Technical Manual

For The

9910A and 9911

High Voltage Capacitance - Inductance Bridge
And
1000 A Range Extender

www.guildline.com

TM9910A-C-00
3 January, 2013

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1. INTRODUCTION

1.1. SCOPE

This document describes the installation, operation, specifications, maintenance and verification of the Guildline Model 9910A High Voltage Capacitance and Inductance Bridge, including the Model 9911 Range Extender. Precautions associated with very high voltage connections and measurements are provided for purposes of user safety and measurement system reliability. This revision supersedes previous revisions as it reflects up to date design improvements from units previously manufactured.

The Model 9910A High Voltage Capacitance and Inductance Bridge has a switch for reversal of the dissipation factor dials, to allow the measurement of heavy current inductors. The Model 9911 (optional) is a 1000:1 external Range Extender to allow test currents up to 1000 A to be used.

1.2. GENERAL DESCRIPTION

The Model 9910A High Voltage Capacitance and Inductance Bridge brings the superior accuracy of the Current Comparator to those applications too stringent or demanding for conventional Schering Bridges. Referred to an external gas-filled standard capacitor, accuracy and resolution are better than 15 ppm. The instrument is ideally suitable for low-cost, high voltage, power cable measurements.

The Model 9911 will allow the measurement of inductance up to 7 Henries, which is especially useful for accurate determination of reactor losses.

The Model 9911 also extends the capacitance ratio capability of the Model 9910A from 1000 : 1 to 1,000,000 : 1

1.3. WARNING

CARE SHOULD BE EXERCISED TO OBSERVE THE PROPER GROUNDING TECHNIQUE.

SEE SECTION 3 OTHERWISE DAMAGE TO THIS INSTRUMENT COULD RESULT AND THE FRONT PANEL MAY BECOME ENERGIZED.

1.4. OVERVIEW

The model 9910A High Voltage Capacitance and Inductance Bridge is housed in an attractive metal cabinet. There is a 3U space allocated at the top of the cabinet to install a null detector so that it is positioned at eye level. The null detector is an optional item. Guildline Instruments can supply either the Signal Recovery Model 5210 Dual Phase Analog Lock-in Amplifier or the Stanford Research Systems Model SR830 DSP Dual Phase Lock-in Amplifier. A 1.3 Vrms reference signal synchronized to the line frequency is provided on the 9910A that can be used as the reference input of the lock-in amplifier.

The bridge section is located below the detector with the capacitance ratio and dissipation dials dominating the panel. The bridge comparator toroid is mounted at the rear of the cabinet within a magnetic shield. The feedback and lead compensation amplifiers are within a magnetic shielded box. The connectors and ground terminals for connection to the standard and unknown capacitors are on the back.

Extensive use is made of shielded cables. Critical areas are magnetically shielded, and the cabinet is fabricated with steel material that acts as an electrostatic shield to avoid stray pick-up.

A separate range extender or compensated current transformer, (Model 9911) is available of circular construction with a center hole for feed through turns. The internal windings are brought out to terminals mounted on the base plate.

Note that the High Voltage Source required for excitation of the Capacitance or Inductance being measured is not supplied with the 9910A.

1.5. PRINCIPLE OF OPERATION

1.5.1. AC Current Comparator

The AC current comparator is a multiple winding toroidal transformer device in which the primary and secondary windings carry alternating currents and the detector winding is used for detection of A.C. flux in the core. When the primary and secondary ampere-turns are equal and opposite there is zero resultant A.C. flux in the core. The presence of flux in the core is indicated by the high gain frequency selective detector or dual phase lock-in amplifier, in both magnitude and phase.

1.5.2. Capacitance Bridge

The measurement of capacitors at voltages greater than 100 volts when using a high voltage Schering Bridge is only as accurate as the resistance ratio of the two low voltage elements. The accuracy of the dissipation factor measurements depends on the relative phase angle of the two resistors. When comparing a high value of capacitance and a low value standard capacitor, a large resistance ratio must be used and difficulty is experienced in maintaining phase angle equality between these two resistors.

The Current Comparator Capacitance Bridge uses turns ratio in place of resistance ratio and has a fixed accuracy of ±15 ppm which is not affected by ratios as high as 1000:1. A switch selectable primary winding, (Nx) of 1 to 1000 turns in a 1, 2, 5, 10 sequence is provided. A secondary set of windings, (Ns) provides for a resolution of 1 part in 10^6 with 3 decades of windings from 100 turns to 1 turn and 3 decades of fractional turns from 0.1 to 0.001 turn. Two decades of fixed dissipation values and three decades of fractional values are provided with a resolution of 1 part in 10^6. A switch for reversing the dissipation measuring dials is provided for balancing inductance instead of capacitance on the primary side of the comparator.

Figure 1-1 shows simplified schematic diagram of the 9910A High Voltage Capacitance and Inductance Bridge.

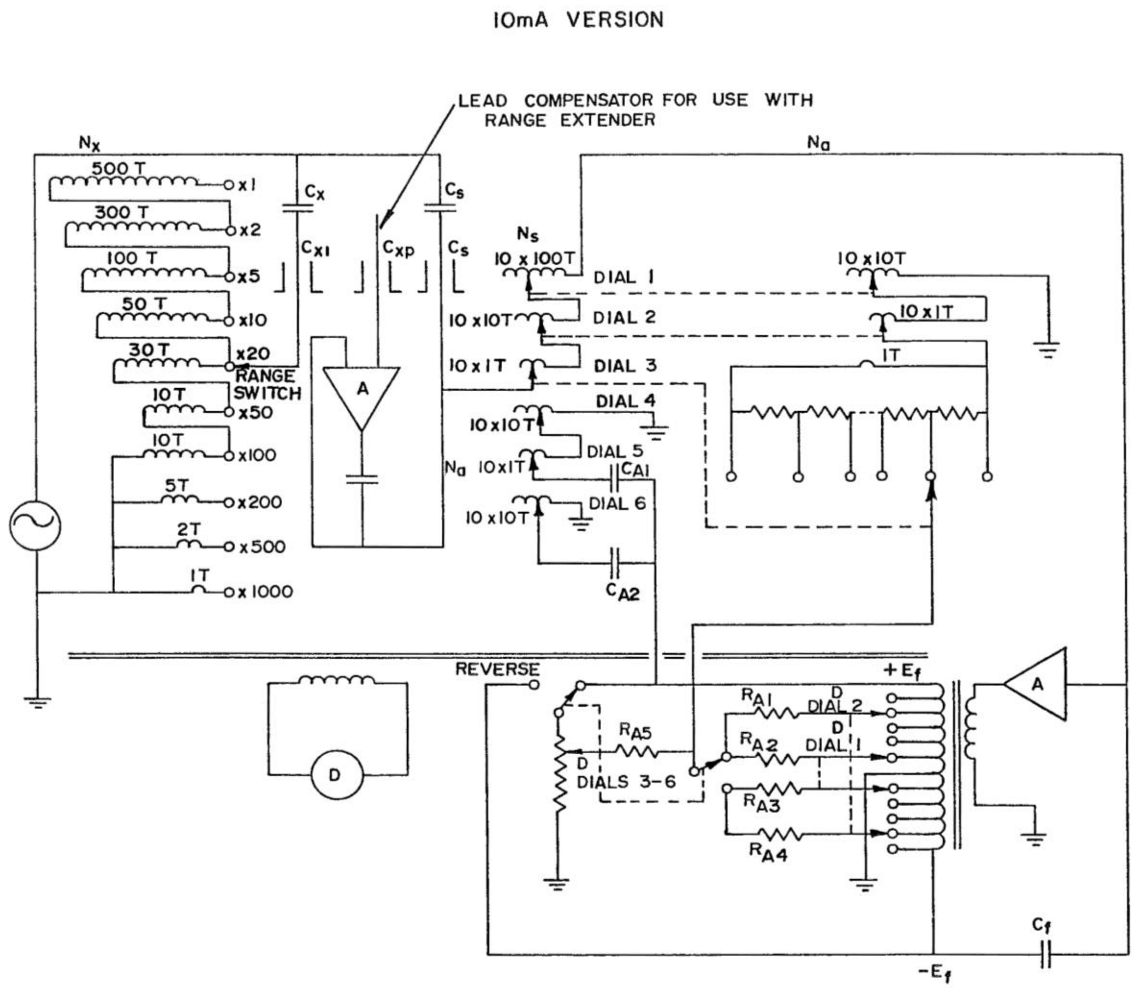

Figure 1-1 : Model 9910A Capacitance and Inductance Bridge Diagram

2. INSTALLATION

2.1. PRELIMINARIES

2.1.1. Unpacking

Remove the 9910A High Voltage Capacitance and Inductance Bridge and the other items from the shipping container to a suitable location. The instrument is thoroughly mechanically and electrically inspected before shipment, and is carefully packed. It should therefore be free from mars, scratches and faults when received. Nevertheless, the customer should inspect the instrument for physical damage, ensure that all items on the packing list are present, and test the instrument electrically, as soon as possible after receipt.

