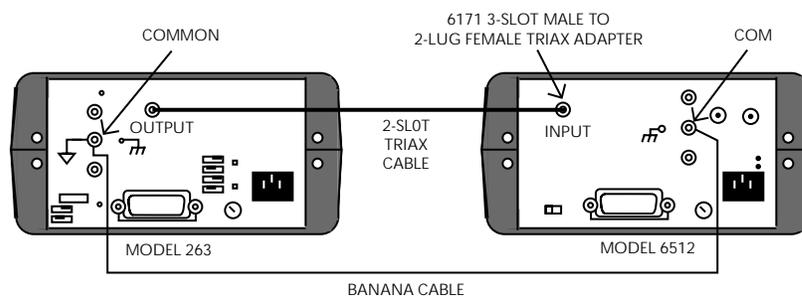


Figure 7-3

Connections for Model 6512 calibration

7.4.11 Coulombs calibration

Use the following procedure to calibrate the 20nC range. Once this range is calibrated, the two remaining ranges are automatically calibrated.

1. Connect the Model 263 Calibrator/Source to the Model 6512, as shown in Figure 7-3.
2. Place the Model 6512 in the coulombs function, and select the 20nC range.
3. While in standby, program the Model 263 to source 19.0000nC.
4. On the Model 6512, enable zero check and then zero correct. Disable zero check, and enable suppress to null the effects of zero check hop.
5. Press the OPERATE button on the Model 263. The calibrator will source for one second.
6. Adjust the display of the Model 6512 for a reading of 19.000nC using the ADJUST buttons of the Model 6512.
7. Repeat steps 4 through 6 until the reading on the Model 6512 reads 19.000nC after OPERATE is pressed on the Model 263 calibrator.
8. Enable the Model 6512 zero check mode.

7.4.12 Volts calibration

Calibration of the volts function should be performed in the following order: 200mV, 2V, 20V, and 200V ranges. The 200V range will require that an external 190V source be applied to the Model 263.

Proceed as follows:

1. Connect the Model 263 to the Model 6512, as shown in Figure 7-3.
2. Place the Model 6512 on the volts function, and select the 200mV range.
3. Zero correct the Model 6512 by enabling zero check and zero correct in that order.
4. Program the Model 263 to output 00.000mV, and release zero check on the Model 6512.
5. Zero the display of the Model 6512 by pressing SUPPRESS.
6. Program the Model 263 to output 190.000mV.
7. Adjust the display of the Model 6512 to read 190.00mV using the ADJUST buttons on the Model 6512.
8. Program the Model 263 to output 00.000mV by pressing ZERO.
9. On the Model 6512, disable zero correct and suppress.
10. Using Table 7-4 as a guide, repeat steps 3 through 9 for the 2V and 20V ranges.

11. With the Model 343A set to zero volts, connect it to the Model 263, as shown in Figure 7-4. Leave the Model 263 connected to the Model 6512, as shown in Figure 7-3.
12. Select the 200V range and zero correct the Model 6512 by enabling zero check and zero correct in that order.
13. Set the Model 343A to output 190.000V to the Model 263.
14. Release zero check on the Model 6512, and program the Model 263 to output the external voltage source by pressing SHIFT VOLTS.
15. Adjust the display of the Model 6512 to read 190.00V using the ADJUST buttons of the Model 6512.
16. Place the Model 263 and the Model 343A in standby.
17. On the Model 6512, disable zero correct.
18. Turn off the Model 343A, and disconnect it from the Model 263.

Table 7-4
Model 6512 volts calibration

6512 range	263 output voltage	External DC calibrator voltage	6512 reading
200mV	190.000mV	—	190.00mV
2V	1.90000V	—	1.9000V
20V	19.0000V	—	19.000V
200V	EXT VOLTS	190.000V	190.00V

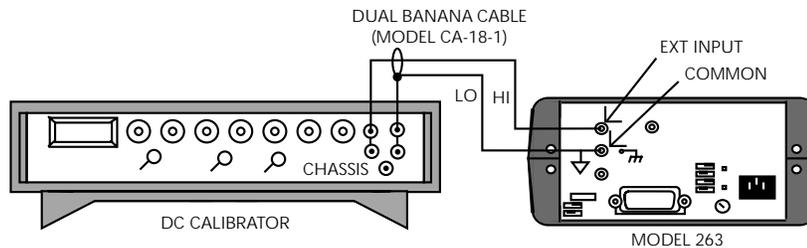


Figure 7-4
Connections for external voltage source

7.4.13 Ohms calibration

Perform the following procedure to calibrate the ohms function of the Model 6512:

1. Connect the Model 263 to the Model 6512 as shown in Figure 7-3. Note that Model 263 COMMON must be connected to Model 6512 COM.
2. Enable GUARD on the Model 263, and set the Model 6512 guard switch to the "ON" position.
3. Place the Model 6512 in the ohms function, and select the 20G Ω range.
4. Zero correct the Model 6512 by enabling zero check and zero correct in that order.
5. Program the Model 263 to output the 10G Ω resistance. The actual value of that resistance will be displayed by the Model 263.
6. Release zero check on the Model 6512, and allow the resistor reading to settle.
7. Adjust the display, using the ADJUST buttons of the Model 6512, to correspond to the reading on the Model 263.
8. Disable guard on the Model 263, and set the Model 6512 GUARD switch to the "OFF" position.
9. Using Table 7-5 as a guide, repeat steps 4 through 7 for the 200M Ω , 2M Ω , and 200k Ω ranges.

Table 7-5

Model 6512 ohms calibration

6512 range	6512 guard	263 guard	263 calibration resistance * (Nominal)
20G Ω	ON	Enabled	10G Ω
200M Ω	OFF	Disabled	100M Ω
2M Ω	OFF	Disabled	1M Ω
200k Ω	OFF	Disabled	100k Ω
20k Ω	OFF	Disabled	10k Ω

* Set Model 6512 reading to exact resistance displayed on Model 263 using Model 6512 ADJUST keys.

10. Set the Model 6512 to the 20k Ω range.
11. Zero correct the Model 6512 by enabling zero check and zero correct in that order.
12. Set the Model 263 to the 10k Ω range, and press ZERO to source ohms to the Model 6512.
13. Release zero check on the Model 6512. The reading on its display is test lead resistance and zero offset.

14. Enable suppress on the Model 6512 to zero the display.
15. Press ZERO on the Model 263 to source 10k Ω to the Model 263. The actual value of that resistor will be displayed by the Model 263.
16. Adjust the displayed reading on the Model 6512 to correspond to the reading on the Model 263.

7.4.14 Permanent storage of calibration constants

The procedures given in the preceding paragraphs will temporarily store calibration constants in internal RAM memory and will be lost when the instrument is turned off. For calibration to be permanent, you must perform NVRAM storage. Once all points have been calibrated, press PROGRAM SELECT to exit the calibration program. Assuming that the calibration jumper is in the enable position, calibration constants will be stored in NVRAM, and the following message will be displayed briefly:

Stor

Also, constants for uncalibrated ranges are derived at this point.

If the calibration jumper is in the disable position, NVRAM storage will not take place, and the following message will be displayed briefly:

Out

Only changed constants are affected with uncalibrated ranges unaffected. The new calibration constants will be used by the instrument until power is turned off. Temporary calibration is denoted by the flashing exponent decimal points.

7.4.15 IEEE-488 bus digital calibration

Digitally calibrating the Model 6512 over the IEEE-488 bus requires the use of a calibration program, which is listed in Appendix D (paragraph D.9).

NOTE

The manual calibration adjustments covered in paragraphs 7.4.7 and 7.4.8 must be performed before performing digital calibration.

Procedure:

1. With the power off, connect the Models 263 and 6512 to the GPIB interface of the computer.
2. With the power off, connect the Model 263 to the Model 6512, as shown in Figure 7-3. Also connect the external voltage calibrator to the Model 263, as shown in Figure 7-4.
3. Turn on the Models 6512 and 263, and the external voltage calibrator, and allow a two-hour warm-up period before beginning calibration.
4. Set the IEEE-488 primary address of the Model 263 to 8, and set the primary address of the Model 6512 to 27.
5. Enter the calibration program into the computer. (See Appendix D for complete details.)
6. To calibrate the instrument, run the program, and follow the instructions on the CRT display.
7. After all functions are calibrated, the program will prompt for permanent storage of calibration constants in NVRAM. This feature allows you to stop at this point in order to avoid permanent calibration. Unless calibration is made permanent, the calibration constants will be lost when the instrument is turned off.
8. If selected, storage of calibration constants into NVRAM is performed as indicated by the "Stor" message on the Model 6512. If instead the message "out" is displayed, the calibration jumper is in the disable position, and calibration constants will be lost when the Model 6512 is turned off. (See paragraph 7.4.3 for information on the calibration jumper.)

7.4.16 Additional calibration points

The electrometer calibration points discussed in the preceding paragraphs were chosen to optimize instrument accuracy without making the calibration procedure overly tedious and time consuming. As noted earlier, these calibration points are permanently stored in NVRAM when the correct storage sequence is performed.

Although this calibration method is more than adequate to allow the instrument to meet or exceed specifications, it is possible to temporarily calibrate those ranges not directly calibrated as part of the calibration procedure (for example, certain amps ranges or the external feedback function). With the calibration jumper in the disabled position, place the instrument in the desired function, and select the range to be calibrated. Apply the necessary calibration signal, and enter

that value into the instrument's memory, either with the front panel calibration program, or over the IEEE-488 bus (The flashing exponent decimal points will indicate parameters have been entered). The nominal adjustment range is $\pm 6\%$ ($\pm 12\%$ in external feedback). However, it is important to note that such calibration will be only temporary as these parameters will be lost when the power is turned off. Under these conditions, the instrument will revert to calibration constants previously stored in NVRAM the next time it is turned on. Note that the IEEE-488 DCL and SDC commands will also cancel temporary calibration constants.

As an example of this procedure, let us assume that you wish to temporarily calibrate the 2mA range—a range that is not part of the normal calibration sequence. The following basic procedure could be used to calibrate this range.

1. Select the amps mode, and place the instrument on the 2mA range.
2. Zero correct the instrument by enabling zero check and then zero correct in that order.
3. Connect a suitable calibration signal to the instrument. Typically, calibration is done at 95% of full range, or 1.9000mA in this case.
4. Disable zero check, and enter the front panel calibration program, as described in paragraph 7.4.9. The instrument will then display a reading that reflects its present calibration point for the selected range. The exact point can be set by using the ADJUST buttons to set the displayed value to exactly 1.9000mA.
5. After all points have been calibrated, exit the program by pressing SHIFT then SELECT.
6. If bus calibration is desired instead, send the calibration signal over the bus. In this case the command would be: A1.9E-3X.
7. Any non-standard calibration points will be only temporary, as stated earlier.

7.5 Special handling of static-sensitive devices

CMOS devices operate at very high impedance levels for low power consumption. As a result, any static charge that builds up on your person or clothing may be sufficient to destroy these devices if they are not handled properly. When handling these devices, use the precautions below to avoid damaging them.

NOTE

In order to avoid damage, assume that all parts are static sensitive.

1. ICs should be transported and handled only in containers specially designed to prevent static build-up. Typically, these parts will be received in anti-static containers of plastic or foam. Keep these devices in their original containers until ready for installation.
2. Remove the devices from their protective containers only at a properly grounded work station. Also, ground yourself with a suitable wrist strap before handling parts.
3. Handle the devices only by the body; do not touch the pins.
4. Any printed circuit board into which the device is to be inserted must also be grounded to the bench or table.
5. Use only anti-static type de-soldering tools.
6. Use only grounded-tip soldering irons.
7. Once the device is installed on the PC board, it is usually adequately protected, and normal handling can resume.

7.6 Disassembly instructions

If it is necessary to troubleshoot the instrument or replace a component, use the following disassembly procedure. An exploded view of the instrument may be found in Figure 7-5.

