UNIVERSAL BRIDGE B221

AND

LOW IMPEDANCE ADAPTOR Q221

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CONTENTS (Part I - B221)

(Continued overleaf)

CONTENTS (Part 2 - Q221)

ILLUSTRATIONS (Part 1 - B221)

ILLUSTRATIONS (Part 2 - Q221)


WAYNE KERR
Universal Bridge B221
3 6·3 µMho
4
·0 0 4 1 8 µF
Range
G
-1
1
0·1
C
1
-1
Supply
Sensitivity
E
Trim G
Trim C

Part 1 - Universal Bridge B221

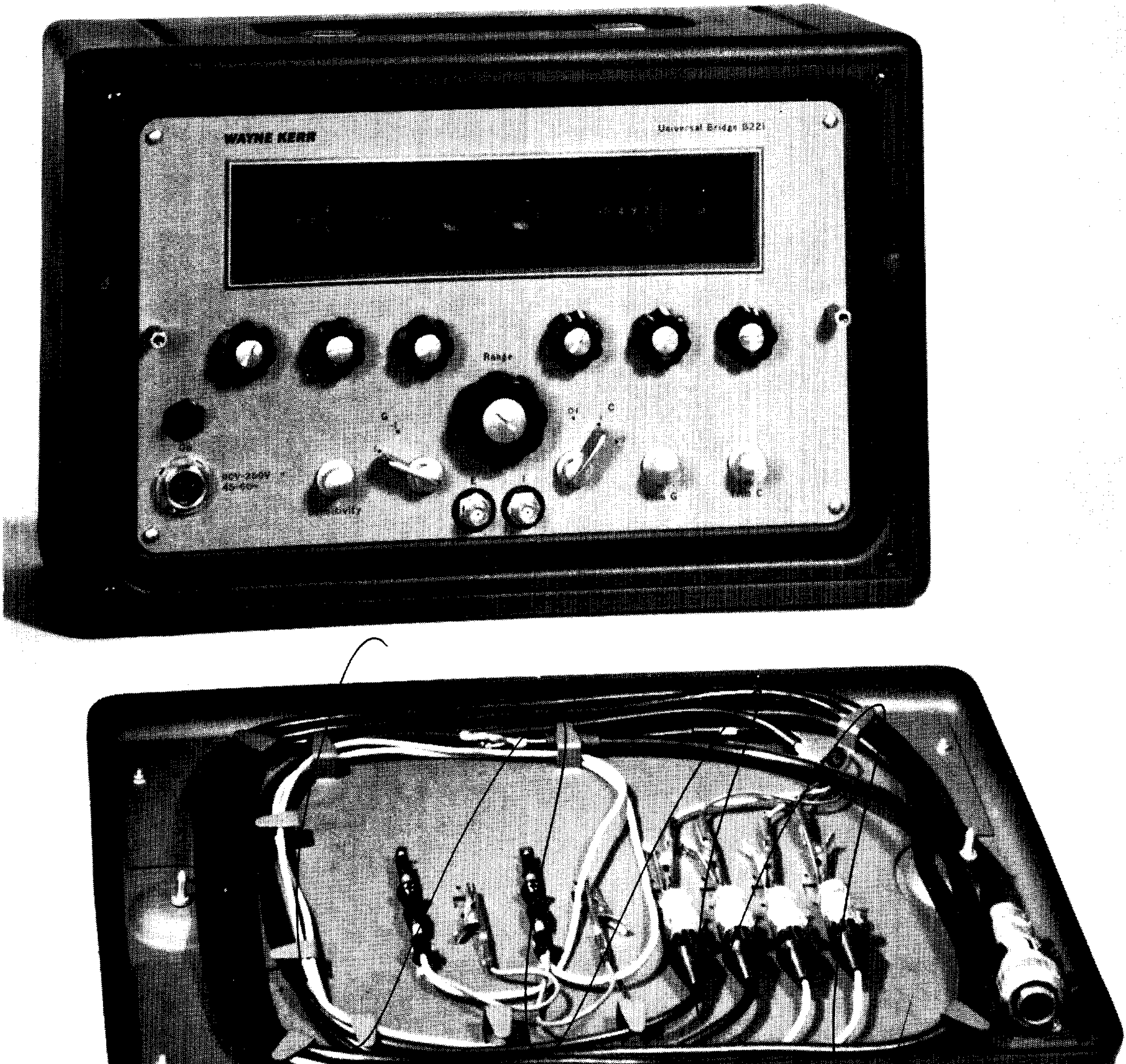
INTRODUCTION

Universal Bridge B221 operates at audio frequencies and provides accurate values for all types of electrical components over an extremely wide measurement range. The internal Standards are of conductance and capacitance, but the Bridge measures positive or negative conductance or resistance, together with capacitance or inductance. Two displays provide, simultaneously but without any interaction, values for the resistive and reactive terms of any Unknown, including all cyphers, the decimal point and the units of measurement.

The Bridge has an internal source and detector operating at a fixed frequency (normally 1592 c/s to simplify calculations involving $2\pi f$) but can be operated with an external source and detector at any audio frequency. Suitable instruments for this purpose include the Wayne Kerr Audio Signal Generator S121 and (above 100 c/s) Waveform Analyser A321. Full details of these instruments are available separately: their use with the B221 Bridge is described in this Manual.

A valuable property of the Bridge is its ability to make accurate measurements even when long connecting cables are used and whilst the component under test remains connected in a circuit. Thus, remote measurements can be undertaken when environmental tests are to be made on components situated in ovens, refrigerators and pressure or humidity enclosures. Further, individual components forming part of a printed circuit board or encapsulated assembly can be measured without disconnecting them from the associated wiring and components. This facility is achieved by using the Neutral terminals of the Bridge, enabling any arm of a delta-network to be measured in the presence of the two other arms.

This (the third) issue of the Instruction Manual has been revised to present a more straightforward operating procedure, and the Manual is now produced in two parts. Part 1 deals with the Universal Bridge and Part 2 with the Low Impedance Adaptor Q221, these two parts each including the relevant information on operation with an external source and detector.


WAYNE KERR
Universal Bridge B221
Range
G
C
G
C

BRIDGE SET, UNIVERSAL, CT530

10S/6625-99-948-8768

The Services version of Wayne Kerr Universal Bridge B221 is designated B221S and has the Service reference number CT530. Performance of the two instruments is identical but, in addition to certain internal constructional differences which do not affect the information contained in this Manual, there are certain external differences.

1 CT530 is supplied (see facing illustration) with a lid suitable for housing all the measurement cables and the power input cable. The lid can be attached to the front panel for transit purposes or to the rear panel whilst the instrument is in operation.

2 Power input to the CT530 is by means of a Plessey Mk. IV connector on the front panel in place of the moulded three-pin connector which is fitted to the rear panel of the Commercial instrument.

3 In place of the illuminated push on/push off button for a.c. power, the CT530 has a toggle switch. The two magic eyes provide a visual reminder that the instrument is switched 'on'.

4 Low Capacity Clip Leads are supplied as standard equipment with CT530 (these are optional extras for the Commercial instrument).

Bridge Set, Universal, CT530, does not include Low Impedance Adaptor Q221.

SPECIFICATION

Measurement Ranges

R (+ve or −ve)			G (+ve or −ve)			Range	C (× 1)*			L (1592 c/s)‡		
Min (0·1%)	Max for 0·1%	First Divsn	First Divsn	Min for 0·1%	Max (0·1%)		First Divsn	Min for 0·1%	Max (0·1%)	Min (0·1%)§	Max for 0·1%§	First Divsn
9MΩ	100MΩ	50,000MΩ	·00002μmho	·01μmho	·111μmho	1	·002μμF	1μμF	11·1μμF	900H	10kH	5MH
0·9MΩ	10MΩ	5,000MΩ	·0002μmho	·1μmho	1·11μmho	2	·02μμF	10μμF	111μμF	90H	1kH	0·5MH
90kΩ	1MΩ	500MΩ	·002μmho	1μmho	11·1μmho	3	·2μμF	100μμF	1111μμF	9H	100H	50kH
9kΩ	100kΩ	50MΩ	·02μmho	10μmho	111μmho	4	·000002μF	·001μF	·0111μF	0·9H	10H	5kH
900Ω	10kΩ	5MΩ	·2μmho	100μmho	1111μmho	5	·00002μF	·01μF	·111μF	90mH	1H	500H
90Ω	1kΩ	500kΩ	·002mmho	1mmho	11·1mmho	6	·0002μF	·1μF	1·11μF	9mH	·1H	50H
9Ω	100Ω	50kΩ	·02mmho	10mmho	111mmho	7	·002μF	1μF	11·1μF	0·9mH	10mH	5H

Accuracy	±0·1% (see Table). On Ranges 6 and 7, corrections must be made for the leads.
Discrimination	G and C: 0·02% of Maximum (see Table). R and L: 0·02% of Minimum (see Table).
Source Frequency	Internal: 1592c/s ($\omega = 10^4$) ± 1%. (Other frequencies to special order). External: 50c/s – 20kc/s.
Power Requirement	100 – 125V or 200 – 250V, 40 – 60c/s. Consumption approximately 25W.
Dimensions	Width: 17 in. (43 cm.). Height: 11½ in. (29 cm.). Depth: 7½ in. (19 cm.).
Weight	25 lb. (11 kg.).

The extension of the measurement ranges obtained with Adaptor Q221 is specified in Part 2.

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* All figures become one-tenth of values quoted when C switch is set to 0·1.

‡ Frequency-dependent: $L = 1/\omega^2 C$.

§ Accuracy of 0·1% applies if source frequency is measured: otherwise 2% applies.

OPERATING INSTRUCTIONS

SETTING UP

Power Requirement

Set the voltage selector at the rear of the instrument to the appropriate tapping for the supply voltage. Connect the power cable to a suitable plug [green to ground (earth), red to live and black or blue to neutral]. The instrument will operate from supplies of 100-125V and 200-250V, 40-60 c/s, and consumes approximately 25 watts. The Bridge is switched on or off by pushing the Supply button on the front panel.

Measurement Cables

The Bridge is supplied with two screened measurement cables, each terminated in a pair of crocodile clip leads. One cable (E) is associated with the voltage transformer on the source side of the Bridge: the other cable (I) is associated with the current transformer on the detector side of the Bridge circuit. In each case the green lead is connected to the screening (braid) and these leads are the two Neutral connections. The exposed metal sleeve between the two moulded sections is also connected to Neutral.

If Low Capacity Clips are to be used, these should be connected to the E and I sockets of the Bridge in place of the normal measurement cables. Again the Neutral connections are provided by the green crocodile clip leads.

Trimming

Link together the two Neutral leads. This can be achieved by clipping the green lead from one cable on to the green clip lead or metal sleeve of the other cable. Do not make any connection other than this. Turn the Range switch to position 7 (the number appears between the two magic eyes) and set all six decade controls to zero. Set the G and C switches to '1' and turn the Sensitivity control to an approximate mid-position. Adjust the Trim G and Trim C controls for maximum shadows on the magic eyes, finally increasing the sensitivity to maximum (fully clockwise). This trimming adjustment will hold good for all Ranges from 7 down to 3.

If the Range switch is turned to position 2 or 1, the trimming operation should be repeated on this Range. When either of these two Ranges is used, maximum accuracy will be obtained by substituting Low Capacity Clip Cables for the normal measurement cables. Whichever type of connection is employed, it is important (on Ranges 1 and 2) to arrange that the measurement leads are laid out for the trimming operation in the same relative positions as they will occupy for the actual measurement.

MEASUREMENT PROCEDURE

Connections to Unknown

For normal (*two-terminal*) measurements the Neutrals are linked as described under 'Trimming' and the component under test is connected between the two red clip leads. When the Low Capacitance Clips are used instead of the normal measurement cables, the Neutrals must be linked by connecting together the two green clip leads. The component under test is then connected between the two spring-loaded end connectors.

For *three-terminal* measurements the two green leads must remain linked and one of these is taken also to the third terminal of the Unknown. The Bridge then measures only the component situated between the two red leads.

Four-terminal measurements are made by separating the two Neutral connections. Input to the component or network under test is then provided by the red and green leads associated with the E cable and the output is applied to the red and green leads associated with the I cable.

Coarse Balance

Set the G switch to '1' for all measurements of positive conductance (or positive resistance). Set the C switch to '1' for capacitance measurements or to '–1' for inductance measurements. The Range switch should remain in position 7.

Adjust the Sensitivity control until the least sensitive (top left) magic eye shadow just begins to open. Rotate the continuously-variable (vernier) G and/or C controls until the magic eyes are seen to open. If this occurs when the controls are moved only slightly from the 0 setting it indicates that the Range switch setting must be reduced from position 7. In this instance the procedure could be repeated on Range 6 or 5.

If (on Range 7) the eyes have not opened when the vernier control(s) are fully clockwise, additional G or C must be inserted by operating the appropriate switched decade controls.

Fine Balance

When, on any range, a first indication of the value of the Unknown has been obtained on the vernier control(s), the Range switch setting can be reduced by two positions and the first and second digits of the value set-up on the appropriate switched decade controls. Re-adjustment of the venier control(s) for maximum shadow will then provide the final balance with a four-figure reading of the major term. As the final balance is approached the Sensitivity control should be advanced progressively until fully clockwise.

Refer to final paragraph of 'Trimming' if the Range switch is moved to positions 1 or 2.

When the approximate value of any component is known before measurement, the appropriate Range and decade settings can be selected in advance. Much of the balance procedure described above can then be omitted.

INTERPRETATION OF RESULTS

When the Bridge is balanced, the two dial displays show values for the Unknown in terms of the equivalent *parallel* components of conductance and capacitance. When inductance is measured, the C multiplier switch will be in the '-1' position and the value of the Unknown is obtained from the C dial, using the expression:

$$L = 1/(\omega^2 C)$$

where $\omega = 2\pi \times$ frequency of measurement.

If the Bridge is operated at the normal frequency of 1592 *c/s*, $\omega^2 = 10^8$.

The equivalent *series* components of the Unknown can be derived from the Bridge dial readings at balance by using the following expressions:

$$R_S = 1/[G_P(1+Q^2)] \qquad (1)$$

$$C_S = C_P(1-1/Q^2) \qquad (2)$$

$$L_S = 1/[\omega^2 C_P(1+1/Q^2)] \qquad (3)$$

The value of Q can be calculated directly from the numerical readings presented by the decade controls without reference to the Range in use, the units of measurement or the position of the decimal point. At 1592 c/s, Q is always equal to the ratio of the numerical reading on the C decades to that on the G decades. For example, if balance is obtained on Range 4 with ·000625 µF and 12·50 µmhos (where the digits underlined are those presented by the decade controls—first C decade at zero in this example) then, ignoring the decimal point, Q = 0625/1250 = 0·5. If the C multiplier switch is on 0·1, the reading on the C decade must be divided by ten before Q is computed.

Note: When the Bridge is operated at 1592 c/s, $\omega^2 = 10^8$. Referring to equation (1), it can be seen that

$$\text{if } Q \ll 1,\ R_S \simeq 1/G_P.$$

Referring to equations (2) and (3), it can be seen that

$$\text{if } Q \gg 1,\ C_S \simeq C_P$$

$$\text{and } L_S \simeq 1/(\omega^2 C_P).$$

G_P and C_P are the Bridge readings of the equivalent parallel components.

Tables of reciprocals are provided at the end of this Manual.

SOURCE

The internal source operates at 1592 c/s ±1 per cent. This value was chosen to simplify calculations, since $2\pi f$ (or ω) is 10^4.

When it is desired to operate the Bridge at frequencies other than 1592 c/s, an external source can be employed. This should be capable of providing an output of 10-30V r.m.s. into an impedance of approximately 20kΩ. The larger output is required at low frequencies but the input to the Bridge must never exceed 40V r.m.s. The frequency coverage available depends on the measurement accuracy desired and the following figures provide a guide to this.

200c/s–10kc/s: Better than ±0·25%
100c/s–200c/s and 10kc/s–15kc/s: Better than ±0·5%
50c/s–100c/s and 15kc/s–20kc/s: Better than ±1%

The source output should have a low harmonic content and *any d.c. component must be blocked externally*. Wayne Kerr Audio Signal Generator S121, which covers 10c/s to 120kc/s, is an ideal instrument for this function. The external source is connected to the Bridge by means of a screened cable, using the jack and socket provided on the rear panel. Insertion of the plug automatically disconnects the internal source from the Bridge circuits.