The customer should refer to the warranty card for further instructions, if any damage or deficiency is found.

The following items are included with each new unit;

i. Technical Manual (TM9910A)
ii. Two Spare Fuses 1/2A Time Delay, Glass Tube (GPN 099-20120)
iii. Two Spare Fuses 1A Time Delay, Glass Tube (GPN 099-21000)
iv. Five Cable Assemblies, GR - GR RG58C/U 1.8m, (GPN 250-05031)
v. One Cable Assembly, BNC – BNC RG58C/U 1.5m. (GPN 250-05030)
vi. Two Neon Lamps, Red, (GPN 240-23005)

2.1.2. Power Voltage Selection

Note that the 9910A is provided with a fused power entry with an isolation transformer such that both 120 Volt and 240 Volt power line sources can be accommodated. Verify that the markings as shown on the rear of the cabinet matches the local power line voltage and frequency. Contact Guildline Instruments Limited if the markings do not match.

Locate the Capacitance Bridge on a firm bench top location and plug the line cord of the instrument into a source of the proper voltage, i.e. 120 volts 60 Hz or 240 volts 50 Hz, according to the marking as shown on the rear of the cabinet. Note that for 240 volts 50 Hz units, a power plug suitable for the local receptacle must first be installed on the line cord if required.

Where the molded plug on the line cord supplied with the instrument does not match the local power outlet socket, the plug can be removed and replaced with one that does fit the local service. The plug should be re-wired as follows:

Brown wire	-	Line input
Blue wire	-	Neutral input
Green/Yellow	-	Ground (safety)

The 9910A is shipped with a fuse installed in the main chassis. Refer to Table 2-1 for the correct fuse selection if replacement of the fuse is required.

2.1.3. Fuse Replacement

Only fuses with specified current rating type should be used for replacement if necessary. One fuse is required in the 9910A main chassis. See Table 2-1.

FUSES	
120 Volts, 60 Hz	240 Volts, 50 Hz
1A, 250V, (T) Glass Tube type	1/2A, 250V, (T) Glass Tube type

Table 2-1 : Fuse Ratings

2.1.4. Line Voltage Changes

No external line voltage selection is provided for power entry. The power entry line voltage may be changed internal to the 9910A if required. Refer to Section 9 for the wiring changes that are required.

2.1.5. Setup and Power On

a. Verify that the power switch is off.

b. Remove any excess packing material from around the front and back panels that are provided for shipping purposes only.

c. Install the null detector if not included with the system. The null detector may be plugged into the power bar at the back of the cabinet after checking that the voltage selection is suitable to the AC power source.

d. Connect the input power cord from the 9910A to the AC power outlet.

e. Turn on the power switch on the 9910A Bridge and the null detector.

f. You should see the red "POWER" indicator on the front panel light up.

g. The 9910A System should now be ready to use. Refer to the specific Operation Manual for operation of the null detector.

2.2. INCOMING INSPECTION

If there appears to be no initial faults in turning on the 9910A Bridge and the Null Detector, the null detector may be setup to locate balance on the bridge with 1000 pF capacitors connected to the Cx and Cs connectors at the back of the 9910A Chassis. Refer to Section 3 for setting up and performing a capacitance ratio measurement. Note that the power entry module Reference Signal will need to be connected to the Reference Input of the Null Detector. The Reference Signal has a nominal value of 1.3 Vrms and should be suitable for most Dual Phase Lock-in Amplifiers.

Note 1: Large out of balance conditions on the 9910A Bridge must be avoided because the high sensitivity of the flux detector will saturate the detector input and a balance can then not be achieved. An initial balance should be obtained without any voltage being applied to the capacitors or inductors on the inputs to the 9910A Bridge. This is possible due to the high sensitivity of the instrument which enables the system to utilize the ambient field always present.

Note 2: Always ensure that proper grounding technique as shown in Section 3 is used. Otherwise damage to the instrument could result and the front panel may become energized.

Note 3: The high voltage supply to the capacitors must be current limited to less than 2 amperes to prevent damage to the comparator wiring if flash over occurs.

2.3. 9910A FRONT PANEL

Figure 2-1 : 9910A Front View

2.3.1. POWER

The power-on indicator is lighted when the Power switch is turned to the “ON” position.

2.3.2. OFF/ON Switch

Power is applied to the 9910A when the On/Off switch is turned to the “ON” position.

2.3.3. Is mA Meter

The Is mA Meter reads the current through the standard capacitor and has a full scale of 10 milliamperes.

2.3.4. D.C. LEVEL & Adjust

The D.C. Level push button is depressed and the trimmer is adjusted, through the hole below the push button, to give zero deflection on the I_S meter. This ensures that there is no D.C. current flowing through the windings of the amplifier output transformer.

2.3.5. C's Switch

The C's switch has three positions, 100 pF, 1000 pF and EXT. When using a 100 pF or 1000 pF standard capacitor and lead compensation is desired this switch is set to the appropriate position and the C's trim is adjusted. This function is only effective when measuring capacitors with the four terminal method. When the switch is in the 'EXT' position an external trim capacitor may be connected at the back of the 9910A main chassis to the terminals marked 'Ext trim H' and 'Ext trim L'.

2.3.6. C's Trim & Adjust

The C's trim is adjusted when lead compensation is desired in four terminal measurement mode. Adjustment is accomplished by depressing the push button and adjusting the trimmer below it to obtain a balance on the Null Detector. This is only effective when measuring capacitors with the four terminal mode.

2.3.7. Cx TERM Switch

The Cx TERM Switch is used to switch from three to four terminal measurement of the Cx capacitor. The C's Trim function is used to allow compensation for lead impedance.

2.3.8. Cx/Cs Dials

Six decades are provided to measure the ratio of Cx/Cs providing a resolution of 1 part in 10^6.

2.3.9. D Dials

Five decades of positive dissipation factor are provided. The last three are read off a three section 10 digit digital potentiometer. The reversing switch to the left of the ten turn potentiometer can be switched to negative and negative dissipation values may be measured.

2.3.10. Ratio Switch

The RATIO Switch enables ratios of Cx/Cs from 1:1 to 1000:1 in decade multiples of 1, 2, 5 and 10 to be measured.

2.3.11. Protection Gas Gaps

Two GAS-GAPS are mounted behind the front panel, behind a clear Plexiglas cover connected between the capacitor input terminals and GND to protect against break-down of the capacitors under test.

2.3.12. GND

This terminal provided on the front panel is bonded to the front panel and the main chassis metallic surfaces. This terminal can be used as a secondary connection to earth ground as an additional precaution against the front panel being energized due to a break-down of the capacitors under test or some other fault. Note that ground connections from the devices under test and optional items should be all joined at the GND terminal at the back of the main chassis to act as single connection point that avoids ground loops in the setup.

