

1657 RLC Digibridge®

Instruction Manual

Form 1657-0120-07/B1

©QuadTech, Inc., 1992
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Product will be marked with this symbol (ISO#3684) when it is necessary for the user to refer to the instruction manual in order to prevent injury or equipment damage.

Instruction Manual Changes

These two supplementary pages contain information of improvements or modifications not documented in the current manual. All references to GenRad in the manual now apply to QuadTech, Inc.

Page -Specifications (Power & Mechanical)

Power should be 90 -250V AC, 50 -60 Hz. Voltage switching is automatic and no longer selected by rear panel switch. 60 Watts maximum.

Weight should be 10 lbs. (4.5 kg) net, 15 lbs. (6.8 kg) shipping.

Environment reads, Altitude < 2000m, Installation Category 1, Pollution Degree 1

Page - Table of Contents (Parts List and Diagrams -Section 6)

Power supply board (1657-4720) layout and diagram (page 6-13) replaced by Power supply assembly part number 700011 (no diagrams, repair by module exchange)

Page 1-4 -Figure 1-2, Rear Panel Controls and Connectors

Rear view should show new power supply assembly (PN 700011) without line-voltage switch.

Page 1-4 -Table 1-2, Rear Panel Connectors and Controls

Ref No. 2R -&  Fuse is 6/10A, 250V, 3AG Type, Slow Blow. Replace only with the same type and rating. To replace, remove fuse drawer by pressing up on release tab.

Ref No. 3R -Line-voltage switch has been deleted, power input is from 90 -250V AC

Page 1-4 -Table 1-3, Accessories

A quantity of two spare fuses are supplied, 6/10A, 250V, 3AG Type, Slow Blow (QuadTech part number 5330-1100)

Page 2-1 -Safety Inspection

Before operating the instrument inspect the power inlet module on the rear of the unit to

 ensure that the **properly rated fuse is in place**, otherwise damage to unit is possible. Fuse is 6/10A, 250V, 3AG Type, Slow Blow.

The 1657 is shipped with a standard U.S. power cord, QuadTech PN 4200-0300 (with Belden SPH-386 socket or equivalent, and 3 wire plug conforming to IEC 320) or an approved international cord set. Make sure the instrument is only used with these or other approved international cord sets, which ensures the instrument is provided with connection to protective earth ground.

In all installations the instrument should be positioned with consideration for ample air flow to the side and rear panel ventilation holes. An open space around the instrument of at least 3 inches (75mm) is recommend. The surrounding environment should be free from excessive dust to prevent contamination of electronic circuits.

Instruction Manual Changes (continued)

WARNING

If this instrument is used in a manner not specified in this manual protection to the operator and equipment may be impaired.

Page 2-1 -Power-Line Connection

Power line switch for 115V or 230V operation has been removed, switching is automatic for voltages between 90 -250V AC.

Page 2-2 -Figure 2-2

Figure 2-2 does not apply. Only certified line cords which comply with IEC 227 or IEC 245 should be used.

Page 3-2 -Paragraph 3.1 Basic Procedure, step a

Power line switch for 115V or 230V operation has been removed, switching is automatic.

Page 5-1 -Paragraph 5.2, Instrument Return

Contacts for QuadTech are:	Sales	800-253-1230
	Service	800-253-1230
	Technical Assistance	978-461-2100

Page 5-2 & Page 5-3 -Caution Note

Power line switch for 115V or 230V operation has been removed, switching is automatic.



Page 5-7 -& Paragraph 5.6.1 & Figure 5-3, Disassembly

Power Supply Assembly shown has been replaced by Power Supply Assembly PN 700011.

Page 5-10 -Instrument Cleaning Instructions

Monthly (more or less depending on usage) the built-in test fixture should be cleaned with a soft brush and isopropyl alcohol. Avoid getting excess alcohol on instrument paint surfaces, otherwise damage to the finish can result. For additional instrument cleaning instructions refer to paragraph 5.7.1 (Care of the Test Fixture) and paragraph 5.7.2 (Care of the Display Panel).

Power Supply Assembly shown in Figure 5-8 has been replaced by Power Supply Assembly PN 700011.

Page 5-12 - Paragraph 5.8.2, Power Supply

Trouble Analysis procedure does not apply to new Power Supply Assembly P/N 700011.

Page 6-2 - Figure 6-2, Rear View

Rear view should show new power supply (PN 700011) without line-voltage switch

Page 6-3 - Mechanical Parts List, Rear

Items 1 - 4 (power connector, fuse extractor post, line voltage switch & cover) deleted on new assembly

Page 6-12 & Page 6-13 - Parts and Diagrams

Power Supply Board and Parts List shown, PN 1657-4720 has been replaced by Power Supply Assembly, PN 700011. The 700011 Assembly must be repaired by module exchange.

Specifications

Measurement Mode: Measures R series or parallel; L and Q series or parallel; C and D series or parallel. All measurement modes are pushbutton selectable.

Displays: LED-type numerical display with automatically positioned decimal points and illumination of units. For R LC, five digits (99999) and simultaneously for DQ, four digits (9999).

Measurement Speed: Greater than 3 measurements per second.

Test frequencies: Pushbutton selection between 2. Accuracy re panel legends: +2%, -.01%. Actual frequencies: for 1657-9700, 1020.0 Hz +/- .01% (panel legend "1 kHz") and 120.00 Hz +/- .01%; for 1657.9800, 1000.0 and 100.00 Hz +/- .01%.

Applied Voltage: 0.3 V rms maximum.

Ranges: Pushbutton selection with automatic front-panel guidance. Three basic ranges (best accuracy, see table) of 2 decades each, for each parameter. Automatic extensions to min and max, as tabulated.

Parameter	Minimum	Basic ranges	Maximum
R; 120 Hz*	00.001 Ω	2 Ω to 2 MΩ	99.999 MΩ
R; 1 kHz	00.001 Ω	2 Ω to 2 MΩ	9.9999 MΩ
L; 1 kHz	0.0001 mH	0.2 mH to 200 H	999.99 H
L; 120 Hz*	00.001 mH	2 mH to 2000 H	9999.9 H
C; 1 kHz	0.0001 nF	0.2 nF to 200 μF	999.99 μF
C; 120 Hz*	00.001 nF	2 nF to 2000 μF	99999 μF
D (with C)	.0001	(fully automatic)	9.999
Q (with L)	00.01	(fully automatic)	999.9

*120 Hz or 100 Hz, depending on the instrument.

Accuracy: For R, L, and C: +/- 0.2% of reading in basic ranges, if quadrature component is small (D < 0.1, Q > 10, etc). See table. D accuracy: +/- .001 in basic ranges, for D < 0.1 (otherwise, see table). Q accuracy: +/- .01 in basic ranges, for Q < 1 (otherwise, see table).

Parameter	Basic accuracy			Cross-term factor
	Low extension	Basic ranges	High extension	
R; either frequency	±[4 mΩ,	0.2% of rdg,	(R/10 MΩ)% of rdg] (1 + Q)
L; 1 kHz	±[0.4 μH,	0.2% of rdg,	(L/1000 H)% of rdg] (1 + 1/Q)
L; 120 Hz*	±[4 μH,	0.2% of rdg,	(L/10 kHz)% of rdg] (1 + 1/Q)
C; 1 kHz	±[0.4 pF**,	0.2% of rdg,	(C/1000 μF)% of rdg] (1 + D)
C; 120 Hz*	±[4 pF**,	0.2% of rdg,	(C/.01 F)% of rdg] (1 + D)
D (with C)	±[.001 + 0.2 (1 + D)% of rdg] K [†]
Q (with L)	±[.01 + 0.2 (1 + Q)% of rdg] K [†]

*120 Hz or 100 Hz. **Fixed offset "zero" capacitance is < 1.5 pF.

†K = (LC basic accuracy as % of rdg) / 0.2%. Therefore, K = 1 on basic ranges.

Environment: TEMPERATURE: 0° to 50°C operating, -40° to +75°C storage. HUMIDITY: 0 to 85% R.H., operating.

Supplied: Power cord, axial-lead adaptors, instruction manual.

Power: 90 to 125 or 180 to 250 V, 50 to 60 Hz. Voltage selected by rear-panel switch. 25 W maximum.

Mechanical: Bench mounting. DIMENSIONS: (wxhxd): 375x112x343 mm (14.8x4.4x13.5 in.). WEIGHT: 5.6 kg (12.3 lb) net, 10 kg (22 lb) shipping.

Description	Catalog Number
1657 RLC Digibridge®	
120-Hz and 1-kHz Test Frequencies	1657-9700
100-Hz and 1-kHz Test Frequencies	1657-9800

Accessories

Extender Cable with banana plugs/alligator clips	1657-9600
Extender Cable with type 874 coaxial connectors	1688-9600
Remote Test Fixture (requires BNC adaptor)	1689-9600
BNC Adaptor	1689-9601
BNC Cable Assembly (for 1689-9600, 1689-9601)	1689-9602

Warranty



QuadTech warrants that Products are free from defects in material and workmanship and, when properly used, will perform in accordance with QuadTech's applicable published specifications. If within one (1) year after original shipment it is found not to meet this standard, it will be repaired, or at the option of QuadTech, replaced at no charge when returned to a QuadTech service facility.

Changes in the Product not approved by QuadTech shall void this warranty.

QuadTech shall not be liable for any indirect, special or consequential damages, even if notice has been given of the possibility of such damages.

This warranty is in lieu of all other warranties, expressed or implied, including, but not limited to any implied warranty or merchantability or fitness for a particular purpose.

SERVICE POLICY

QuadTech policy is to maintain product repair capability for a period of five (5) years after original shipment and to make this capability available at the then prevailing schedule of charges.

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Introduction – Section 1

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1.1 PURPOSE.

The 1657 Digibridge digital impedance meter embodies use of a microprocessor and other LSI circuitry to provide excellent performance at low cost.

A few clearly labeled pushbuttons and the versatile built-in test fixture make this instrument a model for convenience. Measurement results are clearly shown with decimal points and units, which are automatically presented to assure correctness. Display resolution is 5 digits for R, C, and L (4 for D or Q) and the basic accuracy is 0.2%.

Long-term accuracy and reliability are assured by the measurement system. It makes these accurate analog measurements over many decades of impedance without a single calibration or "trimming" adjustment (not even in original manufacture).

The built-in test fixture, with a pair of plug-in adaptors, receives any common component part (axial-lead or radial-lead) so easily that insertion of the DUT is a one-hand operation. True 4-terminal connections are made automatically. Extender cables and other accessories are available for measurements at a distance from the Digibridge.

1.2 GENERAL DESCRIPTION.

Convenience is enhanced by the arrangement of test fixture on the front ledge, with push buttons farther forward and display behind. The display panel is inclined and recessed to enhance visibility of digital readouts and mode indicators. These indicators serve to inform and guide the operator as he operates the simple controls.

The instrument stands on a table or bench top. The sturdy metal cabinet is attractively and durably finished,

in keeping with the long-life circuitry inside. Glass-epoxy circuit boards interconnect and support high-quality components to assure years of dependability.

Adaptability to any common ac power line is assured by the removable power cord and the convenient line-voltage switch. Safety is enhanced by the fused, isolating power transformer and the 3-wire power connection. A comprehensive functional description is given in Theory, Section 4. Electrical and physical characteristics are listed in Specifications at the front of this manual, dimensions in Installation, Section 2. Controls are described below, and their use in Operation, Section 3.

1.3 CONTROLS, INDICATORS, AND CONNECTORS.

Figure 1-1 shows the front panel controls and indicators. Table 1-1 identifies them with descriptions and functions.

Similarly, Figure 1-2 shows the rear panel and Table 1-2 identifies

and describes the rear panel controls and connectors.

1.4 ACCESSORIES.

Gen Rad makes several accessories that enhance the usefulness of this instrument. Two extender cables facilitate making connections to those devices and impedance standards that do not readily fit the built-in test fixture. A remote test fixture (used with BNC adaptor and cable assembly) provides convenience and relatively easy maintenance, and saves wear on the built-in test fixture. All of these test-fixture accessories provide for true 4-terminal connections (and guard) to the device being measured, without appreciable reduction in measurement accuracy. Other useful accessories are offered, such as standards for checking the performance of the Digibridge. Refer to Table 1-3 and Section 5.

