Contents

GR 1657
RLC Digibridge™

Form 1657-0120-A

Concord, Massachusetts, U.S.A. 01742
January, 1978
ID-0100

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 RLC, 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: Low extension	Basic accuracy: Basic ranges	Basic accuracy: High extension	Cross-term factor
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 kH)% 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, 48 to 62 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**
Extender Cable (for remote measurements)	**1657-9600**

Patent applied for.

Introduction—Section 1

1.1 PURPOSE.

The 1657 Digibridge™ is a digital impedance meter embodying 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. An extender cable is available for measurements at a distance from the instrument, typically for bulky components.

1.2 GENERAL DESCRIPTION.

Convenience is enhanced by the arrangement of test fixture on the front ledge, with pushbuttons farther forward and display behind. The display panel is inclined and recessed to enhance visbility 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.

GenRad makes several accessories that enhance the usefulness of this instrument. The extender cable facilitates making connection to those devices and impedance standards that do not readily fit the built-in test fixture. The cable branches into 5 parts, each with a stackable banana plug, 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.

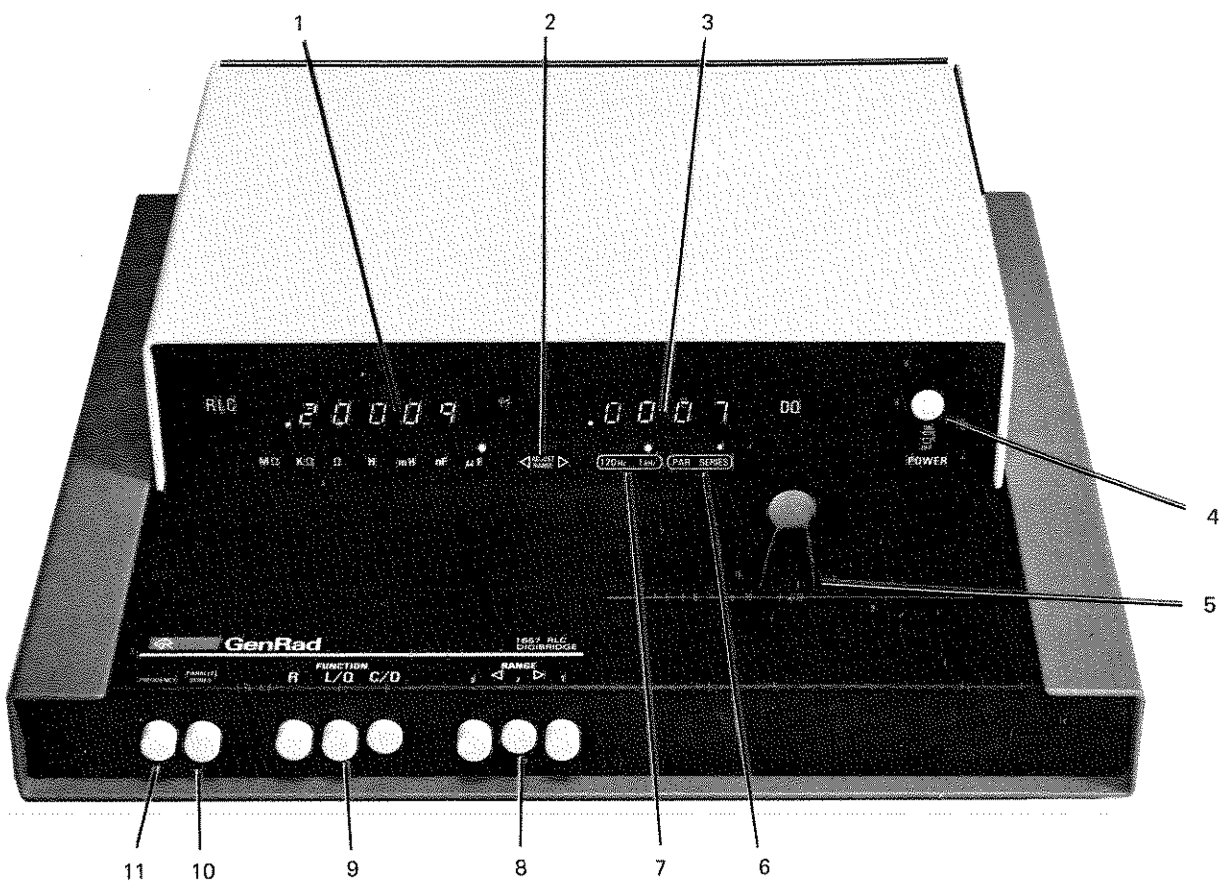

Figure 1-1. Front panel controls and displays.

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 MΩ, kΩ, 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 pushbuttons	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 pushbutton	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).

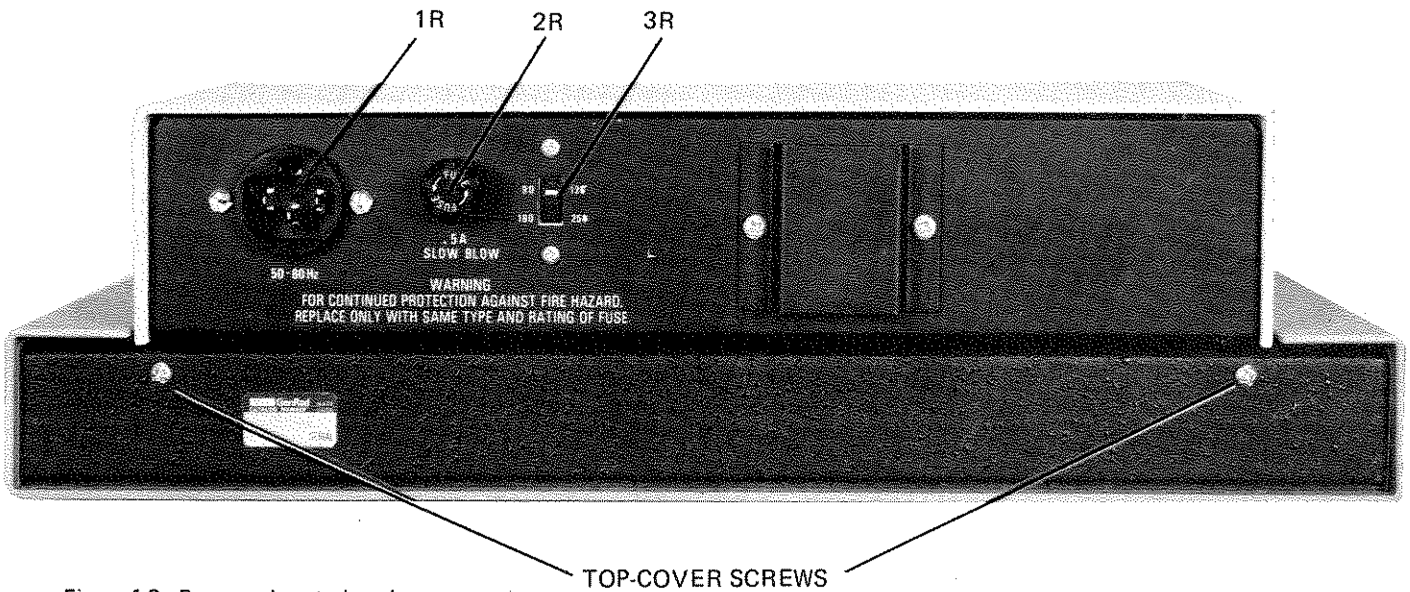

Figure 1-2. Rear panel controls and connectors.