2.4. 9910A REAR PANEL CONNECTORS AND PLUGS

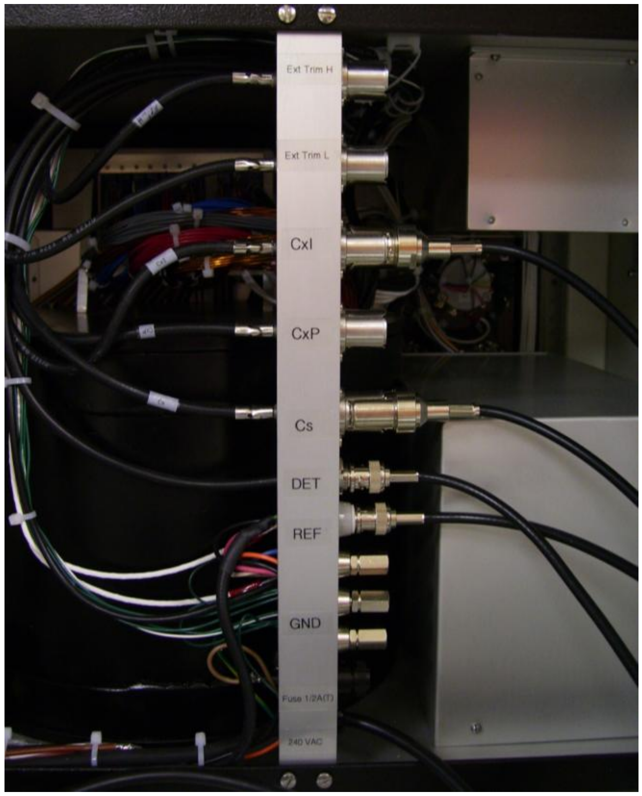

Figure 2-2 : 9910A Rear View

2.4.1. Mains Power Line Input

The 9910A Bridge has a **Mains Power Bar** located at the top of the back of the cabinet. A line cord is supplied which is connected to the power bar input and is rated for 120/240 Volts. The power bar has multiple outlets of which one is connected to the 9910A in the cabinet. The 9910A isolation transformer is configured for either 120 Volts or 240 Volts input depending on which line voltage is requested at the time of order. The 9910A main chassis is connected to one of the power bar outlets. Extra outputs on the main power bar can be used to supply power to the Null Detector or other devices that may be required.

A 1 or 1/2 Amp time delay fuse is installed in the 9910A main chassis.

2.4.2. 1.3 VAC Reference

A BNC connector is provided on the power entry module that provides a nominal 1.3 VAC signal for use as a reference signal synchronized to the line frequency. The voltage may be increased to 2.6 VAC if required.

2.4.3. GND

There are three terminals connected to a common strip, for connection of external ground wires. This is the ground point of the instrument and is connected to mains ground through the power line cord. These three terminals should be used as the common ground connection for measurement setups to avoid ground loop problems.

2.4.4. DET

The **DET** BNC connector nearest the bottom of vertical connector panel is the output of the bridge section, which is to be connected to the signal input of the Null Detector with the BNC coaxial cable supplied.

2.4.5. Cs Connector

The **Cs Connector** is a shielded GR type connector to which the Cs capacitor is connected.

2.4.6. CxP Connector

The **CxP Connector** is the potential connection for the Cx capacitor when using four terminal configurations.

2.4.7. CxI Connector

The **CxI Connector** is the current terminal for Cx and is used for three and four terminal measurements.

2.4.8. EXT TRIM L Connector

The **EXT TRIM L Connector** is the low side of a connection to an external trim capacitor.

2.4.9. EXT TRIM H Connector

The **EXT TRIM H Connector** is the high side of a connection to an external trim capacitor. A pair of GR Type coaxial cables is supplied for connection of the external trim capacitor.

3. MEASUREMENT GUIDE

3.1. CAPACITANCE MEASUREMENT

This section contains information regarding the measurement of capacitance. The 9910A should not initially be turned on. The Null Detector should be turned on once the sensitivity setting has been set to a minimum. The connection of the reference capacitor and the capacitor to be measured is described below. Note that the Null Detector reference input must be phase aligned to the detector output signal before a proper Null condition can be detected.

Note 1: Large out of balance conditions on the 9910A Bridge must be avoided because the high sensitivity of the flux detector will saturate the detector input and a balance can then not be achieved. An initial balance should be obtained without any voltage being applied to the capacitors or inductors on the inputs to the 9910A Bridge. This is possible due to the high sensitivity of the instrument which enables the system to utilize the ambient field always present.

Note 2: Always ensure that proper grounding technique as shown in the setup drawings in this section is used. A good connection to earth ground must be supplied otherwise damage to the instrument could result and the front panel may become energized if a fault in one of the high voltage units under test such as a flash over should occur.

Note 3: The high voltage supply to the capacitors must be current limited to less than 2 amperes to prevent damage to the comparator wiring if flash over occurs.

3.1.1. Capacitance Ratio Measurement Cx/Cs, (three terminal method)

1. The bridge current is limited to a maximum of 10 mA on the Cs side and is indicated on the Is mA meter. The supply voltage required to pass this current through the standard capacitor should be calculated and not exceeded during the test. For maximum resolution the Cs current should not be less than 1 mA.

2. To check the leads, connect the capacitors as shown in Fig. 3-1, using the cables to be used with the bridge. Note that the high side of the voltage is not connected at this time. Slowly increase the supply voltage source output to maximum. If the leads are properly shielded there should be no signal as seen on the detector.

3. Set the RATIO switch to the nominal ratio of the capacitors to be compared and the first Cx / Cs dial to step ten (X). Set the Cx TERM switch to 3 for a three terminal connection.

4. Connect capacitors as shown in Fig. 3-2.

5. Turn the ON/OFF power switch to the ON position.

6. Press the DC LEVEL ADJ button and with a screwdriver, adjust the control below this button to bring the pointer on the Is meter to within 10 divisions of zero. Precise adjustment is not necessary and will not affect measurement of accuracy.

7. Unless the Cx / Cs dials are within 10% of the true setting, sudden application of the full supply voltage to the capacitors will tend to cause the bridge to oscillate due to its high sensitivity. The start of initial balance should be made at reduced voltage. Set the supply voltage to give approximately one milliampere or less on the Is meter to start. The voltage can be calculated using the formula;

$$\mathbf{E = 0.001 / 2\pi f Cs}$$

Where E is the voltage, f is the frequency and C is the capacitance in Farads

For example, where Cs is 1000 pF, and 60 Hz is used;
the voltage for 1 mA = 0.001 / (2 x 3.1416 x 60 x .001/1000,000) = 2,653 Volts.

8. Use Table 3-1 to establish the initial settings of the measuring dials and the range multiplier. For example; if Cx = 400 pF and Cs = 100 pF the multiplier would be 10:1 and the dial setting would be 0.400 000. If the value of the capacitance is not known it is best to start with dials set at 0.500 000 and change the multiplier until a change in detector zero crossing is observed. Measuring dials can then be manipulated to further reduce out of balance while detector sensitivity is increased. The normal balance procedure outlined below can then be followed.

Cx (pF)	**Cs (pF)**	**Ratio**	**Dials in Use**	**Resolution (parts in 10^6)**
100	100	1:1	6	1
1,000	100	10:1	6	1
10,000	100	100:1	6	1
100,000	100	1000:1	6	1
1,000	1000	1:1	6	1
10,000	1000	10:1	6	1
100,000	1000	100:1	6	1
1,000,000	1000	1000:1	6	1

Table 3-1 : Capacitance Ratios and Ranges

8. Slowly increase the Null Detector sensitivity while adjusting the “Cx / Cs” and “D” factor dials to bring the bridge into a balanced state. The Reference Phase control of the Null Detector should be adjusted so that the ratio dials vary the In Phase balance and the dissipation dials vary the Quadrature balance.

9. Once a full sensitivity balance is obtained the supply voltage can be slowly increased to the maximum predetermined magnitude required for the measurement.