DETECTOR

The internal detector is a two-stage amplifier tuned to 1592 c/s. One magic eye indicator is connected to a point between the two stages and the second magic eye is connected to the output of the second stage. Each magic eye has two shadows, of differing sensitivity. Thus, four degrees of sensitivity are available at any one time and a front-panel control enables the overall sensitivity to be varied. When the Bridge is balanced, the shadows are at a maximum (i.e. the eyes are open).

When the Bridge is operated with an external source at frequencies other than 1592 c/s, an external detector must also be provided. This must operate satisfactorily from an input falling to 10-20µV near balance and should have an input impedance of not less than 100kΩ. It is essential to employ a tuned amplifier, adjusted to the same frequency as the source, as this minimizes the effect of harmonics masking the point of balance at the required frequency.

When measurements are made at the lowest frequency (50-200c/s) the sensitivity required is 1 to 5 microvolts. In general it is preferable to use a high-gain detector to obtain the required sensitivity, rather than to increase the source voltage. Wayne Kerr Waveform Analyser A321 (covering 20c/s to 20kc/s) is suitable for use as an external detector above 100c/s. Connection to the external detector must be made with screened cable, using the jack and socket provided on the rear panel. Insertion of the plug automatically disconnects the internal detector from the Bridge circuits.

Note: When an external source and detector are in use, the Bridge should be disconnected from the a.c. power supply.

Certain bridges must be modified slightly before they are used with an external source and detector. The instruments affected are all serial numbers from 1293 to 1440 inclusive, except 1366, 1383 and 1428. Also affected are the following: 1443, 1444, 1445, 1446, 1448, 1456, 1460, 1462, 1463 and 1466. The modification needed on these instruments is as follows:

1. Remove both jacks from the rear panel and expose the wiring.
2. Strap together the two jack contacts nearest to the rear panel i.e. two metal braids. Repeat on the other jack.
3. Re-assemble with the aluminium screens on to the rear panel.

TEST JIGS

It is possible, within the limits of the trimming controls, to balance out the conductance and stray capacitance of test jigs, etc. An accurate absolute measurement of the component under test can therefore be made. With the test jig alone connected to the measurement leads the Trim controls should be adjusted on the range to be used for measurement. If the component is now connected to the jig, its correct value can be measured directly.

LEAD CORRECTIONS

When the Bridge is used for the measurement of conductances exceeding 10 millimhos (resistances of less than 100 ohms), capacitances exceeding 1 microfarad* or inductances of less than 10 millihenrys*, an allowance must be made for the series resistance and inductance of the measurement cables and the bridge transformers.

The *total* values for the two cables can be taken as 0·14 ohm and 1·5 microhenrys. The corresponding values of resistance and inductance (also reactance) for the two Bridge Transformers can be obtained from Tables 2 and 3, (page 17). The procedure for applying the correction is as follows.

The Bridge readings must first be converted from the *parallel* to the equivalent *series* components, and the correction is applied more easily if made in terms of resistance and reactance.

Let the Bridge readings be G and $+C$ or $-C$.

Then parallel components of resistance (R_p) and reactance (X_p) are given by:

$$R_p = 1/G \qquad \text{and} \qquad X_p = 1/2\pi fC$$

Equivalent *series* components are given by:

$$R_s = R_p/(1+Q^2) \quad \text{and} \quad X_s = \pm X_p/(1+1/Q^2)$$

where $$Q = R_p/X_p.$$

The corrected series values are obtained by subtracting the total resistance (leads+transformers) from R_s, and by subtracting the reactance of the total inductance (leads + transformer leakage) from X_s, [i.e. corrected series reactance $= X_s - 2\pi f$ (inductance of leads + leakage inductance of Bridge transformers)]. Denoting these true series values by R_{ST} and X_{ST}, the result can be converted back to the *parallel* components, if desired, by the expressions:

$$\text{True } R_p = R_{ST}(1+Q^2) \text{ and}$$

$$\text{True } X_p = X_{ST}(1+1/Q^2).$$

When X_s represents inductive reactance, the true value, X_{ST}, will be less than X_s.

When X_s represents capacitive reactance, this must be regarded as negative. The true value in this instance will be more negative by the amount [$2\pi f$ (inductance of leads+leakage inductance of Bridge transformers)].

MAJOR AND MINOR TERMS

The Range Switch operates on G and C simultaneously and the maximum values on each Range are such that

$$G_{max} = \omega C_{max}$$

$$(\text{or } R_{min} = 1/\omega C_{max}).$$

On any given range the larger of the two readings (G and C) is the major term of the Unknown and the smaller reading is the minor term. It will be realised that when the Range switch setting has been progressively reduced until a four-figure reading is obtained for the major term, the minor term may show as less than four significant figures. For many applications this is no limitation since the reduced reading accuracy is associated with the term which, in itself, is usually of less importance. However, it is possible to obtain a capacitance range 1/10th of normal by setting the C multiplier switch to the 0·1 position. Use of this facility provides increased reading accuracy for the minor term when this is the reactive component. When the C switch is set to 0·1, the Bridge dial reading of capacitance must be *divided* by 10.

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* That is, reactance less than 100 ohms. Values quoted apply at 1592 c/s and must be computed for other measurement frequencies. The effect of shunt loading is described on page 16 ('In Situ Measurements').

CERAMIC CAPACITORS

With certain capacitors the value changes considerably with the value of d.c. polarizing voltage. In such instances a polarizing potential can be applied as shown in Fig. 1. The blocking capacitor should have a value at least 100 times that of the Unknown.

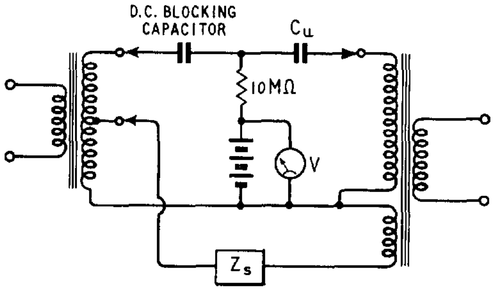


Fig. 1. Polarizing Ceramic Capacitors

ELECTROLYTIC CAPACITORS

The alternating potential applied across capacitors being measured on the Bridge is so low that it is generally unnecessary to polarize them. If it is necessary to measure them with a d.c. potential applied, the arrangement shown in Fig. 2 can be used. The two capacitors, C, should be reasonably matched and of known value, very much smaller than C_u. The Unknown capacitance is given by

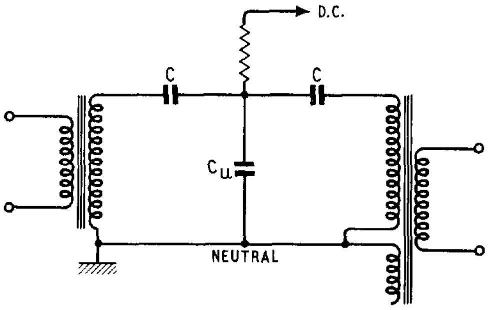


Fig. 2. Polarizing Electrolytic Capacitors

$$C_u = C^2/C_m$$

where C_m is the value measured on the Bridge. The phase-shift introduced by this circuit may necessitate setting the G multiplier switch to -1 when balancing out the losses.

LOSS ANGLE

The loss angle or power factor of capacitors can be computed from the values measured on the Bridge.

$$\tan\delta = G/\omega C$$

$$\cos\varphi = G/Y \simeq G/\omega C = \tan\delta$$

An allowance for the impedance of the measuring leads must be made when dealing with large-value capacitors. This is described on page 13.

IRON-CORED INDUCTORS

Great care must be taken when interpreting the results obtained from measurements on iron-cored coils and transformer windings. With mains transformers, for example, the core will have only its initial permeability due to the low value of the a.c. potential applied from the Bridge. The effective permeability at full operating voltage may be as much as twenty times higher.

With high-permeability materials such as mu-metal, the effective permeability changes so rapidly with excitation, even at very low levels of magnetization, that widely different values of inductance may be obtained on different ranges of the Bridge or even on two Bridges of the same pattern. Therefore, unless the operating conditions are simulated, the measurements made are of value only for comparison purposes.

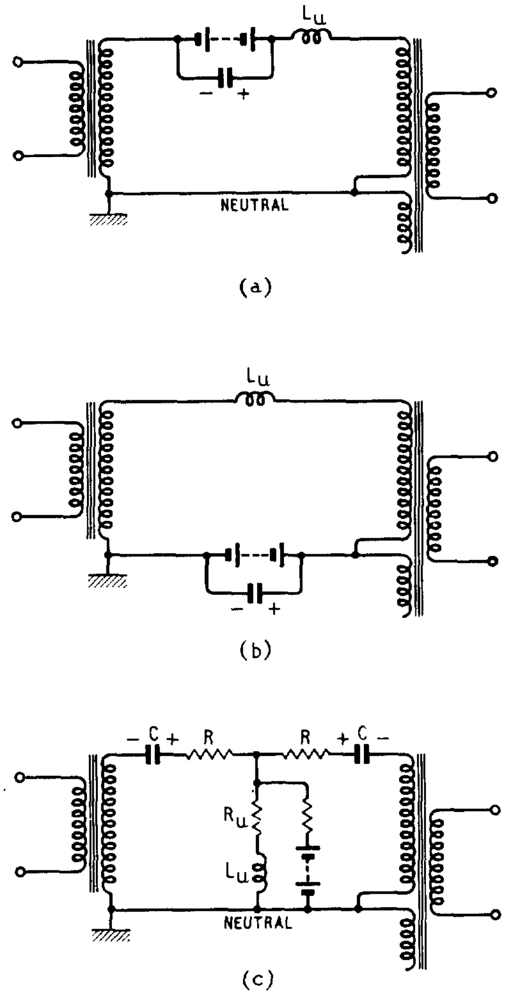
INDUCTORS PASSING D.C.

It is often necessary to measure inductors carrying a known value of direct current and three ways of doing this are shown in Fig. 3. In Fig. 3(a) the d.c. supply, with a large-value capacitor by-passing it, is connected in series with the inductor being measured. This arrangement cannot be used, however, if one terminal of the d.c. supply is connected to Ground, as this would short-circuit the Bridge voltage transformer. The maximum values of current that may be passed through the Bridge are given in Table 1. Under no circumstances must these values be exceeded.

TABLE I

MAXIMUM PERMISSIBLE CURRENT THROUGH BRIDGE

Range	1	2	3	4	5	6	7
Max. D.C.	50mA	50mA	0·5A	0·5A	1·0A	1·0A	1·0A



(a)

(b)

(c)

Fig. 3. Inductors Passing D.C.

With the arrangement shown in Fig. 3(b) the d.c. supply is connected between the two Neutral leads. If one terminal of the d.c. supply is grounded it must be connected to the Neutral of the *E* lead. The limitations on current specified in Table 1 must be observed.

If the reactance of the by-pass capacitor shown in Fig. 3(a) and (b) is significant, it can be allowed for by calculating its equivalent inductance value at the Bridge frequency and *adding* this to the effective *series* value derived from the measurement.

Where it is required to pass a current through the inductor in excess of the values given in Table 1, the arrangement shown in Fig. 3(c) may be used. The resistors *R* must have a value of 50 to 100 times the impedance of the Unknown, and the capacitors *C* a reactance which is low compared with the value of *R*. The *T*-network may then be regarded as equivalent to a capacitor in parallel with a resistor connected straight across the Bridge. The equivalent *series* components of the Unknown are given by:

Series Resistance, $R_u = R^2.G_m$

Series Inductance, $L_u = R^2.C_m$

where G_m and C_m are the values measured on the Bridge.

SCREENED COMPONENTS

When resistors or capacitors are enclosed in metal cases and one terminal of the component is connected to the case, this terminal should be connected to the *E* lead from the Bridge. This method of connexion ensures minimum stray pick-up by the case and the component can then be measured in the usual manner.

When measuring sub-standard three-terminal capacitors, care must be taken to ensure that the conditions of measurement are the same as those under which the capacitor was calibrated. A three-terminal capacitor is shown schematically in Fig. 4. In addition to the main capacitance between the high- and low-potential terminals (*H* and *L*) there is the stray capacitance between each terminal and the metal case, *E*. Calibration is normally carried out with the low-potential side joined to the case. Under these conditions the stray capacitance between the *L* terminal and the case is shorted out, leaving the capacitance between *H* and the case in parallel with the main capacitance between *H* and *L*.

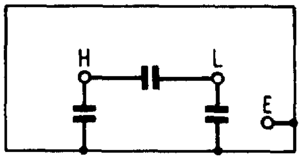


Fig. 4. Three-terminal Capacitor

If the sub-standard is connected to the Bridge with the case connected to Neutral, *both* stray capacitances in the sub-standard will be neutralized and the reading obtained will be low. To this reading must be added the capacitance between *H* and the case. This can be measured on the Bridge by connecting the case to the voltage (*E*) lead from the Bridge, the *H* terminal to the current (*I*) lead and the *L* terminal to Neutral.

TEMPERATURE COEFFICIENTS

Since leads of any length may be used without their capacitance affecting the accuracy of the reactance measurement, and as lead resistance can be allowed for (see page 13), the Bridge is ideally suited to the measurement of temperature and other coefficients of components placed in an oven, refrigerator, pressure chamber, humidity chamber, etc. If full use is made of the decade controls, the discrimination of balance is 0·01 per cent of maximum for the range in use.

IN SITU MEASUREMENTS

It is often convenient to be able to measure an impedance *in situ*, without disconnecting any other components which may be associated with it. This applies particularly when components form part of a printed circuit or encapsulated assembly. Moreover, with certain test jigs, it is often impossible to 'disconnect' the effective shunt and stray capacitances. Generally speaking, any circuit can be resolved into a three-terminal network, the arrangement being as shown in Fig. 5.

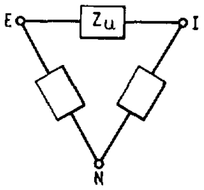


Fig. 5. Three-terminal Network

The impedance to be measured is Z_u and the effect of impedances E–N and I–N must be removed. The arrangement can be considered as a π-network and is shown in Fig. 6 in this form, connected to the Bridge. Z_{EN} shunts the voltage transformer and Z_{IN} shunts the current transformer. In many instances these shunting effects may be disregarded (for reasons given under 'Principle of Operation'). In Fig. 7, for example, it may be possible to measure the impedance between A and B without disconnecting the other components simply by connecting point C to the Bridge Neutral.

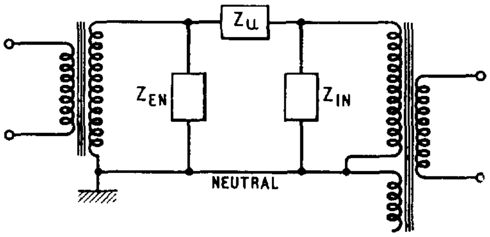


Fig. 6. Three-terminal Measurements.

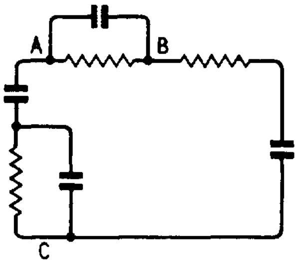


Fig. 7. In Situ Measurements

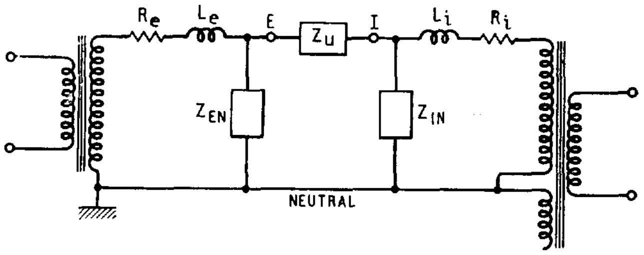


Fig. 8. Shunting Effect

Important: *Under no circumstances must the inner of either measurement lead be connected to Ground while the green wire of the Bridge power cable is grounded.* The Neutral circuit of the Bridge is grounded internally and such action would short-circuit both Bridge transformers.

When it is necessary to connect either measurement lead (inner of E or I) to the chassis or framework of the equipment under test, this equipment must first be isolated from Ground. If this is not practicable, the Bridge must be isolated from Ground by disconnecting the green wire of the power cable from the Ground pin of the plug. Care must be exercised while operating the Bridge in this condition and the Ground connexion should be replaced when isolation is no longer necessary.