WARNING

Disconnect the line cord and any test leads or cables from the instrument before disassembly.

1. Remove the top cover as follows:
 - A. Remove the two screws that secure the top cover to the rear panel.
 - B. Grasp the top cover at the rear, and carefully pull up until the tabs at the front of the cover clear the front panel. The cover may then be pulled completely clear.
 - C. To replace the top cover, reverse the above procedure. Be sure to install the tabs at the front of the cover before completely installing it.
2. Remove the electrometer board as follows:

- A. Remove the four screws that secure the top shield to the electrometer board.
 - B. Carefully lift the shield clear of the board.
 - C. Disconnect the input wires from the electrometer board.
 - D. Disconnect the power transformer wires on the electrometer board.
 - E. Remove the three screws that secure the electrometer board to the standoffs adjacent to the power transformer.
 - F. Carefully remove the electrometer board, taking care not to touch the PC board surfaces or any components. When the board is partially removed, disconnect the ribbon cable at the mother board end.
3. Remove the mother board as follows:
 - A. Disconnect the display board ribbon cable near the front of the instrument.
 - B. Remove the standoffs, spacers, and screws that secure the mother board to the bottom case. Do not remove the three standoffs down the center of the board.
 - C. Remove the two screws that secure the rear panel to the bottom case, and remove the mother board and rear panel as a single unit.
 4. The display board can now be removed as follows:
 - A. Remove the two screws securing the display board to the front panel.
 - B. Disconnect the DIP cable connected to the mother board.
 - C. Remove the display board by lifting up and back until the tabs at the bottom of the case are clear and then lift the display board free.
 5. The instrument can be re-assembled by reversing the above procedure. Make sure that all boards are properly seated and secured, and that all connections are properly made. To ensure proper operation, shields must be replaced and fastened securely.

WARNING

To ensure continued protection against safety hazards, power line ground (the green wire connected to the AC power receptacle) must be connected to the rear panel and mother board.

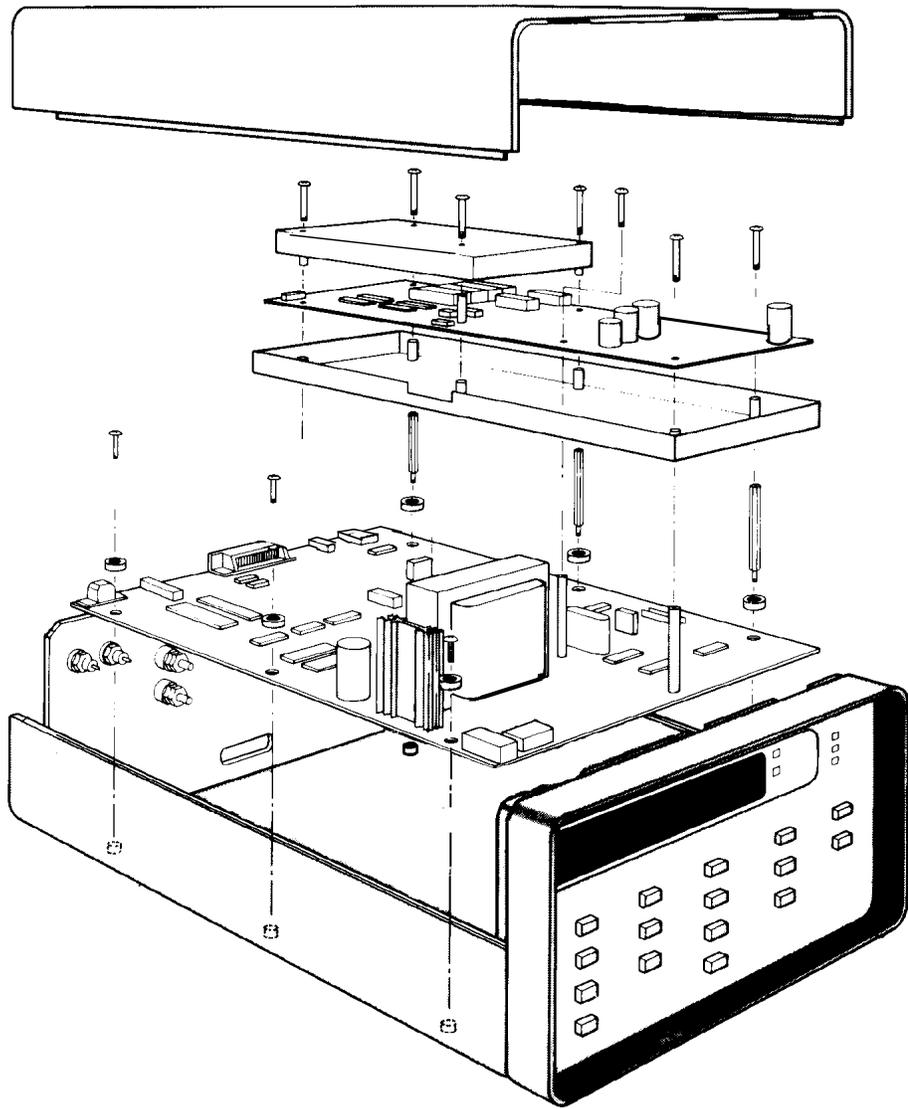


Figure 7-5
Exploded view

7.7 Troubleshooting

The troubleshooting information contained in this section is intended for qualified personnel having a basic understanding of analog and digital circuitry. The individual should also be experienced at using typical test equipment, as well as ordinary troubleshooting procedures. The information presented here has been written to assist in isolating a defective circuit or circuit section. Isolation of the specific component is left to the technician. Note that schematic diagrams and component layout drawings, which are an essential aid in troubleshooting, are located at the end of Section 8.

WARNING

The electrometer board shield is connected to the inner shield of the triaxial input, which is connected either to analog common (unguarded) or guard (guarded). Thus, the shield can float up to $\pm 800\text{V}$ above chassis ground.

7.7.1 Recommended test equipment

Success in troubleshooting complex equipment like the Model 6512 depends not only on the skill of the technician, but also relies on the use of accurate, reliable test equipment. Table 7-6 lists the minimum recommended equipment for troubleshooting the Model 6512. Other equipment such as logic analyzers and capacitance meters could also be helpful, especially in difficult situations.

Table 7-6
Recommended troubleshooting equipment

Equipment	Application
DMM with 0.015% basic accuracy, 10M Ω input impedance (Keithley Model 197A or equivalent).	Power supply and DC voltage checks; analog signal tracing; continuity; static logic levels.
Dual-trace, triggered sweep oscilloscope, DC-50MHz bandwidth.	Digital and analog waveform checks.

7.7.2 Power-up self-test

Upon power up, the Model 6512 will automatically test RAM memory and check for proper calibration constants. If a RAM memory error occurs, the following message will remain on the display:

r.r.

If a RAM error occurs, the instrument will be completely inoperative, and you should assume that a problem exists within the instrument. The problem should be rectified before using the instrument.

If a calibration error occurs, the two exponent decimal points will flash. The instrument will be functional under these conditions, but the instrument is probably out of calibration, and measurements will not be accurate. Use the calibration procedures in paragraph 7.4 of this section to calibrate the instrument. Note that this error may also indicate a defective NVRAM.

7.7.3 Self-diagnostic program

The self-diagnostic program can be used to test the front panel LEDs, access the firmware revision level, and enter a special mode to allow signal tracing through the instrument. Enter the diagnostic program as follows:

1. Turn off the instrument for at least three seconds if it is presently turned on.
2. Press and hold the TRIG button, and then turn on power.
3. The instrument will then turn on all front panel LEDs and display segments. The instrument will remain in this configuration as long as the TRIG button is held in. The display should appear as follows:

-1.8.8.8.8.8.

4. The software revision level will then be displayed when the TRIG button is released. A typical example is:

A1

Note that the revision level of your instrument may be different.

5. At this point, the instrument will enter the diagnostic mode that switches the instrument among the zero (common), calibration (reference), and signal phases of its measurement cycle. The unit can be cycled through these phases by repeatedly pressing the TRIG button. The decimal point will indicate the range. During the zero (common) phase, the display will appear as follows:

P=0

6. During the calibration (reference) phase, the display will show:

P=C

7. Finally, the display will show the following message during the signal phase:

P=S

8. To remove the instrument from the diagnostic mode, turn off the power.

During normal operation, the instrument cycles through these three phases in rapid succession. This cycling action makes it difficult to troubleshoot the instrument utilizing normal signal-tracing techniques. However, by using the diagnostic program to “freeze” the instrument on the appropriate phase, troubleshooting is greatly simplified. Table 7-7 summarizes phases, display messages, and signals applied to the A/D converter during each of the three phases.

Table 7-7

Diagnostic program phases

Phase	Display message	A/D converter input signal
Zero (Common)	P=0	Analog Common
Calibration (Reference)	C=0	-2V Reference
Signal	P=S	Output of Ranging Amplifier

7.7.4 Power supply checks

All power supply voltages should be checked first to make sure they are within the required limits. If the various operating voltages are not within the required limits, troubleshooting the remaining circuitry can be quite difficult.

Table 7-8 outlines the various power supply voltages that should be checked. In addition to the usual voltage checks, it is a good idea to check the various supplies with an oscilloscope to make sure that no noise or ringing is present.

WARNING

The electrometer board shield is connected to analog common and can float up to 800V above chassis ground, depending on the input signal.

7.7.5 Relay configuration

Instrument functions are controlled by configuring the input amplifier with a number of relays. These relays are themselves controlled by serial-parallel converter ICs that decode control information from the microprocessor. Since each relay must assume a given state for proper operation, it is possible to verify input configuration switching by determining which relays are energized for every range and function.

Table 7-9 gives a summary of status for each of the twelve relays associated with the electrometer input section. You can verify proper relay operation for a given combination by selecting the range and function in question and then measuring the control voltage at the IC driver output. When a relay is energized (on), the voltage at the output will be high, while approximately 0V will be seen with the relay de-energized (off) (except K302 and K303, which are energized when driven with 0V, and de-energized when driven to +5V).

Table 7-8

Power supply checks

Step	Item/component	Required condition	Remarks
1	S102 Line Switch	Set to 115 or 230 as required.	Line voltage selection.
2	F101 Line Fuse	Check for continuity.	Remove fuse to check.
3	Line power	Plugged into live receptacle; power on.	
4	+5V Digital Supply	5V, $\pm 5\%$	Referenced to digital common.
5	$\pm 210V$ Supplies	+240V, -240V, $\pm 15\%$	Referenced to analog common.
6	+5V Analog Supply	+5V, $\pm 5\%$	Referenced to analog common.
7	-9.1V Supply	-9.1V, $\pm 5\%$	Referenced to analog common.
8	$\pm 5V$ Bootstrap Supplies	+5V, -5V, $\pm 5\%$	Referenced to bootstrap common.
9	± 24 Supplies	+27.5V, -27.5V, $\pm 15\%$	Referenced to preamp out.

Table 7-9

Relay configuration

		Relay											
Function	Range	K309	K310	K308	K311	K312	K307	K303	K304	K305	K306	K301	K302
Volts	200mV											X	
	2V											X	
	20V											X	
	200V											X	
Ohms	2k Ω	X		X							X	X	
	20k Ω	X		X							X	X	
	200k Ω	X		X						X		X	
	2M Ω	X		X								X	
	20M Ω				X	X					X	X	
	200M Ω				X	X				X		X	
	2G Ω				X	X			X			X	
	20G Ω				X	X			X			X	
	200G Ω				X	X			X			X	
	Amps	2pA					X		X				
20pA						X		X					X
200pA						X		X					X
2nA					X	X		X					X
20nA					X	X		X					X
200nA					X	X		X					X
2 μ A		X		X				X					X
20 μ A		X		X				X					X
200 μ A		X		X				X					X
2mA			X					X					X
20mA			X					X					X
Coulombs		200pC	X						X				
	2nC	X						X					X
	20nC	X						X					X
External Feedback	200mV							X					X
	2V							X					X
	20V							X					X
Zero Check		*	*	*	*	*	X	*			*	*	

X = Relay Energized. * = These relays may also be energized depending on range and function.