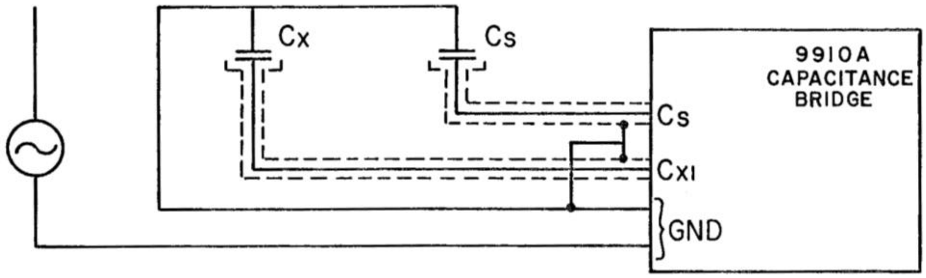

Figure 3-1 : Lead Check

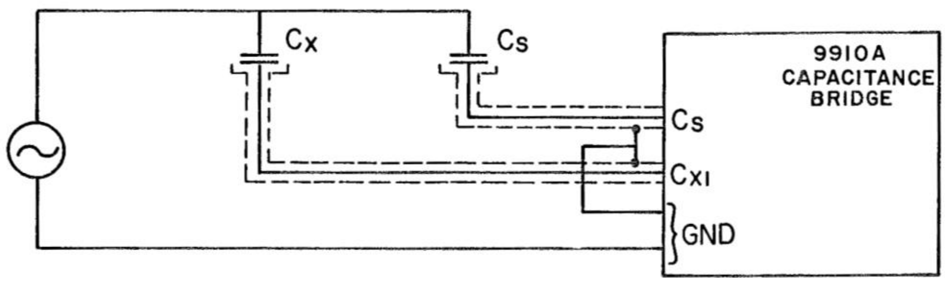

Figure 3-2 : 3 Terminal Measurement

3.1.2. Capacitance Ratio Measurement Cx/Cs, (four terminal method)

When very large capacitors are measured, the impedance of the capacitor is small and the lead impedance can no longer be considered negligible. While the lead impedances in the standard capacitor are below 1 x 10^{-7} of the standard capacitor impedance, the internal impedance of the current comparator winding may be as high as several parts per 10^6 of the standard capacitor impedance. For accuracies approaching 1 part per 10^6, lead compensation is required. The 9910A should not be initially turned on.

1. To check the leads, connect the capacitors as shown in Fig. 3-4, using the cables to be used with the bridge. Note that the high side of the voltage is not connected at this time. Slowly increase the supply voltage source output to maximum. If the leads are properly shielded there should be no signal as seen on the detector.

2. To calibrate the lead compensation circuit, connect the voltage supply end of the standard capacitor into the CxP terminal as shown Fig. 3-3, then;

   - Set the **C's** switch to the value of Cs (1000pF, 100pF or EXT)
   - Set the **Cx TERM** switch to the 4 terminal position.
   - Switch the **ON/OFF** power switch to ON

- Switch the Null Detector sensitivity to minimum.
- Press the **C's TRIM** push button which applies a test voltage to Cs and with a screwdriver and adjust the control below the button to bring the Null Detector to a balance condition.
- Switch the detector sensitivity back to the lowest sensitivity and the bridge ON/OFF power switch to OFF.

2. Connect the capacitors as shown in Fig. 3-4, using the same Cs and Cx cables just compensated.
3. Obtain balance on the Null Detector as described in Section 3.1.8-9.

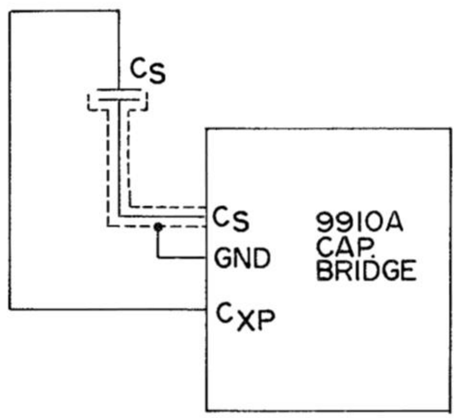

Figure 3-3 : Lead Calibration

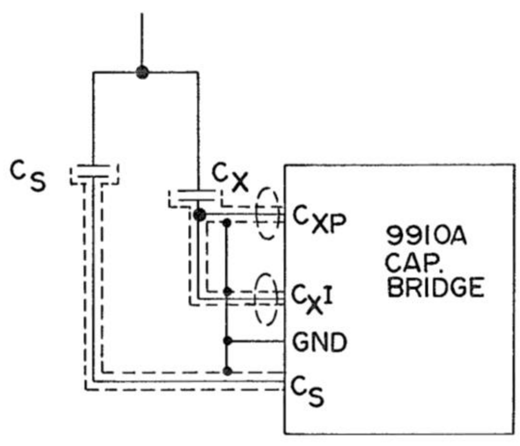

Figure 4 : 4 Terminal Measurement

3.1.3. Capacitance Ratio Measurement Using the 9911 Range Extender

The Model 9911 Range Extender is used for measurement of capacitance ratios exceeding 1000:1. It is basically a 10:1 transformer with 1000 turn secondary winding and 100 turn primary winding. Higher ratios are obtained by the addition of external primary windings through the center hole of the transformer. The Range Extender transformer has a rating of 1000 ampere turns which should not be exceeded. The maximum current in the secondary is therefore 1 ampere and with the bridge range switch set at 1000, the Is meter should not exceed 1 milliamperes.

NOTE

> Four terminal lead compensation is only available for two values for standard capacitor Cs, namely 100 pF & 1000 pF and provision is made or the use of an external capacitance connection. An external lead compensation capacitance equal to that of the Cs may be connected at the EXT TRIM L and the EXT TRIM H connectors on the back panel of the main chassis.
> Otherwise for other values of Cs only three terminal measurement is available.

The current through the primary of the Range Extender will depend on the capacitance ratio and if feed-through turns are used, the cables should be heavy enough to carry the charging current of the measured capacitor. For maximum accuracy, the Range Extender should be connected to the single turn bridge winding, (i.e. RATIO switch at 1000), to minimize the burden on the Range Extender transformer. However, it is more convenient to use fixed feed-through windings and change the RATIO switch for different capacitor ratios. The error caused by this method is normally not significant if the bridge ratio switch is not set below 200:1

1. To check the leads, connect the capacitors as shown in Fig. 3-5, using the cables to be used with the bridge. **Note that the high side of the voltage is not connected at this time.** Slowly increase the supply voltage source output to maximum. If the leads are properly shielded there should be no signal as seen on the detector.
2. To calibrate the lead compensation circuit, connect the voltage supply end of the standard capacitor into the CxP terminal as shown Fig. 3-3, then;
   - Set the **C's** switch to the value of Cs (1000pF, 100pF or EXT)
   - Set the **Cx TERM** switch to the 4 terminal position.
   - Switch the **ON/OFF** power switch to ON
   - Switch the Null Detector sensitivity to minimum.
   - Press the **C's TRIM** push button which applies a test voltage to Cs and with a screwdriver and adjust the control below the button to bring the Null Detector to a balance condition.

3. Switch the detector sensitivity back to the lowest sensitivity and the bridge ON/OFF power switch to OFF.
4. Connect the leads again as in step 1 but also connect the supply voltage as in Fig. 3-5.
5. Set up the Model 9911 for the capacitance ratio desired, using Table 3-2 as a guide.
6. To minimize the effect of mutual inductance, the use of twisted or co-axial leads in the lead arrangement shown in Fig. 3-5, is recommended.

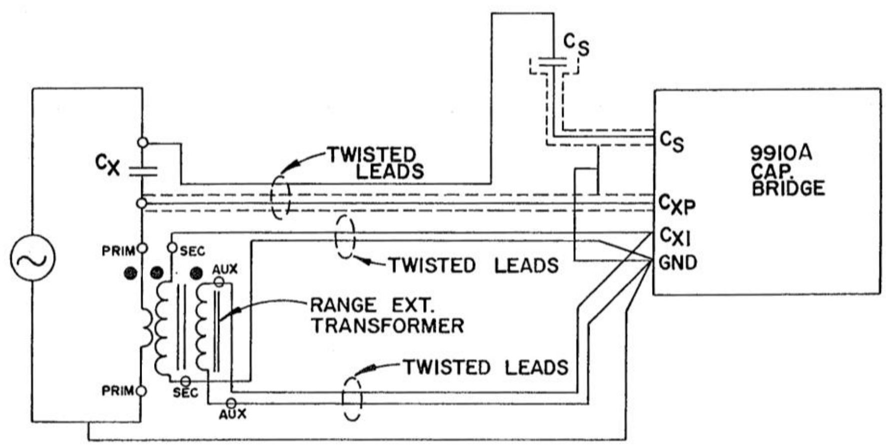

Figure 3-5 : 4 Terminal Measurement With Range Extender

6. Set the C_X TERM SWTICH to position 4 (four terminal connection with lead compensation).
7. Set the RANGE switch to the appropriate range and the Cx / Cs dial to step ten (X).
8. Turn the ON/OFF power switch to the ON position.
9. Press the DC LEVEL ADJ button and with a screwdriver, adjust the control below this button to bring the pointer on the Is meter to zero.
10. Turn on the power to the capacitors under test. (At reduced voltage if capacitance ratio is not known).
11. Adjust the “Cx / Cs” dials and “D” dials to reduce the bridge balance to a null on the detector.