When the shunting effects (Z_{EN} and Z_{IN} of Fig. 6) cannot be ignored, the series resistance and leakage inductance of the Bridge transformers must be taken into account. The measurement circuit must now be drawn as in Fig. 8 and a simple calculation, described in succeeding paragraphs, must be made in order to correct the readings obtained from the Bridge.

The loading effect of the Unknown impedance itself is small and can be ignored. It is only when the shunt impedances are low compared with Z_u that errors arising are of importance. Therefore Z_u can be considered as an open-circuit and the shunting effects on either side of the Unknown can be considered separately.

The fall in potential at E caused by the load Z_{EN} will depend on the ratio of Z_{EN} to the impedance of R_e and L_e, the effective series resistance and leakage inductance of the voltage transformer. A similar argument applies to the current side of the Bridge and the two effects are additive.

Table 2 gives the average values of effective resistance and leakage inductance of the windings for each tapping. When it is necessary to correct for shunt loading the following formulae may be used to calculate the true value of impedance, Z_u, from the value read on the Bridge, Z_m.

With loading on the voltage transformer only:

$$Z_u = (1 - Z_e/Z_{EN}).Z_m$$

where $Z_e = R_e + j\omega L_e \ (\omega = 10^4)$.

With loading on the current transformer only:

$$Z_u = (1 - Z_i/Z_{IN}).Z_m$$

where $Z_i = R_i + j\omega L_i$.

With both transformers loaded:

$$Z_u = [1 - (Z_e/Z_{EN} + Z_i/Z_{IN})].Z_m.$$

TABLE 2

Turns (Tap)	Voltage Transformer (T1)			Current Transformer (T2)		
	R_e	L_e	X_e	R_i	L_i	X_i
1	0·025Ω	0·36μH	0·0036Ω	0·017Ω	0·63μH	0·0063Ω
10	0·025Ω	0·36μH	0·0036Ω	0·032Ω	0·9μH	0·009Ω
100	1·2Ω	18·0μH	0·18Ω	1·54Ω	46·0μH	0·46Ω
1000	72·0Ω	1·44mH	14·4Ω	68·0Ω	1·02mH	10·2Ω

If the loading is at the end of leads, add 75·6 milliohms and 0·3μH per yard of Uniradio 32. The transformer taps in use for the various ranges are given in Table 3.

TABLE 3

RANGE	TRANSFORMER TURNS	
	Voltage (T1)	Current (T2)
1	1000	1000
2	100	1000
3	100	100
4	10	100
5	10	10
6	1	10
7	1	1

NETWORK CHARACTERISTICS

The facility for three-terminal measurements and the readiness with which either or both the conductance and reactance Standards can be made effectively negative merely by switching to a winding of reverse sense, make the Bridge a most efficient instrument for measuring the characteristics of networks. Transfer admittance, for example, is measured simply by the arrangement shown in Fig. 9. The input of the network is connected between the voltage terminal and Neutral. The output is connected, in series with its terminating resistance R_T, between the I lead and Neutral. The right-hand side of R_T will be at Neutral potential when the Bridge is balanced and the network will then be correctly terminated.

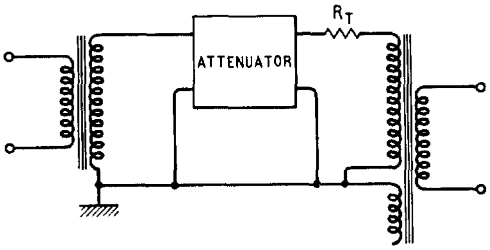


Fig. 9. Network Characteristics

Let the transfer admittance, defined as the current flowing in the terminating resistor for unit input voltage, be $|Y|\angle\theta$. Then, at balance:

$$|Y|\angle\theta = \pm G_m \pm j\omega C_m$$

where G_m and C_m are the values of conductance and capacitance read on the Bridge.

Then $\quad |Y| = (G_m^2 + \omega^2 C_m^2)^{\frac{1}{2}}$

and $\quad \theta = \tan^{-1}(\pm\, \omega C_m/G_m)$.

ATTENUATOR MEASUREMENTS

The characteristics of attenuators can be measured quite simply on the Bridge and the circuit arrangement is shown in Fig. 10. With the resistor R_T in the position shown the attenuator is correctly terminated at balance, when the right-hand side of R_T will be at Neutral potential.

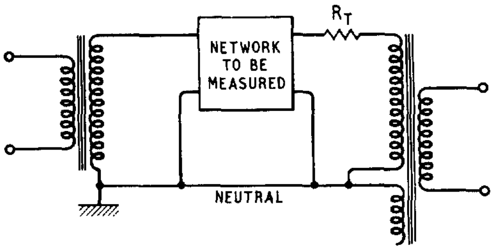
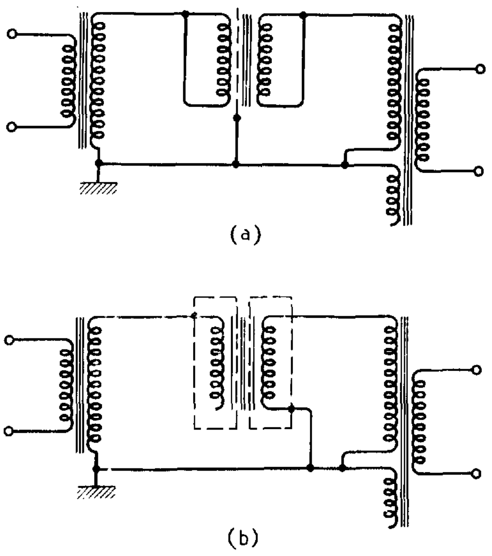


Fig. 10. Attenuator Measurements

If the Bridge is balanced with the attenuator set to zero, a value equal to the matching impedance R_T will be measured. If the attenuator steps are now switched in, the voltage attenuation can be calculated accurately from the ratio of the apparent change in value of R_T.

EFFECTIVENESS OF TRANSFORMER SCREENS

The effectiveness of screens between transformer windings can be determined using the arrangements shown in Fig. 11. The method of measurement when the transformer has a single interwinding screen is shown in Fig. 11 (a) and, in Fig. 11 (b), the method of connexion when each winding has a separate screen is shown.



(a)

(b)

Fig. 11. Transformer Screens

With perfect screening there should be no feed through the transformers if connected as shown. Any effective capacitance between the windings will be indicated on the Bridge.

TURNS RATIOS

The turns ratio of a.f. transformers can be obtained by using an arrangement similar to that shown in Fig. 9, substituting the transformer for the Network. The value of R_T must be high compared with the output impedance of the transformer. Assuming the transformer has a primary: secondary turns ratio of $1{:}N$ and that the primary is connected to the E lead of the Bridge, the voltage produced across the secondary will be $N.E.$ The secondary current (at balance) is given by $I = NE/R_T$. The conductance reading of the bridge, G_b, is equal to I/E. Therefore the turns ratio, N, is given by $R_T \times G_b$.

50c/s - 20kc/s OPERATION

Reference should be made also to the sections on ‘Source’ and ‘Detector’, which include details of suitable external equipments and a guide to the measurement accuracy over the frequency range.

The Bridge is direct-reading in terms of conductance and capacitance, at all frequencies. However, when inductance is measured, conversion from the bridge capacitance dials will depend on the measurement frequency:

$$L = 1/(\omega^2 C) = 1/(4\pi^2 f^2 C)$$

$$\text{mH} = 25{\cdot}3/(f^2.\mu\text{F})$$

Permissible Bridge loading restricts the maximum capacitance that can be measured accurately at frequencies above 1592 c/s. [However, it should be noted that as the frequency is increased, the restriction in the Bridge coverage is accompanied by a corresponding extension in the measurement range of the Low Impedance Adaptor].

Table 4 provides a guide to the maximum capacitance and minimum inductance values that can be measured accurately on the Bridge at selected frequencies throughout the band. In all instances lead corrections must be applied when the admittance of the Unknown exceeds 10 millimhos (i.e. when the impedance is less than 100 ohms)—see ‘Lead Corrections’ (page 13).

When the Bridge is used on Range 1 or 2 (for the measurement of large values of resistance and/or reactance) at frequencies above 2000c/s, particular care must be taken to avoid heavy shunt loading to the Neutral from either the voltage or current leads. If such loading is present, the measured value of the Unknown should be corrected using the formulae given on page 17.

TABLE 4

Source Frequency	Maximum Capacitance	Minimum Inductance
50c/s	10μF	1H
60c/s	10μF	0·7H
100c/s	10μF	250mH
200c/s	10μF	63mH
400c/s	10μF	16mH
800c/s	10μF	4mH
1000c/s	10μF	2·5mH
1592c/s	10μF	1mH
2kc/s	8μF	0·8mH
4kc/s	4μF	0·4mH
8kc/s	2μF	0·2mH
10kc/s	1·6μF	0·16mH
15kc/s	1μF	0·11mH
20kc/s	0·8μF	0·08mH

PRINCIPLE OF OPERATION

The design of the Universal Bridge is based on the transformer ratio-arm principle. A full explanation of the theory of operation is given in Wayne Kerr Monograph No. 1, 'The Transformer Ratio-Arm Bridge', available on request.

Balance of the Unknown impedance is against Standards of conductance and capacitance in parallel. Tappings on the two Bridge transformers, connected to decade controls, permit measurements to be made accurately on a wide range of impedance in any quadrant of the complex plane.

An internal oscillator adjusted to 1592c/s ($\omega = 10^4$) provides the Source voltage. A buffer amplifier isolates the oscillator from the Bridge circuits, to which four-terminal connexions can be made. The Detector is a tuned two-stage amplifier, incorporating a sensitivity control, with a double-shadow 'magic eye' associated with each stage. Instruments can be supplied to special order with Source and Detector tuned to frequencies other than 1592c/s.

A simplified diagram of the circuit arrangement is shown in Fig. 12, where Z_u and Z_s are the Unknown and Standard impedances respectively.

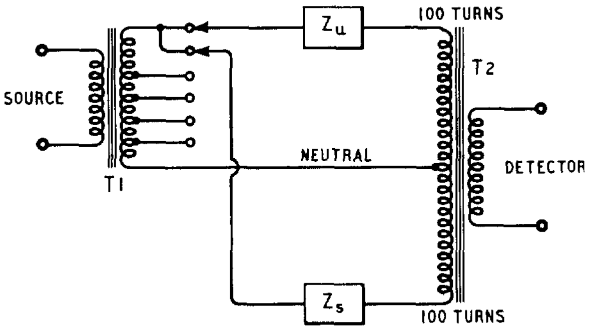


Fig. 12. Principle of Operation

Balance will be indicated by the Detector, connected to the secondary of the current transformer *T*2, when equal currents flow from either end of the centre-tapped primary of *T*2. In this condition, the potential across the primary will be zero and, therefore, the right-hand terminals of Z_u and Z_s will be at Neutral potential. Thus the same voltage is applied to both impedances and, for equal currents to flow in the two halves of *T*2 primary, the resistive and reactive components of the Unknown impedance must be equal to those of the Standard.

For a given value of Unknown impedance the Bridge can be balanced in three ways. The value of the Standards can be adjusted, differing potentials can be applied to the two impedances, or the currents they pass can be fed through unequal numbers of turns on the primary of *T*2. A selection of taps on *T*2 primary and on the secondary of the voltage transformer *T*1 permit a wide range of Unknown values to be measured against a minimum number of Standard components.

The Standard components are resistive and capacitive but, by reversing the sense of their connexions to the current transformer, an impedance in any quadrant of the complex plane can be measured. As the Standards are connected in parallel, the Bridge measures the equivalent parallel components of the Unknown.

Since, at balance, no potential exists across *T*2 primary, it is possible to connect an impedance between the right-hand terminal of Z_u and Neutral without affecting the accuracy of measurement. The only effect will be to reduce the sensitivity of the Detector and this can be compensated for by increasing the gain.

It is possible also to connect an impedance between the left-hand terminal of Z_u and Neutral. This shunt impedance will reduce the voltage applied to Z_u, but will reduce also the voltage applied to Z_s, in proportion to the turns ratio. The accuracy is therefore unaffected and any loss in sensitivity can again be compensated for by increasing the detector gain.

The transformers are so designed that very heavy shunting is possible without seriously affecting the accuracy of measurement. Components can in most instances, therefore, be measured *in situ*.

CIRCUIT DESCRIPTION

POWER SUPPLY

The Instrument operates from supplies of 40 to 60 c/s, consuming about 25 watts. A circuit diagram is provided at the back of this Handbook and from this it can be seen that the power transformer is tapped to suit supplies of 100–125 and 200–250V. The full-wave rectifier, V4, supplies approximately 15mA at 250V.

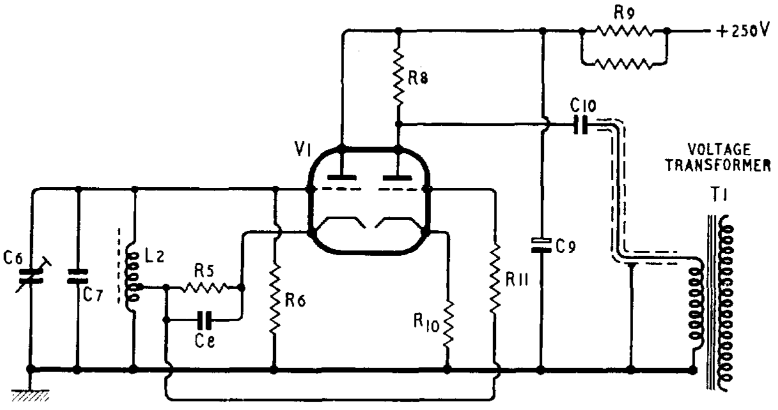


Fig. 13. Source Circuit

SOURCE

Refer to Fig. 13. One section of the double triode operates in an LC oscillator circuit and a fraction of the alternating potential is fed at low impedance to the right-hand section of *V*1, serving as a buffer amplifier. Inductor *L*2 has a ferrite pot core and the frequency of oscillation is set to precisely 1592c/s by adjustment of the trimmer capacitor *C*6. A potential of approximately 30V is developed across *T*1 secondary.

DETECTOR

The Detector circuit, shown in Fig. 14, consists of a two-stage tuned-anode amplifier using ferrite pot cores and silvered-mica capacitors. A double-shadow 'magic eye' is connected to each stage, providing four degrees of sensitivity overall. The Sensitivity control (*RV*4) affects both 'magic eyes' and balance is indicated by maximum shadow.

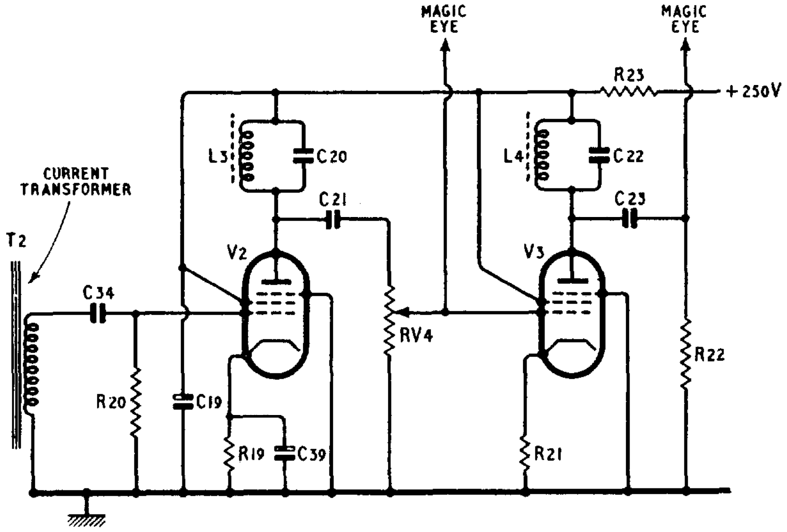


Fig. 14. Detector Circuit

BRIDGE CIRCUIT

The Bridge circuit, shown in simplified form in Fig. 15, consists essentially of the voltage transformer *T*1, tapped to provide an accurately-related selection of voltages across the Unknown and Standard impedances, and the current transformer *T*2.