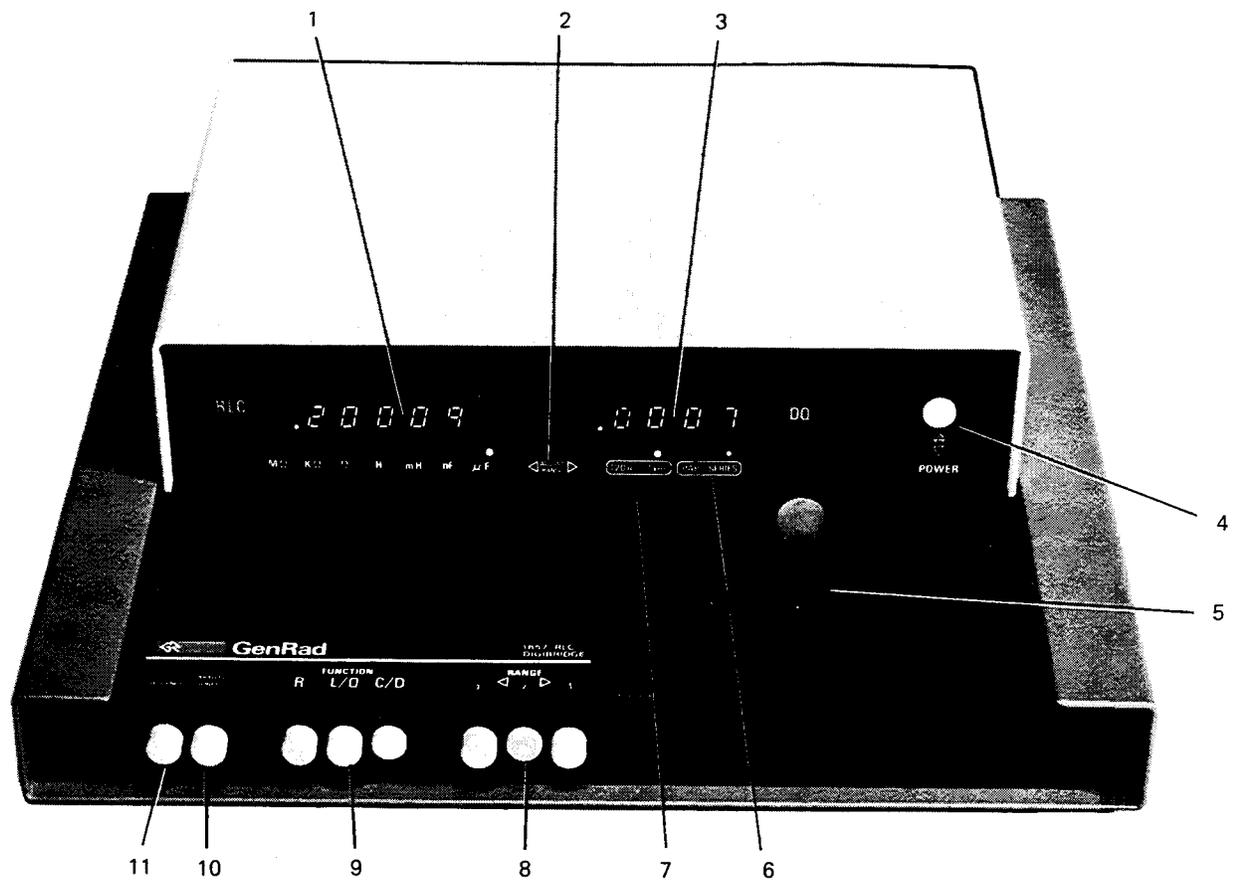


Figure 1-1. Front panel controls and displays.

Table 1-1
FRONT PANEL CONTROLS AND INDICATORS

Figure 1-1 Ref.No.	Name	Description	Function
1	RLC display	Digital display, 5 numerals with decimal points. Unit labels $M\Omega$, $k\Omega$, Ω , mH, nF, μF , with 7 lights.	Display of principal measured value. Light spot indicates units.
2	ADJUST RANGE lights	Arrowheads with a light behind each.	Guides operator to optimum range. Left arrow means "try next pushbutton to left." Right arrow means the converse. No light means "Correct range." Also see para 3.3.
3	DQ display	Digital display, 4 numerals with decimal points.	Display of secondary measured value, D if you select C/D, Q if you select L/Q with item 9.
4	POWER switch	Pushbutton (push again to release).	Turns instrument ON when in, OFF when out. OFF position breaks both sides of power circuit.
5	Test fixture	Pair of special connectors; each makes dual contact with inserted wire lead of DUT.	Receives radial-lead part, making 4-terminal connection automatically. Adaptors are supplied to make similar connection with axial-lead part.
6	PARALLEL/SERIES lights	Legend with 2 lights.	Indicates the selection of parallel or series equivalent circuit of the DUT (by item 10). Refer to para 3.5.
7	Frequency lights	Legend with 2 lights, 120 Hz, 1 kHz, (or 100 Hz, 1 kHz).	Indicates the selection of test frequency by item 11.
8	RANGE pushbuttons	Set of 3 interlocked, latching pushbuttons, labeled 3, 2, 1. The latched button is released by depressing another one.	Manual selection of measurement range, in conjunction with item 9.
9	FUNCTION push-buttons	Set of 3 pushbuttons, similar to item 8, labeled R, L/Q, C/D.	Manual selection of parameter to be measured: resistance, inductance, or capacitance.
10	PARALLEL/SERIES pushbutton	Pushbutton (push again to release).	Manual selection of equivalent circuit. Item 6 indicates the one in use.*
11	FREQUENCY push-button	Pushbutton, like item 10.	Manual selection of frequency. Item 7 indicates the frequency in use.*

*When these buttons are "in", the selections are PARALLEL and 120 Hz (100 Hz).

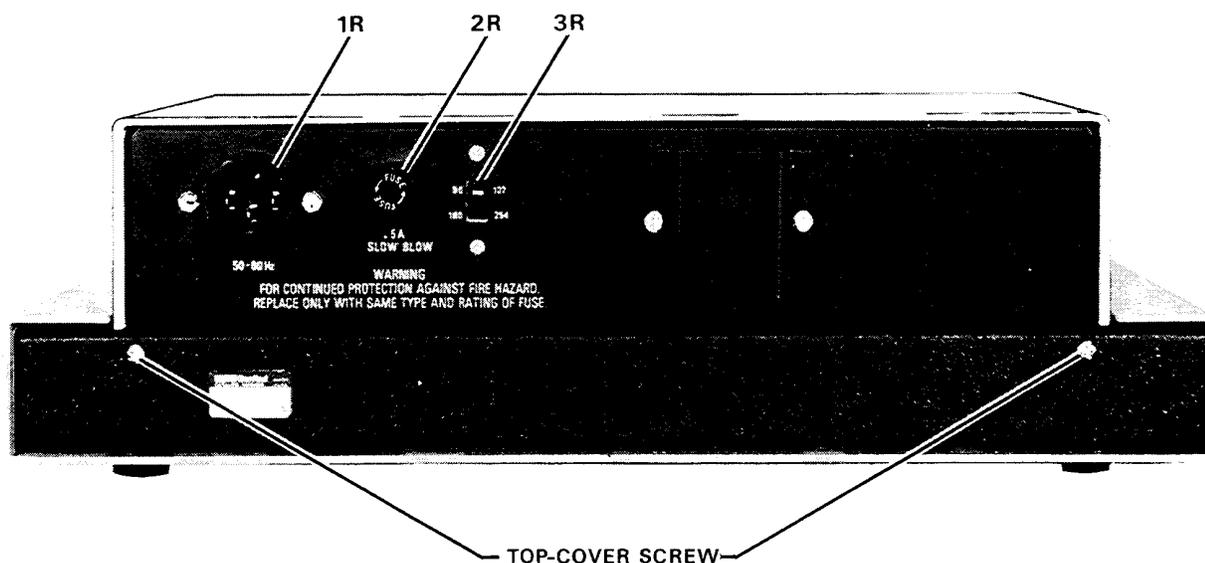


Figure 1-2. Rear panel controls and connectors.

Table 1-2
REAR PANEL CONNECTORS AND CONTROLS

Figure 1-2 Ref. No.	Name	Description	Function
1R	Power connector, (labeled 50-60 Hz)	Safety shrouded 3-wire plug, conforming to International Electrotechnical Commission 320.	Ac power input. Use appropriate power cord, such as GR 4200-9625, with Belden SPH-386 socket or equivalent.
2R	Fuse (labeled 0.5 A, 250 V, SLOW BLOW)	Fuse in extraction post holder.	Short circuit protection. Use Bussman type MDL or equivalent fuse, 1/2 A, 250 V rating.
3R	Line-voltage switch	Slide switch. Vertical motion: upper position, 90 to 125 V; lower position, 180 to 250 V	Adapts power supply to line-voltage ranges, as indicated. To operate, use small screwdriver, not any sharp object.

Table 1-3
ACCESSORIES

Quantity	Description	Part Number
1 supplied	Power cord, 210 cm (7 ft) long, 3-wire, AWG No. 18, with molded connector bodies. One end, with Belden SPH-386 socket, fits instrument. Other end is stackable (hammerhead) conforming to ANSI standard C73.11-1966 (for 125 V).	4200-9625
2 supplied	Test-fixture adaptors, for axial-lead parts	
	Reorder number, for a set of four:	1657-5996
1 available	Rack mount kit (slides forward for complete access).	1657-9000
1 available	Extender Cable with banana plugs/alligator clips. Length 100 cm (40 in.)	1657-9600
1 available	Extender Cable with type 874 coaxial connectors. Length 30 cm (12 in.)	1688-9600
1 available	Remote Test Fixture (requires BNC adaptor)	1689-9600
1 available	BNC Adaptor	1689-9601
1 available	BNC Cable Assembly (for 1689-9600, 1689-9601). Length 90 cm (36 in.)	1689-9602

Installation – Section 2

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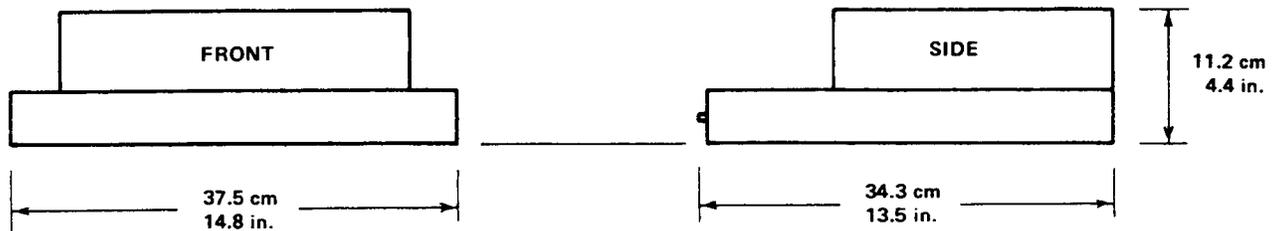


Figure 2-1. Overall dimensions.

2.1 UNPACKING AND INSPECTION.

If the shipping carton is damaged, ask that the carrier's agent be present when the instrument is unpacked. Inspect the instrument for damage (scratches, dents, broken parts, etc.). If the instrument is damaged or fails to meet specifications, notify the carrier and the nearest GenRad field office. (See list at back of this manual). Retain the shipping carton and the padding material for the carrier's inspection.

2.2 DIMENSIONS

Figure 2-1.

The instrument is supplied in the bench configuration, i.e., in a cabinet with resilient feet for placement on a table. The overall dimensions are given in the figure.

2.3 POWER-LINE CONNECTION.

The power transformer primary windings can be switched, by means of the line voltage switch on the rear panel, to accommodate ac line voltages in either of 2 ranges, as labeled, at a frequency of 50 or 60 Hz, nominal. Using a small screwdriver, set this switch to match the measured voltage of your power line.

If your line voltage is in the lower range, connect the 3-wire power cable (P/N 4200-9625) to the power connector on the rear panel (Figure 1-2) and then to the power line.

The instrument is fitted with a power connector that is in conformance with the International Electrotechnical Commission publication 320. The 3 flat contacts are surrounded by a cylindrical plastic shroud that reduces the possibility of electrical shock whenever the power cord is being unplugged from the instrument. In addition, the center ground pin is longer, which means that it mates first and disconnects last, for user protection. This panel connector is a standard 3-pin grounding-type receptacle, the design of which has been accepted world wide for electronic instrumentation. The connector is rated for 250 V at 6 A. The receptacle accepts power cords fitted with the Belden type SPH-386 connector.

The associated power cord for use with that receptacle, for line voltages up to 125 V, is Gen Rad part no. 4200-9625.

It is a 210-cm (7 ft), 3-wire, 18-gage cable with connector bodies molded integrally with the jacket. The connector at the power-line end is a stackable hammerhead design that conforms to the "Standard for Grounding Type Attachment Plug Caps and Receptacles," ANSI C73. 11-1966, which specifies limits of 125 V and 15 A. This power cord is listed by Underwriters Laboratories, Inc., for 125 V, 10 A.

If the fuse must be replaced, be sure to use a "slow blow" fuse of the current and voltage ratings shown on the rear panel, regardless of the line voltage.

If your line voltage is in the higher range selectable by the line voltage switch, use a power cord of the proper rating (250 V, 15 A) that mates with both instrument and your receptacle. It is possible to replace the "hammerhead" connector on the power cord that is supplied with a suitable connector. Be sure to use one that is approved for 250 V, 15 A. A typical configuration is shown in Figure 2-2.

2.4 LINE-VOLTAGE REGULATION

The accuracy of measurements accomplished with precision electronic test equipment operated from ac line sources can often be seriously degraded by fluctuations in primary input power. Line-voltage variations of +/-15% are commonly encountered, even in laboratory environments.

Although most modern electronic instruments incorporate some degree of regulation, possible power source problems should be considered for every instrumentation setup. The use of line-voltage regulators between power lines and the test equipment is recommended as the only sure way to rule out the effects on measurement data of variations in line voltage.

2.5 TEST-FIXTURE CONNECTIONS.

2.5.1 Test Fixture on the Digibridge.

Because an unusually versatile test fixture is provided on the front shelf of the instrument, no test-fixture connection is generally required. Simply plug the device to be measured (DUT) into the test fixture, with or without its adaptors. For details, refer to paragraphs 3.1, 3.2. Accessories can be attached to extend and adapt the test fixture, as described below.

2.5.2 Remote Test Fixture.

Connection of the DUT at a remote test fixture requires proper adaptors and cable connections from the Digibridge. Obtain the following accessories. (See Table 1-3.)

- BNC Adaptor 1689-9601
- BNC Cable Assembly 1689-9602, or equivalent
- Remote Test Fixture 1689-9600, or equivalent handler or special fixture.

This remote test fixture functions like the one supplied on the Digibridge. True "Kelvin" connections are made at the points of contact with the DUT leads. Install as follows:

- a. Remove any adaptors, if present, from the test fixture.
- b. Plug the BNC adaptor into the basic test fixture with the BNC connectors facing forward. Lock the connection with the 2 captive thumb screws. (The screws must be seated to complete the ground connection.)
- c. Connect the cable assembly to the adaptor on the Digibridge and to the remote test fixture as indicated in Table 2-1.

NOTE

User provided cables and/or remote test fixtures can be used, particularly if the DUT is to be handled automatically. See paragraph 3.7 for comments on cable and fixture capacitance.

2.5.3 The 1657-9600 Extender Cable (Banana Plugs).

The accessory extender cable 1657-9600 is available to connect to DUTs that are multiterminal, physically large, or otherwise unsuited for the built-in test fixture. This cable is particularly convenient for connecting multiterminal components with binding posts that accommodate banana plugs. Use the following procedure to install the extender cable on the instrument.