Cx / Cs Ratio	Bridge Ratio Switch	Range Extender Winding	Max. Primary Current (A)
2,000	200	Fixed 100 turn primary	10
5,000	500	Fixed 100 turn primary	10
10,000	1,000	Fixed 100 turn primary	10
20,000	200	Feed-through 10 turn primary	100
50,000	500	Feed-through 10 turn primary	100
100,000	1,000	Feed-through 10 turn primary	100
200,000	1,000	Feed-through 5 turn primary	200
500,000	1,000	Feed-through 2 turn primary	500
1,000,000	1,000	Feed-through 1 turn primary	1,000

Table 3-2 : Cx / Cs RATIOS

3.2. VOLTAGE TRANSFORMER CALIBRATION

3.2.1. General Theory

The 9910A Bridge in normal operation measures the current through the "unknown" capacitor in amplitude and phase with respect to the current through the standard capacitor.

If a second and identical standard capacitor were connected in place of the "unknown capacitor and a different supply voltage fed to it, (See Fig. 3-6) then the current through the second capacitor would be proportional to, and 90˚ out of phase with, the voltage supplied.

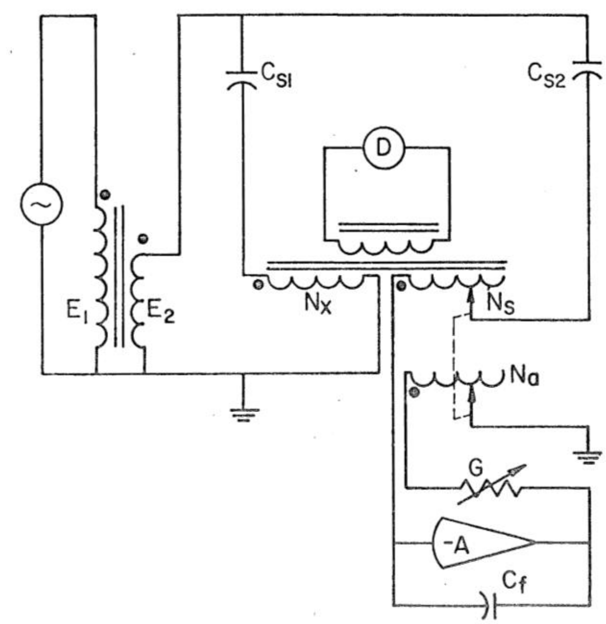

Figure 3-6 : Voltage Transformer Calibration Setup Step I

The bridge in this configuration will measure the voltage ratio:

$$E2 / E1 = (Nx / Ns) \times (1 + jD) \quad (1)$$

Where: Nx / Ns = dial setting.

The voltage ratio in equation (1) is based on using equal known capacitors in the Cs1 and Cs2 positions. In practice, two capacitors of different values may be used and the transformer voltage ratio equation becomes:

$$E2 / E1 = (Cs2 / Cs1) \times (Nx / Ns) \times (1 + jD) \quad (2)$$

The measurement of the **Cs2 / Cs1** ratio must be made separately.

3.2.2. Method of Measurement

1. Connect the voltage transformer and two high quality air or gas dielectric capacitors as shown in Fig. 3-6.

2. Measure the ratio of the capacitors as described in section 3.1.1 or 3.1.2.

$$Cs2 / Cs1 = Nx / Ns \qquad (3)$$

The dissipative factor of these capacitors should not exceed one or two parts per million and can be ignored.

3. Re-connect the circuit as shown in Fig. 3-7 and obtain a balance. The voltage ratio is calculated from:

$$E2 / E1 = (Cs2 / Cs1) \times (Nx / Ns) \times (1 + jD) \qquad (4)$$

Note that the positions of the capacitors Cs1 and Cs2 are interchanged in the two measurements. Cs2 will normally be equal or larger than Cs1 and the larger capacitor must be on the Cx side of the bridge in order to use the RATIO switch for 6 figure resolution.

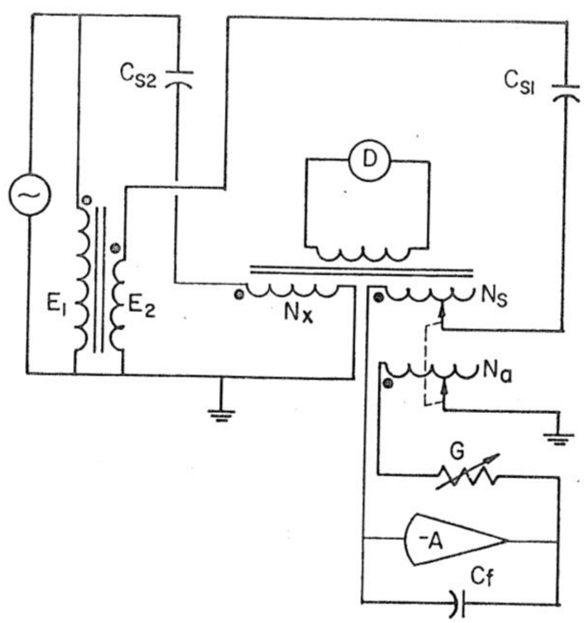

Figure 3-7 : Voltage Transformer Calibration - Step II

3.2.3. Range and Accuracy of Voltage Transformer Measurement

The typical range of voltage transformer ratios that can be measured is indicated in the following Table 3-3.

Transformer Ratio	Cs2 (pF)	Cs1 (pF)	Cs1 (Max. kV)	Bridge Ratio 1	Bridge Ratio 2
1	1000	1000	26	1	1
1,000	1000	1000	26	1	1,000
10	1000	100	260	10	1
10,000	1000	100	260	10	1,000
100	5000	50	520	100	1
100,000	5000	50	520	100	1,000

Table 3-3 : Voltage Transformer Ranges

The same specifications for accuracy of the 9910A Bridge apply to each of the two measurements required for voltage transformers. Any voltage coefficient of the Cs1 capacitor should be taken into account when calculating the voltage ratio from equation (4).

3.3. INDUCTANCE MEASUREMENT

3.3.1. General Theory

The 9910A Bridge with 9911 Range Extender can be used for measuring inductors by reversing the current through the Range Extender primary. This reactive component of current when reversed, is in phase with the current through the standard capacitor and a bridge balance can be obtained with the dials reading in terms of equivalent capacitance ratio.

However, the resistive or in-phase component of current is also reversed and the dissipation factor equivalent will be negative.

The Model 9910A Bridge has the five decades of dissipation factor reversible for this purpose.

3.3.2. Method of Measurement and Calculations

1. Inductance

At balance the inductive component is indicated on the Cx / Cs dials in terms of its equivalent capacitance Cx. The value Cx is given by the following equation.

Cx = (Bridge Ratio) x (Range Extender Ratio) x (Cx / Cs dial reading) x Cx

Or $$Cx = K (r \times Cs) \qquad (5)$$

Where: **K = (Bridge Ratio) x (Range Extender Ratio)**

And **r = Cx / Cs dial reading**

The equivalent reactance of Cx is equal to the reactance of the inductor being measured:

Or $$X_{Lx} = X_{Cx}$$

$$2\pi f L_x = 1 / (2\pi f Cx) \qquad (6)$$

Substituting for Cx from (5)

$$2\pi f Lx = 1 / (2\pi f K r Cs)$$

Or $$Lx = 1 / \left((2\pi f)^2 K r Cs\right) \qquad (7)$$

Note that the accuracy of the 9910A Bridge in the measurement of capacitance ratio does not depend essentially on the accuracy of the frequency. However, in computing inductance the frequency of the supply is the dominating factor, as equation (7) indicates.