The primary of *T*2 consists of two separate windings on a core of high-permeability metal. One winding is fed from the Unknown impedance and the other from the Standards circuit. Balance occurs when the ampere-turns in the two windings are of equal magnitude but opposite sense.

The Neutral connexion from the voltage transformer is taken to the centre-tap of the Standards winding on the current transformer. By connecting the Standards to a winding of appropriate sense, positive or negative conductance and capacitance can be measured.

The Neutral connexion of the Unknown winding on the current transformer is linked to that of the Standards winding for most two- and three-terminal measurements. The link is removed for four-terminal measurements, to provide two Neutrals.

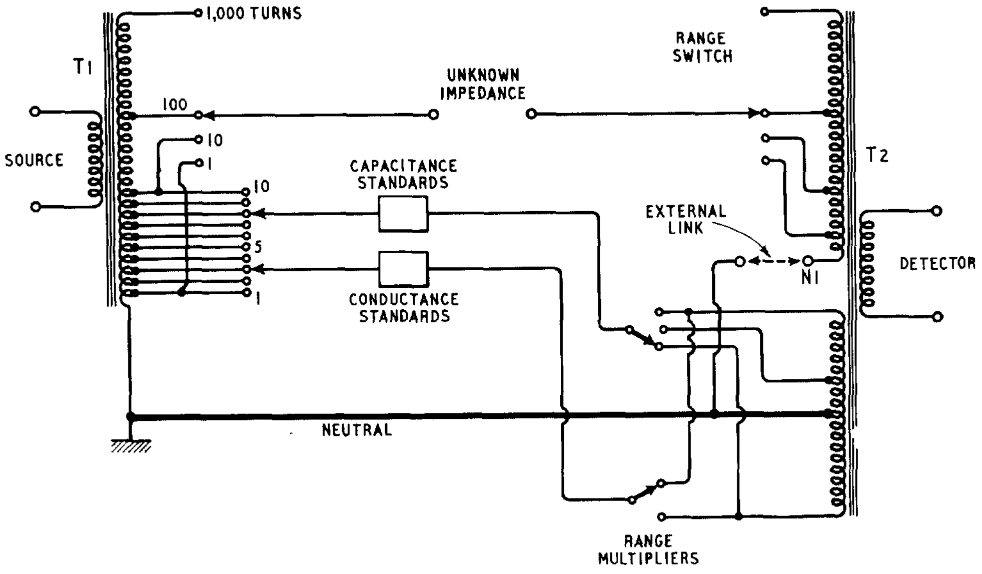


Fig. 15. Bridge Circuit

STANDARDS

For details of the Standards arrangement the complete circuit diagram at the back of this Handbook should be referred to.

Switched decades are provided by two fixed resistors (*R*15, *R*16) and two fixed capacitors (*C*12, *C*14) which can be switched independently in 1-turn steps to taps of from 0 to 10 turns on the voltage transformer. This gives each Standard effectively ten different values.

To provide the continuously-variable conductance decade, a linear potentiometer (*RV*2) is connected across nine turns of the voltage transformer and produces a variable voltage across a close-tolerance resistor (*R*17). This is illustrated in Fig. 16. The continuously-variable reactive decade is provided by a variable air-spaced capacitor (*C*11) connected to the 3-turn tap on *T1*.

The values of the conductance and capacitance Standards are so chosen that they normally cover the same range. However, to extend the effective range of one Standard with respect to the other, *T2* is tapped to provide a capacitance range one-tenth of normal. The range multiplier switches have the following settings:

G 1 and −1. (−1 for negative conductance).

C 0·1, 1 and −1. (−1 for inductance).

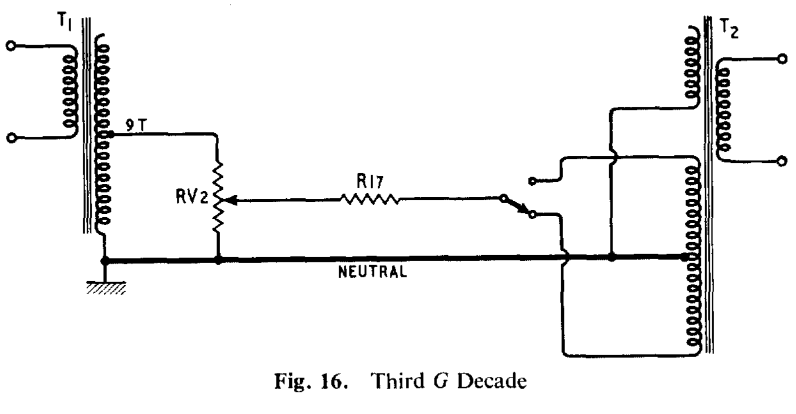


Fig. 16. Third *G* Decade

TRIMMING OF STANDARDS

The two main resistive Standards (*R*15, *R*16) are wire-wound and slightly inductive. Their phase angle is reduced to zero by means of trimming capacitors (*C*36, *C*15 and *C*16) connected in parallel with them.

The 0·001µF Standard (*C*12) does not require correction. Losses in the 0·01µF Standard (*C*14) are compensated for by a resistive current fed into the current transformer through a tap of opposite sense. This is shown in Fig. 17. *RV*1 is adjusted to balance out the resistive current produced by the losses in *C*14. *R*12, *R*13 and *R*14 form an attenuator to obviate the use of high-value resistors which might become unstable. *R*13 is always connected to a tap having the same number of turns as that connected to *C*14 but of opposite sense. The trimming holds, therefore, for all positions of the *C* multiplier switch.

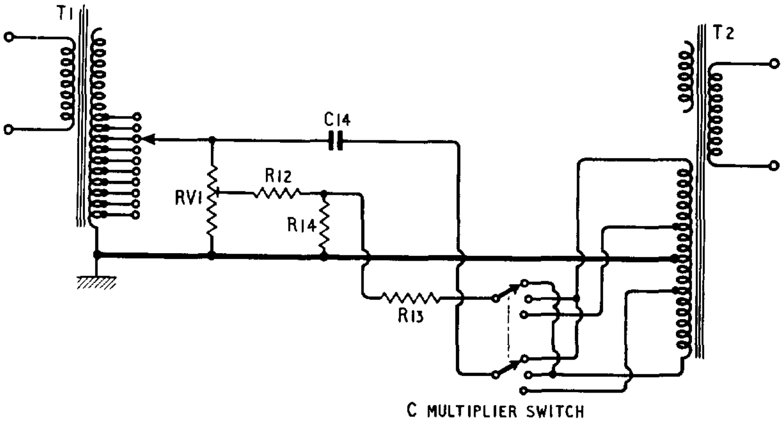


Fig. 17. *C* Phase Trimming

RESIDUAL CAPACITANCE TRIMMING

To compensate for the residual capacity of the continuously-variable Standard *C*11, a trimmer (*C*13) feeds a current into *T*2 through a tap of opposite sense. The arrangement is shown in Fig. 18. Whatever the connexion of *C*11 to the current transformer, the trimmer *C*13 is always connected to a tap having the same number of turns but of opposite sense. Once *C*13 is adjusted, therefore, the trimming holds for any position of the *C* multiplier switch.

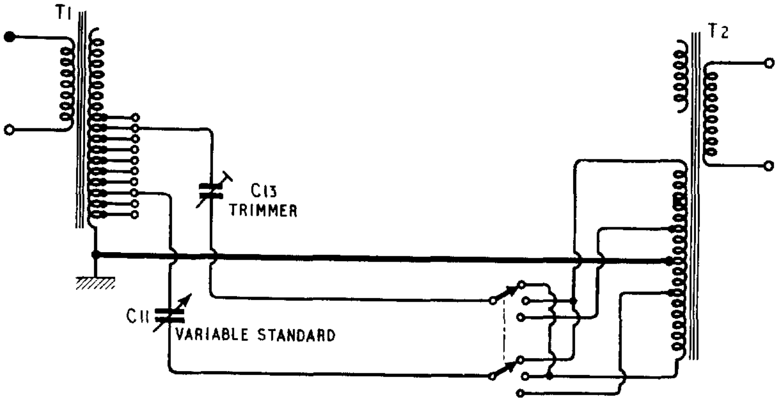


Fig. 18. Residual Capacitance

MAIN BRIDGE TRIMMING

The circuit arrangement of the two external trimming controls (Trim *G*, Trim *C*) is shown in Fig. 19.

A compensating voltage from the 9-turn tap on *T*1 is fed via *R*18 to the slider of a potentiometer (Trim *G*) connected across the +100 and −100 taps of *T*2. This allows the effective value of *R*18 to be made either positive or negative.

The capacitive trimming consists of a fixed 33µµF capacitor (*C*18) and a 100µµF variable capacitor (*C*17) connected across the positive and negative ends of the Standards winding on the current transformer. The same voltage as that used for conductance trimming is fed to their junction. With this arrangement the effective value of *C*17 can be made either positive or negative.

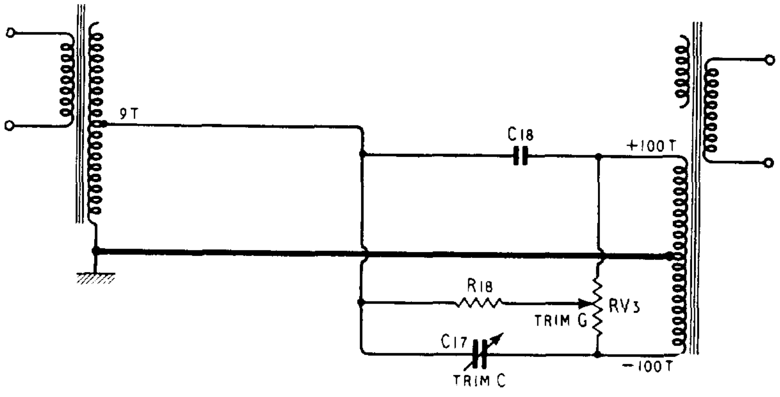


Fig. 19. Trim Controls

UNKNOWN CONNEXIONS AND RANGE SWITCH

The circuit arrangement of the connexions to the Unknown impedance and the facilities for range changing are shown in Fig. 20.

The impedance to be measured is connected between the voltage transformer and the Unknown winding of the current transformer via the Range switch (*S*7). The Range switch connexions to the taps on the transformers are such that in each of the seven positions the preceding range is effectively multiplied by ten.

Physical connexion to the Unknown is by means of two external coaxial cables. The screen of each cable is connected to the associated Neutral of the Bridge. For two- and three-terminal measurements the two Neutrals are linked: this method of connexion prevents the inherent capacitance of the cables shunting the measurement terminals.

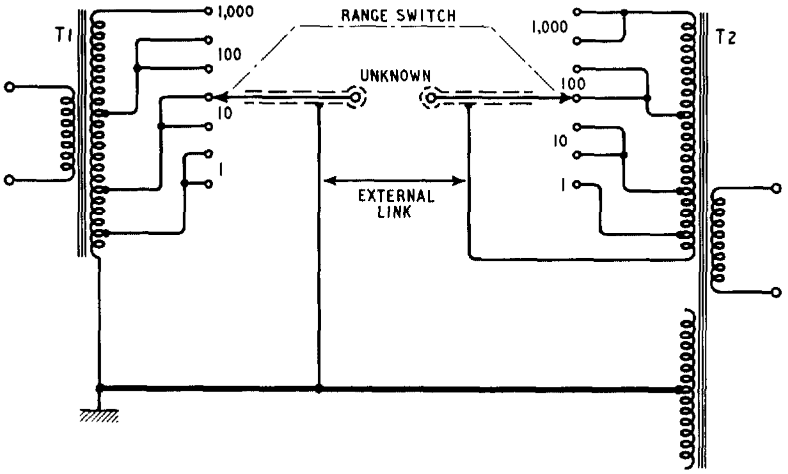


Fig. 20. Range Switch

MEASUREMENT VOLTAGE

The a.c. voltage applied to the component being measured on the Bridge cannot be specified accurately, measurements being made by comparative values of the Standard and Unknown currents. The voltage varies from range to range but is constant over any one range. Approximate values are:

Bridge Range	R.M.S. Voltage
1	30 V
2 and 3	3 V
4 and 5	0·3 V
6 and 7	30mV

MAINTENANCE AND SERVICE

Important: *No attempt should be made by unskilled personnel to service the Bridge. Maintenance, and particularly any trimming using the pre-set controls, must be carried out by a qualified service engineer in accordance with the following instructions.*

SOURCE AND DETECTOR

The location of any fault in the oscillator or detector amplifier circuits will be indicated by checking the valve potentials against the values shown in Table 5. These readings were obtained with an AVOmeter model 7 (negative lead to chassis) and are average values: variations of up to ±20 per cent must be expected.

TABLE 5

Valve	Electrode	Pin No.	Avo Range	Voltage
V1	Cathode 1	8	100V d.c.	35V
V1	Cathode 2	3	10V d.c.	4·2V
V1	Anode 1	6	400V d.c.	250V
V1	Anode 2	1	400V d.c.	120V
V2	Cathode	2	10V d.c.	1·5V
V3	Cathode	2	10V d.c.	1·1V
V3	Screen	7	400V d.c.	75V
V4	Cathode	7	400V d.c.	255V

OVERALL GAIN

To check the overall gain, first set-up the Bridge according to the procedure given on page 11 but with the Range switch on position 3. Using two 100-ohm (20 per cent) resistors, connect one between inner and neutral of the *E* lead and the other across the *I* lead. Leave the Sensitivity control at maximum and adjust the variable conductance control to read 5(0·05µ Mho). The most sensitive 'magic eye' section should close completely. This degree of sensitivity is required only when the Low Impedance Adaptor is in use: for all normal Bridge measurements one-tenth of such sensitivity provides adequate discrimination.

OSCILLATOR FREQUENCY

The oscillator frequency is adjusted in the final test procedure to 1592c/s±0·25 per cent. If a Frequency Standard or Frequency Counter is available, it can be fed with the measuring potential from the Bridge. The Source frequency will be obtained with an accuracy determined by the Standard or Counter. RANGE SW TO POS. # 1.

An alternative method, depending only on the Bridge itself and two components, can be used if the Bridge Standards have been checked (see pages 25 and 26). The components required are a high-stability resistor and a high-precision mica capacitor. The exact values are not important but should be about 10*k*Ω and 0·01µF (1*k*Ω and 0·1µF could be used as an alternative). The method is as follows:

1 Measure the resistor and record the value of conductance *G*.

2 Measure the capacitor and record the value of capacitance *C*.

3 Connect the two components in series and measure the effective conductance G_m and effective capacitance C_m of the combination.

It can be shown that

$$\omega = \left\{ G_m/[(C^2/G)\,(1-G_m/G)] \right\}^{\frac{1}{2}} \quad . \quad . \quad .(1)$$

or $$\omega = (G/C)\,.\,[(C/C_m)-1]^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad .(2)$$

Equation (1) or (2) can be used to establish accurately the angular frequency of the Bridge Source. The tables used for the calculation should preferably be five-figure. If the Bridge Standards were checked correctly, the values of *G*, *C*, G_m and C_m should be obtained with an accuracy of ±0·1 per cent. The angular frequency will then be obtained with an accuracy of better than ±0·3 per cent.

BRIDGE ACCURACY

An important feature of the Universal Bridge is the ease with which the accuracy can be checked and, if necessary, the Standards re-set. As described earlier, the B221 uses only one, fixed, Standard per decade; the steps of the decades, and the Bridge ratios, being obtained from the ratio-transformers. The Standards fitted to the Bridge are adjusted to an accuracy of 0·05 per cent and should have a long-term stability of the same order. The ratio-transformers have an accuracy an order higher, about 0·01 per cent.

Before the Standards are checked, the following points should be noted. If high accuracy is required in measuring any component, all three decade controls must be in use. There is no requirement for these three controls to be checked to the same order of accuracy. Ignoring the decimal point and units, consider the reading 1234. The 1 is given by the first decade, the 2 by the second, and the figures 34 by the continuously-variable control. The reading accuracy is within 0·1 per cent. If the Standard of the first decade is 0·1 per cent in error, the true value could be 1235 or 1233. The same effect would be caused by an error of 0·5 per cent in the second decade, or 3 per cent in the continuously-variable control.