- a. Remove the adaptors, if present, from the test fixture.
- b. Plug the single-connector end of the extender cable into the Digibridge test fixture so that its blades enter both slots and the cable lies away from the display panel. Lock the connector with the two captive thumb screws.
- c. Note the color coding of the five banana plugs. Be sure that the "low" terminals (both potential and current) connect to one end of the DUT and the "high" terminals to the other end. Connect guard to a shield if any, but not to either end of the DUT.

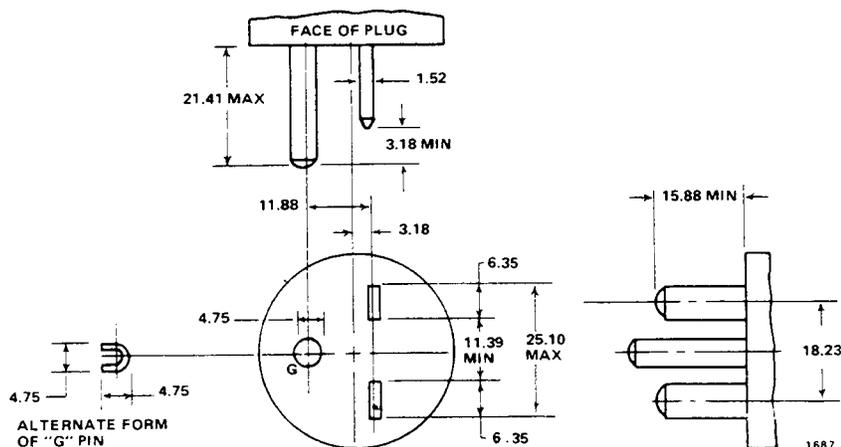


Figure 2-2. Configuration of 250-V, 15-A plug. Dimensions in mm. This is listed as NEMA 6-15P. Use for example Hubbell plug number 5666.

Table 2-1
TEST FIXTURE CONNECTIONS VIA BNC ADAPTOR 1689-9601

Test-Circuit Function	BNC Connector on 1689-9601 (at Digibridge)	Color Code in 1689-9602 Cable	Connection* at 1689-9600 Test Fixture (Remote)
I- (current, low) P- (potential, low)	I _L , Left P _L , Left-center	Black Black/white	I-, Right P-, Right-center
P+ (potential, high) I+ (current, high)	P _H , Right-center I _H , Right	Red/white Red	P+, Left-center I+, Left

*Left and right are defined with the fixture oriented for right reading of legend.

P-(potential, low) = Black/white
 I-(current, low) = Black
 P+(potential, high) = Red/white
 I+(current, high) = Red
 Guard = Black/green

Notice that the 2 wires with red must connect to the same end of the DUT, through a coaxial tee if the DUT is a 2-terminal device; the 2 wires labeled with black, connect to the other end, similarly. Connect the outer (shield) contacts to the shield or case of the DUT only if it is isolated from both ends of the DUT.

2.5.4 The 1688-9600 Extender Cable ("Type 874" Connectors).

The accessory extender cable 1688-9600 can be used to connect a DUT that is multiterminai, physically large, or otherwise unsuited for the built-in test fixture. This low-capacitance cable is used, for example, to connect type-874 connected impedance standards or a special test fixture. Make connections as follows:

- Remove the adaptors, if present, from the test fixture.
- Plug the single-connector end of the extender cable into the Digibridge test fixture so that its blades enter both slots and the cable lies away from the display panel. Lock the connector with the two captive thumb screws.
- Using the branched end of the cable, connect to the DUT with careful attention to the following color code.

The cable tips are type 874 coaxial connectors, which mate with a broad line of components and adaptors.

EXTENDER CABLE COLOR CODE
 RED AND RED: I+, current drive to "high" end of DUT.
 RED AND WHITE: P+, potential connection to same.
 BLACK AND BLACK: I-, current return at DUT "low".
 BLACK AND WHITE: P-, potential connection to same.
 OUTER CONTACTS: G, guard connection to shield or case.

2.6 EXTERNAL BIAS.

Figure 2-3.

WARNING

To minimize electrical shock hazard, limit bias to 30V.
 Bias voltage is present at connectors, test fixtures and on capacitors under test.
 Capacitors remain charged after measurement.
 Do NOT leave instrument unattended with bias applied.

Full bias voltage appears on test leads, bias-voltage source terminals, and on the leads of the component being measured. Capacitors that have been charged are dangerous until properly discharged; the user must follow safe procedures to assure discharge. For safety, all personnel operating the instrument with bias must be aware of the hazards, follow safe procedures, and never leave the equipment unattended with bias voltage applied.

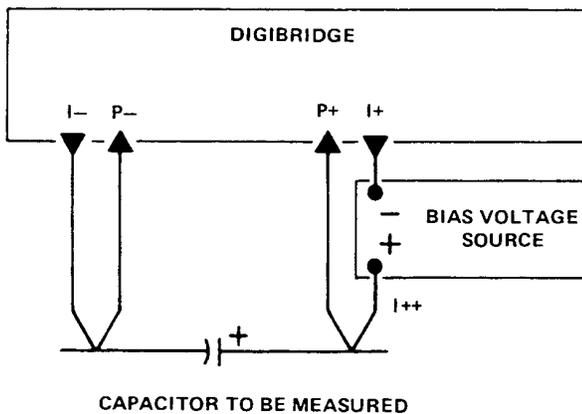


Figure 2-3. Connection of a bias voltage source to enable measurement of capacitors with bias applied. Because the measurement current (up to 30 mA rms) must pass through the bias source, it must be capable of being both source and sink for peaks of about 45 mA. Observe the voltage limits and procedural warnings in the text. Refer to the text also for discharge circuitry.

2.6.1 Basic Bias Connections.

In order to measure a capacitor with dc bias voltage applied, connect an external voltage source, as follows:

- Attach the remote test fixture or an extender cable as described in paragraph 2.5. Observe the color coding explained there.

b. Connect a suitable bias voltage source (see below) in series with the I+ connection, basically as shown in the diagram, with the following details.

With the Remote Test Fixture. Disconnect the red coded BNC cable end from the remote test fixture and connect one end of plain BNC cable there instead.

Connect the red coded BNC cable end to the negative terminal of the bias voltage source. Connect the remaining free end of the plain BNC cable to the positive terminal of the bias voltage source. Connect the DUT to the test fixture in the usual way.

With 1657-9600 Extender Cable (Banana Plugs). Connect the red banana plug to the negative terminal of the bias voltage source. Connect a suitable banana plug patch cord to the positive terminal. We designate the free end of this patch cord as I++, as shown in the diagram.

With 1688-9600 Extender Cable ("Type 874 Connectors").

Connect the "red and red" cable to the negative terminal of the bias voltage source. Connect a suitable type-874 patch cable to the positive terminal. We designate the free end of this patch cable as I++, as shown in the diagram.

c. If either of the extender cables (not the remote test fixture) is used, connect the DUT as follows. If capacitance is large (range 1), make 2 connections to each capacitor terminal (Kelvin connections). That is, I- and P- to capacitor negative terminal; P+ and I++ to capacitor positive terminal.

If the capacitance is smaller (range 2 or 3) the banana plugs can be stacked or a tee used with type-874 connectors and a single connection made to each capacitor terminal: I- /P- to the negative terminal, P+/I++ to the positive.

To make 3-terminal (or 5-terminal) measurements, also connect guard (see paragraph 2.5) to the guard terminal, shield, case, or ground of the capacitor, provided that this is insulated from the 2 main terminals of the capacitor. Do not connect guard to the case of a capacitor if the case is one of its 2 main terminals.

2.6.2 Bias Voltage Source Description

The bias voltage source must satisfy several criteria:

1. Supply the desired terminal voltage (dc)
2. Serve as source for charging current.
3. Serve as source and sink for the measuring currents (ac), which are 45, 0.45, and .0045 mA, peak, for measurements on ranges 1, 2, and 3, respectively.
4. Present a low, linear terminal impedance ($\ll 10$ ohms) at measuring frequency.

If the bias voltage source is a regulated power supply with the usual characteristic that it functions properly only as a source, not a sink, then the following test setup is

recommended. Connect across the power supply a bleeder resistor that draws dc current at least as great as the peak measuring current (item 3 above). In parallel with the bleeder, connect a 100-pF capacitor. (If the power supply has exceptionally good transient response, the capacitor is not necessary.)

No single bleeder resistor will suffice for all bias conditions, so it may be necessary to switch among several. Each resistance must be small enough to keep the power supply regulator current unidirectional (as mentioned above) for the smallest bias voltage in its range of usefulness. Also the resistance and dissipation capacity must be large enough so that neither the power supply is overloaded nor the resistor itself damaged for the highest bias voltage in its range of application.

NOTE

For convenience, a suitable active current sink can be used in lieu of bleeder resistors.

A discharge circuit is also required. (Do not depend on the above-mentioned bleeder resistor.) A dual discharge circuit is recommended. Connect a clip lead with a $10\text{-}\Omega$ resistor in series and another plain clip lead to the I-/Pjunction. Provide the loose ends of these with insulated alligator clips for use when completing the discharge path across the DUT. For a recommended procedure, refer to para 3.6.

If the measurement program warrants the expense of a test fixture for biased-capacitor measurements, its function should be equivalent to that of the circuit described above. It should be equipped with convenient switching to remove the bias source, discharge through $10\text{ }\Omega$, and finally to short out the capacitor after measurement. For automated test setups, it is also feasible to precharge the capacitors before they are attached to the test fixture and to discharge them after they have been removed.

CAUTION

To avoid damage to the instrument, limit the bias voltage to 30 V, maximum, in any precharging bias supply, used as mentioned above.

2.7 ENVIRONMENT.

The Digibridge can be operated in nearly any environment that is comfortable for the operator. Keep the instrument and all connections to the parts under test away from electromagnetic fields that may interfere with measurements.

Refer to the Specifications at the front of this manual for temperature and humidity tolerances. To safeguard the instrument during storage or shipment, use protective packaging. Refer to Section 5.

Operation – Section 3

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3.7 CORRECTION FOR CABLE	3-8

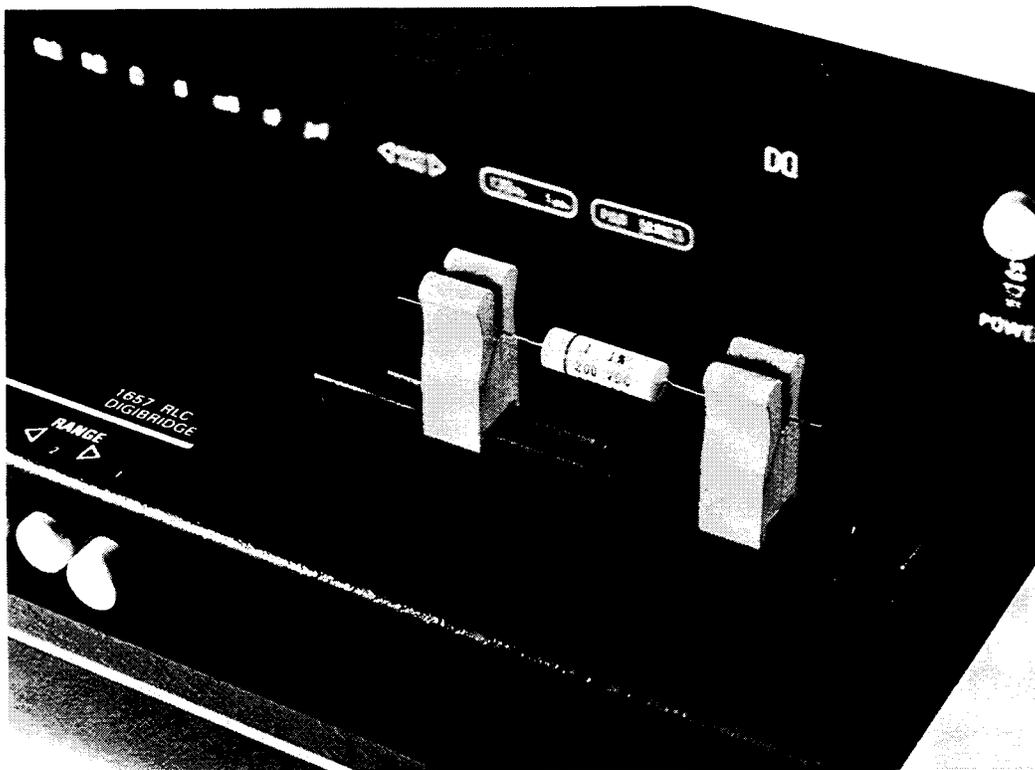


Figure 3-1. Use of the test fixture adaptors.

3.1 BASIC PROCEDURE.

For initial familiarization, follow this procedure carefully. For details, refer to later paragraphs in Operation.

a. Before connecting the power cord, slide the linevoltage switch (rear panel) to the position that corresponds to your power-line voltage. Power must be nominally either 50 or 60 Hz ac, either 120 or 220 V. (Refer to specifications at front of this manual.) The 1657-9700 can be run on 50 Hz but with some loss of accuracy for 120-Hz measurements in high range extensions. Similarly, the 1657-9800, if run on 60-Hz power, experiences some extraneous noise in 100Hz measurements in high range extensions.

If the fuse must be replaced, be sure to use a "slow blow" fuse of the rating shown on the rear panel.

b. Connect a typical device, whose impedance is to be measured, as follows. (This device under test is denoted DUT.)

NOTE

Clean the leads of the DUT if they are noticeably dirty, even though the test-fixture contacts will usually bite through a film of wax to provide adequate connections.

Radial-lead DUT: Insert the leads into the test fixture slots as shown in the photograph, Figure 1-1. For details of wire size and spacing limits, refer to para 3.2.

Axial-lead DUT: Install the test-fixture adaptors, supplied, one in each slot of the test fixture, as shown in the accompanying figure. Slide the adaptors together or apart so the body of the DUT will fit easily between them. Press the DUT down so that the leads enter the slots in the adaptors as far as they go easily. For details of wire size and DUT size limits, refer to para 3.2.