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	1686-1910
1 recommended	Extender cable for connection to multi-terminal standards and large or remote DUT's. Length 100 cm (40 in.).	1657-9600

Installation—Section 2

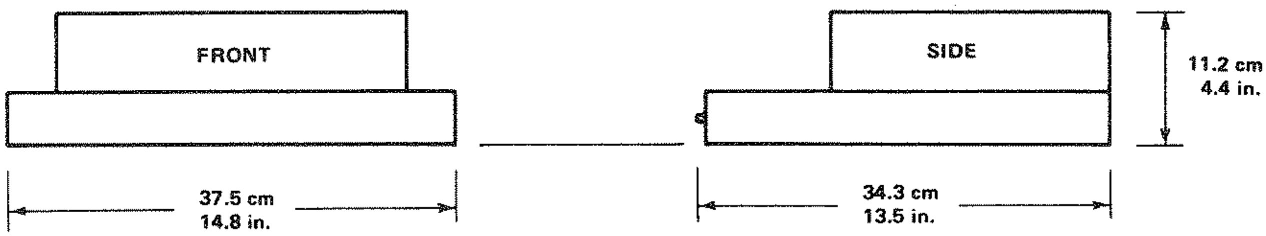

Figure 2-1. Overall dimensions.

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 acommodate line voltages in either of 2 ranges, as labeled, at a frequency of 48 to 62 Hz, ac. Using a small screwdriver, set this switch to match the measured voltage of your power line.

Connect the 3-wire power cable (P/N 4200-9625) to the line and to the power connector on the rear panel (Figure 1-2).

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 eliminates 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, ensuring 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, and is rated for 250 V at 6 A. It also meets requirements of Underwriter's Laboratories in the U.S. and the Canadian Standards Association. The receptacle accepts power cords fitted with the Belden type SPH-386 connector.

The associated power cord for use with that receptacle is GR part no. 4200-9625. It is a 210-cm (7-ft.), 3-wire, 18-gauge 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. (Specifies 125 V, 15 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.

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.

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 para 3.2.

The accessory extender cable 1657-9600 is needed to connect to DUT's that are multiterminal, physically large, or otherwise unsuited for the built-in test fixture. (Refer to Table 1-3.) This cable is also needed to connect impedance standards for accuracy checks. Use the following procedure to install the extender cable on the instrument:

a. Remove the adaptors, if present, from the test fixture. See para 3.1.

b. Plug the single-connector end of the extender cable into the test fixture, so that its blades enter both slots, and lock the connector with the 2 captive thumb screws.

c. Notice the color coding of the 5 banana plugs:

I+ = RED P+ = RED/WHITE Guard = BLACK/GREEN
I- = BLACK P– = BLACK/WHITE.

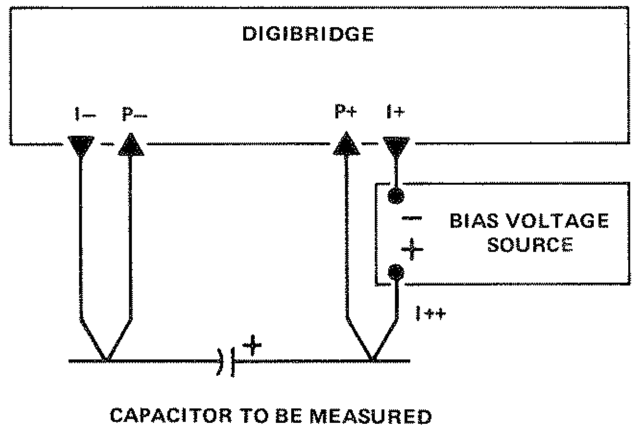

Figure 2-2. Connection of a bias voltage source to enable measurement of capacitors with bias applied. Because the measurement current (up to 30 mA rms) must pass through the bias source, it must be capable of being both source and sink for peaks of about 45 mA. Observe the voltage limits and procedural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

2.6 EXTERNAL BIAS.

Figure 2-2.

WARNING

- **To minimize electrical 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.**

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.