The highest reading accuracy is obtained when all three decades are at maximum, giving a reading of 11110. With the Sensitivity control at maximum, a 1 per cent change in the continuous variable can be noticed. This corresponds to 0·1 per cent in the second decade and 0·01 per cent in the first decade. The highest accuracy is obtained, therefore, by adjusting the Standard in the first decade to 0·01 per cent, the Standard in the second to 0·1 per cent, and the continuously-variable control to 1 per cent. If this is done, the Bridge can often be used for measurements to an accuracy of 0·02 per cent.

One further point to be noted is that an aged Standard has a better long-term accuracy than a new one. Consequently, whenever possible the existing Standards should be adjusted by means of series or shunt elements in preference to being replaced.

CHECKING AND ADJUSTING STANDARDS

The absolute accuracy of the Bridge can be determined using only two external fixed Standards, one a resistor, the other a capacitor. As the Bridge Standards are themselves adjusted to 0·05 per cent, the reference Standards must be known with certainty to at least this degree of accuracy. The ideal reference Standards are a 0·01 per cent resistor of either 1000 or 10 000 ohms, and a 0·01 per cent capacitor of either 0·1 μF or 0·01 μF. Using a reference of less than 1000 ohms (resistance or reactance) causes difficulty with the series impedance of the leads etc.; above 10 000 ohms trouble can arise from the spurious shunt elements. Even with a 0·01 μF Standard the connexions to the Bridge must be made carefully because 1 $\mu\mu F$ represents an error of 0·01 per cent, and this capacitance is produced by two inches of wire exposed outside the Neutral screen.

CONDUCTANCE STANDARDS

The procedure for checking the conductance Standards of the Bridge is described for a 1000-ohm external reference. If a 10 000-ohm reference is used, the Bridge range settings stated must be reduced by 1.

1 With the measurement leads (Neutrals linked) in position, and the *G* and *C* multipliers both set to 1, switch to Range 6, set all capacitance controls to zero, the two switched conductance decades to zero, but set the continuously-variable conductance control at 06 (·006μMho).

2 Adjust the two Trim controls for exact balance with the Sensitivity control set fully clockwise. The reason for setting the variable control at 06 is to ensure that, when the Standard used in the first decade is checked, balance is possible without using the un-checked second decade, whether the Standard be slightly high or low.

3 Connect the $1k\Omega$ reference resistor to the measurement leads and balance the Bridge by means of the *first* and *third* conductance controls only. To obtain a clean balance it may be necessary to adjust the Trim *C* control or to change the *C* multiplier switch setting to −1 and, after any necessary re-trimming, to operate the variable *C* control. If the exact point of balance lies between 1·005 and 1·007 mMho, the first decade Standard is within the specified tolerance and no adjustment is necessary.

If balance does not occur within these limits, suitable series or shunt resistors should be added to the Standard in the Bridge. These resistors do not have to be close tolerance.

If it is desired to adjust the first decade Standard to 0·01 per cent, carry out the procedure described in 3a and 3b.

3a Disconnect the reference resistor and repeat steps 1 and 2 with the Range switch in position 5.

3b Re-connect the reference resistor, set the first conductance decade to 10 (⊕) and, if necessary, add series or shunt resistors to the first decade Standard until balance occurs between 1000·5 and 1000·7μMho. Adjust the *C* controls as described in para. 3.

4 Disconnect the reference resistor and repeat step 1.

5 Adjust the two Trim controls for exact balance with the Sensitivity control set fully clockwise.

6 Re-connect the reference resistor, set the second conductance decade to 10 (⊕) and balance the Bridge using the continuously-variable control. The exact point of balance should be between 1·005 and 1·007mMho. If necessary, add series or shunt resistors to the Standard of the second decade to bring the balance point within this range.

7 Set *all* decade controls at zero, disconnect the reference resistor and switch to Range 7. With the Sensitivity control fully clockwise, adjust the two Trim controls for a precise balance.

8 Re-connect the reference resistor and balance the Bridge. The reading should lie within half a scale division of the 10 calibration mark (1mMho). If outside this tolerance, set to 10 and balance the Bridge by adjusting the pre-set potentiometer *RV*5.

The calibration points 1 to 9 on the continuously-variable control can be checked quickly with a decade resistor box but this item is not essential. The alternative procedure is as follows.

9 Zero the Bridge on Range 3 and then set the first decade control to 1 (1·000μMho).

10 Connect the outer terminals of a 10*k*Ω potentiometer to the inner and Neutral respectively of the *E* measurement lead. Connect one end of a 100*k*Ω (20 per cent) resistor to the inner of the *I* measurement lead and the other end of this resistor to the wiper terminal of the potentiometer.

11 With the Sensitivity control set at mid-position, adjust the potentiometer to balance the Bridge.

12 Without disturbing the potentiometer adjusted in para. 11, change to Range 5, set the first decade to zero, and balance the Bridge using the continuously-variable control. Balance should occur within half a scale division of the 1 calibration mark.

Repeat the procedure described in paras. 9, 10, 11 and 12 with settings at 2, 3, etc. to 9. If desired, intermediate points can be checked by using both switched decades in para. 9.

By means of successive adjustments to the pre-set potentiometer *RV*5, it should be possible to bring the accuracy at all settings to within half a scale division. Any serious departure from this calibration is most likely to be due to a worn track on potentiometer *RV*2, in which instance it should be replaced. Play in the drive mechanism linking the potentiometer to the dial can also cause trouble. The degree of engagement between the racks and pinions can be adjusted by re-positioning an eccentric cam.

CAPACITANCE STANDARDS

Succeeding paragraphs describe the procedure for checking the capacitance Standards of the Bridge, using a 0·1 μ*F* external reference. If a 0·01μ*F* reference is used, the Bridge range settings stated must be reduced by 1.

1 With the measurement leads (Neutrals linked) in position, and the *G* and *C* multiplier switches both set to 1, switch to Range 6, set all conductance controls to zero, the two switched capacitance decades to zero, but set the continuously-variable capacitance control at 2(·002μ*F*).

2 Adjust the two Trim controls for exact balance with the Sensitivity control set fully clockwise. The reason for setting the variable control at 2 is to ensure that, when the Standard used in the first decade is checked, balance is possible without using the unchecked second decade, whether the Standard be slightly high or low.

3 Connect the 0·1μ*F* reference capacitor to the measurement leads and balance the Bridge by means of the *first* and *third* capacitance controls only. To obtain a clean balance it may be necessary to adjust the Trim *G* control. If the exact point of balance lies between ·1019 and ·1021μ*F*, the first decade Standard is within the specified tolerance and no adjustment is necessary.

If balance does not occur within these limits, remove *C*37 and replace it with a low-loss capacitor of suitable value.

If it is desired to check the first decade standard to 0·01 per cent, carry out the procedure described in 3a and 3b.

3a Disconnect the reference capacitor and repeat steps 1 and 2 with the Range switch in position 5.

3b Re-connect the reference capacitor, set the first capacitance decade to 10 (⊕) and, if necessary, make further changes to the value of *C*37 until balance occurs between ·10019 and ·10021μ*F*. Adjust Trim *G* if necessary.

4 Disconnect the reference capacitor and repeat step 1.

5 Adjust the two Trim controls for exact balance with the Sensitivity control set fully clockwise.

6 Re-connect the reference capacitor, set the second capacitance decade to 10(⊕) and balance the Bridge using the continuously-variable control and Trim *G*. The exact point of balance should be between ·1019 and ·1021μ*F*. If outside these limits, unseal trimmer *C*38 and adjust this component as necessary.

7 Set *all* decade controls at zero, disconnect the reference capacitor, and switch to Range 7. With the Sensitivity control fully clockwise, adjust the two Trim controls for a precise balance.

8 Re-connect the reference capacitor and balance the Bridge using the continuously-variable capacitance decade. The reading should lie within half a scale division of the 10 calibration mark (·1μ*F*). If outside this tolerance, first check that the racks and pinions are engaging properly and if necessary adjust the eccentric cam. The relative settings of the dial and variable capacitor can be altered slightly but, if this is done, *C*13 will have to be re-set as described in step 10.

9 Set *all* decade controls at zero, disconnect the reference capacitor, switch to Range 1 and, with the Sensitivity control set fully clockwise, adjust the two Trim controls for a precise balance.

10 Change the *C* multiplier switch position from 0 to 0·1 and to −1. The Bridge should remain balanced on all three positions. If it does not, unseal trimmer *C*13 and make a small adjustment. Repeat the process and adjust Trim *C* until the setting is found where balance is maintained on all three switch positions.

The calibration points 1 to 9 on the continuously-variable control can be checked quickly with a decade capacitor box but this item is not essential. The alternative procedure is as follows:

11 Zero the Bridge on Range 2 and then set the first capacitance decade control to 1 (10μμ*F*). Connect a variable capacitor, covering the range 10–90μμ*F*, to the measurement leads.

12 With the Sensitivity control set at mid-position, adjust the variable capacitor to balance the Bridge.

13 Without disturbing the variable capacitor, change to Range 4, set the first decade to zero and balance the Bridge using the continuously-variable control. Balance should occur within half a scale division of the 1 calibration mark.

Repeat the procedure described in paras. 11, 12 and 13 with settings at 2, 3, etc. to 9. If desired, intermediate points can be checked by using both switched decades in para. 11.

Should the calibration error exceed half a division at some points, adjustment should be made to the mechanism linking *C*11 to the dial. This adjustment *must* be followed by a repetition of the procedure described in paras. 9 and 10.

PHASE CORRECTION

Succeeding paragraphs describe firstly the adjustment of the two trimmer capacitors which off-set the slightly inductive properties of the two wire-wound conductance Standards and, secondly, the adjustment of the pre-set potentiometer which controls the current compensating for the losses associated with the larger capacitance Standard.

1 Zero the Bridge on Range 4.

2 Select a 10*k*Ω *carbon* resistor slightly below the nominal value, so that balance is obtained with the first and last *G* decades only (the centre decade *must* remain at zero).

3 Adjust trimmer *C*16 to obtain a clean balance.

4 Change to Range 5, return the first decade to zero and set the second decade at 10 (⊕).

5 By means of the variable *G* decade and trimmer *C*36, obtain a clean balance.

The pre-set potentiometer *RV*1 is adjusted in the Test Department while a 3-terminal 10μμ*F* absolute Standard is connected to the Bridge. The potentiometer is not likely to need re-adjustment and, unless a capacitor of accurately-known power factor is available, the original potentiometer setting should not be disturbed.

If the external reference capacitor used for checking the decades has a tolerance of 0·01 per cent, the power factor will probably be quoted (at 1000c/s). This factor will be virtually unchanged at 1592c/s. The capacitor could be used, therefore, to check the setting of *RV*1.

Part 2 - Low Impedance Adaptor Q221

INTRODUCTION

The lower limit of impedance measurement that can be made accurately with the Universal Bridge is determined by lead resistance and the winding resistance of the Bridge transformers. The Low Impedance Adaptor, designed to operate in conjunction with the Bridge, extends the range of measurement to include large values of capacitance and very small values of resistance and inductance.

Measurements with the Bridge itself are of the equivalent *parallel* components of conductance and capacitance, obtained by applying a reference potential to the Unknown and measuring the resulting current. The function of the Adaptor is to reverse the procedure to one of passing a reference current through the Unknown and measuring the resulting voltage. This reversal is achieved with a resistive *T*-network where the shunt arm consists of the Unknown. The required value is derived very simply from the Bridge dial-readings in terms of the equivalent *series* components of resistance and inductance.

The prime function of the Adaptor is to permit measurements on impedances of less than ten ohms to be made *with the first decade switches set permanently to zero.* Under these conditions the value of the Unknown has a negligible effect on the reference current and measurements are of the specified accuracy. Only when absolute accuracy is a secondary consideration to the detection of small changes should the first decade be used. The usefulness of very fine discrimination and measurements from 10 to 100 ohms are described in the text.

SPECIFICATION

Measurement Ranges

R		L‡		C§	
First Division	Maximum*	First Division	Maximum*	Minimum*	First Division
20 μΩ	10 mΩ	·002 μH	1 μH	10,000 μF	5F
200 μΩ	100 mΩ	·02 μH	10 μH	1,000 μF	·5F
2 mΩ	1 Ω	·2 μH	100 μH	100 μF	·05F
20 mΩ	10 Ω	2 μH	1 mH	10 μF	·005F

Accuracy

R: ±1% ±25 μΩ.
L: ±1% ±0·005 μH.
C: Frequency-dependent (see Text).

* Values quoted apply with first G and C decade switches at zero (see Text). With all three decades in use: R maximum and L maximum are increased by a factor of 10, and C minimum is decreased by a factor of 10.

‡ All L values decreased by a factor of 10 with multiplier on C×0·1.

§ All C values apply only at 1592 c/s. See text for other frequencies.

Discrimination	R:	0·2% of Maximum (see Table).	
	L:	0·2% of Maximum (see Table).	
	C:	Frequency-dependent (see Text).	
Dimensions	Base Diameter:	$5\frac{1}{16}$ in.	(12·9 cm.).
	Height:	$3\frac{5}{16}$ in.	(8·5 cm.).
Packed Weight	Not exceeding	$5\frac{1}{2}$ lb.	(2·5 kg.).

OPERATING INSTRUCTIONS

MEASUREMENT PROCEDURE

1 Remove the measurement cables from the Bridge and connect them to the sockets provided on the Low Impedance Adaptor.

2 Connect the two cables from the Adaptor to the corresponding sockets on the Bridge.

3 Turn the Bridge Range switch to position 3. The Bridge must *always* be on this Range when the Low Impedance Adaptor is in use.

4 Turn the Low Impedance Adaptor to the desired range and connect the two leads from the 'blue' socket to either side of the impedance to be measured.

5 Connect the neutral (green) lead from the 'white' cable between the unknown impedance and the neutral clip from the 'blue' cable.

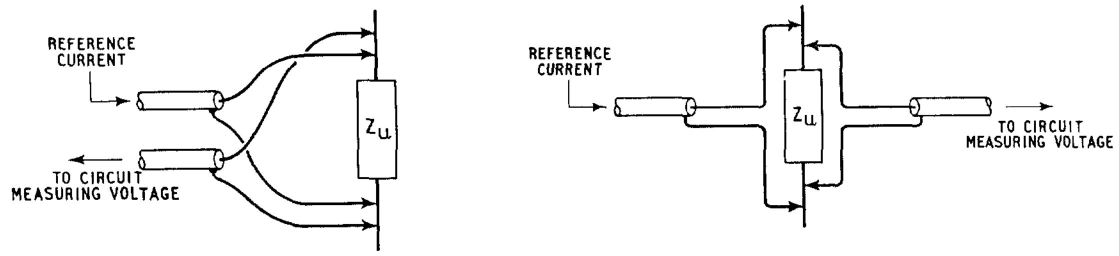
6 Clip the 'inner' (red) lead from the 'white' cable on to the neutral clip of this same cable. This provides the necessary condition of only a single-point contact between one side of the Unknown and the detector for the initial trimming adjustment.

7 Set the Bridge decade controls to zero and adjust the Trim G and Trim C controls for maximum shadow on the magic eyes.

8 Transfer the red lead from the 'white' cable to the other side of the Unknown. The points of connection for the two leads from the 'white' cable must be immediately adjacent to the impedance it is desired to measure. The two connections from the 'blue' cable should lie outside these. This is illustrated in Fig. 21 (below right) where the reference current is obtained from the 'blue' cable and connection to the 'circuit measuring voltage' is by the 'white' cable.

9 Set the G and C switches as follows:
  both at 1 for R and L,
  G at 1 and C at −1 for R and C,
  either or both at −1 for mutual or
  transfer impedance.

10 Adjust the second switched decades and vernier controls of the Bridge to obtain maximum shadow on the magic eyes. The first switched decades should not be employed if the measured value is to be derived from the simplified expressions shown for each of the four ranges on the Low Impedance Adaptor.



INCORRECT USE OF CONNECTING LEADS

LEADS DISPOSED FOR MINIMUM COUPLING. VOLTAGE MEASURED ACROSS UNKNOWN ONLY

Fig. 21. Connexion to the Unknown

INTERPRETATION OF RESULTS

The equivalent series components of the unknown impedance are derived from the Bridge dial readings at balance by using the conversion formulae shown for each of the four ranges on the Low Impedance Adaptor. These formulae are reproduced in Fig. 22.

Capacitance can be also be derived from the Conversion Chart on page 35. In either case, however, the results apply only at 1592 c/s (see '50 c/s — 20 kc/s Operation' on page 32).