NOTE

To remove each adaptor, lift with a gentle tilt left or right. For a DUT with very short leads it is important to orient each adaptor so its internal contacts (which are off center) are close to the DUT.

Other DUTs, Remote Connections, and Bias.

For connections via extender cables and remote test fixtures, refer to the installation instructions of paragraph 2.5. For connection of bias voltage and operating procedures with bias, refer to paragraphs 2.6 and 3.6. For convenience, the typical color coding used in extender cables is repeated below.

Red: I+, current connection to "high" end of DUT. .

Red & white: P+potential connection to same.

Black: I-, current connection to low end of DUT. .

Black & white: P-, potential connection to same

Black & Green: G, guard connection to shield or case (if isolated from the preceding terminals). Do not-connect G to the case of a capacitor if the case serves as (or is connected to) one of its 2 main terminals.

Figure 3-1.

Notice that the 2 red tips must connect to the same end of the DUT. The terminals with white bands are potential connections; with no bands, current terminals.

c. Set the pushbuttons according to the desired measurement, as follows:

Power. Depress the POWER button so that it stays in the depressed position. (To turn the instrument off, push and release this button so that it remains in the released position.)

Function. For resistance, depress R. For inductance, depress L/Q. For capacitance, depress C/D. Be sure that one of these buttons is in the depressed position.

Frequency. For measurement at 1 kHz, push and release the FREQUENCY button until the 1-kHz light comes on. For 120 (100) Hz, push the same button so that the 120-Hz (100.Hz) light comes on.

Parallel or Series. For series equivalent circuit, push and release the PARALLEL/SERIES button until the SERIES light comes on. For parallel equivalent circuit, push this button so that the PARALLEL light comes on. (The choice is significant for lossy capacitors or inductors, not for lowloss reactive components or non-reactive resistors.) For further explanation, refer to para 3.5.

Range. Depress the middle (RANGE-2) button first and watch the ADJUST RANGE lights. If the right-pointing arrow is lighted, depress RANGE button at the right. If the left-pointing arrow is lighted, depress RANGE button at the left. When neither arrow is lighted, the range you have selected is correct. (Be sure that one of the RANGE buttons is in the depressed position.) Additional comments on range choices are below.

d. Read the measurement on the main displays. The R LC display is the principal measurement, complete with decimal point and units, which are indicated by the light spot behind M, k, , H, mH, nF, or uF.* The DQ display is D if the C/D FUNCTION button is in, Q if the L/Q button is in.

e. After any change in DUT or measurement conditions, before looking at the displays, notice the ADJUST RANGE lights. Interpret them as follows:

Neither light. Correct range. (There are minor exceptions.)

Left Light. Wrong range; try next RANGE button to left.

Right Light. Wrong range; try next RANGE button to right.

Both Lights. Overrange or invalid display. If FUNCTION is correct and RANGE is highest, the measurement is valid but because of an overrange condition, the basic 0.2% accuracy cannot be guaranteed. (If you switch to RANGE 2, one of the lights will go out.) If both lights are lit on RANGE 2, either the FUNCTION is inappropriate for the DUT or it is not properly connected. For more details, refer to para 3.3.

*If the extender cable is used, it may be necessary to correct for its capacitance.

3-2 OPERATION

3.2 CONNECTION OF THE DUT.

3.2.1 The Integral Test Fixture.

The test fixture provided on the front ledge of the Digi

bridge provides convenient, reliable, guarded 4-terminal connection to any common radial-lead or axial-lead component.

If the slots of your test fixture have rounded ends, the slots accommodate wires of any diameter from 0.25 mm (.01 in., AWG 30) to 1 mm (.04 in., AWG 18), spaced from 6 to 98 mm apart (0.23 to 3.9 in.) or equivalent strip conductors. Each "radial" wire must be at least 1 cm long (0.4 in.). However, if the slots of your test fixture have square ends, they will accommodate wires spaced as close as 4 mm (0.16 in.) and each "radial" wire must be at least 4 mm (0.16 in.) long. The divider between the test slots contains a shield, at guard potential, with its edges exposed. The adaptors accommodate wires of any diameter up to 1.5 mm (.06 in., AWG 15). The body of the DUT that will fit between these adaptors can be 80 mm long and 44 mm diameter (3.1x1.7 in.) maximum. Each "axial" wire must be at least 3 mm long (0.12 in.).

For radial-lead parts, remove each adaptor from the test fixture by a gentle pull upward, made easier by bending the adaptor left or right (never forward or back). For axial-lead parts, insert the adaptors, one in the left slot and the other in the right slot of the test fixture, by pushing vertically downward. They can be slid left and right to match the length of DUT to be measured. Notice that the contacts inside the adaptor are off center; be sure to orient the adaptors so the contacts are close to the body of the DUT, especially if it has short or fragile leads.

Insert the DUT so one lead makes connection on the left side of the test fixture, the other lead on the right side. Insertion and removal are smooth, easy operations and connections are reliable if leads are clean and straight.

Be sure to remove any obvious dirt from leads before inserting them. Be sure the contact pair inside each half of the test fixture is held open by a single item ONLY, whether that is one lead of an axial-lead DUT or one adaptor, to obtain true "Kelvin" connections.

3.2.2 Test Fixture Accessories.

An accessory extender cable or adaptor, cable, and remote test fixture, as described in Table 1-3, is needed to connect any DUT that is multiterminal, physically large, or otherwise unsuited for the built-in test fixture.

A cable is needed, for example, to connect impedance standards, a remote test fixture, capacitors to be measured with bias, etc. For connection to the instrument, refer to paragraph 2.5. For measurements with bias, refer to paragraphs 2.6 and 3.6. The color code for the branched end of each cable is given in paragraph 3.1. To correct for cable capacitance, refer to paragraph 3.7.

3.3 FUNCTION AND RANGE SELECTIONS.

3.3.1 Function Pushbuttons.

The selection of the principal parameter to be measured is almost self-explanatory. Depress the appropriate FUNCTION button: R, L/Q or C/D to measure resistance, inductance, or capacitance. The instrument will tolerate, to some degree, a poor choice of function, but accuracy is thereby reduced. The readout will indicate a completely wrong choice of function, as explained below. Notice that the appearance of a device can be misleading. (For example, a faulty inductor can be essentially capacitive or resistive; a component part can be mislabeled or unlabeled.)

If both ADJUST RANGE lights are on, the RANGE 2 button is in, the RLC display is blank, and the DUT is properly connected, then the choice of function is probably wrong. Most likely, if the L/Q button is in, the DUT is capacitive; or if the C/D button is in, the DUT is inductive.

Observe the DQ display for an indication of poor choice of function (though tolerable). Large D or small 0 may indicate that the "reactor" being measured is practically a resistor at the measuring frequency. If the C/D button is in and the D reading is between 1 and 10 (or blank, as it will be for $D > 10$) it is possible that the DUT is enough like a resistor to be measured best with the R button in. Similarly, if the L/Q button is in and the Q reading is between zero and 1, it is possible that the DUT is enough like a resistor to be measured best with the R button in. Notice that when the R button is in, the DO display is always blank. On the other hand, any D or Q display is valid, even if the "wrong" function has been selected. (The C or L display can be blank.)

If the R button is in (a resistor is being measured) the easy way to determine whether the DUT is reactive is to try making C/D and L/Q measurements. If you obtain a valid C measurement with $D < 1$, the DUT is capacitive. The smaller this D value, the less accurate the R measurement. Similarly, if you obtain a valid L measurement with $Q > 1$, the DUT is inductive. The larger this Q value the less accurate the R measurement. (See para 3.4.)

3.3.2 Range Pushbuttons.

Range selection is also nearly self-explanatory. Follow the ADJUST RANGE lights. The left light means: "Push the next range button to the left." The right-hand light means: "Push the next range button to the right." Continue until both lights go out. The instrument will usually display a measurement (at reduced accuracy) even though the range is not optimum. The following details about range are best understood with reference to para 3.4 (particularly the RLC basic accuracy graph).

The RANGE buttons are placed in order of decreasing impedance, 3-2-1. The "highest" range is therefore Range 1 for C/D; but it is Range 3 for R and L/Q.

Table 3-1
FULL SCALE READOUTS ON EACH SUBRANGE

Manual range	Automatic subrange	R		L		C	
		1 kHz	120 (100) Hz	1 kHz	120 (100) Hz	1 kHz	120 (100) Hz
1 (Z ₀ = 10 Ω)	1A	19.999 Ω	19.999 Ω	1.9999 mH	19.999 mH	19.999 μF	199.99 μF
	1B*	999.99 Ω	999.99 Ω	99.999 mH	999.99 mH	999.99 μF	9999.9 μF
	1C**	-----	-----	-----	-----	-----	99999. μF
2 (Z ₀ = 1 kΩ)	2A	1.9999 kΩ	1.9999 kΩ	.19999 H	1.9999 H	.19999 μF	1.9999 μF
	2B*	99.999 kΩ	99.999 kΩ	9.9999 H	99.999 H	9.9999 μF	99.999 μF
3 (Z ₀ = 100 kΩ)	3A	.19999 MΩ	.19999 MΩ	19.999 H	199.99 H	1.9999 nF	19.999 nF
	3B*	9.9999 MΩ	9.9999 MΩ	999.99 H	9999.9 H	99.999 nF	999.99 nF
	3C**	-----	99.999 MΩ	-----	-----	-----	-----

* Each "B" subrange covers a full decade (example, 20 to 200 Ω) in the basic range and an upper range extension (example 200 to 999 Ω), in which accuracy is reduced and the ADJUST RANGE light(s) is on.

** Each "C" subrange is a further extension of the highest range (example, 10 to 99.9⁺ MΩ).

Each basic range is slightly more than 2 decades wide, from an R LC display of 01900, with an automatic decimal point change between the decades, to 19999. (The symbol 0 represents a blanked zero. Initial zeroes to left of the decimal point are always blanked out of the RLC display.) Each of the 3 ranges goes beyond its basic range, with both upper and lower range extensions (shown by lighter lines in the RLC basic accuracy graph). Several of these extensions are seldom used because they overlap "basic" portions of other ranges and because the operator is alerted to this fact by an ADJUST RANGE light.

Each range includes 2 or 3 subranges, distinguished by the automatic decimal-point shift. The operator does NOT control them. Subranges are detailed in Table 3-1. Notice, for example, if you select RANGE 1, C/D, 1 kHz, then there are 2 subranges: 19uF and 999uF. If a series of measurements is made with C increasing slowly above 19uF, the automatic subrange change takes place at 21. But with C decreasing, the change takes place at 20. This hysteresis eliminates a possible cause of flickering of the display.

The "low" extension of each range goes from 01900 down to 00000, without any change in decimal point, but with reduced accuracy. The number of digits in this display is always adequate for the specified accuracy. Any measurement in the low extension of either Range 2 or the highest range causes the appropriate ADJUST RANGE arrow to be lighted. But there is no such light in the low extension of the lowest range (because there is no lower range to select).

The "high" extension of each range is a factor of 5 (with 2 exceptions), going from 19999 up to 99999, and finally to blank, without any change in decimal point, but with reduced accuracy. Any measurement in the high extension of either the lowest range or Range 2 causes the appropriate ADJUST RANGE arrow to be lighted. However in

3-4 OPERATION

the high extension of the highest range, both ADJUST RANGE arrows are lighted (to indicate a useful "overrange" condition).

The high extension of the top range for Rand C only, at 120 Hz (100 Hz) only, is a factor of 50, going from 19999, with an automatic decimal-point change, up to 99999, and finally to blank, with reduced accuracy. (Both ADJUST RANGE arrows are lighted as described above.)

A special case warrants explanation. (This is a minor exception to the basic procedure of para 3.1.) It is possible

for both ADJUST RANGE lights to be out and yet the RANGE and FUNCTION buttons to be incorrectly set.

This condition result's from either faulty connection to the DUT or a numerically small negative Lor C measurement. Sometimes a loose or dirty connection to the DUT causes

an erratic RLC display. A small negative L or C (wrong function selected) causes a zero display. In either case, check connections at the test fixture and try all 3 FUNCTIONS to see which is appropriate, R, L/Q, or C/D.

3.4 ACCURACY.

3.4.1 Graphs.

Figures 3-2, 3-3, and 3.4

The following accuracy graphs supplement the statement of accuracy in the specifications, at the front of this manual.

Figure 3.2 shows that the R LC basic accuracy of 0.2% is realized over 6 decades of impedance if the correct range is selected (as indicated by the ADJUST RANGE lights being out). The reduction of accuracy is shown for all of the "low" and "high" range extensions. This basic RLC accuracy is valid only for "pure" R, L, or C. For the effect

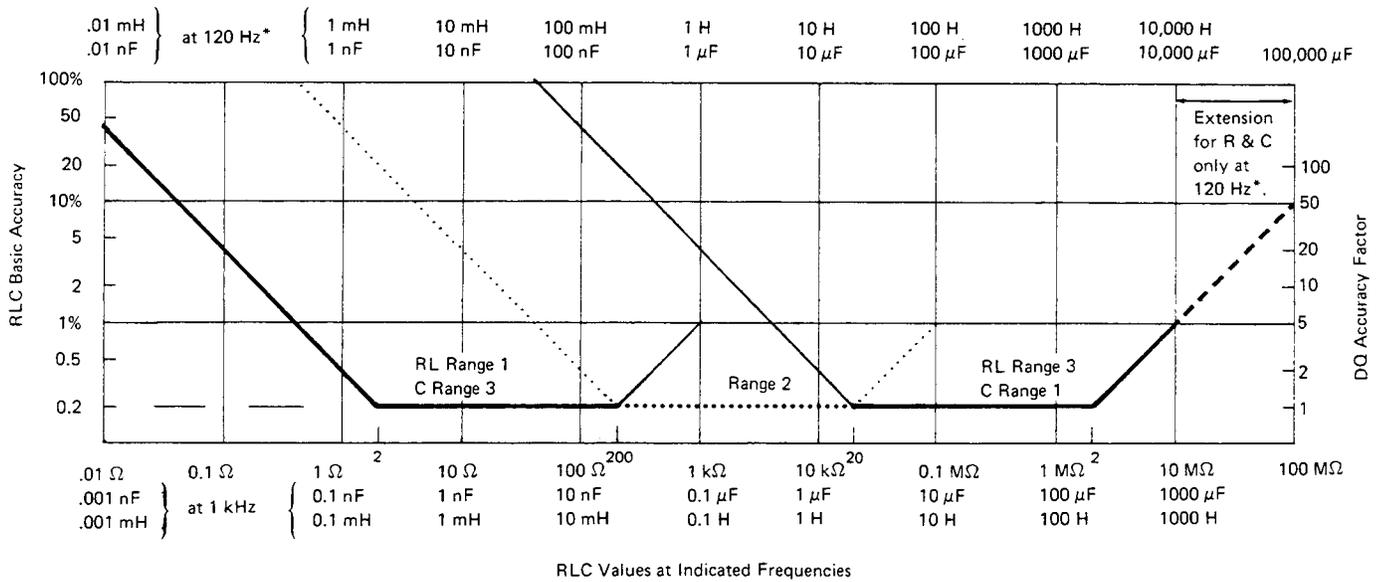


Figure 3-2. R L C basic accuracy as a percent of reading. Heavy lines (solid and dotted) represent best choice of range. Range 2 is dotted. Notice that Land C scales above graph are for 120 Hz (*equally valid for 100 Hz) and the 2 below graph are for 1 kHz. The DQ accuracy factor (right-hand scale) is the multiplier that, applied to the DQ Basic Accuracy, yields complete DQ accuracy, for range extensions as well as the basic ranges (where RLC accuracy is 0.2%).

of quadrature impedance, multiply each basic accuracy value by the RLC accuracy factor; *see* below.