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

a. Attach the extender cable as described in para 2.5. Observe the color coding explained there.

b. Connect the I+ tip to the negative terminal of a suitable voltage source (see below). Provide a wire from its positive terminal, with a banana plug or alligator clip, which we can designate as the I++ tip.

c. Connect the DUT. 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.

d. If the capacitance is smaller (range 2 or 3) the banana plugs can be stacked and a single connection made to each capacitor terminal: I–/P– to the negative terminal, P+/I++ to the positive.

e. To make 3-terminal (or 5-terminal) measurements, also connect the G cable tip 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 G to the case of a capacitor if the case is one of its 2 main terminals.

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 ($\ll 10\ \Omega$) 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-μF 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-Ω resistor in series and another plain clip lead to the I-/P- junction. 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 Ω, 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

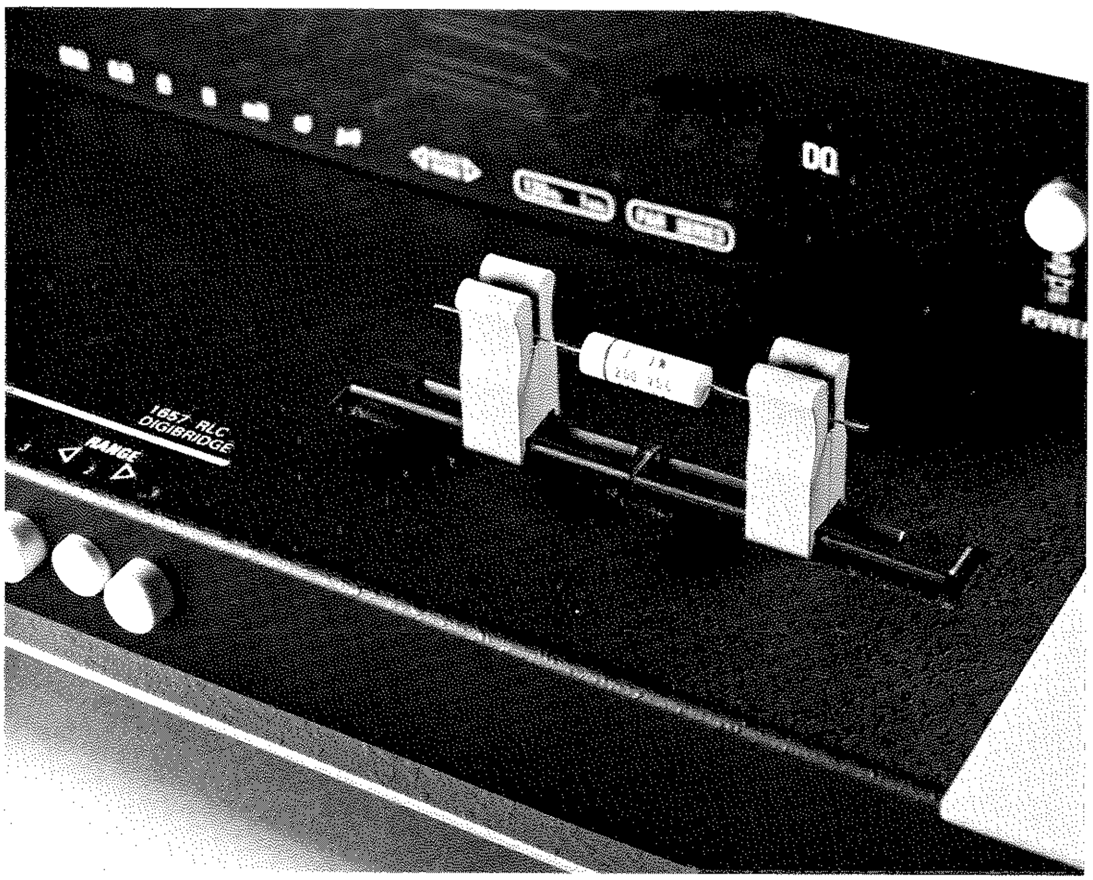

Figure 3-1. Use of the test fixture adaptors.