7.7.6 Ranging amplifier gain configuration

The ranging amplifier can have one of four gain values: X10, X1, X0.1, or X0.01. The actual value will depend on the selected range and function, as summarized in Table 7-10. This information can be used to determine if the ranging amplifier is working properly. To do so, select the desired range and function, and apply an appropriate signal to the input of the electrometer. Measure the signal at the PREAMP and 2V ANALOG OUTPUT terminals, and see if the correct scaling factor is applied.

Table 7-10
Ranging amplifier gains

Function	Range	Gain
Volts	200mV	X10
	2V	X1
	20V	X0.1
	200V	X0.01
Amps	2pA	X10
	20pA	X1
	200pA	X0.1
	2nA	X10
	20nA	X1
	200nA	X0.1
	2μA	X10
	20μA	X1
	200μA	X0.1
	2mA	X10
	20mA	X1
Ohms	2kΩ	X10
	20kΩ	X1
	200kΩ	X1
	2MΩ	X1
	20MΩ	X1
	200MΩ	X1
	2GΩ	X1
	20GΩ	X0.1
	200GΩ	X0.01
Coulombs	200pC	X10
	2nC	X1
	20nC	X0.01
External feedback	200mV	X10
	2V	X1
	20V	X0.1

For example, with the instrument on the 20V range, an input signal of 19V could be applied. Assuming the input amplifier is operating properly, the voltage seen at the PREAMP OUT should also be 19V. The ranging amplifier should apply a gain of X0.1 in this case, so the voltage seen at the 2V ANALOG OUTPUT should be 1.9V. If the PREAMP OUT signal is correct, but the 2V ANALOG OUTPUT is not, the ranging amplifier or associated control circuits are not functioning properly.

7.7.7 A/D converter and display

Use the procedure listed in Table 7-11 to make sure the A/D converter and display circuits are operating properly. The operation of these circuits should be verified before attempting to troubleshoot the analog circuitry.

7.7.8 Input and ranging amplifiers

The input and ranging amplifiers condition the input signal, transforming it into a 0-2V DC voltage that is usable by the A/D converter. The exact conditioning process will depend on the selected range and function. With the voltage ranges, for example, the signal is merely attenuated (20V and 200V ranges) or amplified (200mV range), and inverted. For the amps function, the input signal must undergo current-to-voltage conversion.

The procedures outlined in Tables 7-12 and 7-13 may be used as an aid in troubleshooting the input amplifier and ranging circuits. Note that the procedure in Table 7-13 assumes that the input amplifier is operating properly.

WARNING

Up to 300V may be present between PREAMP OUT and COM.

7.7.9 Digital circuitry

Problems with the digital circuitry could cause erratic operation. Check the various components associated with the digital circuitry, including the IEEE-488 interface, using the procedure given in Table 7-14.

7.7.10 Display board

Check the display board by using the procedure in Table 7-15.

Table 7-11

A/D converter checks

Step	Item/component	Required condition	Remarks
1		Turn on power, select 2V range, and short input.	All A/D checks referenced to analog common.
2	U127, pin 10	1.2288MHz gated clock	A/D clock.
3	U127, pin 7	307.2kHz gated clock	A/D synchronous clock.
4	U127, pin 6	153.6Hz gated clock	A/D synchronous clock.
5	U127, pin 5	76.8kHz gated clock	A/D synchronous clock.
6	U127, pin 3	38.4kHz gated clock	A/D synchronous clock.
7	U127, pin 1	300Hz gated clock	A/D synchronous clock.
8	U135, pin 6	+5 to \approx 0V pulse train 3 μ sec every 22 μ sec	Charge balance synchronization signal.
9	U138, pin 7	Integrator ramp	
10	U137, pin 10	\approx 1.5V DC	Comparator reference.
11	U137, pin 7	Variable pulse train 0V to +5V	Comparator output.
12	U126, pin 6	Variable pulse train 0V to +5V	Reference current generator.
13	U135, pin 8	Variable pulse train 0V to +5V	A/D data output.
14	U136, pin 10	\approx 5msec positive-going pulse	Control line for charge balance/single slope.
15	U126, pin 9	100msec positive-going pulse	Integrator control line.

Table 7-12

Preamplifier checks

Step	Item/component	Required condition	Remarks
1	Range	Power-on, 200mV range, zero check off	
2	Apply 190mV DC input	190mV	Measure at PREAMP OUT and COM unless otherwise noted.
3	Apply 1.9V DC input	1.9V	
4	Apply 19V DC input	19V	
5	Apply 190V DC input	190V	Remove before selecting amps function.
6	Function, range	Select AMPS, 2mA range 1.9V	
7	Apply 1.9mA input	1.9V	
8	Range	Select 20mA range	
9	Apply 19mA input	1.9V	
10	Range	Select 190 μ A range	
11	Apply 190 μ A input	19V	
12	Function	Select VOLTS, enable zero check	Zero correct if necessary.
13		0V	
14	Function	Select OHMS	Referenced to PREAMP OUT.
15	R304, pin 1	10V, \pm 0.1V	Referenced to PREAMP OUT.
16	R304, pin 2	1V, \pm 0.01V	Referenced to PREAMP OUT.
17	R304, pin 3	0.1V, \pm 0.001V	

Table 7-13*Ranging amplifier checks*

Step	Item/component	Required condition	Remarks
1	Range	Power-on, 200V DC range, zero check off	Measure between 2V ANALOG OUTPUT and COM.
2	Apply 190V DC to input	1.9V	Check X0.01 gain.
3	Range	Select 20V DC range	
4	Apply 19V DC to input	1.9V	Check X0.1 gain.
5	Range	Select 2V DC range	
6	Apply 1.9V DC to input	1.9V	Check X1 gain.
7	Range	Select 200mV DC range	
8	Apply 190mV DC to input	1.9V	Check X10 gain.

Table 7-14*Digital circuitry checks*

Step	Item/component	Required condition	Remarks
1	Range	Power-on, 200V DC range	All voltages referenced to digital common.
2	U109, pin 40	+5V, $\pm 5\%$	+5V digital supply.
3	U109, pin 2	500 μ sec negative pulse every 1.6msec	Interrupt clock.
4	U109, pin 3	Stays low <1sec on power-on, then goes high ($\approx 4V$)	MPU reset.
5	U109, pin 4	655kHz clock	Data strobe.
6	U109, pin 6	655kHz clock	Address strobe.
7	U109, pin 37	Variable pulse train	A/D data.
8	U102, pin 6	Variable pulse train	A/D control.
9	U102, pin 3	Negative-going pulse every 350msec	Meter complete pulse

Table 7-15*Display board checks*

Step	Item/component	Required condition	Remarks
1	Power	Power-on, 200V DC range, zero check on	All voltages referenced to digital common.
2	U201, pin 9	+5V, $\pm 5\%$	+5V digital supply.
3	U201,U202 pins 11-18	Variable pulses	Segment drivers.
4	U204, pins 11-18, U205, pins 15-18	Variable pulses	Digit drivers.
5	U209, pins 10-15	1msec negative-going pulses every 10msec	
6	P1016, pin 14	Press COUL, ZERO CHECK, TRIG, or DATA ON button	Pulse present when key is pressed.
7	P1016, pin 15	Press AMPS, SHIFT, RECALL, or SUPPRESS	Pulse present when key is pressed.
8	P1016, pin 16	Press VOLTS, OHMS, AUTO, ZERO CORRECT, or PROGRAM button	Pulse present when key is pressed.

7.8 Input stage balancing procedure

If the input FET (Q308) or associated bias resistors are replaced, the following procedure should be used to rebalance the circuit. This procedure may also be used if the offset adjustment potentiometer (R314) has insufficient range. The procedure involves checking the number of counts of offset with jumper W303 in position B.

Proceed as follows:

1. With the power off, remove the top cover and electrometer board shield, as described in paragraph 7.6.
2. Place jumper W303 in position B.
3. Turn on the power, and allow the instrument to warm up for one hour.
4. Select the volts mode and the 200mV range. Do not use auto-ranging.
5. Enable zero check, but leave zero correct disabled.
6. Set the input offset adjustment potentiometer (see Figure 7-2) fully clockwise as viewed from the screw end. The control is a multi-turn potentiometer, so considerable adjustment may be required.
7. Note the number of counts shown on the display, and compare the value to the ranges listed in Table 7-16. From this table, you can determine in which position jumper W303 should be placed. For example, if the display shows between -1200 and +200 counts, jumper W303 should be placed in position C.
8. Place the jumper in accordance with the results of step 7.
9. Turn off the power, and replace the electrometer board shield.
10. Turn on the power, and allow the instrument to warm up for one hour before performing the following adjustment.
11. Set the input offset potentiometer (R314) for a reading of 00.00 ± 1 count on the display.
12. Replace the top cover when the procedure is complete.

Table 7-16

Input stage balancing

Number counts with W303 in position B and R314 fully clockwise	Position of W303
1400 to 2800	A
200 to 1400	B
-1200 to 200	C

7.9 Handling and cleaning precautions

When troubleshooting or otherwise working inside the instrument, care should be taken not to touch PC board traces and open wires to avoid contaminating them with body oils or other foreign matter. In particular, there are two areas within the Model 6512 that have numerous high impedance nodes where contamination could cause degraded performance. These include the input amplifier area on the electrometer board and the ranging amplifier section location on the mother board.

The same general precautions apply when replacing parts in these areas. When desoldering and soldering parts, be careful not to spread the flux around the board to adjacent areas. After replacing parts, or if contamination is suspected, use the following procedure to clean the affected area.

1. Using a squeeze bottle, carefully apply clean, uncontaminated methanol to the area to be cleaned. Use sufficient solution to thoroughly wet the circuit board.
2. Using a small, clean brush, wipe the area thoroughly until it is free of flux or contaminants. In some cases, it may be helpful to tilt the board at an angle and brush contaminants away from the affected area, allowing contaminated residue and methanol to run off the board.
3. Wash the area again with fresh, clean methanol.
4. Once the area is thoroughly cleaned, it should be dried with pressurized dry, clean air or nitrogen. Do not use compressed air from an ordinary air compressor, as oil particles in the air could contaminate the circuit board.
5. After cleaning or parts replacement check to see that any components connected to the Teflon insulators are not physically touching the board or adjacent parts.
6. Allow the board to dry for several hours in a 50°C environment before use.

8

Replaceable Parts

8.1 Introduction

This section contains replacement parts information, schematic diagrams, and component layout drawings for the Model 6512 Electrometer.

8.2 Parts list

Parts for the Model 6512 are listed in tables integrated with the schematic diagrams and component layout drawings on the following pages. See Figure 7-5 in Section 7 for an exploded view of the instrument that identifies many mechanical parts.

8.3 Ordering information

Keithley Instruments, Inc. maintains a complete inventory of all normal replacement parts. To place an order, or to obtain information concerning replacement parts, contact your Keithley representative or the factory. When ordering parts, include the following information:

1. Instrument Model Number
2. Instrument Serial Number

3. Part Description

4. Circuit designation, including schematic diagram and component layout numbers (if applicable).

5. Keithley Part Number

8.4 Factory service

If the instrument is to be returned to the factory for service, carefully pack the unit and include the following:

1. Complete the service form which follows this section, and return it with the instrument.
2. Advise as to the warranty status of the instrument (see the inside front cover for warranty information).
3. Write the following on the shipping label: ATTENTION REPAIR DEPARTMENT.

8.5 Component layout drawings and schematic diagrams

Component layout drawings and schematic diagrams for the mother board, electrometer board, and the display board are located on the following pages.

