RADIO FREQUENCY BRIDGE B601

and

LOW IMPEDANCE ADAPTOR Z601

INSTRUCTION
MANUAL

THE WAYNE KERR COMPANY LIMITED

Sycamore Grove · New Malden · Surrey · England

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INTRODUCTION

Radio Frequency Bridge B601, in conjunction with Low Impedance Adaptor Z601, permits a very wide range of resistance, capacitance and inductance values to be measured accurately at any frequency between 15kc/s and 5Mc/s. The overall coverage is 1mΩ to 10MΩ, 0·01pF to 5000μF and 0·001μH to 0·05H. The Bridge accuracy is generally 1 per cent and the Adaptor (used for measuring impedances of less than 10ohms) is accurate to within 5 per cent.

Separate dials and multiplier switches on the Bridge enable the resistive and reactive terms of an unknown impedance to be measured simultaneously, and further versatility is provided by alternative terminal connections. The transformer ratio-arm circuit used enables balanced and unbalanced impedances to be measured, also balanced impedances with the centre-point earthed. The accuracy and discrimination are maintained when very low Q elements are measured. In addition to all normal two-terminal measurements, the impedance between any pair of terminals in a three-terminal network can be determined. The Bridge is extremely stable, because the impedance at the measurement terminals, and from the terminals to earth, are both very low at balance.

The Low Impedance Adaptor, Z601, is essentially a T-network, alternative measurement ranges being provided by interchangeable pairs of resistors as the series arms: the unknown impedance forms the shunt arm.

Other Adaptors developed for the Bridge are the Transistor Adaptors, Q601, for the measurement of small-signal parameters of pnp or npn transistors. These are described in a separate publication.

SPECIFICATION

OVERALL COVERAGE (BRIDGE WITH ADAPTOR)

Resistance	1mΩ to 10MΩ
Capacitance	0·01pF to 5000μF
Inductance	0·001μH to 0·05H

B601 BRIDGE

Frequency Range	15kc/s to 5Mc/s
Resistance Range	10Ω to 10MΩ
Capacitance Range	0·01pF to 20,000pF
Inductance Range	0·5μH to 0·05H
Accuracy	Direct-reading accuracy of major term is generally ± 1 per cent up to 3Mc/s, falling to ± 2 per cent at 5Mc/s. Inductance measurements are frequency-dependent.
Dimensions (B601)	Width 15 in. (38 cm)
	Height 11 in. (28 cm)
	Depth 9 1/2 in. (24 cm)
Weight (B601)	18 1/4 lb. (8·3 kg)

Z601 ADAPTOR

Resistance Range	0·001Ω to 10Ω
Resistance Accuracy	Above 0·01Ω: Better than ± 5 per cent
Capacitance Range	At 15kc/s: 0·3μF to 5000μF
	At 5Mc/s: 0·001μF to 1·0μF
Capacitance Accuracy	At 15kc/s: 1μF to 5000μF: Better than ± 5 per cent
	At 5Mc/s: 0·003μF to 0·1μF: Better than ± 5 per cent
Inductance Range	0·001μH minimum
	300μH maximum at 15kc/s
	1μH maximum at 5Mc/s
Inductance Accuracy	Above 0·1μH: Better than ± 5 per cent
Dimensions (Z601)	Length 7 1/8 in. (18 cm)
	Height 1 3/8 in. (3·5 cm)
	Depth 1 3/4 in. (4·5 cm)
Weight (Z601)	5 oz. (142 grams)

PRINCIPLE OF OPERATION

The Bridge employs the transformer ratio-arm principle which is described fully in Wayne Kerr Monograph No. 1 - 'The Transformer Ratio-Arm Bridge' by Raymond Calvert. The Monograph - which is freely available - describes also the principles underlying the extension network as used in the Low Impedance Adaptor Z601.

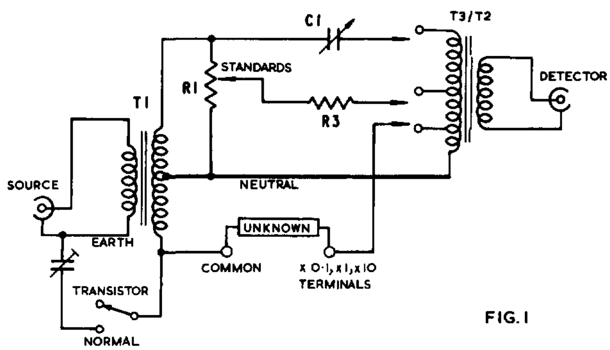

FIG. 1

A simplified diagram of the bridge circuit is shown in Fig. 1 and a complete diagram is included at the back of this manual.

Voltages applied to the Standards and the Unknown from the secondary of transformer T1 are equal in magnitude but of opposite phase. The Standards are adjusted to provide a null indication on the detector and, in this condition, the ampere-turns produced in T3/T2 primary by the current from the Standards is cancelled exactly by that produced by the current from the Unknown side of the Bridge.