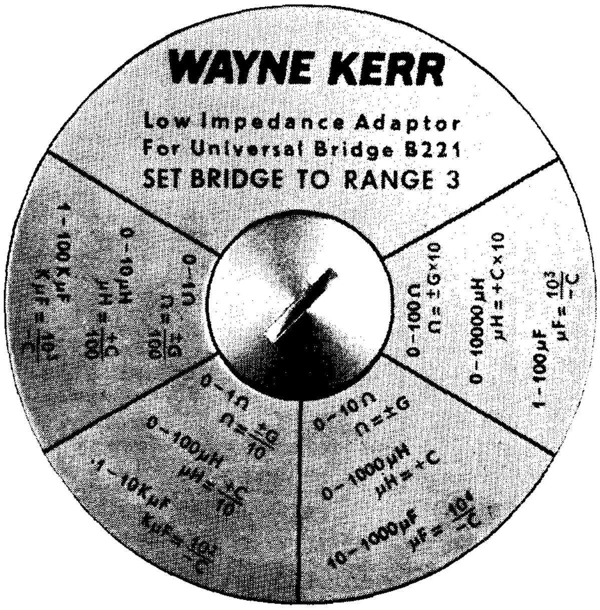


Fig. 22. Adaptor Range Plate

Example (R) Adaptor on 0–1Ω range
(as shown on Q221 dial)
Bridge reading 0·337μMho
Adaptor range plate:
Ω=±G/10
=0·337/10
or R_u=0·0337Ω

Example (L) Adaptor on 0–10000μH range
(as shown on Q221 dial)
Bridge reading 64·8μμF
Adaptor range plate:
μH=+C×10
=64·8×10
or L_u=648μH

Example (C) Adaptor on 1–100μF range
(as shown on Q221 dial)
Bridge reading –17·4μμF
Adaptor range plate:
μF=10^3/-C
=1000/-(-17·4)
or C_u=57·5μF

MEASUREMENT OF REACTANCE

The Bridge is so designed that the resistive and reactive scales cover the same range in ohms. If on a particular range of the Adaptor the Bridge *G* dials cover 0 to 1 ohm, the *C* dials, therefore, cover 0 to 1 ohm also. Assuming the Bridge has been balanced, the procedure for measuring reactance directly in ohms is as follows.

Mentally transfer the figures on the *C* dials to the *G* dials (so that the last digits are coincident) and insert in this transferred reading a decimal point where one occurs on the *G* dials. Apply to this amended reading the scale multiplying factor for ohms given on the Adaptor range plate. The result is the required reactance value.

Example:

Adaptor range plate set to 0–100Ω.
Bridge reading 0·362μ*Mho* and 117·4μμ*F*.
If the figures that appear on the *C* dials (giving the reading 117·4 μμ*F*) had appeared on the *G* dials, the reading would have been 1·174μ*Mho*. This is seen by writing them underneath in corresponding positions:

0·362μ*Mho* (actual reading on *G* scale)
1·174μ*Mho* (figures mentally transferred from *C* scale).

The range plate on the Adaptor gives
$\Omega=\pm G\times 10$
giving for the resistance term
$R_u=0{\cdot}362\times 10$
$=3{\cdot}62$ ohms
and for the reactance term
$X_u=1{\cdot}174\times 10$
$=11{\cdot}74$ ohms.

CONNEXION TO THE UNKNOWN

When very low values of impedance are to be measured *in situ*, some precautions must be observed or large errors may arise. Two faults are indicated by the left-hand illustration of Fig. 21. Firstly, if the two cables are arranged side-by-side and large loops formed at their ends, there is considerable danger that the reference current in one loop may induce a sufficiently large voltage in the other to cause a significant error. Secondly, the voltage being measured is not only the potential drop across Z_u but also that occurring in the leads from Z_u to the point of contact of the current clips.

In this respect it must again be emphasized that the lead coded blue, from the Adaptor to the Unknown, although associated with the *E* plug of the Bridge is effectively the CURRENT lead from the Adaptor. Similarly, the function of the white (*I*) lead is to feed back to the Bridge the VOLTAGE measured across the Unknown.

The areas of the loops involved in the connexions should be kept as small as possible and the coupling between them made as low as possible. This is shown diagrammatically in the right-hand illustration of Fig. 21, which shows also the correct positioning of the current clips outside the voltage clips. These connexions must be made independently on to the leads from the Unknown: the clips must not touch and one set must never be used as a connexion for the other.

ERRORS IN THE MINOR COMPONENT

It must be realised that inaccuracies may occur when measuring the minor component of a complex impedance whose resistive and reactive elements are very different in magnitude at 1592 c/s. (It may be noted that a minor component of 0·1 per cent affects the modulus of the impedance by less than one part in a million.) The Adaptor is not suitable for accurate measurements on small minor components, but a reliable approximation can be obtained if great care is taken in the adjustment of the Trim controls and the leads are disposed for minimum coupling and for minimum disturbance when changed from the trim to the measurement connexions.

A correction to allow for the residual reactance of the Adaptor can be made as follows. The measured values of the resistance and reactance of the Unknown are first obtained in the usual manner. The Unknown is then replaced by a carbon resistor of near value to the resistance of the Unknown, using the shortest possible connexions from the terminals or clips. The resistance and apparent reactance of this resistor are measured. As a carbon resistor has a totally insignificant reactive term at the Bridge frequency, the reactance must be due to the Adaptor or Bridge circuits. In both measurements a note must be made of the sign of the reactance (positive for inductive and negative for capacitive). The true reactance of the Unknown is given by:

(Apparent reactance of Unknown)—(Apparent reactance of carbon resistor).

This true value of reactance can be converted into the corresponding inductance or capacitance from the appropriate expression:

$$L = (\text{True reactance})/10^4,$$

$$\text{or } C = 1/(10^4 \times \text{True reactance}).$$

MEASUREMENT OF R.F. COILS

It must be borne in mind that, although measurements can be made in the millimicrohenry region, the Adaptor is not ideally suited to the measurement of r.f. and v.h.f. coils. This is because skin effect and self-capacitance result in the inductance at the operating frequency of the coils being very different from the value at 1592c/s. The change is dependent upon so many factors (geometry, wire size, spacing, type of insulation, effect of screening and so on) that no useful extrapolation can be made. Furthermore, air-cored coils of small inductance behave, at audio frequencies, like slightly inductive resistors, so that accurate measurement of a minor component would be required.

The Adaptor is useful for comparison measurements and for obtaining the coupling coefficients of i.f. transformers, sections of delay line, etc. Also, in v.h.f. circuits a large proportion of the circuit inductance is contained, often, in the wiring and switches. The geometry in such instances makes possible reasonably accurate measurements using the Adaptor and, in fact, the value of such inductance is difficult to ascertain otherwise because the measurement must be made *in situ*.

MEASUREMENT OF MUTUAL INDUCTANCE

The method of connecting a transformer is illustrated in Fig. 23, where the two resistors are the Standard components in the Adaptor. Assuming that the loading imposed by the secondary *R* is insignificant and that the self-impedance of the primary is so low that it has no effect on the current, the current through the primary will be given by E/R. This will induce into the secondary a voltage of $\pm j\omega M.E/R$, where the sign is determined by the relative sense of the windings. At balance the induced voltage will drive a current, $\pm j\omega M.E/R^2$, through the current transformer of the Bridge. From equation (1), under Principle of Operation, (page 34):

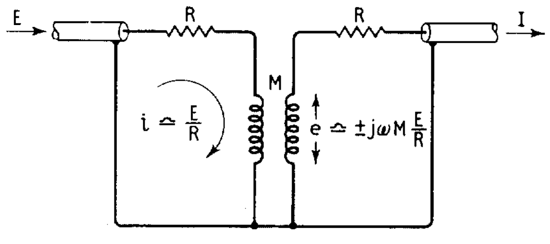


Fig. 23. Measurement of Mutual Inductance

$$\pm j\omega M = R^2 \,.\, I/E.$$

Replacing I/E by the equivalent on the Standards side of the Bridge:

$$j\omega M = \pm j\omega C \,.\, R^2$$

$$\text{or } M = \pm C \,.\, R^2.$$

Mutual inductance is read, therefore, in the same manner as self-inductance, the alternative signs being catered for by the 1 and −1 positions of the C selector switch. The setting required depends on the relative sense of the two windings.

POLARIZING ELECTROLYTIC CAPACITORS

When it is considered necessary to prevent a reverse polarity (caused by the small a.f. measuring voltage) from appearing across an electrolytic capacitor, a polarizing potential of one or two volts from for example a single dry cell can be applied as shown in Fig. 24. Under no circumstances should a high polarizing voltage be used.

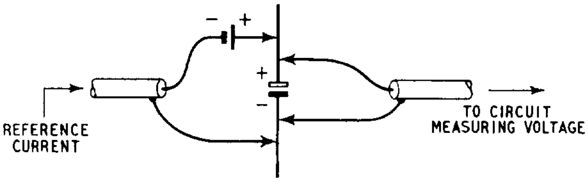


Fig. 24. Polarizing Electrolytic Capacitors

ACCUMULATOR RESISTANCE

The Low Impedance Adaptor can be used for certain measurements on accumulators. A limitation is imposed by the permissible d.c. through the Adaptor resistors. These have a continuous rating of 0·5 watt. The maximum values of d.c. voltage that may be applied to the *Adaptor* terminals (these values *must not* be applied directly to the Bridge), and the corresponding current values, are given below.

Adaptor Range	Maximum d.c. Voltage	Maximum Direct Current into Adaptor
1	7V	140 mA
2	12V	80 mA
3	22V	45 mA
4	40V	25 mA

It must be realised that the measurement will be of the impedance of the accumulator, consisting of a resistance in series with a small reactive component.

50c/s - 20kc/s OPERATION

Resistances of less than 10 ohms are measured in the normal manner.

Inductances of less than 1*mH* (or 10*mH* if the first decade control is operated) are measured on the Low Impedance Adaptor. When the value exceeds 1*mH* (or 10*mH*) the measurement can be made with the Bridge alone provided that a sufficiently high frequency is employed (see table 4, page 18).

Capacitances whose reactance falls below 10 ohms at any one frequency (the dividing line is indicated in table 4) are measured with the Low Impedance Adaptor but the relationships for capacitance, given on the Adaptor range plate, do *NOT* apply at any frequency except 1592c/s. The value of the unknown capacitance is given by the expression

$$C_u = -1/(\omega^2 R^2 C_b).$$

At a frequency of 1592c/s ($\omega = 10^4$) the above expression can be simplified to give the scale multiplying factors for capacitance shown on the Adaptor range plate. These same four factors can be used for computing the measured capacitance at other frequencies if the result is multiplied by a suitable constant (K). This is equivalent to re-writing the above expression as:

$$C_u = K[-1/(\omega_o^2 R^2 C b)]$$

where $\omega_o = 2\pi \times 1592$ and $K = (\omega_o/\omega)^2$.

The value of K at selected frequencies between 50c/s and 20kc/s is shown in the table (below).

Measurement Frequency	K	Measurement Frequency	K
50c/s	1015	1592c/s	1·00
60c/s	704	2kc/s	0·634
100c/s	254	4kc/s	0·158
200c/s	63·4	6kc/s	0·0704
400c/s	15·8	8kc/s	0·0397
600c/s	7·04	10kc/s	0·0254
800c/s	3·97	12kc/s	0·0176
1000c/s	2·54	15·92kc/s	0·01
1200c/s	1·76	20kc/s	0·0063

Example

With the range multiplier switches set at 1(G) and −1 (C), balance was obtained on Range 3 of the Adaptor with a capacitance dial reading of −74·1$\mu\mu F$.

The measurement frequency was 800c/s.

From the Adaptor range plate:

$$\mu F = 10^4/-C \text{ (at 1592c/s)}$$

$$= K[10^4/-C| \text{ at 800c/s.}$$

From the table, K at 800c/s is 3·97.

$$\therefore\ C_u = 3{\cdot}97\ [10^4/-(-74{\cdot}1)]\mu F$$

$$= 3{\cdot}97 \times 135\mu F$$

$$= 536\mu F.$$

With a Bridge dial reading of 10$\mu\mu F$, the maximum values of capacitance that can be measured at a frequency of 400c/s are:

Range plate at 1–100$K\mu F$	1·58 Farads
Range plate at ·1–10$K\mu F$	158 000μF
Range plate at 10–1000μF	15 800μF
Range plate at 1–100μF	1580μF

The range of capacitance measurement is further extended by the use of lower measurement frequencies. Also, if the Bridge dial reading at balance is less than 10$\mu\mu F$, the measured capacitance is of a very high value. Such measurements are obtained with reduced sensitivity and accuracy.

When very large values of capacitance are measured, the inductance of connecting leads becomes of extreme importance and must be kept to the absolute minimum. For example if a capacitor of 200 000μF is measured at 1kc/s, a lead inductance of only $\frac{1}{8}\mu H$ will resonate with the capacitor. Even $^1/_{80}\mu H$ will cause a 10 per cent error in the measured capacitance value.

Note: *ALL measurements with the Low Impedance Adaptor* must *be made with the Bridge on Range* 3. *At all frequencies the results are derived from the simplified formulae* (*used in preceding paragraphs*) *only if the first decades of the Bridge are at zero* (*see 'Discrimination and Accuracy'—next section*)

DISCRIMINATION AND ACCURACY

The Low Impedance Adaptor serves merely as an impedance invertor between the Bridge and the Unknown, measurement being made on the Bridge itself. This has two decade switches and a continuously-variable control on each component and is consequently capable of a discrimination of 0·02 per cent. Such a high discrimination extended to the Adaptor ranges can be useful for comparison of component values or the detection of small changes such as in temperature coefficient measurements. This order of discrimination is obtained only when the first decades are in use and, in these circumstances, the approximations referred to under 'Principle of Operation' are not justified. Absolute values cannot be derived with an accuracy of 1 per cent, therefore, using the simplified formulae, but can be calculated from the balance equation:

$$R^2/Z_u + 2R = 1/(G_b + j\omega C_b).$$

It may be found more convenient to make an absolute measurement without using the first decades and employ this as a reference for subsequent comparisons where increased discrimination is important.

From the foregoing considerations it follows that Range 4 of the Adaptor should be used for measurements up to only 10 ohms if maximum absolute accuracy is required. Above this value the Bridge should be used. Where high discrimination between values of resistance is essential and the first decades are used, the true value can be found either from the balance equation or by reference to the correction curves given at the end of this Handbook.

If an unstable value of impedance, such as the resistance of a defective switch contact, is to be measured, only an approximate reading is necessary. The continuously-variable controls alone should be used to obtain balance. If the switched decades are operated, the discrimination may be such that the random drift in resistance occurs more rapidly than the controls can be adjusted, making balance impossible.

CURRENT THROUGH THE UNKNOWN

The absolute value of alternating current passing through the Unknown cannot be specified accurately: the Bridge measurements are obtained by comparison. The values given are, therefore, approximate.

Adaptor Range	R.M.S. Current through Unknown
1	8mA
2	5mA
3	2mA
4	0·7mA

PRINCIPLE OF OPERATION

Refer to Fig. 25. When the Bridge is balanced, the voltage across the current transformer winding is, for all practical purposes, zero. Resistor R_2 is therefore effectively in parallel with the Unknown, Z_u. If the value of R_2 is very high compared with Z_u, the shunting effect is negligible and can be ignored. The current through the Unknown is then equal to $E/(R_1+Z_u)$. If R_1 also is made very high compared with Z_u, the effect of Z_u on the current is negligible and can be ignored. With these two approximations:

current through the Unknown,

$$i=E/R_1$$

voltage across the Unknown,

$$e=Z_u\,.\,E/R_1$$

current fed back to Bridge,

$$I=e/R_2=Z_u\,.\,E/R_1R_2.$$

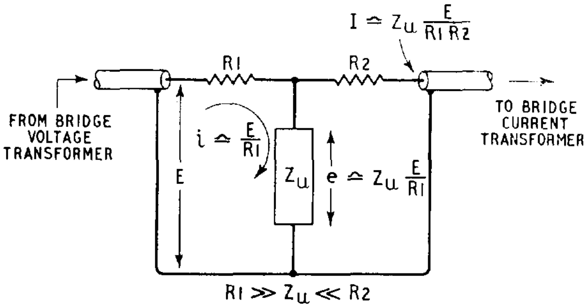


Fig. 25. Principle of Operation

For convenience, R_1 and R_2 are made equal, so that:

$$R_1=R_2=R$$

and

$$I=Z_u\,.\,E/R^2$$

or

$$Z_u=R^2\,.\,I/E \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The current I flows in the Bridge current transformer and E is the potential provided by the voltage transformer. The ratio I/E is therefore the admittance represented by the Bridge dial readings at balance. The value of the Unknown impedance is obtained (using equation 1) by multiplying the admittance read off the Bridge by R^2 and translating mhos as ohms. By making R^2 a suitable multiple of 10, the system becomes direct-reading.