Model 6512 Digital Board, Parts List

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
C101	CAP,4700UF,-20,+100%,16V,ALUMINUM	C-313-4700
C102,112,116-118,123, 125-127	CAP,.1UF,20%,50V,CERAMIC	C-237-.1
C104,134		
C105,113	CAP, 10UF,-20+100%,25V,ALUM ELEC	C-314-10
C106	CAP,1UF,20%,50V, CERAMIC	C-237-1
C107,111	CAP,10UF,20%,20V,TANTALUM	C-179-10
C119,124	CAP,22PF,10%,1000V,CERAMIC	C-64-22P
C120	CAP, 0.1UF, 20%, 100V, POLYESTER	C-305-.1
C121	CAP,.01UF,20%,500V,CERAMIC	C-22-.01
C122	CAP, 33PF, 20%, 500V, CERAMIC	C-22-33P
C128	CAP, 150PF, 20%, 500V CERAMIC	C-22-150P
C130	CAP, .01UF, 10%,100V POLYPROPYLENE	C-306-.01
C139	CAP, .047UF, 20%,100V POLYESTER	C-305-.047
	CAP,.33,.20%,50V POLYESTER DIELECTRIC	C-344-.33
CR102-106,113	DIODE,SILICON,IN4148 (DO-35)	RF-28
CR110	DIODE,BRIDGE,VM18	RF-52
F101	FUSE, .125A, 250V,3AG SLO-BLO	FU-20
J1010	CONNECTOR	CS-377
J1011	CONN, AC RECEPTACLE	CS-388
J1014	CONN,DUAL 7-PIN-BERG	CS-389-5
J1015,1018	CONN,3 PIN	CS-339-3
J1017	PIN, CONTACT (TEST POINT)	24249
J1023	CONNECTOR, HEADER	CS-784-6
J1024	CONNECTOR, HEADER	CS-784-4
Q103,107	TRANS, N CHANNEL JFET (TO-92)	TG-139-1
Q104,110	TRANS, P CHANNEL JFET, J270 (TO-92)	TG-166-1
Q105,108	TRANS,N CHANNEL FET,2N4392 (TO-92)	TG-128-1
Q106	TRANSISTOR SELECTION	617-600
R101,102,117	RES,100,5%,1/4W,COMPOSITION OR FILM	R-76-100
R103,135	RES,330,5%,1/4W,COMPOSITION OR FILM	R-76-330
R104,110	RES,10M,5%,1/4W,COMPOSITION OR FILM	R-76-10M
R105	RES NET, 1K, 2%, 1W	TF-183-1
R107	RES,30K,5%,1/4W,COMPOSITION OR FILM	R-76-30K
R108,109	RES NET, 10K,2%,1.3W	TF-179-1
R114	RES,1K,5%,1/4W,COMPOSITION OR FILM	R-76-1K
R119	RES,10K,5%,1/4W,COMPOSITION OR FILM	R-76-10K
R128	RES, 200K, .1%, 1/4W METAL FILM	R-264-200K
R131	RES, 15M, 5%, 1/4W, COMPOSITION OR FILM	R-76-15M
R133	RES,2.2K,5%,1/4W,COMPOSITION OR FILM	R-76-2.2K
R138	RES, 22K 5%, 1/4W, COMPOSITION OR FILM	R-76-22K
R142	RES, 2.0M, .1%, 1/4W METAL FILM	R-321-2M
R143	RES,220K,.1%,1/4W,METAL FILM	R-264-220K
R144	RES,20K,.1%,1/10W,METAL FILM	R-263-20K
R145	RES,2K,.1%,1/10W,METAL FILM	R-263-2K
R146	THICK FILM	TF-150
R149	RES NET, CUSTOM	TF-172
R150	RES,200K,5%,1/4W,COMPOSITION OR FILM	R-76-200K
R153	RES NET, CUSTOM	TF-171
S101	SWITCH,PUSHBUTTON (6 POLE)	SW-466
S102	SWITCH, SLIDE (DPDT)	SW-397
S103	SWITCH, SLIDE (DPDT)	SW-318
T101	TRANSFORMER	TR-298A
T102	TRANSFORMER	TR-214
U101	STAKING, HS-25	2469-2
U102	IC,QUAD 2 INPUT NAND,74LS00	IC-163
U103,127	IC,12 STAGE BINARY COUNTER,74HC4040	IC-407
U104	IC, 16X16 BIT SERIAL RAM, X2443P	IC-353
U105	IC, DUAL D TYPE FLIP FLOP, 4013	IC-103
U107	IC, 2048 WORDX8 BIT HI SP ST CMOS, 6116	LSI-58
U108,110,116	IC, OCTAL D-LATCH W/3 STATE OUT, 74HC373	IC-338
U109	IC, CMOS 8 BIT MICROPROCESSOR, 146805E2	LSI-60
U111	IC,QUAD 2 INPUT NAND,74HC00	IC-351
U113	IC,GPIB ADAPTER,9914A	LSI-49

Model 6512 Digital Board, Parts List (cont.)

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
U117,128	IC,QUAD 2 INPUT NOR,74HC02	IC-412
U118,135	IC, TRIPLE 3 INPUT NAND, 74HC10	IC-341
U119	IC,OCTAL INTERFACE BUS TRANSCEIVER,75161	IC-299
U120	IC,OCTAL INTERFACE BUS,75160	IC-298
U121,122	IC,OPTOCOUPLER,2601	IC-239
U126	IC,DUAL D-TYPE FLIP FLOP,74HC74	IC-337
U129	INTEGRATED CIRCUIT	IC-136
U130	IC, OP-AMP, ICL7650	IC-316
U133	IC,8 STAGE SHIFT/STORE REGISTER,4094	IC-251
U136,145	IC,TRIPLE 2 CH MULTI/DEMUX,4053	IC-283-1
U137	IC, DUAL, VOLTAGE COMPARATOR, LM393	IC-343
U138	INTEGRATED CIRCUIT	IC-408
U139	IC, 18V OP-AMP, TLC 271	IC-347-1
U143	IC, TRIPLE 3-INPUT OR, 4075	IC-143
VR102	DIODE,ZENER 6.44V,IN4577AGED (DO-7)	DZ-58
VR103	DIODE, ZENER 5.1V,IN751(DO-7)	DZ-59
W101	CONN,3 PIN	CS-339-3
Y101	CRYSTAL, 3.276800MHZ	CR-21
Y102	CRYSTAL, 1.2288MHZ	CR-19

Model 6512 Display Board, Parts List

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
C201	CAP,10UF,20%,20V,TANTALUM	C-179-10
DS-201	DD-31 SELECTION	617-603
DS202-205	DD-30 SELECTION	617-604
DS206	DIGITAL DISPLAY (DOUBLE DIGIT)	DD-39
DS208-213,215-219,221,223,224	PILOT LIGHT,RED,LED	PL-71
DS214	PILOT LIGHT, YELLOW,LED	PL-72
P1016	CABLE ASSEMBLY, 24 CONDUCTOR	CA-30-1
R201,202	RES NET,82,5%,.25W	TF-141
S201-215,217,218	SWITCH, MOMENTARY	SW-435
U201,202	IC, 8 CHANNEL SOURCE DRIVER, UDN2585	IC-405
U203	IC,3-8 LINE DECODER/DEMULTI,74HCT138	IC-398
U204,205	IC,8 CHANNEL CURRENT SINK DRIVER,UDN2595	IC-406
U206	IC, ANALOG MULTIPLEXER, 4051	IC-277

Model 6512 Electrometer Board, Parts List

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
C301,302	CAPACITOR, ELECTROLYTIC	C-240-4.7
C303,304	CAPACITOR, ELECTROLYTIC	C-240-10
C305	CAP,1500UF,-20,+100%,.25V,ALUM ELEC	C-314-1500
C306	CAP, 470UF, -20+100%, 16V ALUMINUM	C-313-470
C307	CAP, .001PF, 2.5%, 630V POLYESTER	C-252-.001
C308	CAP,10PF,10%,1000V,CERAMIC	C-64-10P
C309,310,313,314	CAP, 10UF,-20+100%,.25V,ALUM ELEC	C-314-10
C311,317	CAP, 470UF, +100 TO -10%, 50V, ALUM ELEC	C-276-470
C312	CAPACITOR, POLYSTYRENE	C-31-5P
C315,316	CAP, 1000UF, -20+100%, 16V ALUMINUM	C-313-1000
C318	CAP,22PF,5%,500V,POLYSTYRENE	C-138-22P
C319	CAP,.01UF,20%,500V,CERAMIC	C-22-.01
C320	CAP,470PF,10%, 1000V CERAMIC	C-64-470P
C321	CAP, .02UF, 20%, 500V, CERAMIC	C-22-.02
C322	CAP, 390PF, 5%, 500V, POLYSTYRENE	C-138-390P
CR301,302,319,320	DIODE,SILICON,IN4006 (D0-41)	RF-38
CR303-307,314,317,318,322,323	DIODE,SILICON,IN4006 (D0-41)	RF-38
CR311	DIODE,BRIDGE,VM18	RF-52
CR315,316,321	DIODE,SILICON,IN4148 (DO-35)	RF-28
J1020	PIN, CONTACT	CS-357
K301,302	RELAY (DPST)	RL-86
K303-306	RELAY	RL-44
K307-312	RELAY (SPST)	RL-70
P1014	CABLE ASSEMBLY, 14 CONDUCTOR	CA-27-2
Q301,304,306	TRANSISTOR	TG-146-1
Q302	TRANS,N CHANNEL FET,2N4392 (TO-92)	TG-128-1
Q303,305,307	TRANSISTOR	TG-147-1
Q308	SELECTION, TG-227	617-607C
Q309	TRANSISTOR	TG-145
Q310	TRANSISTOR	TG-177
Q311	TRANS, DUAL NPN IT121 (TO-52)	TG-91
R301,302,320,321	RES, 330K, 10%, 1/2W, COMPOSITION	R-1-330K
R303	RESISTOR, METAL FILM	R-283-900K
R304	RES NET, 900,90,10, .05%	TF-191
R305,308	RESISTOR, ENAMEL	R-329-10K
R306,307	RES, 768, 1%, 1/8W, METAL FILM	R-88-768
R309,323,324	RES,100,5%,1/4W,COMPOSITION OR FILM	R-76-100
R311	RES,180,5%,1/4W,COMPOSITION OR FILM	R-76-180
R312	RES, 100, .1%, 1/2W METAL FILM	R-169-100
R313	SELECTION	617-601
R314,348	POT,10K,10%,.5W,NON-WIREWOUND	RP-104-10K
R315	RES, 1.87K, 1%, 1/8W METAL FILM	R-88-1.87K
R316	RES, 2.78K, .1%, 1/10W, METAL FILM	R-263-2.78K
R317	RES, 5.025K,.1%,1/10W,METAL FILM	R-263-5.025K
R318	RES,5.1K,5%,1/4W,COMPOSITION OR FILM	R-76-5.1K
R319,329,337	RES,2.2K,5%,1/4W,COMPOSITION OR FILM	R-76-2.2K
R322	RES, 100K, 0.1% 1/2W METAL FILM	R-169-100K
R324,327	RES, 560, 10%, 1/2W, COMPOSITION	R-1-560
R326	RES,47,5%,1/4W,COMPOSITION OR FILM	R-76-47
R328,354	RES,5.1K,5%,1/4W,COMPOSITION OR FILM	R-76-5.1K
R330	RES, 100G, 2%, 1.5W, HY MEG	R-289-100G
R331	RES, 100M, .50%, 1/4W, METAL OXIDE	R-269-100M
R332	RESISTOR, EPOXY	R-319-250G
R333,355	RES,100K,5%,1/4W,COMPOSITION OR FILM	R-76-100K
R334	RES,10M,5%,1/4W,COMPOSITION OR FILM	R-76-10M
R335,336	RESISTOR SET	R-322
R338,339	THERMISTOR, PTC	RT-12
R340	RES, 4.02K, 1%, 1/8W, METAL FILM	R-88-4.02K
R341	RES, 402, 1%, 1/8W METAL FILM	R-88-402
R342	RES, 40.2, 1%, 1/8W METAL FILM	R-88-40.2
R344	RES, 715, 1%, 1/8W METAL FILM	R-88-715
R345	RES,243,1%,1/8W,METAL FILM	R-88-243
R346	RES,270,5%,1/4W,COMPOSITION OR FILM	R-76-270
R347	RES,560,5%,1/4W,COMPOSITION OR FILM	R-76-560

Model 6512 Electrometer Board, Parts List (cont.)