Table 3-1

FULL SCALE READOUTS ON EACH SUBRANGE

Manual range	Automatic subrange	R 1 kHz	R 120 (100) Hz	L 1 kHz	L 120 (100) Hz	C 1 kHz	C 120 (100) Hz
1 (Z_o = 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_o = 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_o = 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 RLC display of Ø1900, with an automatic decimal-point change between the decades, to 19999. (The symbol Ø 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: 19-μF and 999-μF. If a series of measurements is made with C increasing slowly above 19 μF, 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 Ø1900 down to ØØØ00, 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 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 R and 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 results from either faulty connection to the DUT or a numerically small negative L or 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 RLC 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

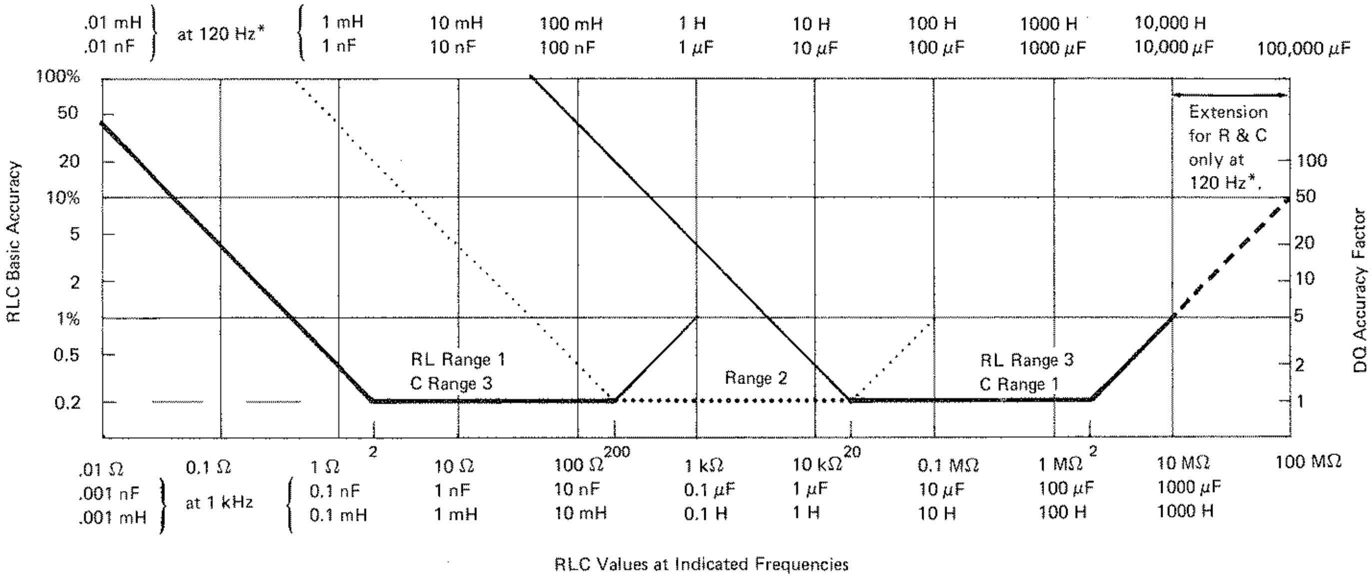

Figure 3-2. R L C basic accuracy as a percent of reading. Heavy lines (solid and dotted) represent best choice of range. Range 2 is dotted. Notice that L and C scales above graph are for 120 Hz (*equally valid for 100 Hz) and the 2 below graph are for 1 kHz. The DQ accuracy factor (right-hand scale) 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 µF and D = 0.5. The RLC basic accuracy is 0.4% and the RLC accuracy factor is 1.5. Therefore, the accuracy of the C measurement is ±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 3-4 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 µF, 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 ±1%.