Figure 3-3 shows the RLC accuracy factor, which depends on D or Q. For example, suppose a capacitor measured at 1 kHz has C = 400 uF and D = 0.5. The R L C basic accuracy is 0.4% and the R L C accuracy factor is 1.5. Therefore, the accuracy of the C measurement is $\pm 0.6\%$. Notice that the D or Q of a resistor (if significant) can be measured by selecting the C/D or L/Q FUNCTION.

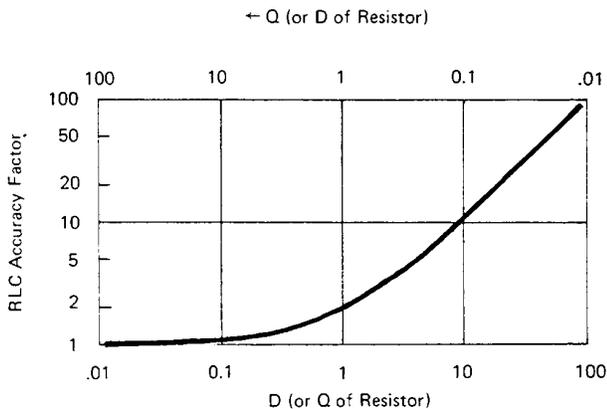


Figure 3-3. R L C accuracy factor as a function of D and Q. Multiply the RLC Basic Accuracy by this factor to obtain complete RLC accuracy for impedances that are not "pure" resistance or reactance. For capacitors and inductors, use the D and Q scales, respectively. For resistors, use the "D of Resistor" scale if capacitive, the "Q of Resistor" scale if inductive.

Figure 3-4 shows the basic DQ accuracy, which is simple function of D or Q. For D read the lower scale and lower curve. For Q read the upper scale and upper curve. The basic DQ accuracy is valid only if measurements are made on one of the 3 basic ranges (where RLC accuracy is best). Otherwise, multiply basic DQ accuracy by the DQ accuracy factor, shown on the right of the "RLC basic accuracy" graph. In the example of C = 400 uF, D = 0.5, the basic D accuracy is 0.5% and the D accuracy factor is 2. Therefore, the accuracy of the D measurement is $\pm 1\%$.

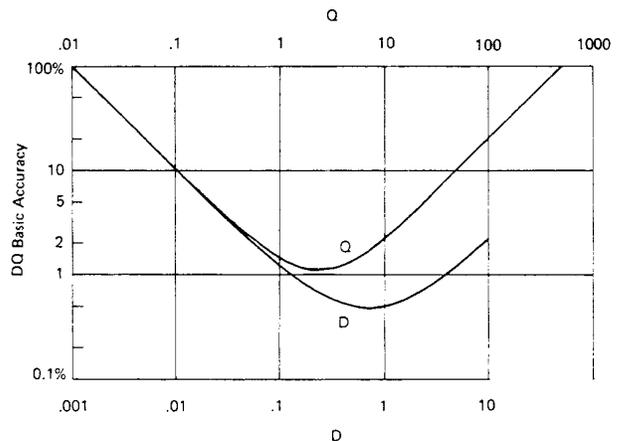


Figure 3-4. DQ basic accuracy as a percent of reading. These curves are directly applicable for measurements in the basic ranges. For measurements on any of the range extensions, refer also to Figure 3-2 for the DQ accuracy factor.

The logarithmic scales on these figures make it very easy to apply the accuracy factors *visually*. For example, suppose a capacitor is being measured on range 2, both ADJUST RANGE lights are out, and the D display is about 1. Figure 3-3 shows that the C accuracy factor is about 1/3 of a decade on the logarithmic scale. On Figure 3-2, find the heavy dotted line (the basic portion of range 2) and point to the basic C accuracy (0.2%) at the left. Now apply the C accuracy factor by moving the pointer up about 1/3 of a decade. The pointer now shows the corrected C accuracy, 0.4%.

3.4.2 Insignificant Digits.

One or more of the digits at the right end of the R LC and/or DQ displays may be insignificant. This is particularly true at the upper extension of a range. If there are more than one insignificant digits in a display, the least significant is typically noisy. That is, it will appear to flicker at random over a range of values and should be ignored.

For example, if you measure a 4-M resistor, the display might ideally be 4.1234 M ; but the one or two final digits might be changing at random. This flickering is entirely normal. The specified accuracy (+/-0.4%) is the key to expected performance; in this example, the last 2 digits are insignificant and the last digit is quite unnecessary. Typically, one would record this measurement as 4.12 +/-0.02 M .

3.5 PARALLEL/SERIES AND FREQUENCY SELECTIONS.

3.5.1 General.

The value of the principal measurement (R, L, or C) of a certain DUT depends on which of 2 equivalent circuits is chosen to represent it. (Many impedance measuring instruments provide no choice in the matter, but this one allows selection.) The more nearly "pure" the resistance or reactance, the more nearly identical are the "series" and "parallel" values. However, for D or 0 near unity, the difference is substantial. Also, the principal measurement often depends on measurement frequency. The more nearly "pure" the resistance or reactance, the less is this dependence. However, for D or Q near unity and/or for measuring frequency near the self-resonant frequency of the DUT, this dependence is quite substantial. We first give general rules for selection of measurement parameters, then some of the theory.

3.5.2 Rules.

Specifications. The manufacturer or principal user of the DUT probably specifies how to measure it. (Usually "series" is specified for C, L, and low values of R.) Select "parallel" *or*: "series" and 1 kHz or 120 Hz (100 Hz) according to the applicable specifications. If there are none known, be sure to

specify with your results whether they are "parallel" or "series" and what the measurement frequency was.

Resistors, below about 1 k : Series, 120 Hz (100 Hz). Usually the specifications call for dc resistance, so select a low test frequency to minimize ac losses. Select "series" because the reactive component most likely to be present in a low-resistance resistor is series inductance, which has no effect on the measurement of series R. As a quick check on whether the DUT is nearly pure resistance, make a separate "parallel" measurement. Rp will be larger than Rs. If the difference is less than 1 %, then 0 is less than 0.1, and the measured Rs is probably very close to the dc resistance.

Resistors, above about 1 k : Parallel, 120 Hz (100 Hz). As explained above, select a low test frequency. Select "parallel" because the reactive component most likely to be present in a high-resistance resistor is shunt capacitance, which has no effect on the measurement of parallel R. As a quick check on whether the DUT is nearly pure resistance, make a separate "series" measurement. If the difference between Rp and Rs is less than 1%, then D is greater than 10, and the measured Rp is probably very close to the dc resistance.

Capacitors below 2 nF: Series, 1 kHz. Unless otherwise specified or for special reasons, always select "series" for capacitors and inductors. This has traditionally been standard practice. Select a high measurement frequency for best accuracy.

Capacitors above 200 uF: Series, 120 Hz (100 Hz). Select "series" for the reasons given above. Select a low measurement frequency for best accuracy and to enable measurement of capacitors larger than 1000uF.

Inductors below 2 mH: Series, 1 kHz. Select "series" as explained above. Select a high measurement frequency for best accuracy.

Inductors above 200 H: Series, 120 Hz (100 Hz). Select "series" as explained before. Select a low measurement frequency for best accuracy and to enable measurement of inductors larger than 1000 H.

3.5.3 Series and Parallel Parameters.

Figure 3-5.

An impedance that is neither a pure reactance nor a pure resistance can be represented at any specific frequency by either a series or a parallel combination of resistance and reactance. Keeping this concept in mind will be valuable in operation of the instrument and interpreting its measurements. The values of resistance and reactance used in the equivalent circuit depend on whether a series or parallel combination is used. The equivalent circuits are shown in Figure 3-5. The relationships between the various circuit elements are as follows.

Resistance and Inductance

$$Z = R_s + j\omega L_s \quad Z = \frac{j\omega L_p R_p}{R_p + j\omega L_p} \quad Z = \frac{R_p + jQ^2 \omega L_p}{1 + Q^2}$$

$$Q = \frac{1}{D} \quad Q = \frac{\omega L_s}{R_s} \quad Q = \frac{R_p}{\omega L_p}$$

$$L_s = \frac{Q^2}{1 + Q^2} L_p \quad L_s = \frac{1}{1 + D^2} L_p$$

$$L_p = \frac{1 + Q^2}{Q^2} L_s \quad L_p = (1 + D^2) L_s$$

$$R_s = \frac{1}{1 + Q^2} R_p \quad R_p = (1 + Q^2) R_s$$

$$R_s = \frac{\omega L_s}{Q} \quad R_p = Q\omega L_p \quad R_p = \frac{1}{G_p}$$

Resistance and Capacitance

$$Z = R_s + \frac{1}{j\omega C_s} \quad Z = \frac{R_p}{1 + j\omega R_p C_p} \quad Z = \frac{D^2 R_p + 1/(j\omega C_p)}{1 + D^2}$$

$$D = \frac{1}{Q} \quad D = \omega R_s C_s \quad D = \frac{1}{\omega R_p C_p}$$

$$C_s = (1 + D^2) C_p \quad C_p = \frac{1}{1 + D^2} C_s$$

$$R_s = \frac{D^2}{1 + D^2} R_p \quad R_p = \frac{1 + D^2}{D^2} R_s$$

$$R_s = \frac{D}{\omega C_s} \quad R_p = \frac{1}{\omega C_p D} \quad R_p = \frac{1}{G_p}$$

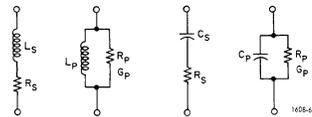


Figure 3-5. Equivalent circuits for a lossy inductor and a lossy capacitor.

3.5.4 Equivalent Series R for Capacitors.

The total loss of a capacitor can be expressed in several ways, including D and "ESR." To obtain equivalent series resistance, one can measure directly (if D is high enough to permit the desired accuracy) or calculate.

Direct Measurement. If, while measuring C, you observe that D is above 0.1 (or some other limit of your choice, see Figure 3-3), push FUNCTION button R and select SERIES.

Both C and ESR should be measured on the same range. If D is below 1, the range should be correct for C, even though the ADJUST RANGE light comes on while you measure ESR. However, if D is above 1, choose the correct "R" range to obtain ESR; and then remeasure C on this range.

Calculation. If D is small, it is better to calculate "ESR" as follows: $R_s = D/2 \text{ fCs}$ where $f = 3.1416$. D and Cs are displayed on the front panel. Frequency f depends on the model of the instrument and the selected frequency as follows (+/- .01%):
 1657-9700: "1 kHz" is 1020.0 Hz; "120 Hz" is 120.0 Hz. 1657-9800: "1 kHz" is 1000.0 Hz; "100 Hz" is 100.0 Hz.

"Equivalent series resistance" is typically much larger than the "ohmic" resistance of the wire leads and foils that are physically in series with the heart of a capacitor. ESR includes also the effect of dielectric loss and is therefore dependent on frequency.

3.5.5 Parallel Equivalent Circuits for Inductors.

Even though it is customary to measure series inductance of inductors, there are situations in which the parallel equivalent circuit better represents the physical device. At low frequencies, the significant loss mechanism is usually "ohmic" or "copper loss" in the wire and the series circuit is appropriate. If there is an iron core, at higher frequencies the significant loss mechanism may be "core loss" (related to eddy currents and hysteresis) and the parallel equivalent circuit is appropriate. Whether this is true at 1 kHz should be determined by an understanding of the DUT, but probably it is so if the following is true: that measurements of L_p at 1 kHz and at 120 Hz (100 Hz) are more nearly in agreement than measurements of L_s at the same 2 frequencies.

3.6 BIAS.

To measure a capacitor with bias applied, it is necessary to insert a bias voltage source in series with the I+ lead to the DUT and to provide a means of discharging it. Refer to para 2.6 for installation of the recommended circuit.

WARNING

To minimize shock hazard, limit bias to 30 V.
Bias voltage is present at connectors, test fixtures and on capacitors under test.
Capacitors remain charged after measurement.
Do not leave instrument unattended with bias applied.

Although special precautions are not required, we recommend the following procedure, to assure controlled conditions for both charging and discharging capacitors.

- a. Set the bias voltage to zero.
- b. Attach the DUT, with correct polarity.
- c. Raise the bias voltage to the specified value.
- d. Allow a specified charging and soaking time.
- e. Observe and record the specified measurements (usually Cs and D).
- f. Set the bias voltage source to zero.
- g. Connect the 10-n discharging circuit.
- h. After about 2 s, connect the safety short circuit.
- i. Remove the DUT and the discharging circuits.