2. "Q" Factor

At balance, the admittance of the inductor is measured in terms of the admittance of an equivalent capacitor. The admittance is given by the following equation.

$$G + j\omega C = -1 / (R + j\omega L) \qquad (8)$$

$$= -(R + j\omega L) / \left(R^2 + \omega^2 L^2\right)$$

$$= -R / \left(R^2 + \omega^2 L^2\right) + jwL / \left(R^2 + \omega^2 L^2\right)$$

Note that the negative sign is to account for reversal of the current.

Separating real and imaginary terms gives:

$$G = -R / \left(R^2 + \omega^2 L^2\right) \tag{9}$$

$$\omega C = \omega L / \left(R^2 + \omega^2 L^2\right) \tag{10}$$

Dividing equations **(9) by (10):**

$$G / \omega C = -R / \omega L$$

The dissipation factor and "Q" are given by:

$$D = G / \omega C$$

$$\text{“Q” Factor} = \omega L / R \tag{11}$$

By substituting in equation **(11):**

$$\text{“Q” Factor} = -1 / D \tag{12}$$

3. Range and Accuracy of Inductance Measurement

The range of inductances that can be measured is indicated in Table 3-4:

Cs (pF)	Bridge Ratio	Range Extender Ratio	Max. Inductance for full resolution (H)	Max. Inductor Current (A)
1000	100:1	10:1	7	10
1000	1000:1	1000:1	0.007	1000
100	100:1	10:1	70	10
100	1000:1	1000:1	0.07	1000

Table 3-4 : Inductance Measurement Range

The inductor under test must have a minimum "Q" factor 10 for a null balance to be achieved. The specifications for accuracy of the 9910A Bridge & 9911 Extender are listed in Section 7.

4. THEORY OF OPERATION

4.1. AC CURRENT COMPARATOR

The AC current comparator is a multiple winding toroidal transformer device (see Fig. 4-1) in which the primary and secondary windings carry alternating currents and the detector winding is used for detection of A.C. flux in the core. When the primary and secondary ampere-turns are equal and opposite there is zero resultant A.C. flux in the core. The presence of flux in the core is indicated by a high gain, frequency selective detector in both magnitude and phase.

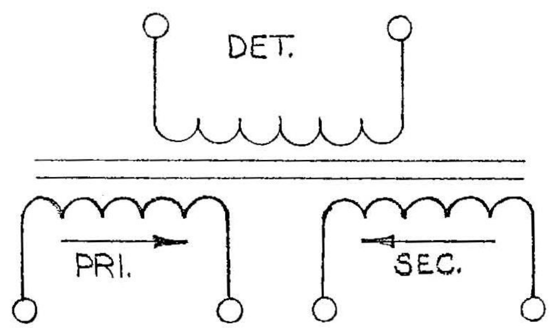

Figure 4-1 : AC Current Comparator

4.2. CAPACITANCE BRIDGE

The measurement of capacitors at voltages greater than 100 volts with a high voltage Schering Bridge (see Fig. 4-2) and is only as accurate as the resistance ratio of the two low voltage elements. The accuracy of the dissipation factor measurements depends on the relative phase angle of the two resistors.

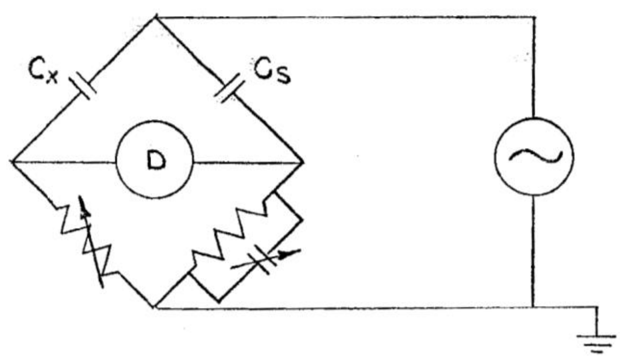

Figure 4-2 : Schering Bridge

For high value of capacitance and a low value standard capacitor, a large resistance ratio must be used and difficulty is experienced in maintaining phase angle equality between these two resistors.

The Current Comparator Capacitance Bridge uses turns ratio in place of resistance ratio and has a fixed accuracy of less than ±15 parts in 10^6 which is not affected by ratios as high as 1000:1.

Figures 4-3 and 4-4 show simplified schematic diagrams of the 10 mA. The 9910A Bridge general schematic is shown in Section 9.

4.3. BASIC OPERATION

4.3.1 Measurement of Capacitance

Two ideal capacitors to be compared are supplied from the same voltage source (Fig. 4-3. The number of turns on the Ns side is varied until the ampere-turns on the Ns and Nx sides are equal and opposite and produce zero flux in the core as seen by the detector winding. Since there is no flux in the core, the Ns and Nx windings have zero reactance and since the winding resistance is negligible in comparison to the reactance of the capacitors, the currents Ix and Is can be calculated as follows:

$$Ix = jE\omega Cx \quad (1)$$

$$Is = jE\omega Cs \quad (2)$$

When detector D indicates zero A.C. flux in the core and:

$$IxNx = IsNs \quad (3)$$

Substituting for Ix and Is in (3):

$$jE\omega CxNx = j\omega CsNs$$

or

$$Cx = CsNs / Nx \quad (4)$$

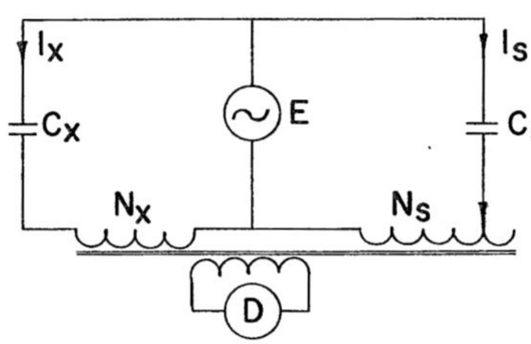

Figure 4-3 : Ideal Capacitors

To maintain the full resolution of the bridge the Nx winding is tapped to enable the Ns / Nx ratio to be made equal to the nominal capacitance ratio Cx / Cs. In this way the bridge has a resolution of 1 part in 10^6 for ratios from 1:1 to 1000:1. Direct adjustment of the number of turns in the Ns winding is practicable only for the first three decades which select comparator turns in groups of 100, 10 and 1.

To achieve six figure resolution by a continuation of this procedure would involve the use of fractional turns which is impossible. The lower three decades of resolution are therefore obtained by switching a known fraction of the Cs current in an additional comparator winding N_A. An amplifier is used to develop a low voltage E_f proportional to and in phase with the supply voltage E (Fig. 4-4). At a bridge balance there is negligible voltage across the Ns windings and with an amplifier of high gain:

$$\mathbf{E_f = E(Cs / C_f)} \qquad \textbf{(5)}$$

Where the current through the N_A winding is:

$$\mathbf{I_A = jE_f\omega C_A} \qquad \textbf{(6)}$$

Substituting for E_f from equation (5):

$$\mathbf{I_A = jE_f\omega Cs(C_A / C_f)} \qquad \textbf{(7)}$$

The contribution to the ampere turns is then reduced by the ratio C_A / C_f **.**

The balance equation becomes:

$$\mathbf{Cx = (Cs / Nx) . [Ns + (C_A / C_f)N_A]} \qquad \textbf{(8)}$$

When the ratio C_A/C_f is adjusted to a suitable decade value, the N_A term in equation (8) becomes an extension of lower range of Ns.