CIRCUIT DESIG.	DESCRIPTION	KEITHLEY PART NO.
R349	RES,5.6K,5%,1/4W,COMPOSITION OR FILM	R-76-5.6K
R350	RES, 150K, 5%, 1/4W COMPOSITION OR FILM	R-76-150K
R351	RES, 16.5K, 1%, 1/8W METAL FILM	R-88-16.5K
R352	RES, 24.9K, 1%, 1/8W, METAL FILM	R-88-24.9K
U301	IC,8 STAGE SHIFT/STORE REGISTER,4094	IC-251
U302,303	IC,HEX INVERTER,74HC04	IC-354
U304	IC, 18V OP-AMP, 741	IC-42
U306	IC,+5V REGULATOR,500mA,7805	IC-93
U307	IC, 3-TERM ADJ REGULATOR LM337	IC-345
U308	IC,VAR POS VOLTAGE REG,100MA,78L05A	IC-223
U309	IC,20V OP-AMP,1012	IC-394
VR301	SELECTION	617-601
VR302,303	DIODE, ZENER 9.1V, IN4739A (DO-35)	DZ-56
VR304	DIODE, ZENER 33V, IN4752A (DO-41)	DZ-68
W303	CONN, 4 PIN	CS-339-4

Model 6512 Mechanical, Parts List

DESCRIPTION	KEITHLEY PART NO.
SHIELD, BOTTOM	617-314
SOLDER LUG	LU-7
CONNECTOR, BNC	CS-520
PUSHBUTTON	228-317-4
PUSHBUTTON	228-317-6B
SHIELD, BOTTOM COVER	617-305B
SHIELD, INPUT TUBE	30472
BINDING POST, RED	BP-11-2
CAP, PROTECTIVE	CAP-30-1
CAP,1000PF,10%,1000V,CERAMIC	C-64-1000P
PUSHBUTTON	228-317-7
PUSHBUTTON	228-317-5B
OVERLAY	6512-308A
SHORTING LINK	BP-6
BINDING POST (METAL)	BP-15
BINDING POST, BLACK	BP-11-0

A

IEEE-488 Bus Overview

A.1 Introduction

This appendix provides an overview of the IEEE-488 bus. For detailed Model 6512 programming information, refer to Section 3.

A.2 Bus description

The IEEE-488 bus, which is also frequently referred to as the GPIB (General Purpose Interface Bus), was designed as a parallel transfer medium to optimize data transfer without using an excessive number of bus lines. In keeping with this goal, the bus has only eight data lines that are used for both data and many commands. Five bus management lines and three handshake lines round out the complement of bus signal lines.

A typical configuration for controlled operation is shown in Figure A-1. The typical system will have at least one controller and one or more devices to which commands are given and, in most cases, from which data is received. Generally, there are three categories that describe device operation: controller, talker, and listener.

The controller does what its name implies: it controls other devices on the bus. A talker sends data (usually to the controller), while a listener receives data. Depending on the instrument, a particular device may be a talker only, a listener only, or both a talker and a listener.

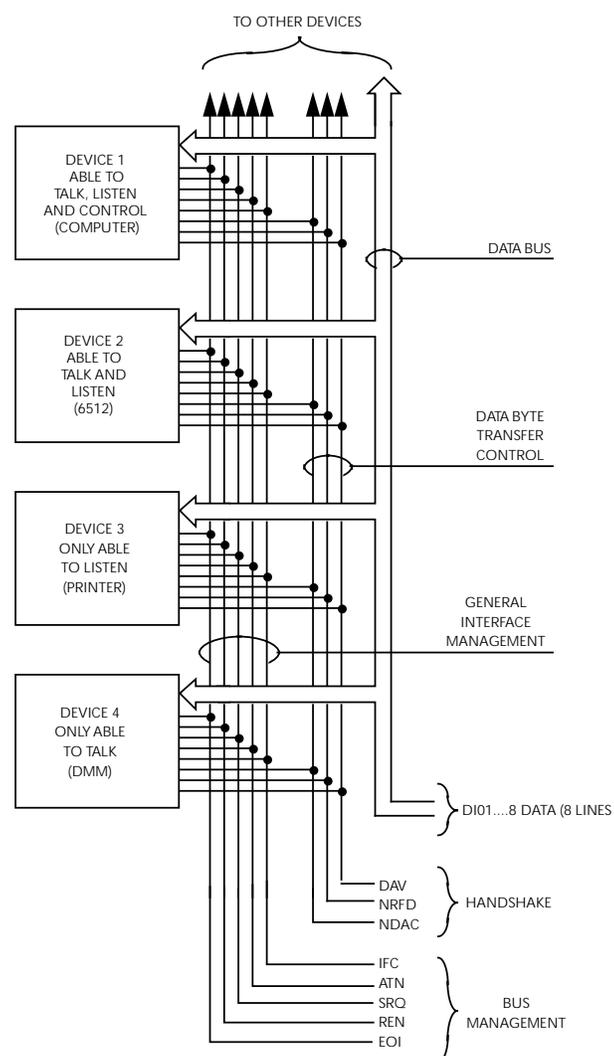


Figure A-1
IEEE-488 bus configuration

There are two categories of controllers: system controller, and basic controller. Both are able to control other instruments, but only the system controller has the absolute authority in the system. In a system with more than one controller, only one controller may be active at any given time. Certain protocol is used to pass control from one controller to another.

The IEEE-488 bus is limited to 15 devices, including the controller. Thus, any number of talkers and listeners up to that limit may be present on the bus at one time. Although several devices may be commanded to listen simultaneously, the bus can have only one active talker for obvious reasons.

A device is placed in the talk or listen state by sending an appropriate talk or listen command. These talk and listen commands are derived from an instrument's primary address. The primary address may have any value between 0 and 30, and is generally set by rear panel DIP switches or programmed in from the front panel of the instrument. The actual listen address value sent out over the bus is obtained by ORing the primary address with 20_{H} . For example, if the primary address is 27 (1B_{H}), the actual listen address is 3B_{H} ($3\text{B}_{\text{H}} = 1\text{B}_{\text{H}} + 20_{\text{H}}$). In a similar manner, the talk address is obtained by ORing the primary address value with 40_{H} . With the present example, the talk address derived from a primary address of 27 decimal would be 5B_{H} ($5\text{B}_{\text{H}} = 1\text{B}_{\text{H}} + 40_{\text{H}}$).

The IEEE-488 standards also include another addressing mode called secondary addressing. Secondary addresses lie in the range of $60_{\text{H}}-7\text{F}_{\text{H}}$. Note, however, that many devices, including the Model 6512, do not use secondary addressing.

Once the device is properly addressed, appropriate bus transactions are set to take place. For example, if an instrument is addressed to talk, it will usually place its data on the bus one byte at a time. The listening device (usually the controller) will then read this information.

A.3 IEEE-488 bus lines

The signal lines on the IEEE-488 bus are grouped into three different categories: data lines, management lines, and handshake lines. The data lines handle bus data and commands, while the management and handshake lines ensure that proper data transfer and bus operation takes place. Each bus line is active low, with approximately zero volts representing a logic 1 (true). The following paragraphs describe the purpose of these lines, which are shown in Figure A-1.

Data lines

The IEEE-488 bus uses eight data lines that allow data to be transmitted and received in a bit-parallel, byte-serial manner. These lines use the convention DIO1-DIO8 instead of the more common D0-D7. DIO1 is the least significant bit, while DIO8 is the most significant bit. The data lines are bidirectional (with most devices), and, as with the remaining lines, low is considered to be true.

Bus management lines

The five bus management lines help to ensure proper interface control and management. These lines are used to send the uniline commands that are described in paragraph B.4.

ATN (Attention)—The ATN line is one of the more important management lines in that the state of this line determines how information on the data bus is to be interpreted.

IFC (Interface Clear)—As the name implies, the IFC line controls clearing of instruments (removing talkers and listeners) from the bus.

REN (Remote Enable)—The REN line is used to place instruments on the bus in the remote mode.

EOI (End or Identify)—The EOI line is usually used to mark the end of a multi-byte data transfer sequence.

SRQ (Service Request)—This line is used by devices when they require service from the controller.

Handshake lines

The bus uses three handshake lines that operate in an interlocked sequence. This method ensures reliable data transmission regardless of the transfer rate. Generally, data transfer will occur at a rate determined by the slowest active listener on the bus.

One of the three handshake lines is controlled by the source (the talker sending information), while the remaining two lines are controlled by accepting devices (the listener or listeners receiving the information). The three handshake lines are:

DAV (Data Valid)—The source controls the state of the DAV line to indicate to any listening devices whether or not data bus information is valid.

NRFD (Not Ready For Data)—The acceptor controls the state of NRFD. It is used to signal to the transmitting device to hold off the byte transfer sequence.

NDAC (Not Data Accepted)—NDAC is also controlled by the accepting device.

The complete handshake sequence for one data byte is shown in Figure A-2. Once data is placed on the data lines, the source checks to see that NRFD is high, indicating that all active devices are ready. At the same time, NDAC should be low from the previous byte transfer. If these conditions are not met, the source must wait until NDAC and NRFD have the correct status. If the source is a controller, NRFD and NDAC must be stable for at least 100nsec after ATN is set true. Because of the possibility of a bus hang up, many controllers have timeout routines that display messages in case the transfer sequence stops for any reason.

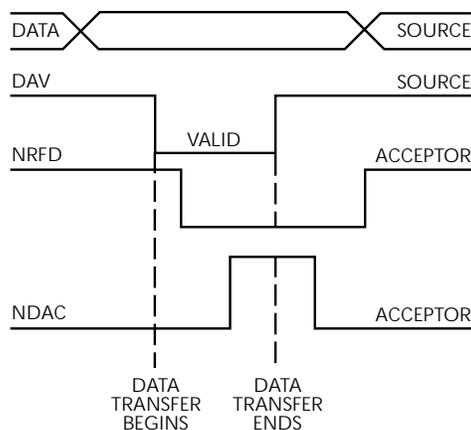


Figure A-2
IEEE-488 handshake sequence

Once all NDAC and NRFD are properly set, the source sets DAV low, indicating to accepting devices that the byte on the data lines is now valid. NRFD will then go low, and NDAC will go high once all devices have accepted the data. Each device will release NDAC at its own rate, but NDAC will not be released to go high until all devices have accepted the data byte.

Once NDAC goes high, the source then sets DAV high to indicate that the data byte is no longer valid. NDAC is returned to its low state, and NRFD is released by each device at its own rate, until NRFD goes high when the slowest device is ready, and the bus is set to repeat the process with the next data byte.

The sequence just described is used to transfer data, talk and listen addresses, as well as multiline commands. The state of the ATN line determines whether the data bus contains data, addresses, or commands as described in the following paragraph.

A.4 Bus commands

While hardware aspects of the bus are essential, the interface would have minimal capabilities without appropriate commands to control communications among the various devices on the bus. This paragraph briefly describes the purposes of the various device commands, which are grouped into the following three general categories:

Uniline Commands—Sent by setting the corresponding bus line true.

Multiline Commands—General bus commands, which are sent over the data lines with ATN true (low).

Device-dependent Commands—Special commands whose meanings depend on device configuration; sent over the data lines with ATN high (false).

These bus commands and their general purposes are summarized in Table A-1.