3.7 CORRECTION FOR TEST FIXTURE ACCESSORIES.

3.7.1 With the Remote Test Fixture.

The remote test fixture, cable assembly, and adaptor (1689-9600, -9602, -9601) introduce about .001 nF of capacitance in parallel with the DUT, a generally negligible error. For the best accuracy, select PARALLEL, C/D, and range 3; measure the capacitance "Cc" with the remote test fixture open (no DUT). Then measure a DUT, PARALLEL, C/D; the RLC display is now $C_c + C_x$, where C_x is the capacitance of the DUT. Therefore, subtract the measured C_c from the RLC display to obtain C_x .

3.7.2 With the 1657-9600 Extender Cable (Banana Plugs).

The 1657-9600 extender cable introduces about .0002 nF of capacitance in parallel with the DUT, a negligible error. For very high precision, the following procedure can be used, determining a correction for measurements of parallel capacitance.

Because the physical arrangement and spacing of the cable branches and connectors is significant, a correction should be determined for each measurement setup. The following procedure applies to connection with a precision 3-terminal capacitor, GR 1404 or 1413, for example:

- a. Install an adaptor, GR 874-Q2, on each of the two coaxial connectors, Land H, of the capacitor.
- b. Connect cable branch G to the ground post of the "low" terminal adaptor. With a clip lead or plain wire, connect this point to the ground post of the "high" adaptor.
- c. Connect cable branch P- to the main post of the "low" adaptor and stack I- on top of P-.
- d. Similarly, connect P+, with I+ stacked on top of it, to the main post. of the "high" adaptor.
- e. Measure this total capacitance, the sum of the desired measurement and the cable capacitance, $C_x + C_c$.
- f. Carefully lift the stacked pair of cable tips, I+/P+, from the "high" adaptor and hold them about 0.5 cm (1/4 in.) above the binding post where they were connected.
Do NOT rearrange the cable branches or change their spacing more than is absolutely necessary to follow these directions. Hold the plastic tips (not the wires) and touch the guard (G) circuit firmly with a couple of fingers, to minimize the effect of capacitance in your body.
- g. Measure the cable capacitance, C_c .
- h. Subtract the result of step g from that of step e, to obtain the desired measurement, C_x .

3.7.3. With the 1688-9600 Extender Cable

("Type 874" Connectors).

The 1688-9600 extender cable introduces no parallel capacitance that can be resolved on the 1657 Digibridge, if the shielding between "high" and "low" is maintained consistently. For example, to connect a 3-terminal DUT having two type 874 connectors, use a type 874 tee for the red and red/white cables, and another type 874 tee for the black and black/white cables.

3.8 CARE OF DISPLAY PANEL.

Use caution when cleaning the display window, not to scratch it nor to get cleaning substances into the instrument. Use soft cloth or a ball of absorbent cotton, moistened with a mild glass cleaner, such as "Windex" (Drackett Products Co., Cincinnati, Ohio). Do NOT use a paper towel; do NOT use enough liquid to drip or run.

If it should be necessary to place marks on the window, use paper-based masking tape (NOT any kind of marking pen, which could be abrasive or react chemically with the plastic). To minimize retention of any gummy residue, remove the tape within a few weeks.

Theory – Section 4

4.1 INTRODUCTION.

4-1

4.2 PRINCIPAL FUNCTIONS.

4-2

4.1 INTRODUCTION.

4.1.1 General.

This instrument uses an unusual method of measurement, which is quite different from those used in previous impedance meters or bridges. A thorough understanding of this method will be helpful in unusual applications of the instrument. The following paragraph gives a brief overall description outlining the measurement technique to one familiar with impedance measurement methods. A more detailed description of operation, specific circuitry, and control signals is given later.

4.1.2 Brief Description of the 1657 Digibridge.

This Digibridge™ uses a new measurement technique, in which a microprocessor calculates the desired impedance parameters from a series of 8 voltage measurements.* These measurements include quadrature (90°) and inverse (180°) vector components of the voltage across the "unknown" impedance Z_x and the voltage across a standard resistor R_s carrying the same current as Z_x . Each of these measurements is meaningful by itself, because the current through Z_x is not controlled. But the 8 measurements are all made in rapid sequence with the same phase-sensitive detector and analog-to-digital converter. Therefore properly chosen differences between these measurements subtract out fixed offset errors, and ratios between the differences cancel out the value of the common current and the scale factor of the detector-converter.

The phase-sensitive detector uses 4 reference signals, precisely 90° apart, that have exactly the same frequency as the test signal, but whose phase relationship to any of the analog voltages (such as the 8 mentioned above) or currents (such as the current through Z_x and R_s) is incidental. Therefore, no precise analog phase shifter or waveform squaring circuit is required. Correct phase relationships are maintained by generating test signal and reference signals from the same high-frequency source.

There are no calibration adjustments in the Digibridge, thanks to the measurement technique. The only precision

components in this instrument are three standard resistors and a quartz-crystal stabilized oscillator. There is no reactance standard. For example, C and D are calculated by the microprocessor from the set of 8 voltage measurements and predetermined values of frequency and the applicable standard resistance.

The microprocessor also controls the measurement sequence, using programs in the ROM memory and a few manual selections. The desired parameters, C and D, $\tan \theta$, or R; equivalent circuit, series or parallel; and frequency, either 120 Hz (100 Hz) or 1 kHz, are selected by front panel controls. There are also three manually selected ranges, which have wide overlap. The optimum range for any measurement is indicated by panel lights.

Each range is 2 decades wide, with reduced-accuracy extensions both above and below. For example, consider resistance measurement on Range 1 (Figure 3-2). The 2 decades extend from 02.000 Ω , with an automatic decimal-point shift at 02.100 going up (at 020.00, going down) to 200.00 Ω . The range extensions go as far as can be displayed without further decimal-point shifting: upwards to 999.99 Ω , downwards to 00.001 Ω . Leading zeroes before the decimal-point (0) are blanked out.

Test frequencies are within 2% of the front-panel indication. However, for reasons related to rejection of power-line-frequency stray signals that could be picked up by the DUT, thereby causing measurement errors, the actual frequencies are as follows --accurate to $\pm 0.01\%$ -

catalog number 1657-9700: 1020.0 Hz, 120.00 Hz

catalog number 1657-9800: 1000.0 Hz, 100.00 Hz.

4.1.3 Block Diagram.

Figure 4-1.

The block diagram shows the microprocessor (μP) in the upper right corner connected by data and address buses to digital circuitry including RAM and ROM memories, status and control latches, and the front-panel display.

Analog circuitry is shown in the lower part of the diagram, where Z_x is supplied with a test signal at frequency f from a sine-wave generator, driven by a crystal-controlled digital frequency divider circuit. The front-end amplifier circuit supplies an analog signal that represents 2 impedances alternately: the internal standard, R_s , and the DUT, Z_x .

*Patent applied for.

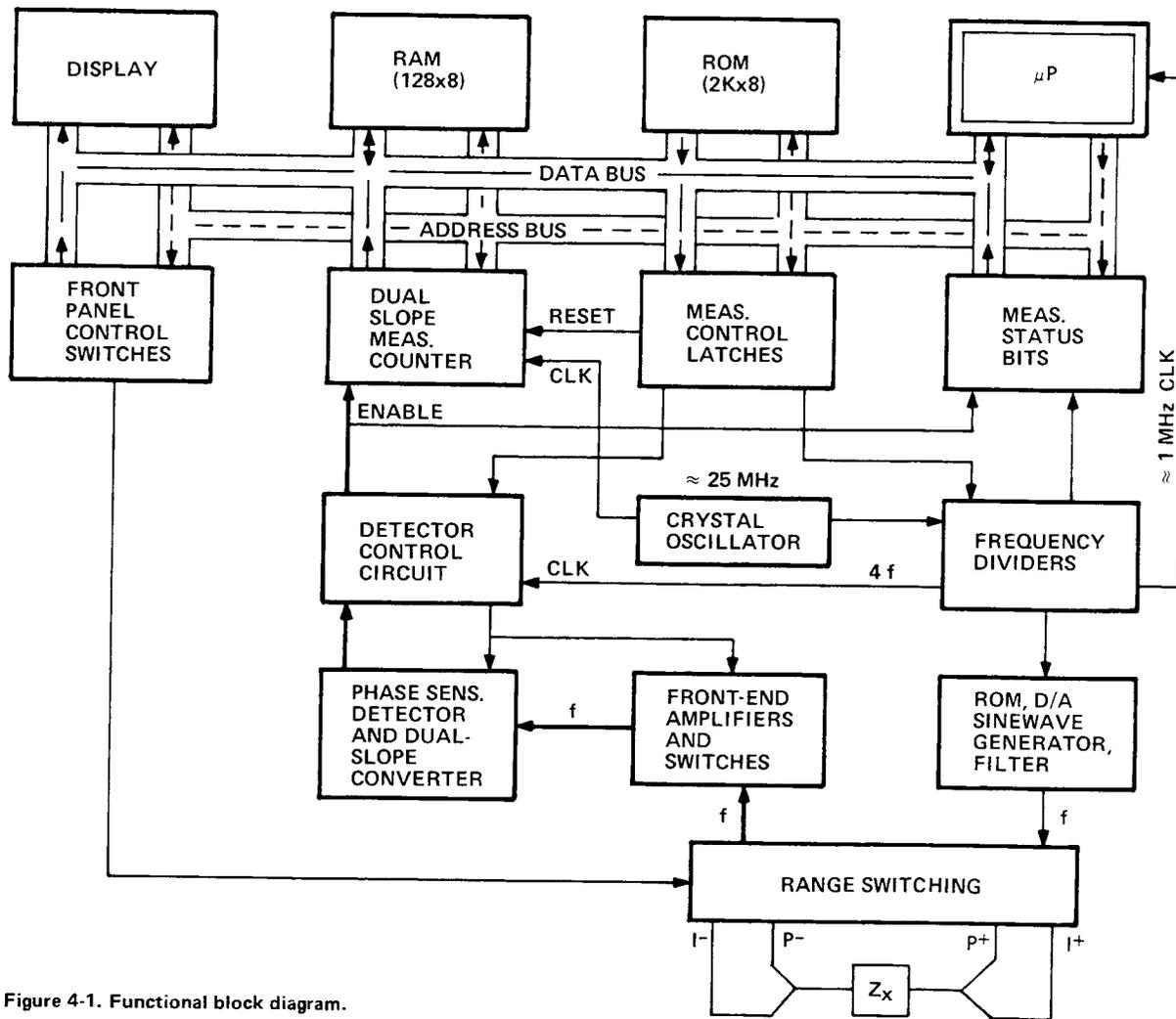


Figure 4-1. Functional block diagram.

The detector control block provides sampling commands (in 4 phases). The detector is a dual-slope converter, including an integrator and comparator, which converts each phase component of the analog signal proportionally into a period of time. The dual-slope measurement is converted into a digital number by a counter that is gated by this period. From this information and manually selected criteria, the microprocessor calculates the RLC and DQ values subsequently displayed.

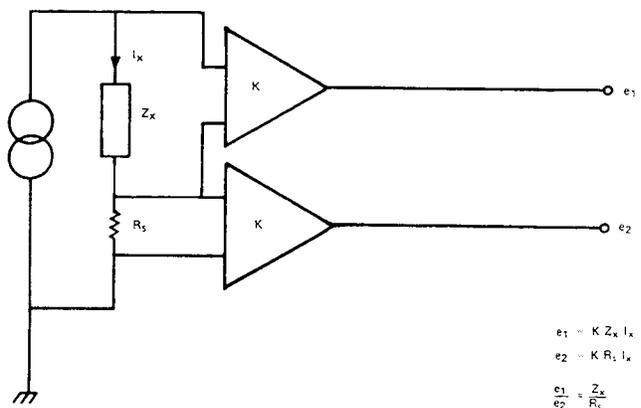
4.2 PRINCIPAL FUNCTIONS.

4.2.1 Elementary Measurement Circuit. Figure 4-2.

The measurement technique is shown diagrammatically. A sine-wave generator drives current I_x through the DUT Z_x and standard resistor R_s in series. Two differential amplifiers with the same gain K produce voltages e_1 and e_2 . Simple algebra, some of which is shown in the figure, leads to the expression for the "unknown" impedance:

$$Z_x = R_s \frac{e_1}{e_2}$$

Notice that this ratio is complex and that (unless you are measuring resistance) both a magnitude and a loss value are automatically calculated from Z_x and frequency.



$$\begin{aligned} e_1 &= K Z_x I_x \\ e_2 &= K R_s I_x \\ \frac{e_1}{e_2} &= \frac{Z_x}{R_s} \end{aligned}$$

Figure 4-2. Elementary measurement circuit.

4.2.2 Frequency and Time Source.

Figure 4-3.

A necessary standard for accuracy is the frequency of the test signal; and equally important are the generation of 4-phase references for detection and clocks for the microprocessor. Frequency and timing requirements are implemented by derivation from a single very accurate oscillator, operating near 25 MHz. Digital dividers and logic circuitry provide the many clocks and triggers, as well as driving the sine-wave generator described below.

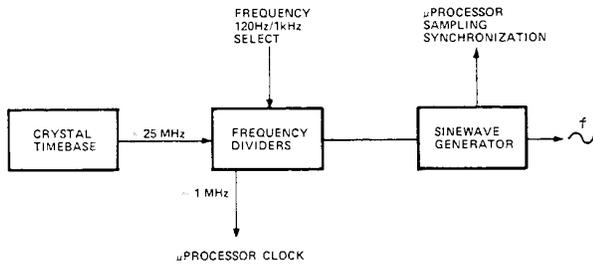


Figure 4-3. Frequency and timing source. A pushbutton determines the frequency select function. Several clocks and synchronizing pulses as well as the measurement signal f are derived from the accurate time-base signal.

4.2.3 Sine-Wave Generation.

Figure 4-4.