Different ranges are provided on the Standards side by separate multiplier switches which connect the resistive and capacitive standards to differing taps on T3/T2 primary. T3 is actually an auto-transformer which provides T2 with a tapping point equivalent to 0·1 turn. Inductance ranges are achieved by switching the left-hand connection of C1 to the lower instead of the upper end of T1 primary, thus reversing the phase of the current fed by C1 into T3/T2. Different ranges on the Unknown side are provided by alternative terminal connections to T3/T2 primary, giving range factors of x 0·1, x 1 and x 10.

For certain types of measurement (for example, when using the Transistor Adaptors) it is necessary to have the COMMON terminal isolated from earth. For normal measurements, particularly unbalanced impedances, a trimmer capacitor is switched into circuit to equalise the capacitance (to earth) on the unknown and standards sides of the bridge respectively. Information on the correct setting of this switch and selection of the appropriate terminals for a specific type of measurement is given in the relevant sections of the Operating Instructions.

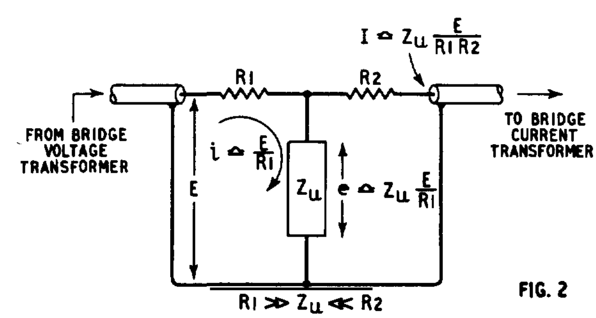

FIG. 2

As stated earlier, a complete description of the principles underlying the Low Impedance Adaptor is included in Monograph No. 1. The functional circuit of the Adaptor, Fig. 2, shows the approximate expressions for voltage and current, from which the simplified equations (given later) are derived.

Source An oscillator capable of supplying at least 0·1V, and preferably up to 3V, into an impedance of 100 ohms is required. It is essential that the source be well screened. Suitable instruments include the following:

Wayne Kerr Source/Detector SR268	(100kc/s - 100Mc/s)
Wayne Kerr Video Oscillator 022D	(10kc/s - 10Mc/s)
Marconi Instruments TF144H	(10kc/s - 72Mc/s)
Airmec 201 or 858	(30kc/s - 30Mc/s)
Marconi Instruments TF867A	(15kc/s - 30Mc/s)
Marconi Instruments TF885A/1	(25c/s - 12Mc/s)
Advance E2	(100kc/s - 100Mc/s)
Advance B4/B	(30kc/s - 30Mc/s)
General Radio 1300A	(20kc/s - 12Mc/s)

Detector This should have a sensitivity of 1-5 microvolts. A number of Communications receivers, H. F. Wave Analysers and Bridge Detectors are suitable, including the following:

Wayne Kerr Source/Detector SR268	(100kc/s - 100Mc/s)
Airmec 853	(30kc/s - 30Mc/s)
Plessey PR152	(550kc/s - 30Mc/s)
General Radio 1212A	(50c/s - 5Mc/s)

The sources and detectors as specified above enable the bridge to be used for measurements to the stated accuracy. Smaller driving voltages or less sensitive detectors will result in reduced measuring accuracy.

It is essential that both source and detector be well screened, from each other and from the unknown impedance, since any direct coupling between them will give rise to an error in measurement. With the detector at maximum sensitivity there should be no measurable signal when the detector plug is withdrawn from its socket on the bridge and its outer connected to the bridge framework.

Types of Measurement

Before the initial setting-up procedure can be started, the appropriate connections must be made to the Earth and Neutral terminals to suit the measurement conditions. The switch located beneath the lid, adjacent to the Earth terminal, should always be set to 'Normal': the exception is when the Neutral terminal is connected to Earth, such as when the Q601 Adaptors are in use, in which case the switch should be set to 'Transistor'. The alternative arrangements are as follows:

a) Small components connected directly to the bridge terminals: Earth and Neutral terminals left free.

b) Balanced impedances isolated from earth: Earth and Neutral terminals left free.

c) Balanced impedances with centre-point earthed: Earth terminal to earth of Unknown, Neutral left free.

d) Unbalanced impedances: Earth terminal to Common terminal and to earth of Unknown, Neutral left free.

e) Screened connecting leads: If lengths of screened lead are used to connect the Unknown to the Bridge terminals, the screens should be linked at the bridge end and connected to the Neutral terminal. If the series impedance of the leads can be neglected, the only effective impedance is that of the Unknown.

f) Three-terminal impedances: If it is desired to measure the impedance between terminals 0 and P of a three-terminal impedance (see Fig. 3) the third terminal, Q, should be connected to Neutral.