Table A-1

IEEE-488 bus command summary

Command type	Command	Comments
Uniline	REN (Remote Enable) EOI (End or Identify) IFC (Interface Clear) ATN (Attention) SRQ (Service Request)	Set up for remote operation. Marks end of transmission. Clears interface. Defines bus contents. Device requesting service.
Multiline		
Universal	LLO (Local Lockout) DCL (Device Clear) SPE (Serial Poll Enable) SPD (Serial Poll Disable)	Locks out front panel controls. Returns device to default conditions. Enables serial polling. Disables serial polling.
Addressed	SDC (Selective Device Clear) GTL (Go To Local) GET (Group Execute Trigger)	Returns to default conditions. Cancels remote state. Triggers device for reading.
Unaddressed	UNL Unlisten UNT (Untalk)	Removes all listeners from bus. Removes talker from bus.
Device-dependent*		Programs Model 6512 operating modes.

* See Section 3 for a complete description of device-dependent commands.

Uniline commands

ATN, IFC, and REN are asserted only by the controller. SRQ is asserted by an external device. EOI may be asserted either by the controller or other devices depending on the direction of data transfer. The following is a description of each command. Each command is sent by setting the corresponding bus line true.

REN (Remote Enable)—REN is sent to set up instruments on the bus for remote operation. Generally, REN should be asserted before attempting to program instruments over the bus.

EOI (End or Identify)—EOI is used to positively identify the last byte in a multi-byte transfer sequence, thus allowing data words of various lengths to be transmitted easily.

IFC (Interface Clear)—IFC is used to clear the interface and return all devices to the talker and listener idle states.

ATN (Attention)—The controller asserts ATN while transmitting addresses or multiline commands.

SRQ (Service Request)—SRQ is asserted by a device when it requires service from a controller.

Universal commands

Universal commands are those multiline commands that require no addressing. All devices equipped to implement such commands will do so simultaneously when the command is transmitted. As with all multiline commands, these commands are transmitted with ATN true.

LLO (Local Lockout)—LLO is sent to instruments to lock out their front panel controls.

DCL (Device Clear)—DCL is used to return instruments to some default state. Usually, instruments return to their power-up conditions.

SPE (Serial Poll Enable)—SPE is the first step in the serial polling sequence, which is used to determine which device has requested service.

SPD (Serial Poll Disable)—SPD is used by the controller to remove all devices on the bus from the serial poll mode and is generally the last command in the serial polling sequence.

Addressed commands

Addressed commands are multiline commands that must be preceded by the device listen address before that instrument will respond to the command in question. Note that only the addressed device will respond to these commands:

SDC (Selective Device Clear)—The SDC command performs essentially the same function as the DCL command except that only the addressed device responds. Generally, instruments return to their power-up default conditions when responding to the SDC command.

GTL (Go To Local)—The GTL command is used to remove instruments from the remote mode. With some instruments, GTL also unlocks front panel controls if they were previously locked out with the LLO command.

GET (Group Execute Trigger)—The GET command is used to trigger devices to perform a specific action that depends on device configuration (for example, take a reading). Although GET is an addressed command, some devices may respond to GET without addressing.

Unaddress commands

The two unaddress commands are used by the controller to remove any talkers or listeners from the bus. ATN is true when these commands are asserted.

UNL (Unlisten)—Listeners are placed in the listener idle state by the UNL command.

UNT (Untalk)—Any previously commanded talkers will be placed in the talker idle state by the UNT command.

Device-dependent commands

The meaning of the device-dependent commands will depend on the configuration of the instrument. Generally, these com-

mands are sent as one or more ASCII characters that tell the device to perform a specific function. For example, the command sequence FOX is used to place the Model 6512 in the volts mode. The IEEE-488 bus actually treats these commands as data in that ATN is false when the commands are transmitted.

A.5 Command codes

Each multiline command is given a unique code that is transmitted over the bus as 7 bit ASCII data. This section briefly explains the code groups, which are summarized in Figure A-3.

Addressed Command Group (ACG)—Addressed commands and corresponding ASCII codes are listed in columns 0(A) and 0(B).

Universal Command Group (UCG)—Universal commands and values are listed in columns 1(A) and 1(B).

Listen Address Group (LAG)—Columns 2(A) through 3(B) list codes for commands in this address group. For example, if the primary address of the instrument is 27, the LAG byte will be an ASCII left bracket.

Talk Address Group (TAG)—TAG primary address values and corresponding ASCII characters are listed in columns 4(A) through 5(B).

The preceding address groups are combined together to form the Primary Command Group (PCG). The bus also has another group of commands, called the Secondary Command Group (SCG). These are listed in Figure A-3 for informational purposes only; the Model 6512 does not have secondary addressing capabilities.

Note that these commands are normally transmitted with the 7 bit code listed in Figure A-3. For many devices, the condition of DIO8 is unimportant. However, many devices may require that DIO8 has a value of logic 0 (high) to properly send commands.

B

General Bus Commands

B.1 Introduction

General bus commands are those commands such as DCL (Device Clear) that have the same general meaning regardless of the instrument. General commands supported by the Model 6512 are listed in Table B-1. Note that commands requiring addressing assume that the Model 6512 primary address is set to 27 (its default address).

B.2 REN (Remote Enable)

The remote enable command is sent to the Model 6512 by the controller to set up the instrument for remote operation. Generally, the instrument should be placed in the remote mode before you attempt to program it over the bus. Simply setting REN true will not actually place the instrument in the remote mode. Instead the instrument must be addressed to listen after setting REN true before it will go into remote.

Table B-1
General bus commands

Command	Description	Effect on Model 6512	Typical controller syntax*
REN	Remote Enable	Goes into remote when addressed.	REMOTE 727
IFC	Interface Clear	Enters talker and listener idle states.	ABORT 7
LLO	Local Lockout	Front panel controls locked out.	LOCAL LOCKOUT 7
GTL	Go to Local	Cancels remote.	LOCAL 727
DCL	Device Clear	Returns to default conditions.	CLEAR 7
SDC	Selective Device Clear	Returns to default conditions.	CLEAR 727
GET	Group Execute Trigger	Triggers reading in T2 and T3 modes.	TRIGGER 727
	Set REN false	Cancels LLO.	LOCAL 7
SPE, SPD	Serial Polling	Requests status byte.	S=SPOLL (727)

* Indicates typical controller syntax required to send corresponding general bus commands. Hewlett-Packard BASIC syntax shown.

B.3 IFC (Interface Clear)

The IFC command is sent by the controller to place the Model 6512 in the local, talker, and listener idle states. The unit will respond to the IFC command by cancelling front panel TALK or LISTEN lights, if the instrument was previously placed in one of those modes.

B.4 LLO (Local Lockout)

The LLO command is used to remove the instrument from the local operating mode. After the unit receives LLO, all its front panel controls except POWER will be inoperative. REN must be true for the instrument to respond to LLO. REN must be set false to cancel LLO.

B.5 GTL (Go To Local)

The GTL command is used to take the instrument out of the remote mode. With some instruments, GTL may also cancel LLO. With the Model 6512, however, REN must first be placed false before LLO will be cancelled.

B.6 DCL (Device Clear)

The DCL command may be used to clear the Model 6512 and return the unit to its power-up default conditions. Note that the DCL command is not an addressed command, so all instruments equipped to implement DCL will do so simultaneously. When the Model 6512 receives a DCL command, it will return to the default conditions listed in Table B-2.

B.7 SDC (Selective Device Clear)

The SDC command is an addressed command that performs essentially the same function as the DCL command. However, since each device must be individually addressed, the SDC command provides a method to clear only a single, selected instrument instead of clearing all instruments simulta-

neously, as is the case with DCL. When the Model 6512 receives the SDC command, it will return to the power-up default conditions listed in Table B-2.

Table B-2
Default conditions

Mode	Default value*	Status**
Function	F0	Volts
Range	R0	Auto-range
Zero Check	C1	Enabled
Zero Correct	Z0	Disabled
Suppression	N0	Disabled
Trigger	T6	Continuous, External
Data Format	G0	Prefix, no suffix
Data Store	Q7	Disabled
SRQ Mode	M00	Disabled
EOI and Bus Hold-off	K0	Both disabled
Terminator	Y=:	<CR> <LF>

* Indicates corresponding device-dependent command and option; see Section 3.
** Instrument status on power-up, or after receiving DCL or SDC.

B.8 GET (Group Execute Trigger)

GET may be used to trigger the Model 6512 to take readings if the instrument is placed in one of the two GET trigger modes. More information on trigger modes may be found in Section 3.

B.9 Serial polling (SPE, SPD)

The serial polling sequence is used to obtain the Model 6512 status byte. The status byte contains important information about internal functions, as described in Section 3. Generally, the serial polling sequence is used by the controller to determine which of several instruments has requested service with the SRQ line. However, the serial polling sequence may be performed at any time to obtain the status byte from the Model 6512.

C

Interface Function Codes

C.1 Introduction

The interface function codes define the Model 6512's ability to support various IEEE-488 interface functions and should not be confused with programming commands found elsewhere in this manual. The interface function codes for the Model 6512 are listed in Table C-1. These codes are also listed for convenience on the rear panel adjacent to the IEEE-488 connector.

Table C-1

Model 6512 interface function codes

Code	Interface function
SH1	Source Handshake Capability
AH1	Acceptor Handshake Capability
T5	Talker (Basic Talker, Serial Poll, Talk-only Mode, Unaddressed to Talk on LAG)
L4	Listener (Basic Listener, Unaddressed to Listen on TAG)
SR1	Service Request Capability
RL1	Remote/Local Capability
PP0	No Parallel Poll Capability
DC1	Device Clear Capability
DT1	Device Trigger Capability
C0	No Controller Capability
E1	Open-collector Bus Drivers
TE0	No Extended Talker Capabilities
LE0	No Extended Listener Capabilities

The codes define Model 6512 capabilities as follows:

SH (Source Handshake Function)—SH1 defines the ability of the Model 6512 to initiate the transfer of message/data over the data bus.

AH (Acceptor Handshake Function)—AH1 defines the ability of the Model 6512 to guarantee proper reception of message/data transmitted over the data bus.

T (Talker Function)—The ability of the Model 6512 to send data over the bus to other devices is provided by the T function. Model 6512 talker capabilities exist only after the instrument has been addressed to talk, or when it has been placed in the talk-only mode.

L (Listener Function)—The ability for the Model 6512 to receive device-dependent data over the bus from other devices is provided by the L function. Listener capabilities of the Model 6512 exist only after the instrument has been addressed to listen.

SR (Service Request Function)—The SR function defines the ability of the Model 6512 to request service from the controller.

RL (Remote-Local Function)—The RL function defines the ability of the Model 6512 to be placed in the remote or local modes.

PP (Parallel Poll Function)—The Model 6512 does not have parallel polling capabilities.

Interface Function Codes

DC (Device Clear Function)—The DC function defines the ability of the Model 6512 to be cleared (initialized).

DT (Device Trigger Function)—The ability for the Model 6512 to have its readings triggered is provided by the DT function.

C (Controller Function)—The Model 6512 does not have controller capabilities.

TE (Extended Talker Function)—The Model 6512 does not have extended talker capabilities.

LE (Extended Listener Function)—The Model 6512 does not have extended listener capabilities.

E (Bus Driver Type)—The Model 6512 has open-collector bus drivers.

D

Example Programs

D.1 Introduction

This appendix includes examples programs written in BASIC to demonstrate simple programming techniques for the Model 6512. Programs include:

- Basic I/O program that allows you to send commands and obtain readings.
- Data store program that stores and recalls 100 readings.
- SRQ program that demonstrates the error bit and error word.
- Status word program that requests and displays the status, error, and data words.
- Calibration program to aid in calibrating the Model 6512 (see Section 7 for complete details on calibration).

D.2 Computer hardware requirements

The following computer hardware is required to run the example programs:

- IBM PC, AT, or compatible computer.
- Keithley KPC-488.2, KPS-488.2, or KPC-488.2AT, or CEC PC-488 IEEE-488 interface for the computer.
- Shielded IEEE-488 connecting cable (Keithley Model 7007).