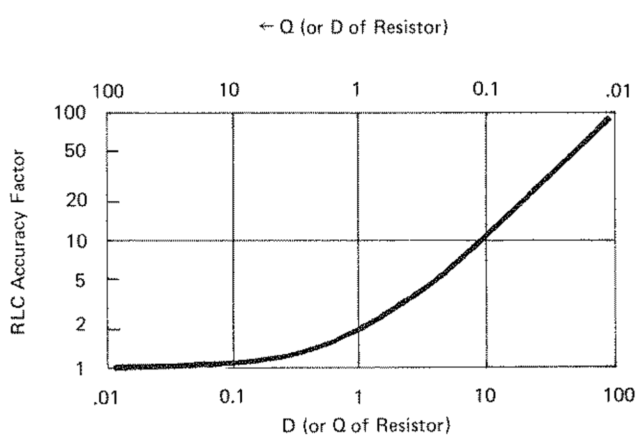

Figure 3-3. R L C accuracy factor as a function of D and Q. Multiply the RLC Basic Accuracy by this factor to obtain complete RLC accuracy for impedances that are not "pure" resistance or reactance. For capacitors and inductors, use the D and Q scales, respectively. For resistors, use the "D of Resistor"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

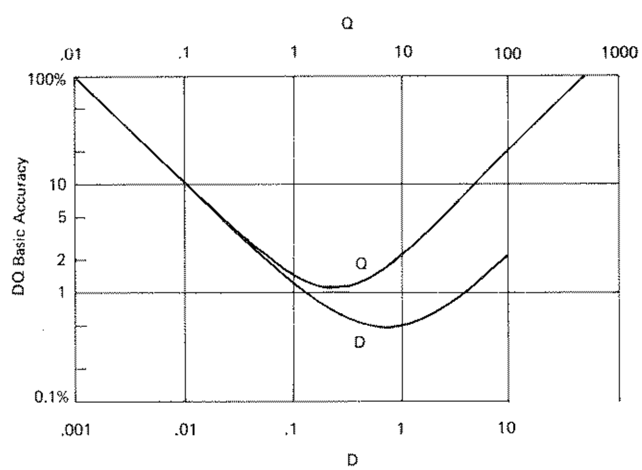

Figure 3-4. DQ basic accuracy as a percent of reading. These curves are directly applicable for measurements in the basic ranges. For measurements on any of the range extensions, refer also to Figure 3-2 for the DQ accuracy factor.

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 RLC 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-MΩ resistor, the display might ideally be 4.1234 MΩ; 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 ± .02 MΩ.

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 Q 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 kΩ: 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. R_p will be larger then R_s. If the difference is less then 1%, then Q is less than 0.1, and the measured R_s is probably very close to the dc resistance.

Resistors, above about 1 kΩ: 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 R_p and R_s is less than 1%, then D is greater than 10, and the measured R_p 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 μF: 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 1000 μF.

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

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

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

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

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

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

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

Resistance and Capacitance

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

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

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

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

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

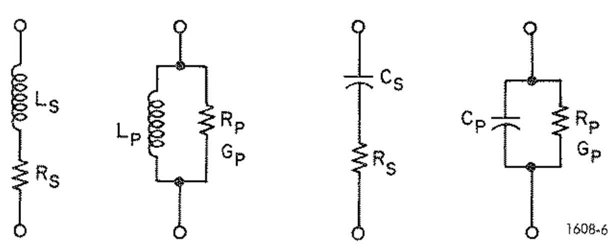

Figure 3-5. Equivalent circuits for a lossy inductor and a lossy capacitor.

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: $R_S = D/2\pi f C_S$, where $\pi = 3.1416$. D and C_S 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 C_s and D).
f. Set the bias voltage source to zero.
g. Connect the 10-Ω discharging circuit.
h. After about 2 s, connect the safety short circuit.
i. Remove the DUT and the discharging circuits.

3.7 CORRECTION FOR CABLE.

The extender cable adds capacitance in parallel with the DUT (because shielding of the tips is imperfect). The 1657-9600 cable adds about 0.5 pF. 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, L and 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.