Starting with a digital signal at 256 times the selected test frequency, the sine-wave generator provides the test signal that drives a small but essential current through the DUT.

Binary dividers count down from 256 F , providing 128 F , 64 F , 32 F ,... 2 F , F . This set of signals is used to address a read-only memory which contains a 256-step approximation to a sine function. The ROM output (as an 8-bit binary number) is converted by a D/A converter to a somewhat "noisy" sine-wave, which is then smoothed by filtering before its use in the measurement of a DUT.

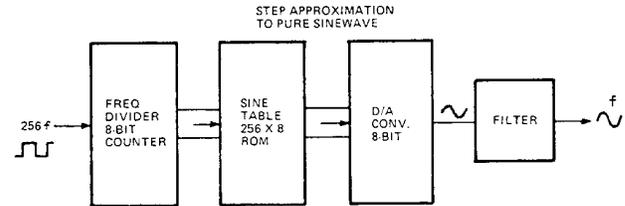


Figure 4-4. Sine-wave generator. Given a square wave at 256 f , from preceding dividers, this generator uses a ROM containing the mathematical sine function to form a finely stepped approximation to a sine wave at frequency f . A filter provides smoothing.

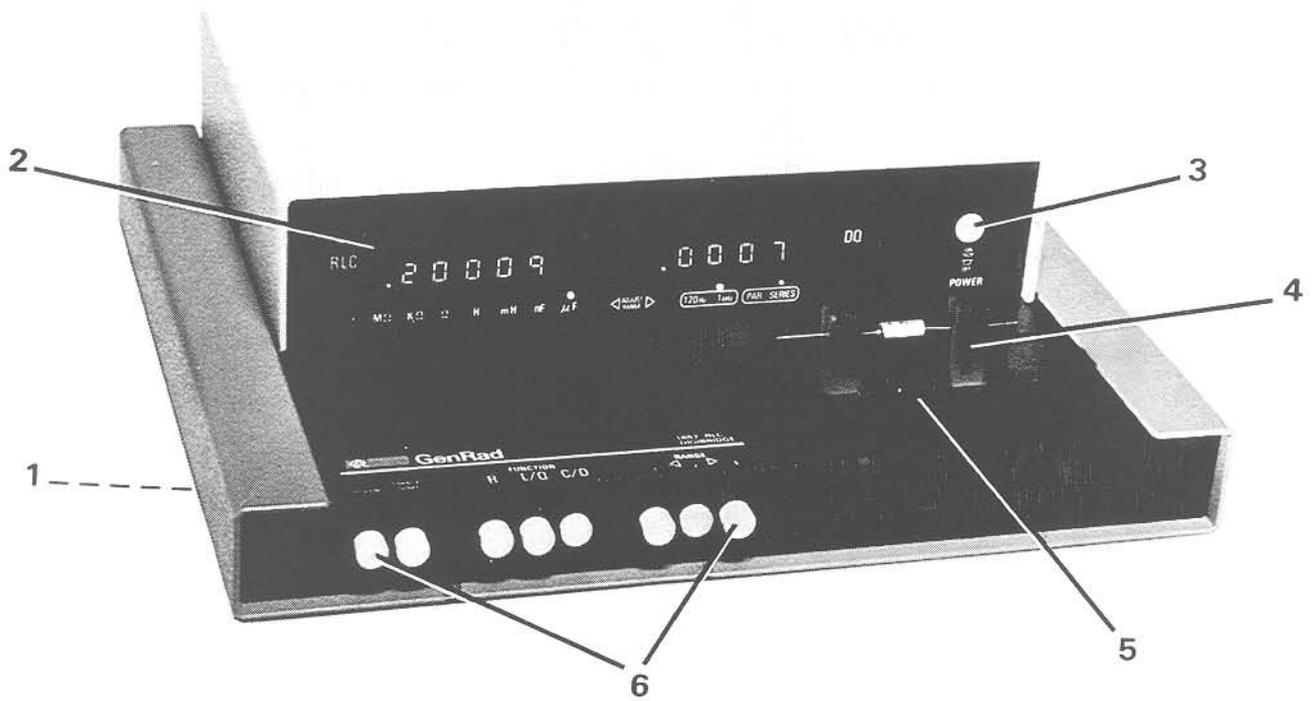


Figure 6-1. Front view showing mechanical replaceable parts.

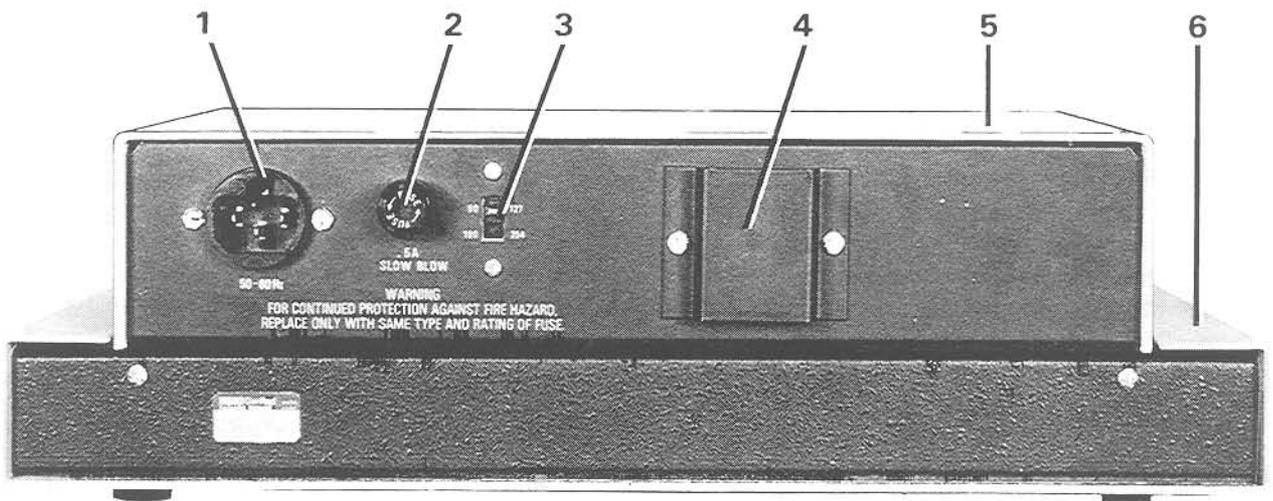


Figure 6-2. Rear view showing mechanical replaceable parts.

MECHANICAL PARTS LIST

FRONT (Figure 6-1)

Item	Description	Gen Rad Part	Mftr	Mftr Part No.
1	Foot (4 required) each:	5260-2051	24655	5260-2051
2	Display panel (120 Hz)	1657-7001	24655	1657-7001
	(or) Display panel (100 Hz)	1657-7002	24655	1657-7002
3	Switch actuator rod assembly	1657-2810	24655	1657-2810
4	Adaptor for axial leads (2 supplied)			
	Set of four for replacements	1657-5995	24655	1657-5995
5	Test fixture upper assembly, with rounded ends of slots	1657-2200	24655	1657-2200
	(includes dross tray	1657-7700	24655	1657-7700
	and foamed plasticpad)	1657-7800	24655	1657-7800
	Matching test fixture contacts (4 required; included on 1657-4700 board) each:	1686-1940	24655	1686-1940
5 (alt)	Test fixture upper assembly, with squared ends of slots	1689-2000	24655	1689-2000
	(includes dross tray and pad as above)			
	Matching test fixture contacts (4 required; included on 1657-4700 board) each:	1689-1015	24655	1689-1015
6	Push button cap (8 supplied)	5111-0450	71590	B-315 WT

REAR (Figure 6-2)

Item	Description	Gen Rad Part	Mftr	Mftr Part No.
1	Power connector J1	4240-0210	24655	4240-0210
2	Fuse extractor post F1	5650-0100	75915	342-004
3	Line voltage switch S2	7910-0832	82389	11A-1266
4	Cover	1657-8120	24655	1657-8120
5	Top cover	1657-8060	24655	1657-8060
6	Bottom shell	1657-8000	24655	1657-8000