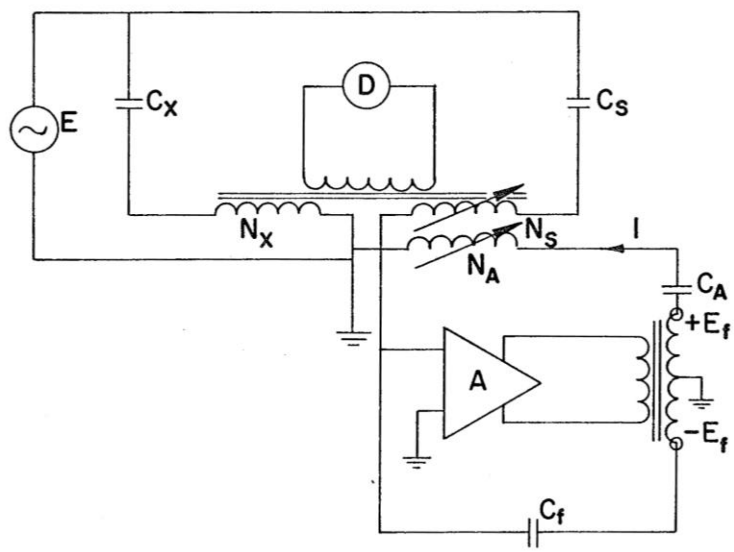

Figure 4-4 : 6 Figure Resolution

4.3.2 Measurement of Dissipation Factor

For measurement of the equivalent loss conductance Gx of the unknown capacitor, the amplifier previously described is used to inject "In Phase" current through Gz as shown in Figure 4-5.

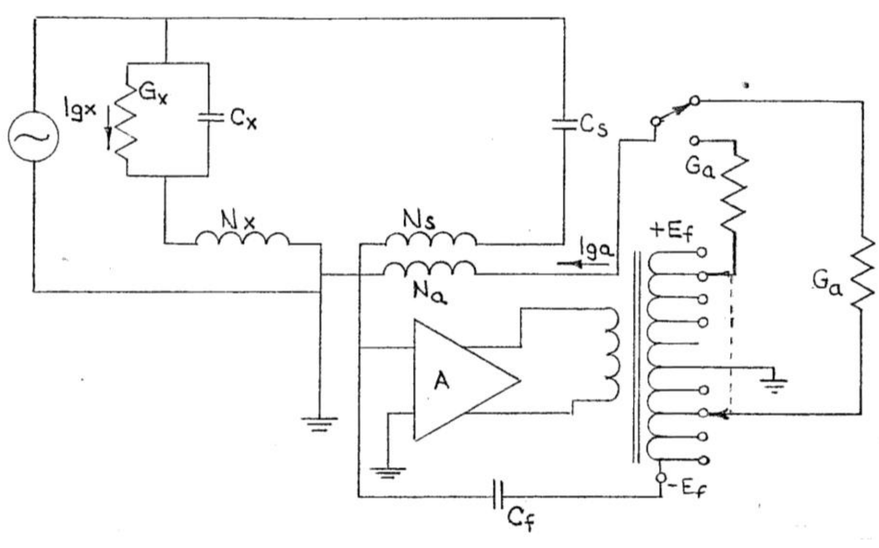

Figure 4-5 : Dissipation Factor

The equations for the “In Phase” component are:

$$\mathbf{Iga = \eta E_f Ga} \qquad \mathbf{(9)}$$

Where η is the fraction of E_f selected.

From equation (5) in section 4.3.1:

$$\mathbf{E_f = E(Cs / C_f)}$$

Substituting this into equation (9):

$$\mathbf{Iga = \eta GaE(Cs / C_f)} \qquad \mathbf{(10)}$$

And: $$\mathbf{Igx = EGx} \qquad \mathbf{(11)}$$

When the detector indicates zero flux in the core:

$$\mathbf{IgxNx = IgaNa} \qquad \mathbf{(12)}$$

Substituting from equations (9) & (11):

$$\mathbf{EGxNx = \eta GaNaE(Cs / C_f)}$$

$$\mathbf{Gx = \eta Ga[CsNa / C_f Nx]} \qquad \mathbf{(13)}$$

It is customary to express the conductance in terms of the dissipation factor D:

$$\mathbf{D = Gx / \omega Cx}$$

Where: $$\mathbf{Cx = Cs(Ns / Nx)}$$

From (4) & (13) then:

$$\mathbf{D = \eta Ga[CsNa / C_f Nx] \,.\, [nx / \omega CsNs]} \qquad \mathbf{(14)}$$

And: $$\mathbf{D = [\eta Ga / \omega C_f] \,.\, [Na / Ns]} \qquad \mathbf{(15)}$$

The dissipation factor D is made direct reading by making the ratio Na / Ns constant for all dial settings by coupling the switches for the Ns and Na windings as in Figure 4-6.

Conductance balance is achieved by varying the fraction of E_f applied through the conductance Gz.

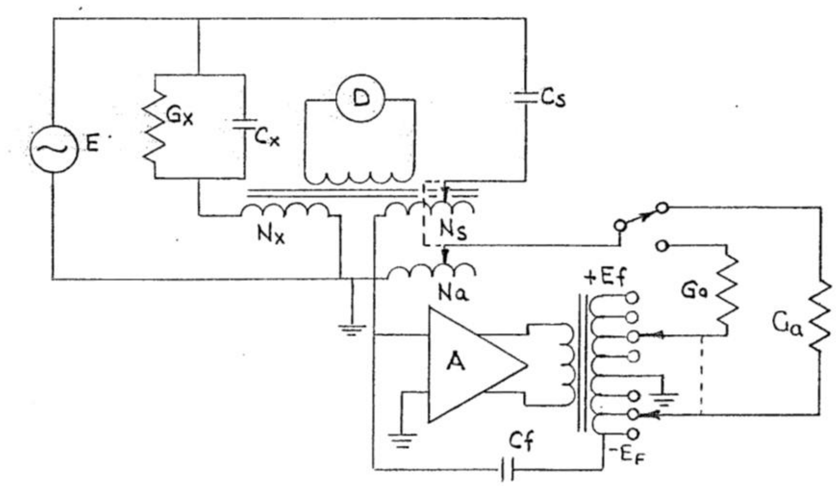

Figure 4-6 : Dissipation Factor, Direct Reading

The capacitance range of the 9910A Bridge as described is 1:1 to 1000:1 where the 1000:1 range is obtained by using a single turn in the Nx winding in conjunction with 1000 turns in the Ns winding of the comparator. The resolution of 1 part in 10^6 of nominal ratio is then provided.

The dissipation factor D range is 11.1110 % or 0.111 110 with a resolution of 0.000 001 or 1 part in 10^6.

4.3.3 Range Extender, MODEL 9911

The model 9911 Range Extender is a two-stage current transformer which is cascaded to the Bridge as shown in Fig. 4-7. Capacitors as large as 1000 *u*F can be measured against a 1000 pF standard by use of the 1000:1 ratio of the Range Extender to give an overall ratio of 1000,000 : 1).

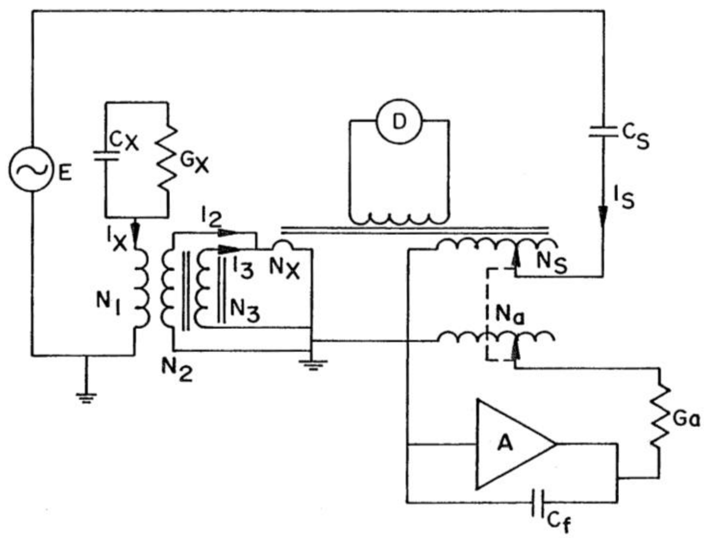

Figure 4-7 : Range Extender

The errors of this specially constructed current transformer when working into the almost short circuit single turn Nx winding does not exceed a few parts in 10^6. The range Extender has two cores and three windings. The primary (N_1) and secondary (N_2) and the outer core, function as an ordinary current transformer. Flux established in the outer core overcomes the voltage drops in the secondary winding and leads. The small current flowing in the auxiliary secondary (N_3) tends to reduce the flux in the inner core to zero. Thus the ampere-turns with respect to this core are virtually balanced and the current ratio $(I_2 + I_3)/ I_x$ corresponds very closely to the turns ratio N_1 / N_2.