It was assumed above that the value of the series resistors of the T-network was so high compared with the Unknown impedance that their shunting effect could be ignored. The balance equation is:

$$R^2/Z_u + 2R=1/(G_b+j\omega C_b)$$

where G_b and C_b are the conductance and the capacitance values read from the Bridge dials. The approximations made in the derivation of equation (1) are based on the assumption that $|R^2/Z_u|$ is much greater than $2R$. This approximation is valid *provided that the first decades are not used.*

CIRCUIT DESCRIPTION

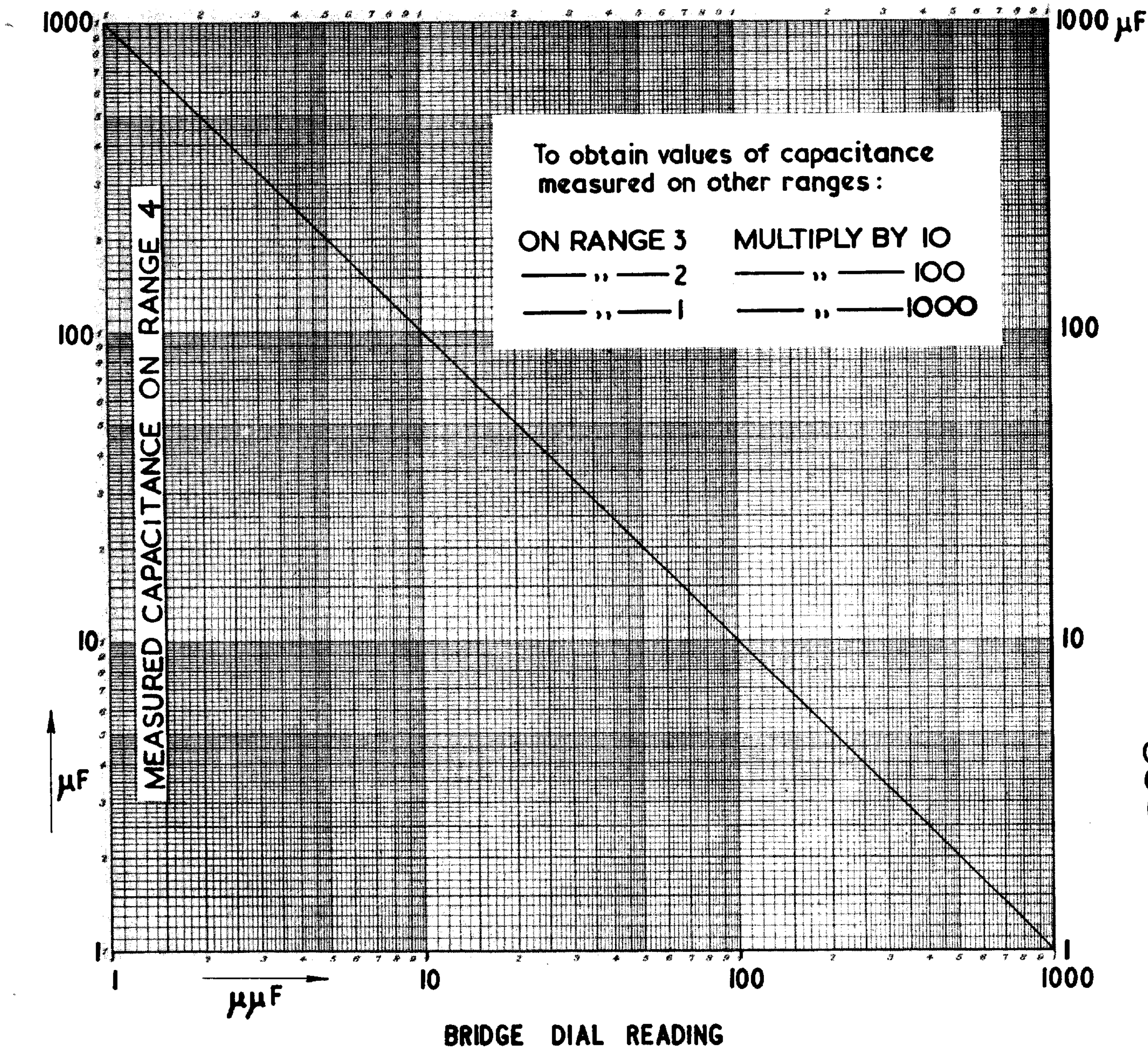
A circuit diagram is provided at the end of this Handbook. Four pairs of equal-value resistors form the switched series elements of a T-network. For most measurements the Blue and White plugs are effectively connected in parallel. The shunt arm of the network is then completed when the Unknown is connected between their inners and Neutral.

The series resistance of each arm is, for the four ranges, $\sqrt{10^4}$, $\sqrt{10^5}$, $\sqrt{10^6}$ and $\sqrt{10^7}$ ohms. The resistors in the Adaptor have slightly lower values to allow for the resistance of connecting leads and the Bridge transformer windings. The capacitors correct the small phase-shift introduced by the leakage inductance of these transformers.

As stated in the Introduction, the function of the Adaptor is to reverse the method of measurement as compared with the Bridge. Thus the Blue plug of the Adaptor, although associated with the E plug of the Bridge, serves to feed a constant *current* to the Unknown. Similarly the White plug of the Adaptor feeds back a voltage to the Bridge.

MAINTENANCE AND SERVICE

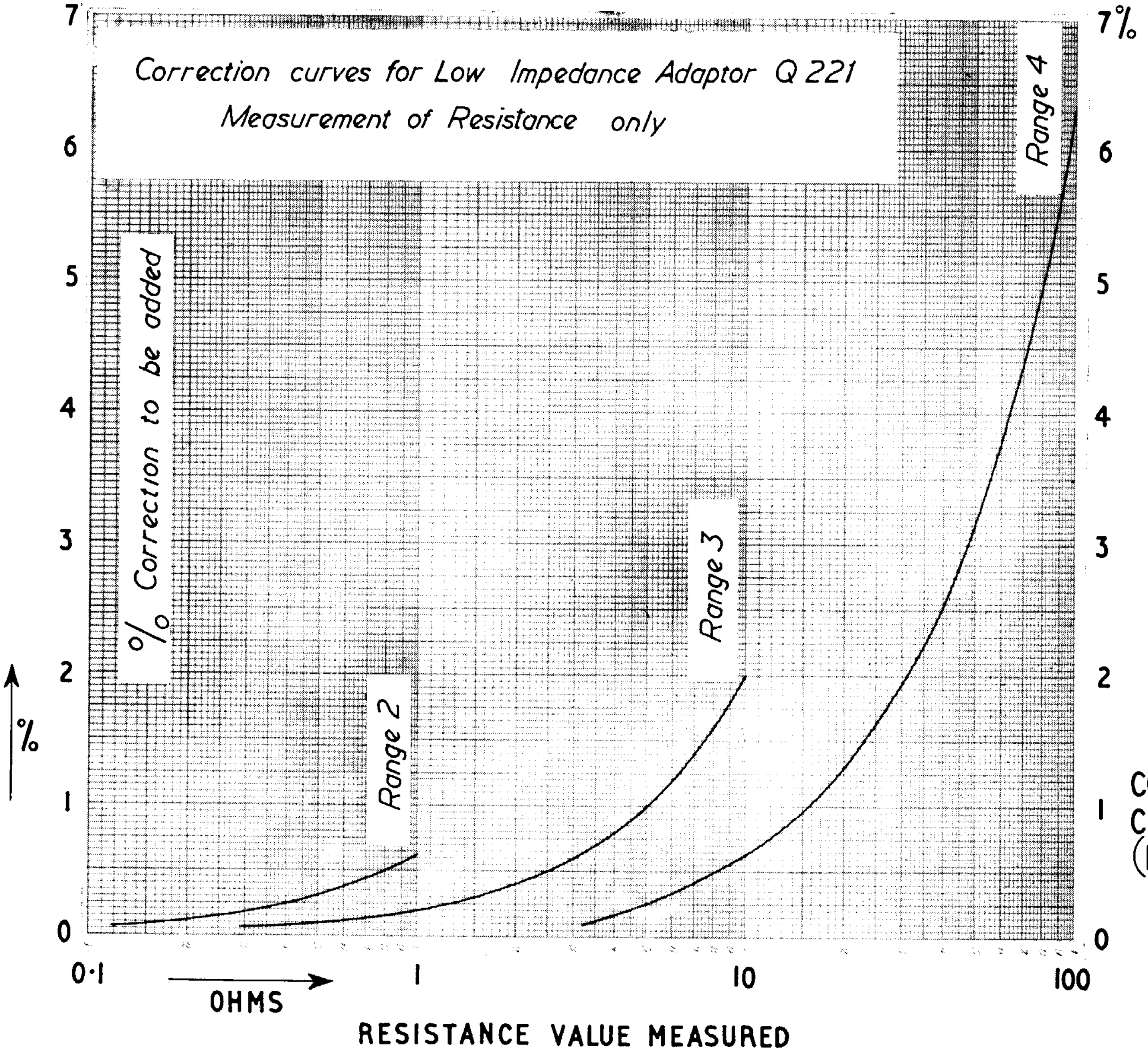
A circuit diagram of the Adaptor is provided at the back of this Handbook. The Bridge itself may be used to check the values of the Adaptor components. The switch and all plugs and sockets must be maintained in good order.



To obtain values of capacitance measured on other ranges:

ON RANGE 3 MULTIPLY BY 10
—— „ —— 2 —— „ —— 100
—— „ —— 1 —— „ —— 1000

CAPACITANCE CONVERSION CHART



CORRECTION CURVES (RESISTANCE)

B221 COMPONENT LIST

Ref.	Value	Tolerance (per cent)
R1–R4	Not used	
R5	5·6 kΩ	±10
R6	470 kΩ	±10
R7	Not used	
R8	22 kΩ	±10
R9	10 kΩ } Two in	±10
R9	10 kΩ } parallel	±10
R10	1·5 kΩ	±10
R11	100 kΩ	±10
R1	100 kΩ	±10
R13	100 kΩ	±10
R14	3·3 kΩ	±10
R15	100 kΩ	±0·05*
R16	10 kΩ	±0·05*
R17	820 kΩ	±1
R18	1 MΩ	±1
R19	1 kΩ	±10
R20	100 kΩ	±10
R21	1 kΩ	±10
R22	2·2 MΩ	±10
R23	47 kΩ	±10
R24–R31	Not used	
R32	2·2 MΩ	±20
R33	1 MΩ	±10
R34	1 MΩ	±10
R35	1 MΩ	±10
R36	1 MΩ	±10
RV1	50 kΩ	Linear
RV2	10 kΩ	Lin. to 5 per cent
RV3	25 kΩ	Linear
RV4	1 MΩ	Log
RV5	50 kΩ	Linear
FS1	500 mA	

* Adjusted in circuit

Ref.	Value	Type
C1–C5	Not used	
C6	400 µµF	Trimmer
C7	5000 µµF	±2 per cent
C8	0·01 µF	350 V
C9	8 µF	350 V
C10	0·01 µF	350 V
C11	440 µµF	Variable
C12	0·001 µF	+0, —1 per cent
C13	3—30 µµF	Trimmer
C14	0·01 µF	+0, —1 per cent
C15	22 µµF	±10 per cent
C16	3—30 µµF	Trimmer
C17	100 µµF	Variable
C18	33 µµF	±10 per cent
C19	1 µF	275 V
C20	5000 µµF	±1 per cent
C21	0·01 µF	350 V
C22	5000 µµF	±1 per cent
C23	0·001 µF	350 V
C24	8 µF	350 V
C25–C33	Not used	
C34	0·001 µF	
C35	0·001 µF	
C36	0·5 —5 µµF	Trimmer
C37	See page 26	
C38	0·5 —5 µµF	Trimmer
C39	1 µF	50 V
T1	Voltage Transformer Type R.T. 3.8	
T2	Current Transformer Type R.T. 4.8	
T3	Mains Transformer	
	Pri: 0–100/125 and 200/250V	
	Sec: 210–0–210 V, 40 mA	
	6·3 V, 1·75 A	
	6·3 V, 1·0 A	

§Measurement Cable (2 per inst.)	D10065
†Low Capacity Clip leads LCC3	D10642
Power Cable Assembly (CT530 only)	D10542
Lid Assembly (CT530 only)	D10544
Bridge Cased Assembly (CT530 only)	D10594

§Specify BNC (bayonet) or Miniature Pye (threaded) connectors.
†LCC3 is fitted with BNC connectors.
LCC2 is fitted with Min. Pye connectors.

RECIPROCALS

	0	1	2	3	4	5	6	7	8	9
1·0	1·00000	99010	98039	97087	96154	95238	94340	93458	92593	91743
1·1	90909	90090	89286	88496	87719	86957	86207	85470	84746	84034
1·2	83333	82645	81967	81301	80645	80000	79365	78740	78125	77519
1·3	76923	76336	75758	75188	74627	74074	73529	72993	72464	71942
1·4	71429	70922	70423	69930	69444	68966	68493	68027	67568	67114
1·5	66667	66225	65789	65359	64935	64516	64103	63694	63291	62893
1·6	62500	62112	61728	61350	60976	60606	60241	59880	59524	59172
1·7	58824	58480	58140	57803	57471	57143	56818	56497	56180	55866
1·8	55556	55249	54945	54645	54348	54054	53763	53476	53191	52910
1·9	52632	52356	52083	51813	51546	51282	51020	50761	50505	50251
2·0	50000	49751	49505	49261	49020	48780	48544	48309	48077	47847
2·1	47619	47393	47170	46948	46729	46512	46296	46083	45872	45662
2·2	45455	45249	45045	44843	44643	44444	44248	44053	43860	43668
2·3	43478	43290	43103	42918	42735	42553	42373	42194	42017	41841
2·4	41667	41494	41322	41152	40984	40816	40650	40486	40323	40161
2·5	40000	39841	39683	39526	39370	39216	39063	38911	38760	38610
2·6	38462	38314	38168	38023	37879	37736	37594	37453	37313	37175
2·7	37037	36900	36765	36630	36496	36364	36232	36101	35971	35842
2·8	35714	35587	35461	35336	35211	35088	34965	34843	34722	34602
2·9	34483	34364	34247	34130	34014	33898	33784	33670	33557	33445
3·0	33333	33223	33113	33003	32895	32787	32680	32573	32468	32362
3·1	32258	32154	32051	31949	31847	31746	31646	31546	31447	31348
3·2	31250	31153	31056	30960	30864	30769	30675	30581	30488	30395
3·3	30303	30211	30120	30030	29940	29851	29762	29674	29586	29499
3·4	29412	29326	29240	29155	29070	28986	28902	28818	28736	28653
3·5	28571	28490	28409	28329	28249	28169	28090	28011	27933	27855
3·6	27778	27701	27624	27548	27473	27397	27322	27248	27174	27100
3·7	27027	26954	26882	26810	26738	26667	26596	26525	26455	26385
3·8	26316	26247	26178	26110	26042	25974	25907	25840	25773	25707
3·9	25641	25575	25510	25445	25381	25316	25253	25189	25126	25063
4·0	25000	24938	24876	24814	24752	24691	24631	24570	24510	24450
4·1	24390	24331	24272	24213	24155	24096	24038	23981	23923	23866
4·2	23810	23753	23697	23641	23585	23529	23474	23419	23364	23310
4·3	23256	23202	23148	23095	23041	22989	22936	22883	22831	22779
4·4	22727	22676	22624	22573	22523	22472	22122	22371	22321	22272
4·5	22222	22173	22124	22075	22026	21978	21930	21882	21834	21786
4·6	21739	21692	21645	21598	21552	21505	21459	21413	21368	21322
4·7	21277	21231	21186	21142	21097	21053	21008	20964	20921	20877
4·8	20833	20790	20747	20704	20661	20619	20576	20534	20492	20450
4·9	20408	20367	20325	20284	20243	20202	20161	20121	20080	20040
5·0	20000	19960	19920	19881	19841	19802	19763	19724	19685	19646
5·1	19608	19569	19531	19493	19455	19417	19380	19342	19305	19268
5·2	19231	19194	19157	19120	19084	19048	19011	18975	18939	18904
5·3	18868	18832	18797	18762	18727	18692	18657	18622	18587	18553
5·4	18519	18484	18450	18416	18382	18349	18315	18282	18248	18215
	0	1	2	3	4	5	6	7	8	9