FEDERAL SUPPLY CODE

FOR MANUFACTURERS

Ref FMC Column

From Defense Logistics Agency Micro fiche

in Parts Lists

H4-2 SB 708-42 GSA-FSS H4-2

Code	Manufacturer	Code	Manufacturer	Code	Manufacturer	Code	Manufacturer
00136	McCoy Electrs., Mt. Holly Springs, PA 17065	15605	Couster Hammer, Milwaukee, WI 53202	66289	Sprague, North Adams, MA 0 247	80894	Pure Carbon, St. Marys, PA 15857
00192	Jones Mfg., Chicago, IL 60118	15782	Houston Inst., Bellair, TX 77401	66300	Simmons, Bayport, NY 11705	81030	Int'l Instr. Org., CT 06477
00194	Walco Electrs., Los Angeles, CA 90018	16801	Fenwal Electrc., Frammingham, MA 01701	58553	Superior Valv., Washington, PA 15301	8 1073	Grayhill, LaGrange, IL 60626
00327	Weylyn Intntl., Westlake, OH 44145	15819	Sinclair & Rush, St. Louis, MO 63111	66730	Thomas & Betts, Elizabeth, NJ 07207	8 1433	Isolatone, Stirling, NJ 07880
00434	Schwaber Electrs., Westburg, NY 11590	16037	Spruce Pine Mica, Spruce Pine, NC 26777	69876	TRW, Cleveland, OH 44117	81312	Winchester, Oakville, CT 06779
00656	Aerowac, New Bedford, MA 02746	16068	Intntl. Diode, Jersey City, NJ 07304	60398	Torrington, Torrington, CT 06790	81349	Military Specifications
00779	AMP Inc., Harrisburg, PA 17105	16179	Omni Spectra, Farmington, MA 48024	61007	Townsend, Braitree, MA 02184	8 1360	Joint Army-Navy Specifications
01009	Alden Products, Brockton, MA 02413	16301	Astrolab, Linden, NJ 07036	6 6 37	Union Carbide, New York, NY 10017	81463	Int'l Rectifier, El Segundo, CA 90246
01121	Allen Bradley, Milwaukee, WI 53204	16352	Acti, Fairlawn, NJ 07410	6 6 64	United Car Fast., Boston, MA	81741	Chicago Lock, Chicago, IL 60641
01261	Litton Inds., Beverly Hills, CA 90213	18495	Sterling Int'l., New Hyde Park, NY 11040	63060	Victoreen, Cleveland, OH 44104	81851	Filtrom, Flushing, NY 11354
01296	TRW, Lawrenceville, GA 30026	16636	Indiana General, Oglesby, IL 6 346	83743	Ward Leonard, Mt. Vernon, NY 10550	81840	Ledex, Dayton, OH 45402
01526	GE, Waynesboro, VA 22980	16758	Dalco, Kokomo, IN 46901	65063	Westinghouse, Bloomfield, NJ 07003	8 2 60	Barry Wright, Watertown, MA 02172
01930	Amerock, Rockford, IL 61101	16850	Precision Dynamics, Burbank, CA 91504	66042	Weston, Newark, NJ 07114	82219	Sylvania, Emporium, PA 15834
01963	Cherry Electrc., Waukegan, IL 60085	16952	Amer Micro Devices, Summerville, SC 29483	70106	Acushnet Cap., New Bedford, MA 02742	82227	No. Amer. Philips, Cheshire, CT 06410
02111	Spectrol Electrs., City of Industry, CA 91745	17117	Elect. Molding, Woonsocket, RI 02895	70109	Adams & Westlake, Elkhart, IN 46514	82273	IN Pattern & Model, LaPort, IN 46350
02114	Ferrocube, Saugerties, NY 12477	17540	Mohawk Springs, Schiller Park, IL 60176	70417	Chrysler, Detroit, MI 4623	82289	Switchcraft, Chicago, IL 60630
02606	Fenwall Lab., Morton Grove, IL 60053	17745	Angstrom Precn., Hagerstown, MD 2 740	70663	Athletic India Rubber, Chicago, IL 60607	82367	Reeves Hoffman, Carlisle, PA 17013
02639	GE, Schenectady, NY 12307	17777	Singer, Somerville, NJ 06676	70661	Amperite, Union City, NJ 0 087	82647	Metals & Controls, Altoona, MA 02703
02660	Amphenol, Bridgeville, IL 60163	17850	Zetex, Concord, CA 64620	70611	Ark-Les Switch, Watertown, MA 02172	82807	Milwaukee Resistor, Milwaukee, WI 53204
02735	RCA, Somerville, NJ 08716	17859	Siliconix, Santa Clara, CA 95054	70892	Bead Chain, Bridgeport, CT 06605	82877	Rotron, Woodstock, NY 12498
02765	Fastex, Des Moines, IA 50018	18324	Signetics, Sunnyvale, CA 94086	70933	Belden, Chicago, IL 60644	83001	IN General Magnet, Milwaukee, WI 46383
03042	Carter Ink., Cambridge, MA 02142	18342	Adia, Kokomo, IN 46902	71256	Roson, Beason, Falls, CT 05403	83003	Varo, Garland, TX 75040
03508	GE, Syracuse, NY 13201	18577	Scanbe, El Monte, CA 91731	7 1279	Cambridge Thermionic, Cambridge, MA 02138	83014	Hartwell, Placenta, CA 92670
03550	Vanguard Electrs., Inglewood, CA 90302	18676	Computer Diode, S. Fairlawn, NJ 07936	71294	Canfield, Clifton Forge, VA 24422	83033	Meissner, Mt. Carmel, IL 62626
03636	Gayburne, Yonkers, NY 10701	18795	Cycon, Sunnyvale, CA 95086	71400	Bussmann, St. Louis, MO 63107	83058	Car Fastener, Cambridge, MA 02142
03877	Transitor Electrs., Wakefield, MA 01880	1891	Durant., Watertown, WI 53094	71450	CTS, Elkhart, IN 46514	83186	Victory Eng., Springfield, NJ 07081
03888	KDI Pyrofilm, Whippany, NJ 07981	19178	Geo., Monson, MA 0 057	71468	Cannon, Los Angeles, CA 90031	83266	Parker Seal, Culver City, CA 90231
03911	Clairex, New York, NY 10001	19209	Zer., Gainesville, FL 32601	7 4 82	Clare, Chicago, IL 64646	83360	H. H. Smith, Brooklyn, NY 11207
04009	Arrow Hart, Hartford, CT 06106	18373	Eastron, Haverhill, MA 0 830	71690	Centralab, Milwaukee, WI 53212	83361	Bearing Spicy, San Francisco, CA
04843	Diptronics, Alberton, NY 11507	19396	Paktron, Vienna, VA 22180	7 6 85	Continental Carbon, New York, NY	83667	Solar Electric, Warren, PA 15385
04713	Motorola, Phoenix, AZ 85008	19811	Catron, Chicago, IL 60622	71707	Crocco Co., Providence, RI 02905	83594	Burruss, Philadelphia, PA 19395
04919	Component Mfg., W. Bridgewater, MA 02379	19644	LGC Electrs., Morehead, NY 14845	71729	LCI, Philadelphia, PA 19134	83766	Men Engrs., Quincy, MA 02171
05079	Transitor Electrs., Bennington, VT 05201	18701	Elect. Inds., Murray Hill, NJ 07974	71744	Chicago Min. Lamp, Chicago, IL 60640	83781	National Electrs., Geneva, IL 60134
05245	Corcom, Chicago, IL 60639	20093	KMC, Long Valley, NJ 07863	71786	Cinch, Chicago, IL 60624	84411	TRW, Ogatsia, NB 69153
05276	ITT Electrs., Pomona, CA 9 786	20754	Fafnir Bearing, New Britain, CT 06050	7 6 23	Daneel, Downey, CA 90241	84836	Lehigh Metals, Cambridge, MA 02140
05402	Controls Co. of Amer., Melrose Pk., IL 60160	21338	Raytheon, Norwood, MA 02062	72136	Electromotive, Willimantic, CT 06226	84970	Sarkes Tarzan, Bloomington, IN 47401
05574	Viking Inds., Chatsworth, CA 91311	2 7 66	Lenox Fusile, Watchung, NJ 07080	72266	Electromotive, New Bedford, MA 02742	84971	Ta Mfg., Los Angeles, CA 90039
06624	Barber Colman, Rockford, IL 6 101	22526	Berg Electrs., New Cumberland, PA 17070	72699	Nytronics, Berkeley, CA 94722	85604	Kepco, Flushing, NY 11352
05840	Barnes Mfg., Mansfield, OH 44801	22589	Elect. Space Fabrctrs., Topton, PA 19562	72786	Daiglight, Brooklyn, NY 11237	86420	Payson Casters, Gurnee, IL 60033
05728	Wakfield Eng., Wakefield, MA 0 880	22753	TD Electrs., Hollywood, FL 33022	72786	Grake, Inc., Newark, NJ 07104	85577	Pre-Herial Prod., Vahamam, MA 02180
06393	Panduit, Tinley Pk., IL 60477	23338	Wawetek, San Diego, CA 92121	72794	Dzus Fastener, W. Islip, NY 11795	85584	RCA, Harrison, NJ 07029
06406	Truelove & Maclean, Waterbury, CT 06708	23421	Raytheon, Franklin Park, IL 60131	72942	Elastic Stop Nut, Union, NJ 07083	85687	REC, New Rochelle, NY 080
06665	Precision Monolith, Santa Clara, CA 95050	23936	Pamotor, Bellingham, CA 94010	72962	Erie, Erie, PA 16512	86800	Cont Electrcs., Brooklyn, NY 11222
06743	Clevite, Cleveland, OH 44110	24361	Indiana Gnr Electrc., Keesby, NJ 08632	72682	Amperec Electrcs., Hicksville, NY 11801	88140	Cutler Hammer, Lincoln, IL 62656
06795	WLS Stamp, Cleveland, OH 44104	24355	Analog Devices, Cambridge, MA 02142	73445	Carling Electric, Hartford, CT 06110	88204	GTE Sylvania, Ipswich, MA 01938
06915	Relcho Pstc., Chicago, IL 60646	24444	General Semicond., Tempe, AZ 85281	73559	Eico Resistor, New York, NY	88219	Gould Nat. Battery, Trenton, NJ 08607
06928	Teledyne Kntcs., Soland Boh, CA 92075	24446	GE, Schenectady, NY 12305	73690	JFD Electrcs., Brooklyn, NY 11219	88419	Cornell Dubilier, Fuquay Varina, NC 27526
06978	Aladdin Electrs., Nashville, TN 37210	24464	GE, Syracuse, NY 13201	73899	JFD Electrcs., Brooklyn, NY 11219	86627	Potter & Brumfield, Princeton, IN 4767
07047	Ross Milton, Southampton, PA 18966	24455	EMC Techniq., Cherry Hill, NJ 08034	73667	Broov-Pin, Ridgefield, NJ 07857	86626	Holzer Control, Boston, MA 02119
07126	Digitron, Pasadena, CA 91105	24802	Gen. Con., Concord, MA 01741	74193	Heremant, Trenton, NJ 08610	86655	United Transformer, Chicago, IL
07237	Elite Signal, Baraboo, WI 53913	24555	Lenox Fusile, S. Plainfield, NJ 07080	74199	Quam Nichols, Chicago, IL 60637	86870	Berkshire Transformer, Kent, CT 06757
07123	Cinch Graphik, City of Industry, CA 91744	24759	Vacrite, Berkeley, CA 94710	74445	Holo-Krome, Hartford, CT 06110	90201	Mallory Cap., Indianapolis, IN 46206
07261	Averch, Culver City, CA 90230	25008	Hubbell, Stratford, CT 06497	74545	Industrial Cndr., Chicago, IL 60618	90303	Mallory Bat., Tarrytown, NY 10591
07263	Fairchild, Mountain View, CA 94040	25829	Amphenol, Danbury, CT 06810	74861	Johnson, Waseca, MN 55393	90634	Gulton Inds., Metuchen, NJ 08840
07387	Birther, N. Los Angeles, CA 90032	26801	Tri-Cony Tube, Nunda, NY 14151	74902	IRCI (TRW), Burlington, IA 5260	90750	Westinghouse, Boston, MA 02118
07595	Amer. Semicond., Arlington Hts., IL 60004	26805	Omni Spectra, Waltham, MA 02154	75074	Kurz-Kasch, Dayton, OH 45401	90852	Hardware Prod., Reading, PA 19602
07699	Magnetic Core, Newburgh, NY 12550	26806	American Zetler, Costa Mesa, CA 62626	75372	Kuka, Mt. Vernon, NY 1066	91146	Continental Wire, York, PA 17405
07707	USM Fastener, Shelton, CT 06484	27014	National, Santa Clara, CA 95051	75376	Kuka, Mt. Vernon, NY 1066	91210	Cannon, Salem, MA 01970
07828	Bodine, Bridgeport, CT 06605	27455	Hartford Universal Bal., Rocky Hill, CT 06067	75626	Lafayette, Syracuse, NY 13291	91210	Gerber, Milwaukee, WI 46544
07829	Bodine, Bridgeport, CT 06605	28480	HP, Palo Alto, CA 94304	75637	Heremant, Trenton, NJ 08610	91417	Harris, Melbourne, FL 32901
07983	State Labs., New York, NY 10003	28485	Heffman Mfg., Kenilworth, NJ 07033	75637	Heremant, Trenton, NJ 08610	91506	Augat Bros., Altoona, MA 02703
07999	Borg Intnl., Delavan, WI 53115	28959	C. C. Magnetics, Rochester, NY 05867	75637	Heremant, Trenton, NJ 08610	91598	Chandler, Westfield, MA 06109
08524	Deutch Fastener, Los Angeles, CA 90045	30043	Heffman Mfg., Kenilworth, NJ 07033	75915	Littelfuse, Des Plaines, IL 60016	91637	Dale Electrcs., Columbus, NE 68601
08556	Bell Electrc., Chicago, IL 60632	30046	Solid State Devices, LaMirada, CA 90638	76005	Lord Mfg., Erie, PA 16512	91637	General Inst., Dallas, TX 76220
08730	Vermaline Prod., Franklin Lakes, NJ 07417	30874	Beckman Inst., Cedar Grove, NJ 07009	76149	Mallory Electrc., Detroit, MI 48204	91836	Kings Electrcs., Tuckahoe, NY 11223
089213	GE, Buffalo, NY 14220	30874	IBM, Armonk, NY 10504	76236	Maurey, Chicago, IL 60616	91916	Mephisto Tool, Hudson, NY 12534
09353	C & K Components., Watertown, MA 02172	30874	Parmag Magnetics, Toledo, OH 43609	7624	Maurey, Chicago, IL 60616	91923	Honeywell, Fressport, IL 61002
09408	Star-Tronics, Georgetown, MA 01830	31019	Stand State Sontc., Montgomery, PA 18936	76487	Maurey, Chicago, IL 60616	92519	Edgerton Greenhouses, Boston, MA 02115
09823	Burgess Battery, Freeport, IL 6 032	31514	Standard Appld Eng., Costa Mesa, CA 92626	76545	Maurey, Chicago, IL 60616	92702	IMC Magnetics, Westbury, NY 1 591
09892	Fenwal Electrcs., Frammingham, MA 01701	31814	Analogic, Wakefield, MA 0 880	76684	Maurey, Chicago, IL 60616	92866	Ampex, Redwood City, CA 94063
09922	Bundy, Norwalk, CT 06851	31951	Trilogic, Pittsburgh, PA 6 23	76864	Maurey, Chicago, IL 60616	92966	Hudson Lab., Kearny, NJ 07032
10025	Glaeser Prod., Linden, NJ 07036	32001	Jensen, Chicago, IL 60626	77147	Maurey, Chicago, IL 60616	93332	Sylvania, Woburn, MA 01801
10039	Chicago Switch, Chicago, IL 60647	32001	Spectrum Control, Fairview, PA 16415	77147	Maurey, Chicago, IL 60616	93346	Amer Electrcs. Labs., Landsale, PA 19446
1 236	CTS of Berne, Berne, IN 46711	33173	GE, Owensboro, KY 42301	77147	Maurey, Chicago, IL 60616	93618	RFC Mfg., Ramsey, PA 6 67
11599	Chandler Evans, W. Hartford, CT 06101	34141	Koehler, Marlboro, MA 0 7 6 2	77166	Maurey, Chicago, IL 60616	93618	Cramer, New York, NY 10013
11983	Nortronics, Minneapolis, MN 55427	34156	Semicon, Costa Mesa, CA 92626	77263	Maurey, Chicago, IL 60616	94154	Raytheon, Quincy, MA 02719
12040	National, Santa Clara, CA 95051	34333	Silicon Genl., Westminster, CA 92683	77316	Maurey, Chicago, IL 60616	94275	Weston, Archibald, PA 07039
12045	Electrc Transistors, Flushing, NY 1 354	34336	Advanced Micro Devices, Sunnyvale, CA 94086	77336	Maurey, Chicago, IL 60616	94322	Tel Labs, Manchester, NH 03102
12498	Teledyne, Mountain View, CA 94043	34649	Intel, Santa Clara, CA 95051	77342	Maurey, Chicago, IL 60616	94589	Dickson, Chicago, IL 60619
12617	Harnin, Lake Mills, WI 5366	34677	Soltron Devices, Jupiter, FL 33468	77542	Maurey, Chicago, IL 60616	94686	Magnecor, Chicago, IL 60630
12671	RCA, Woodbridge, NJ 07095	35923	Constans, Montreal, QUE CAN	77630	Maurey, Chicago, IL 60616	94800	Atlas Ind., Brookline, MA 03033
12697	Clarostrat, Dover, NH 03820	37942	National, Indianapolis, IN 46206	77630	Maurey, Chicago, IL 60616	94800	Garde, Cumberland, RI 02864
12856	Micrometals, City of Industry, CA 91744	38443	Marlin Rockwell, Jamestown, NY 470	77630	Maurey, Chicago, IL 60616	95121	Quality Comp. St. Marys, PA 15857
12954	Dickson Electrcs., Scottsdale, AZ 85252	39317	McGill Mfg., Valparaiso, IN 46383	77630	Maurey, Chicago, IL 60616	95146	Alco Electrcs., Lawrence, MA 0 843
12969	Unirode, Watertown, MA 02172	40931	Honeywell, Minneapolis, MN 55408	77630	Maurey, Chicago, IL 60616	95236	Continental Conn., Woodstock, NY 11377
13034	Electrocraft, Hopkins, MN 66343	42190	Muter, Chicago, IL 60628	77630	Maurey, Chicago, IL 60616	95236	Vitramon, Bridgeport, CT 06601
13103	Thermalloy, Dallas, TX 75234	42498	National, Melrose, MA 02176	77630	Maurey, Chicago, IL 60616	96354	Method, Rolling Meadows, IL 00000
13148	Vogue Inst., Richmond Hill, NY 11418	43334	New Departure-Hyatt, Sandusky, OH 44870	77630	Maurey, Chicago, IL 60616	95784	Amer Brass, Torrington, CT 06790
13150	Vernitron, Laconia, NH 03246	43931	Norma Hoffman, Stamford, CT 06904	77630	Maurey, Chicago, IL 60616	95987	Wexsesser, Chicago, IL 60646
13527	Fairchild, San Rafael, CA 4 803	46171	RCA, New York, NY 10020	77630	Maurey, Chicago, IL 60616	96095	Aerovox H. J. O., Olean, NY 14760
14675	Corning Glass, Corning, NY 14830	48956	Raytheon, Waltham, MA 02154	77630	Maurey, Chicago, IL 60616	96341	Military Assoc., Burlington, MA 01801
14674	Accovac, Escondido, CA 92029	50088	Motek, Carrollton, TX 75006	77630	Maurey, Chicago, IL 60616	96906	Milwavy Standards
14719	Electrocube, San Gabriel, CA 91776	50101	GHZ Devices, S. Chelmsford, MA 0 824	77630	Maurey, Chicago, IL 60616	971	