The capacitance balance equation of the bridge in Fig. 4-7 is:

$$\mathbf{Cs = Ns\left[(Cs / Nx) \, . \, (N_2 / N_1\right]} \qquad \textbf{(16)}$$

At any one range of the bridge the ratio (N_2 / N_x) is constant and the bridge is still direct reading. The maximum C_x current is 1000 amps at a ratio of a million to one, and the feed-through turn N_1 should be heavy enough to carry the charging current of the measured capacitor.

4.3.4 Lead Impedance Compensation

When very large capacitors are measured, the impedance of the capacitor is small and lead impedance can no longer be considered negligible. While the lead impedances in the standard capacitor are below 1 x 10^{-7} of the standard capacitor impedance, the internal impedance of the current comparator winding may be as high as several parts in 10^6 of the standard capacitor impedance.

For accuracies approaching a few parts in 10^6, lead compensation is required. By connecting the high voltage lead of the standard capacitor Cs directly to the high voltage terminal of the measured capacitor as shown in Fig. 4-8 the impedance Z_1 can be considered as part of the source impedance and can be ignored. Since the current through Cs is negligibly small, the effect of Z_3 can also be ignored.

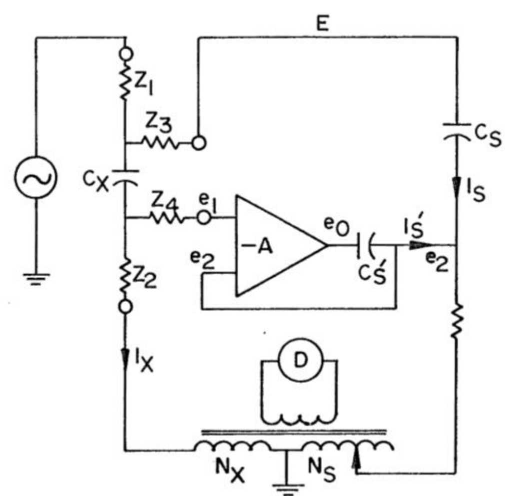

Figure 4-8 : Lead Impedance Compensation

If amplifier A has high input impedance and small output impedance, then at balance:

$$IxNx = Ns(Is + Is')$$

And: $$j\omega CxNx(E - e_1) = j\omega CsNs(E - e_2) + j\omega Cs'Ns(e_0 - e_2)$$

And: $$Cx = Cs(Ns / Nx)\{[(E - e_2)(1 + (Cs'/Cs) + (e_0Cs'/Cs))] / (E - e_1)\} \quad (17)$$

By making the voltage term in (17) equal to unity the balance equations revert to the following simple form:

$$Cx = Cs(Ns / Nx)$$

The lead compensation amplifier circuit in the bridge has the necessary characteristics to make the voltage term bracketed in equation (17) equal to unity, with a control to adjust the compensation for two values of standard capacitor.

4.3.5 Accuracy And Resolution

The 9910A Bridge is a ratio measuring device. While its accuracy is better than 15 parts in 10^6 of full range the final accuracy that may be realized is dependent upon the accuracy and stability of the standard capacitor used as a reference. In order to get the true value of the unknown it is necessary to add algebraically the error of the standard to the measured value of Cx.

Example: **Cs = 100.004 pF**
Dial Reading Cx / Cs = 0.100 056
Ratio Dail = 10:1
Cx = 100.056 – 0.004
Cx = 100.052 pF

If the dial reading was 0.X00560 and the multiplier was 1:1 one figure more resolution would be achieved. In this measurement, the symbol X on the dials indicates a full decade, therefore a reading of 0.X00560 equals 1.000560).

The example is only for errors of the standard which are less than 1000 parts in 10^6. For errors larger than 1000 parts in 10^6, divide the dial reading by Cs.

5. VERIFICATION AND CALIBRATION

The model 9910A is calibrated at the factory using a ratiometric buildup process using a stable bank of capacitances with a suitable voltage source. The Guildline model 99100 Capacitance Reference can be used to perform this type of calibration.

A 1:1 ratio verification can be performed with two standard capacitors of near equal value. The basic bridge ratio and D factor offset may be checked by first measuring the two capacitors in one direction and then reversing the capacitors and making a second measurement. The one half difference of the inverse of one ratio to that of the other measurement should be less than 10 parts in 10^6 of full scale ratio and D factor.

6. TROUBLESHOOTING, MAINTENANCE AND CHECKS

The 9910A Bridge requires very little maintenance. It is recommended that the basic verification be performed periodically to maintain confidence that the unit is capable of making accurate measurements.

Where a problem is experienced the main checks should be the +/- 15 Volt power supplies and a careful examination of the coaxial cables being used as well as the various connectors on the back of the main chassis. A schematic is provided for troubleshooting requirements.

7. SPECIFICATIONS

Direct-Reading Capacitance:	(1:1 nominal ratio), 1.111,110 in steps of 0.000,001 (1 ppm of full scale)		
Direct Reading Dissipation Factor:	-0.110999 to +0.110999 in steps of 0.000,001 (1 ppm of full scale)		
Capacitance Decade Scaling Ratios:	1000, 500, 200, 100, 50, 10, 5 , 2 and 1 to 1		
Current Rating:	Max bridge current through 10 mA through standard capacitor. Current through the measured capacitor is dependent on the capacitance ratio and is not the limiting factor		
Power Requirements:	120 V, 60 Hz, 150 W	240 V, 50 Hz, 150 W	Specify at Time of Order
Weight: 140 lbs	64.3 kgs	Dimensions 21.5" W x 26.3"D x 24" H	51 cm x 57cmx 56 cm

	Capacitance Ratio	Dissipation Factor
Bridge Resolution (All ranges at rated current)	1 ppm of full scale	1 ppm of full scale
Linearity	>1 ppm	0.1% of reading
Accuracy[1] For D factors <0.1%	±15 ppm	±15 ppm
Accuracy[1] For D factors up to 10%	±15 ppm (±0.005 x D Factor)	±1% of reading

Note 1: All ranges – capacitance dials at maximum

9910A Inductance Specifications

Typical ranges according to standard capacitance value C_s, Bridge nominal ratio, and Range Extender ratio

Cs	Bridge Ratio	Range Extender Ratio	Approx Max Inductance for 6 Digit Resolution	Max Inductor Current	Ratio Accuracy[1]
1000 pF	100:1	10:1	7 H	10 A	± 15 ppm
1000 pF	1000:1	1000:1	7 mH	1000 A	± 15 ppm
100 pF	100:1	10:1	70 H	10 A	± 15 ppm
100 pF	1000:1	1000:1	70 mH	1000 A	± 15 ppm

Note 1: 9911 Accuracy not included.

9911 Range Extender Specifications

Maximum Primary Current:	1000A
Maximum Working Voltage:	500 V between Secondary and Case
Turns Ratio:	1000:1 / 10:1
Weight: 33 lbs	15 kg

Bridge Range	Burden	Accuracy
X1000	0.04 Ω	± 3 ppm
X500	0.01 Ω	± 5 ppm
X200	0.2 Ω	± 10 ppm
X100	0.4 Ω	± 25 ppm

8. PARTS LISTS

15800-01-40	9910A HV Capacitance Bridge 60Hz 120V
15800-04-40	9910A HV Capacitance Bridge 50Hz 240V
10721-01-02	9910A General Assembly (99104, 60Hz)
10721-02-02	9910A General Assembly (99104, 50Hz)
16538-01-02	Toroid Assembly 9910A, 60Hz
16538-02-02	Toroid Assembly 9910A, 50Hz
18070-01-02	10 mA Terminal Board Assembly 60 Hz
18070-02-02	10 mA Terminal Board Assembly 50 Hz
10708-01-02	Front Panel Assembly (99104)
10429-03-02	Power Supply PCB
15762-01-02	Main Bridge Amplifier PCB
11909-01-02	9910A Spare Parts KIT (60Hz 120V)
11909-02-02	9910A Spare Parts KIT (50Hz 240V)

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9. DRAWINGS

10721-01-04	High Voltage Capacitance Bridge General Schematic

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