PROPORTIONAL PARTS OF MEAN DIFFERENCES

	1	2	3	4	5	6	7	8	9
1·0									
1·1									
1·2									
1·3									
1·4									
1·5	42	83	125	167	209	250	292	334	375
1·6	37	74	110	147	184	221	258	294	331
1·7	33	65	98	131	164	196	229	262	294
1·8	29	58	88	117	146	175	204	234	263
1·9	26	53	79	105	132	158	184	210	237
2·0	24	48	71	95	119	143	167	190	214
2·1	22	43	65	86	108	130	151	173	194
2·2	20	40	59	79	99	119	139	158	178
2·3	18	36	54	72	91	109	127	145	163
2·4	17	33	50	67	84	100	117	134	150
2·5	15	31	46	62	77	92	108	123	139
2·6	14	29	43	57	72	86	100	114	129
2·7	13	26	40	53	66	79	92	106	119
2·8	12	25	37	49	62	74	86	98	111
2·9	12	23	35	46	58	69	81	92	104
3·0	11	22	32	43	54	65	76	86	97
3·1	10	20	30	40	51	61	71	81	91
3·2	10	19	29	38	48	57	67	76	86
3·3	9	18	27	36	45	53	62	71	80
3·4	8	17	25	34	42	50	59	67	76
3·5	8	16	24	32	40	47	55	63	71
3·6	8	15	23	30	38	45	53	60	68
3·7	7	14	21	28	36	43	50	57	64
3·8	7	14	20	27	34	41	48	54	61
3·9	6	13	19	26	32	38	45	51	58
4·0	6	12	18	24	31	37	43	49	55
4·1	6	12	17	23	29	35	41	46	52
4·2	6	11	17	22	28	33	39	44	50
4·3	5	11	16	21	27	32	37	42	48
4·4	5	10	15	20	26	31	36	41	46
4·5	5	10	14	19	24	29	34	38	43
4·6	5	9	14	18	23	28	32	37	41
4·7	4	9	13	18	22	26	31	35	40
4·8	4	9	13	17	22	26	30	34	39
4·9	4	8	12	16	20	25	29	33	37
5·0	4	8	12	16	20	24	27	31	35
5·1	4	8	11	15	19	23	26	30	34
5·2	4	7	11	15	18	22	25	29	33
5·3	3	7	10	14	18	21	24	28	31
5·4	3	7	10	14	17	20	24	27	30
	1	2	3	4	5	6	7	8	9

PROPORTIONAL PARTS OF MEAN DIFFERENCES

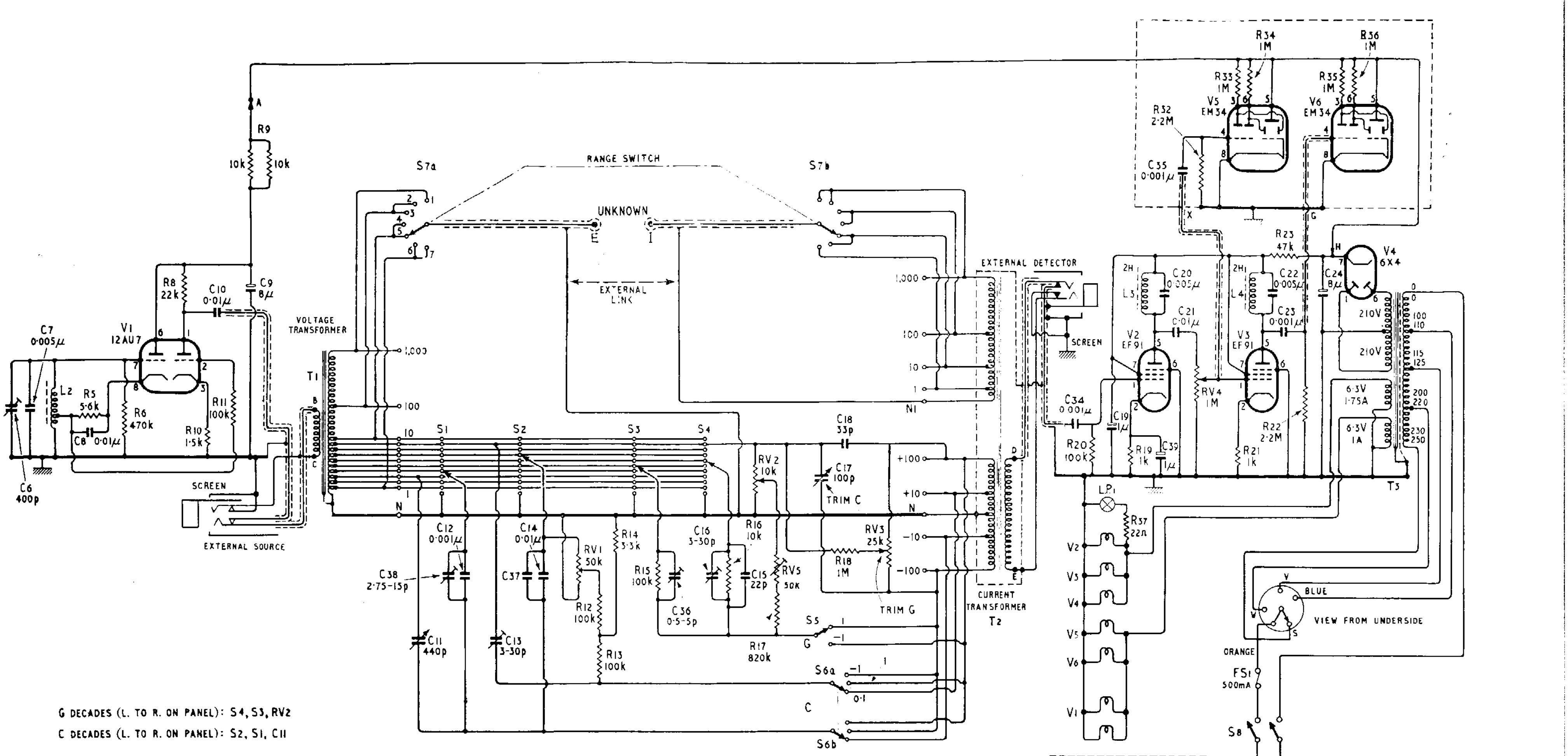
RECIPROCALS —*continued*

	0	1	2	3	4	5	6	7	8	9
5·5	18182	18149	18116	18083	18051	18018	17986	17953	17921	17889
5·6	17857	17825	17794	17762	17731	17699	17668	17637	17606	17575
5·7	17544	17513	17483	17452	17422	17391	17361	17331	17301	17271
5·8	17241	17212	17182	17153	17123	17094	17065	17036	17007	16978
5·9	16949	16920	16892	16863	16835	16807	16779	16750	16722	16694
6·0	16667	16639	16611	16584	16556	16529	16502	16474	16447	16420
6·1	16393	16367	16340	16313	16287	16260	16234	16207	16181	16155
6·2	16129	16103	16077	16051	16026	16000	15974	15949	15924	15898
6·3	15873	15848	15823	15798	15773	15748	15723	15699	15674	15649
6·4	15625	15601	15576	15552	15528	15504	15480	15456	15432	15408
6·5	15385	15361	15337	15314	15291	15267	15244	15221	15198	15175
6·6	15152	15129	15106	15083	15060	15038	15015	14993	14970	14948
6·7	14925	14903	14881	14859	14837	14815	14793	14771	14749	14728
6·8	14706	14684	14663	14641	14620	14599	14577	14556	14535	14514
6·9	14493	14472	14451	14430	14409	14388	14368	14347	14327	14306
7·0	14286	14265	14245	14225	14205	14184	14164	14144	14124	14104
7·1	14085	14065	14045	14025	14006	13986	13966	13947	13928	13908
7·2	13889	13870	13850	13831	13812	13793	13774	13755	13736	13717
7·3	13699	13680	13661	13643	13624	13605	13587	13569	13550	13532
7·4	13514	13495	13477	13459	13441	13423	13405	13387	13369	13351
7·5	13333	13316	13298	13280	13263	13245	13228	13210	13193	13175
7·6	13158	13141	13123	13106	13089	13072	13055	13038	13021	13004
7·7	12987	12970	12953	12937	12920	12903	12887	12870	12853	12837
7·8	12821	12804	12788	12771	12755	12739	12723	12706	12690	12674
7·9	12658	12642	12626	12610	12594	12579	12563	12547	12531	12516
8·0	12500	12484	12469	12453	12438	12422	12407	12392	12376	12361
8·1	12346	12330	12315	12300	12285	12270	12255	12240	12225	12210
8·2	12195	12180	12165	12151	12136	12121	12107	12092	12077	12063
8·3	12048	12034	12019	12005	11990	11976	11962	11947	11933	11919
8·4	11905	11891	11876	11862	11848	11834	11820	11806	11792	11779
8·5	11765	11751	11737	11723	11710	11696	11682	11669	11655	11641
8·6	11628	11614	11601	11587	11574	11561	11547	11534	11521	11507
8·7	11494	11481	11468	11455	11442	11429	11416	11403	11390	11377
8·8	11364	11351	11338	11325	11312	11299	11287	11274	11261	11249
8·9	11236	11223	11211	11198	11186	11173	11161	11148	11136	11123
9·0	11111	11099	11086	11074	11062	11050	11038	11025	11013	11001
9·1	10989	10977	10965	10953	10941	10929	10917	10905	10893	10881
9·2	10870	10858	10846	10834	10823	10811	10799	10787	10776	10764
9·3	10753	10741	10730	10718	10707	10695	10684	10672	10661	10650
9·4	10638	10627	10616	10604	10593	10582	10571	10560	10549	10537
9·5	10526	10515	10504	10493	10482	10471	10460	10449	10438	10428
9·6	10417	10406	10395	10384	10373	10363	10352	10341	10331	10320
9·7	10309	10299	10288	10277	10267	10256	10246	10235	10225	10215
9·8	10204	10194	10183	10173	10163	10152	10142	10132	10121	10111
9·9	10101	10091	10081	10070	10060	10050	10040	10030	10020	10010
	0	1	2	3	4	5	6	7	8	9

PROPORTIONAL PARTS OF MEAN DIFFERENCES

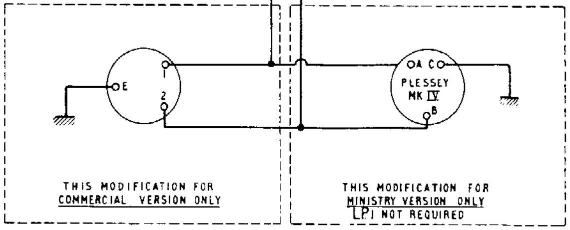
	1	2	3	4	5	6	7	8	9
5·5	3	7	10	13	16	20	23	26	29
5·6	3	6	9	13	16	19	22	25	28
5·7	3	6	9	12	15	18	21	24	27
5·8	3	6	9	12	15	18	20	23	26
5·9	3	6	9	11	14	17	20	23	25
6·0	3	6	8	11	14	16	19	22	25
6·1	3	5	8	11	13	16	19	21	24
6·2	3	5	8	10	13	15	18	21	23
6·3	2	5	7	10	12	15	17	20	22
6·4	2	5	7	10	12	14	17	19	22
6·5	2	5	7	9	12	14	16	19	21
6·6	2	5	7	9	11	14	16	18	20
6·7	2	4	7	9	11	13	15	18	20
6·8	2	4	6	9	11	13	15	17	19
6·9	2	4	6	8	10	12	14	17	19
7·0	2	4	6	8	10	12	14	16	18
7·1	2	4	6	8	10	12	14	16	18
7·2	2	4	6	8	10	11	13	15	17
7·3	2	4	6	7	9	11	13	15	17
7·4	2	4	5	7	9	11	13	15	16
7·5	2	4	5	7	9	11	12	14	16
7·6	2	3	5	7	9	10	12	14	15
7·7	2	3	5	7	8	10	12	13	15
7·8	2	3	5	7	8	10	11	13	15
7·9	2	3	5	6	8	9	11	13	14
8·0	2	3	5	6	8	9	11	12	14
8·1	2	3	5	6	8	9	11	12	14
8·2	1	3	4	6	7	9	10	12	13
8·3	1	3	4	6	7	9	10	11	13
8·4	1	3	4	6	7	8	10	11	13
8·5	1	3	4	5	7	8	10	11	12
8·6	1	3	4	5	7	8	9	11	12
8·7	1	3	4	5	7	8	9	10	12
8·8	1	3	4	5	6	8	9	10	12
8·9	1	3	4	5	6	8	9	10	11
9·0	1	2	4	5	6	7	9	10	11
9·1	1	2	4	5	6	7	8	10	11
9·2	1	2	4	5	6	7	8	9	11
9·3	1	2	4	5	6	7	8	9	10
9·4	1	2	3	4	6	7	8	9	10
9·5	1	2	3	4	5	7	8	9	10
9·6	1	2	3	4	5	6	8	9	10
9·7	1	2	3	4	5	6	7	8	10
9·8	1	2	3	4	5	6	7	8	9
9·9	1	2	3	4	5	6	7	8	9
	1	2	3	4	5	6	7	8	9

PROPORTIONAL PARTS OF MEAN DIFFERENCES



G DECADES (L. TO R. ON PANEL): S4, S3, RV2

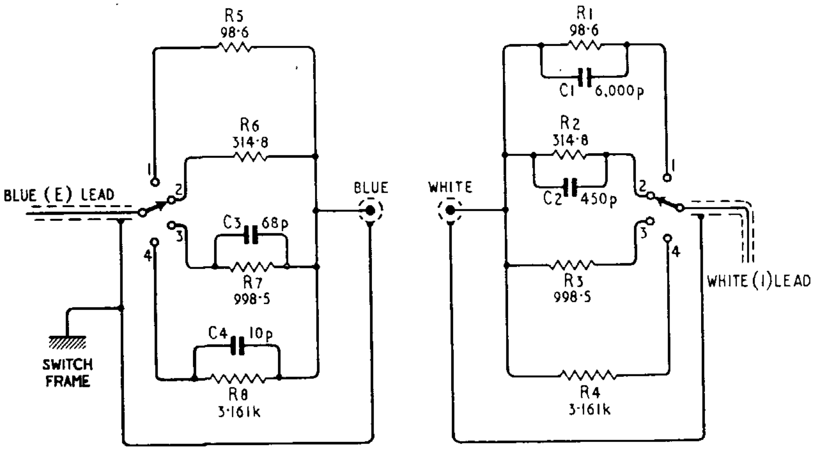
C DECADES (L. TO R. ON PANEL): S2, S1, C11



THIS MODIFICATION FOR COMMERCIAL VERSION ONLY

THIS MODIFICATION FOR MINISTRY VERSION ONLY LP1 NOT REQUIRED

Ref.	Value	Type
R1	98·6 Ω	± 0·5 per cent
R2	314·8 Ω	± 0·5 per cent
R3	998·5 Ω	± 0·5 per cent
R4	3·161k Ω	± 0·5 per cent
R5	98·6 Ω	± 0·5 per cent
R6	314·8 Ω	± 0·5 per cent
R7	998·5 Ω	± 0·5 per cent
R8	3·161k Ω	± 0·5 per cent
C1	6000μμF	± 5 per cent
C2	450μμF	± 5 per cent
C3	68μμF	± 5 per cent
C4	10μμF	± 1μμF



(Above) — B221 Circuit Diagram
(D3125, Issue W)

Left — Q221 Components List and Circuit Diagram
(D9678, Issue F)