D.3 Computer software requirements

In order to use the example programs, you will need the following software:

- Microsoft QBasic (supplied with MS-DOS 5.0 or later), QuickBASIC (version 4.5 or later) or Visual BASIC for MS-DOS may also be used.
- MS-DOS version 5.0 or later (version 3.3 or later may be used if not using QBasic).
- HP-style Universal Language Driver, CECHP.EXE (supplied with Keithley and CEC interface cards listed above).

D.4 General program instructions

1. With the power off, connect the Model 6512 to the IEEE-488 interface of the computer. Be sure to use a shielded IEEE-488 cable for bus connections.
2. Make sure the Model 6512 is set for a primary address of 27. You can check or change the address as follows:
 - A. Press PROGRAM SELECT, and note the displayed primary address. If it is currently set to 27, press SHIFT then EXIT to return to normal display.
 - B. If the address is not set to 27, use the ADJUST keys to set it to the correct value.
 - C. Press PROGRAM SELECT to return to normal display.

3. Make sure that the computer bus driver software (CECHPEXE) is properly initialized.
4. Enter the BASIC editor. For example, if you are using QBasic, simply type the following at the DOS prompt:

```
qbasic <Enter>
```

5. Type in the desired program; check it thoroughly for errors, then save it using a convenient filename.
6. Run the program by pressing <Shift> and <F5> simultaneously.

D.5 Basic input/output program

Program 1 below will allow you to send commands to the Model 6512 and obtain readings. To use this program, simply type in the desired command string at the prompt. When typing in commands, keep the following points in mind:

- Be sure to use only upper-case letters for commands.
- Be certain to terminate each command string with the X character.

After each command is sent to the instrument, the program will request a reading from the instrument and display the results on the computer screen.

Program 1. Basic input/output program

```
' Program to send commands and read data from Model 6512.
OPEN "IEEE" FOR OUTPUT AS #1          ' Open IEEE-488 output path.
OPEN "IEEE" FOR INPUT AS #2          ' Open IEEE-488 input path.
PRINT #1, "REMOTE 27"                ' Put 6512 in remote.
PRINT #1, "CLEAR"                    ' Send DCL.
CLS
Start:
INPUT "Model 6512 Command"; C$       ' Input command.
PRINT #1, "OUTPUT 27;"; C$
PRINT #1, "ENTER 27"                 ' Address 6512 to talk.
LINE INPUT #2, R$                     ' Input reading string.
PRINT R$                              ' Print reading string.
GOTO Start
END
```

D.6 Data store program

Program 2 below demonstrates basic data store operation over the bus. The program sets up the Model 6512 for SRQ on data store full, and it then enables data store at the conver-

sion rate. The program then waits in a loop until it detects an SRQ from the instrument and then reads and displays all 100 readings.

Program 2. Example data store program

```
' Program to use Model 6512 data store feature.
OPEN "IEEE" FOR OUTPUT AS #1      ' Open IEEE-488 output path.
OPEN "IEEE" FOR INPUT AS #2      ' Open IEEE-488 input path.
PRINT #1, "REMOTE 27"           ' Put 6512 in remote.
PRINT #1, "CLEAR"               ' Send DCL.
CLS
PRINT #1, "OUTPUT 27;M2X"        ' SRQ on data store full.
PRINT #1, "OUTPUT 27;Q0C0X"     ' Enable data store, conversion rate.
PRINT "Storing data..."
DO: PRINT #1, "SRQ?"            ' Loop until SRQ occurs.
INPUT #2, S
LOOP UNTIL S
PRINT #1, "SPOLL 27"            ' Serial poll to clear SRQ.
INPUT #2, S
PRINT #1, "OUTPUT 27;C1B1G2X"   ' Set reading mode to data store.
FOR I = 1 TO 100                ' Loop for all 100 readings.
PRINT #1, "ENTER 27"           ' Address 6512 to talk.
LINE INPUT #2, R$               ' Input reading.
PRINT R$                        ' Display reading.
NEXT I
END
```

D.7 SRQ and status byte program

Program 3 below demonstrates SRQ on error and how to obtain and display the status byte. The instrument is first programmed for SRQ on error, and an illegal command option (K5) is sent to generate the error. The U1 error word is re-

quested and displayed (note that the IDDCO bit is set), and the status byte is then obtained by using serial polling. The bits of the status byte are unpacked and displayed in MSB to LSB order. Note that the RQS (B6) and error (B5) bits are set; the ready bit (B4) may also be set.

Program 3. SRQ and status byte program

```
' Program to demonstrate Model 6512 SRQ and status byte.
OPEN "IEEE" FOR OUTPUT AS #1      ' Open IEEE-488 output path.
OPEN "IEEE" FOR INPUT AS #2      ' Open IEEE-488 input path.
PRINT #1, "REMOTE 27"           ' Put 6512 in remote.
PRINT #1, "CLEAR"               ' Send DCL.
CLS
PRINT #1, "OUTPUT 27;M32X"      ' SRQ on error.
PRINT #1, "OUTPUT 27;K5X"      ' Program illegal option.
DO: PRINT #1, "SRQ?"           ' Loop until SRQ occurs.
INPUT #2, S
LOOP UNTIL S
PRINT #1, "OUTPUT 27;U1X"      ' Request error word.
PRINT #1, "ENTER 27"          ' Address 6512 to talk.
INPUT #2, S$                   ' Input status word.
PRINT "U1 Error word: "; S$
PRINT #1, "SPOLL 27"          ' Serial poll to get status byte.
INPUT #2, S
M = 128                         ' Define mask.
PRINT : PRINT "Status byte:": PRINT
PRINT "B7 B6 B5 B4 B3 B2 B1 B0"
FOR I = 1 TO 8                 ' Loop to display bits.
IF (M AND S) THEN PRINT "1 "; ELSE PRINT "0 ";
M = M / 2                      ' Shift mask bit right.
NEXT I
PRINT
END
```

D.8 Status word program

Program 4 below shows how to obtain and display status, error, and data words. The program loops through three times, requesting, reading, and displaying each of the three word strings on the computer screen.

Program 4. Status word program

```
' Program to obtain status words from Model 6512.
OPEN "IEEE" FOR OUTPUT AS #1      ' Open IEEE-488 output path.
OPEN "IEEE" FOR INPUT AS #2      ' Open IEEE-488 input path.
PRINT #1, "REMOTE 27"           ' Put 6512 in remote.
PRINT #1, "CLEAR"               ' Send DCL.
CLS
FOR I = 0 TO 2                   ' Loop for all 3 status words.
PRINT #1, "OUTPUT 27;U"; I; "X" ' Send status word command.
PRINT #1, "ENTER 27"           ' Address 6512 to talk.
INPUT #2, S$                     ' Input status word string.
PRINT "U"; I; "word: "; S$      ' Print status string.
NEXT I
END
```

D.9 Calibration program

Program 5 below can be used as an aid in calibrating the Model 6512 using the equipment covered in Section 7 of this manual. Follow the steps below to use this program:

1. With the power off, connect the Models 263 and 6512 to the GPIB interface of the computer.
2. With the power off, connect the Model 263 to the Model 6512, as shown in Figure 7-3 (Section 7). Also connect the external voltage calibrator to the Model 263, as shown in Figure 7-4.
3. Turn on the Models 6512 and 263, and the external voltage calibrator, and allow a two-hour warm-up period before beginning calibration.
4. Set the IEEE-488 primary address of the Model 263 to 8, and set the primary address of the Model 6512 to 27.
5. Enter the calibration program into the computer. (See the introduction of this appendix for complete details.)
6. To calibrate the instrument, run the program, and follow the instructions on the CRT display.
7. After all functions are calibrated, the program will prompt for permanent storage of calibration constants in NVRAM. This feature allows you to stop at this point in order to avoid permanent calibration. Unless calibration is made permanent, the calibration constants will be lost when the instrument is turned off.
8. If selected, storage of calibration constants into NVRAM is performed as indicated by the "Stor" message on the Model 6512. If instead the message "out" is displayed, the calibration jumper is in the disable position, and calibration constants will be lost when the Model 6512 is turned off. (See paragraph 7.4.3 for information on the calibration jumper.)

Program 5. Calibration program

```

' Model 6512 calibration program using Model 263 Calibrator
OPEN "IEEE" FOR OUTPUT AS #1           ' Open IEEE-488 output path.
OPEN "IEEE" FOR INPUT AS #2           ' Open IEEE-488 input path.
PRINT #1, "REMOTE 8 27"               ' Put 263, 6512 in remote.
PRINT #1, "CLEAR"                     ' Send DCL.
CLS
PRINT "Connect 263 to 6512 input and external voltage source."
PRINT "See Figures 7-3 and 7-4 in Section 7 of manual."
PRINT "Set external voltage source to output 190.00V to 263."
PRINT "Set 6512 GUARD switch to OFF."
PRINT "Press any key to continue."
SLEEP
PRINT "Calibrating..."
PRINT #1, "OUTPUT 8;F1R3V190E-12X"     ' 263: output 190pA.
DATA 3,1.9E-10,5,1.9E-8,8,1.9E-5,11,.019
FOR I = 1 TO 4
READ R
PRINT #1, "OUTPUT 27;F1R"; R; "X"     ' 6512: select I range.
PRINT #1, "OUTPUT 8;R"; R; "X"       ' 263: select I range.
PRINT #1, "OUTPUT 8;Z1O1X"           ' 263: output 0A to 6512.
SLEEP 2
PRINT #1, "OUTPUT 27;Z1X"            ' 6512 zero correct unit.
SLEEP 1
PRINT #1, "OUTPUT 27;C0X"            ' 6512: disable zero check.
SLEEP 5
PRINT #1, "OUTPUT 27;N1X"            ' 6512: enable suppress.
PRINT #1, "OUTPUT 8;Z0X"             ' 263: output I to 6512.
IF I = 1 THEN SLEEP 18 ELSE SLEEP 3
READ R
PRINT #1, "OUTPUT 27;A"; R; "X"      ' 6512: send cal value.
SLEEP 2
PRINT #1, "OUTPUT 27;N0Z0C1X"        ' 6512: disable suppress.
NEXT I
PRINT #1, "OUTPUT 8;O0X"              ' 263: place in standby.
BEEP: PRINT "Amps ranges calibrated: 200pA, 20nA, 20uA, 20mA": PRINT
SLEEP 2
PRINT #1, "OUTPUT 27;F3XR3Z1X"       ' 6512: 20nC range, zero correct.
PRINT #1, "OUTPUT 8;F3R4V19E-9X"     ' 263: program 19nC.
PRINT #1, "OUTPUT 27;C0X"            ' 6512: disable zero check.
SLEEP 2
PRINT #1, "OUTPUT 27;N1X"            ' 6512: enable suppress.
PRINT #1, "OUTPUT 8;O1X"             ' 263: output 19nC.
SLEEP 2.5
PRINT #1, "OUTPUT 27;A19E-9X"        ' 6512: send cal value.
SLEEP 2
BEEP: PRINT "20nC coulombs range calibrated.": PRINT
PRINT #1, "OUTPUT 8;F2R1V190E-3X"    ' 263: program for 190mV.
DATA .19,1.9,19
FOR I = 1 TO 3

```

Example Programs

```
PRINT #1, "OUTPUT 27;C1Z0N0F0R"; I; "X"      ' 6512: select volts range.
PRINT #1, "OUTPUT 8;R"; I; "Z101X"          ' 263: select range, output 0V.
PRINT #1, "OUTPUT 27;Z1XC0X"                ' 6512: z. cor. on,z.chk. off.
PRINT #1, "OUTPUT 27;N1X"                   ' 6512: enable suppress.
PRINT #1, "OUTPUT 8;Z0X"                     ' 263: output programmed voltage.
READ V
SLEEP 2
PRINT #1, "OUTPUT 27;A"; V; "X"             ' 6512: send cal value.
SLEEP 2
NEXT I
PRINT #1, "OUTPUT 27;Z0N0R4X"               ' 6512: select 200V range.
PRINT #1, "OUTPUT 8;F501X"                  ' 263: source external V.
SLEEP 2
PRINT #1, "OUTPUT 27;A190X"                 ' 6512: send cal value.
SLEEP 2 PRINT #1, "OUTPUT 27;C1F2R8X"       ' 6512: Select 20G ohm range.
PRINT "All volts ranges calibrated."
PRINT #1, "OUTPUT 8;F0R8W1G1X"              ' 263: 10G ohm range, guard on.
BEEP: PRINT "Set 6512 GUARD switch to ON, press a key to continue."
SLEEP PRINT "Continuing..."
FOR I = 8 TO 2 STEP -1
IF I = 7 THEN
    BEEP
    PRINT "Set 6512 GUARD switch to OFF position."
    PRINT "Press any key to continue."
    SLEEP
    PRINT "Continuing..."
    PRINT #1, "OUTPUT 8;W0X"                  ' 263: disable guard.
END IF
PRINT #1, "OUTPUT 8;R"; I; "XZ101X"         ' 263: output 0 ohms.
PRINT #1, "OUTPUT 27;C1Z0N0R"; I; "X"      ' 6512: select range.
PRINT #1, "OUTPUT 27;Z1XC0XN1X"            ' 6512: zero unit.
PRINT #1, "OUTPUT 8;Z0X"                     ' 263: source programmed R.
SLEEP 7
PRINT #1, "ENTER 8"                          ' 263: address to talk.
INPUT #2, A                                   ' 263: request resistance value.
PRINT #1, "OUTPUT 27;A"; A; "X"             ' 6512: send cal value.
SLEEP 3
NEXT I
BEEP: PRINT "Ohms ranges calibrated:"
PRINT "20G ohm, 2G ohm, 200M ohm, 20M ohm, 2M ohm, 200k ohm, 20k ohm"
DO WHILE INKEY$ <> "": LOOP
INPUT "Do you wish to permanently store cal constants (Y/N)"; B$
IF B$ = "Y" OR B$ = "y" THEN
    PRINT #1, "OUTPUT 27;L1X"
    PRINT "If cal jumper is in 'ENABLE' position,"
    PRINT "all functions/ranges are permanently calibrated."
    CLOSE : END
END IF
PRINT "Cal constants not stored."
PRINT "Altered ranges temporarily calibrated."
CLOSE : END
```

E

Model 617/6512 Software Compatibility

E.1 Introduction

The Model 6512 Electrometer is very similar to the Model 617 Electrometer/Source. The main difference between the two units is that Model 617 has a built-in voltage source, while the Model 6512 of course does not. This appendix outlines key differences in programming commands between the two units for those who wish to substitute a Model 6512 for a Model 617 in a system application and make the necessary changes to their programs.

E.2 Omitted device-dependent commands

Table E-1 summarizes those commands included in the Model 617 that are not present in the Model 6512. All these commands are related in one way or another to the Model 617 voltage source.

Table E-1
Model 617 commands not used by Model 6512

Command	Description
B4	Voltage source reading mode
D	Display mode
F5	V/I ohms
0	Voltage source operate
V	Voltage source value

E.3 Status word prefixes

The U0, U1, and U2 status words (paragraph 3.2.13) include a model number prefix that identifies the instrument. The Model 617 includes a three-character prefix (617), while the Model 6512 has a four-character prefix (6512). If your current parsing routines expect a specific string length to identify bit positions, you will have to make program adjustments to accommodate the new string lengths.

One simple way to accommodate this change is to strip the Model 6512 status word string of its first character, thereby reducing the string length to that of the Model 617. For example, assume that you are using BASIC, and that the status word resides in a string variable called `Status$`. The following simple statement will truncate the status word string to the same length as the Model 617 string:

```
Status$ = RIGHT$(Status$,LEN(Status$)-1)
```

Note that the first character (6) of the string will be omitted, and the new prefix will read 512. The status word bit positions will then appear in the same relative positions as those in the corresponding Model 617 status word.

E.4 Status word bit positions

Several status word bit positions associated with the Model 617 voltage source are not used by the Model 6512. These bits positions are always set to 0 in the Model 6512.

Index

2V analog output 2-8, 2-18
-2V reference source 6-7

A

Accessories 1-3
AC receptacle 2-7
A/D converter 6-8
A/D converter and display 7-15
Additional calibration points 7-8
Additional signal conditioning 6-6
Addressed commands A-5
Amps calibration 7-5
Amps verification 5-2
Analog outputs 2-18
Applications 4-1

B

Baseline suppression (N) 3-12
Basic input/output program D-2
Basic measurement techniques 2-8
Bus commands A-3
Bus connections 3-22
Bus data transmission times 3-24
Bus description A-1
Bus error 3-24
Bus management lines A-2

C

Calibration 2-6, 7-2
Calibration cycle 7-2
Calibration jumper 7-2
Calibration program 7-4, D-6
Calibration sequence 7-3
Calibration value (A) 3-5
Capacitance measurement 4-5
Capacitor leakage measurements 4-4

Charge measurement considerations 2-17
Chassis ground 2-8
Command codes A-5
COM terminal 2-8
Component layout drawings and schematic diagrams 8-1
Computer hardware requirements D-1
Computer software requirements D-1
Connectors and adapters 1-4
Controller programs 3-2
Controls 2-3
Coulombs calibration 7-6
Coulombs verification 5-3
Current measurement considerations 2-14

D

Data conditions 3-19
Data format (G) 3-7
Data lines A-2
Data storage 2-27
DATA STORE 2-5
Data store mode (Q) 3-13
Data store program D-3
DCL (Device Clear) B-2
Default conditions 3-2
Device-dependent command programming 3-1
Device-dependent command summary 3-2
Device-dependent commands A-5
Device selection 6-10
Digital calibration (front panel or IEEE-488 bus) 7-3
Digital circuitry 6-9, 7-15
Diode characterization 4-3
Disassembly instructions 7-9
Display 2-5
Display board 7-16
Display circuitry 6-11
Display and indicators 2-5

E

Electrometer 2-3
Electrometer commands 3-1
Electrometer input circuitry 2-21
Electrostatic interference 2-31
Engineering units conversion 2-35
Environmental conditions 5-1, 7-3
EOI and bus hold-off modes (K) 3-8
Error conditions 3-18
Example programs D-1
Execute (X) 3-20
Exponent mode (alpha or numeric) 2-6
External feedback procedure 2-23
EXTERNAL TRIGGER INPUT 2-8
External trigger input 2-28
External triggering 2-28

F

Factory service 8-1
Features 1-1
Front panel familiarization 2-2
Front panel messages 3-23
Front panel programs 2-6
Function (F) 3-6

G

Gain stage 6-4
General bus commands B-1
General information 1-1
General program instructions D-1
GET (Group Execute Trigger) B-2
Getting started 1-2
Ground loops 2-31
GTL (Go To Local) B-2
GUARD switch 7-2
Guarded operation 2-11
Guarded resistance measurements 4-6

H

Handling and cleaning precautions 7-16
Handshake lines A-2
High-impedance voltmeter 4-9

I

IDDC error 3-24
IDDCO error 3-24
IEEE-488 address 2-6
IEEE-488 bus 6-10
IEEE-488 bus digital calibration 7-8
IEEE-488 bus lines A-2
IEEE-488 bus overview A-1
IEEE-488 cables 1-3
IEEE-488 connector 2-7
IEEE-488 primary address 1-3
IEEE-488 programming 3-1
IFC (Interface Clear) B-2
Initial conditions 5-1
INPUT 2-7
INPUT cables 1-3
Input capacitance effects 2-33
Input connections 2-8
Input current adjustment 7-4
Input current verification 5-2
Input impedance verification 5-6
Input offset adjustment 7-4
Input/output circuitry 6-10
Input preamplifier 6-2
Input and ranging amplifiers 7-15
Input stage 6-4
Input stage balancing procedure 7-16
Instruction manual 1-2
Insulation resistance measurements 4-6
Interface function codes C-1
Introduction 1-1

L

Leakage resistance effects 2-32
Line frequency 1-3
LINE FUSE 2-7
Line fuse replacement 7-2
Line power 1-2
Line voltage selection 1-3, 7-1
LLO (Local Lockout) B-2
Logarithmic currents 2-23
Low-level leakage current measurements 4-1

M

Making charge measurements 2-15
Making current measurements 2-13
Making voltage measurements 2-9
Maintenance 7-1
Manual addenda 1-2
Manual adjustments 7-3
Measurement considerations 2-31
Memory elements 6-9
Meter complete output 2-29
METER and DATA indicators 2-5
Microcomputer 6-9
Model 617/6512 software compatibility E-1
Multiple commands 3-1
Multiplexer and buffer amplifier 6-7

N

No Remote error 3-24
Non-decade current gains 2-24
Non-standard coulombs ranges 2-23
Non-volatile memory storage (L) 3-9
Normal charge measurements 2-15
Number error 3-24

O

Ohms calibration 7-7
Ohms verification 5-4
Ohms voltage source 6-5
Omitted device-dependent commands E-1
Operation 2-1
Order of command execution 3-1
Ordering information 8-1
Output stage 6-4
Overall functional description 6-1

P

Parts list 8-1
Performance verification 5-1
Permanent storage of calibration constants 7-7
POWER 2-3
Power supplies 6-11
Power supply checks 7-13

Power-up procedure 2-1
Power-up self-test 7-12
Power-up self-test and display messages 2-2
PREAMP OUT 2-8
Preamp out 2-19
Preparation for use 1-2
Primary address 3-22
PROGRAM 2-4

Q

Quick start procedure 1-3

R

Rack mount kits 1-4
RAM memory test 2-2
Range (R) 3-14
Ranging amplifier 6-6
Ranging amplifier gain configuration 7-15
Reading mode (B) 3-5
Rear panel familiarization 2-7
Recommended test equipment 5-2
Relay configuration 7-14
REN (Remote Enable) B-2
Repacking for shipment 1-2
Replaceable parts 8-1
Required calibration equipment 7-3
Resistance measurement considerations 2-18
Resistance measurements 2-17
RFI 2-32

S

Safety symbols and terms 1-2
SDC (Selective Device Clear) B-2
Selecting the data output rate 3-23
Self-diagnostic program 7-12
Self-test and firmware revision level 2-2
Serial polling (SPE, SPD) B-2
Shielded fixture construction 2-22
SHIFT 2-3
Shipment contents 1-2
Source capacitance 2-35
Source resistance 2-34
Special handling of static-sensitive devices 7-9

Specifications 1-2
SRQ mask 3-9
SRQ mask (M) and status byte format 3-9
SRQ and status byte program D-4
Static charge detection 4-11
Status byte 3-10
STATUS indicators 2-5
Status (U) 3-16
Status word 3-16
Status word bit positions E-1
Status word prefixes E-1
Status word program D-5

T

Talk-only mode 3-23
Terminator (Y) 3-20
Test fixtures 1-4
Theory of operation 6-1
Thermal EMFs 2-32
Tilt bail 2-5
Trigger cables 1-4
Trigger mode (T) 3-15
Trigger overrun error 3-24

Triggering example 2-30
Troubleshooting 7-11

U

Unaddress commands A-5
Unguarded resistance measurements 4-5
Uniline commands A-4
Universal commands A-4
Unpacking and inspection 1-2
Using the coulombs function to measure current 2-16
Using external feedback 2-21
Using the ohms function as a current source 2-18
Using suppression 2-26
Using zero correct and baseline suppression 2-25

V

V, Ω GUARD switch 2-7
Valid command strings 3-2

Verification procedures 5-2
V/I resistance measurements with external voltage source 4-8
Voltage coefficients of high-megohm resistors 4-10
Voltage measurement considerations 2-10
Volts calibration 7-6
Volts verification 5-3

W

Warm-up period 2-8
Warranty information 1-1

Z

Zero check 6-6
Zero check (C) 3-6
Zero correct (Z) 3-21
Zero correct and zero check 2-25