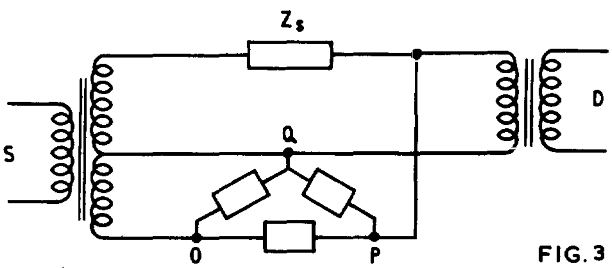

FIG. 3

Terminals 0 and P are connected to Common and one of the multiplier terminals, respectively, in the usual way. Impedances O-Q and P-Q then shunt the bridge transformers and normally do not affect the balance of the bridge.

Initial Setting-up

1 Connect the source and detector to the bridge and make all terminal connections to suit the type of measurement, as detailed in the preceding section, except the Unknown which should not be connected at this stage.

2 Adjust the source to the frequency required for measurement and tune the detector for maximum output at this frequency.

3 Set the R dial to infinity, the C dial to zero and the two multiplier switches to settings appropriate to the value of the unknown. If necessary, a preliminary rough measurement can be made to determine the range required and the unknown then disconnected.

4 Adjust the R and C-L Balance controls for a null indication on the detector. It should not be necessary to repeat this operation unless the source frequency, or the range in use, is altered. It is not necessary to re-trim when changing the multiplier terminal in use.

Selecting the Multiplier Terminal

The values of the resistance and capacitance (or inductance) of the unknown are obtained by multiplying the associated dial reading at balance by two factors:

(a) the range factor, shown in a window above each dial

(b) the terminal factor, marked against the terminal to which the unknown in connected.

For a given value of unknown impedance there will often exist alternative combinations of dial reading, range switching and terminal factor providing a balance. None of these combinations will provide a false balance but the following information enables the most suitable selection, for maximum accuracy, to be made.

The three terminal factors and the corresponding number of turns on the output transformer are:

(a) x0·1 R & L
x10C
(Effectively 0·1 turn)

(b) x1·0 R & L
x1·0C
(1 turn)

(c) x10 R & L
x0·1C
(10 turns)

As a general rule, low values of impedance are measured between the Common and x0·1 R & L terminals and, correspondingly, high values between Common and x10 R & L.

The choice of terminal will normally be determined by the value of the major component of a complex impedance but, where the minor term also is required, a compromise may be necessary in order to obtain a convenient dial reading.

When using the bridge at higher frequencies it is important that the terminal selected should be that associated with the lowest possible number of turns on the output transformer. This minimises any errors due to the effects of leakage inductance. If the larger number of turns has to be in circuit at high frequencies, great care must be taken to ensure that the series inductance and shunt capacitance of the external connections are kept to a minimum.

The accompanying table shows the resistance and capacitance ranges, for various accuracies, for every combination of multiplier terminal and range switch positions.

Measurement of R and C

When the initial setting-up procedure has been completed, connect the unknown to the bridge and adjust the two main dials for a null indication on the detector. The resistance and capacitance values for the equivalent parallel components of the unknown impedance are obtained by multiplying the R and C dial readings at balance by the associated range and terminal factors.

Example:

R dial:	1·45kilohms
R multiplier:	R x10
Terminal:	x0·1 R & L (x10C)
Measurement frequency:	2Mc/s

R value = 1·45 x 10 x 0·1kΩ
= 1·45kΩ

C dial:	56picofarads
C-L multiplier:	C x1·0

C value = 56 x 1·0 x 10pF
= 560pF

The expressions for calculating the equivalent series components are given later in this section.

Measurement of R and L

When the initial setting-up procedure has been completed, connect the unknown to the bridge and adjust the two main dials for a null indication on the detector. The resistance value for the equivalent parallel components of the unknown is obtained by multiplying the R dial reading by the associated range and terminal factors.

The inductance value for the equivalent parallel components of the unknown is measured in terms of negative capacitance, i. e. the value of capacitance which has the same reactance at the frequency of measurement. To derive the inductance value the source frequency must be known accurately - to an order better than 1 per cent if the values derived from the bridge are not to be subject to an increased tolerance. The derivation of the inductance is most easily achieved with reactance charts, as follows:

1 Find the reactance of the capacitance value, as shown on the C dial, at the frequency of measurement.

Terminals Used	R Window Multiplier	Min. R for 1 per cent	Max. R for 5 per cent	Max. R for 20 per cent	C-L Window Multiplier	Min. C for 30 per cent	Min. C for 5 per cent	Max. C for 1 per cent
x0·1 R & L x10 C	R x0·1	10Ω	200Ω	1kΩ	C x0·1	1pF	10pF	220pF
	R x1·0	100Ω	2kΩ	10kΩ	C x1·0	10pF	100pF	2200pF
	R x10	1kΩ	20kΩ	100kΩ	C x10	100pF	1000pF	22000pF
x1·0 R & L x1·0 C	R x0·1	100Ω	2kΩ	10kΩ	C x0·1	0·1pF	1pF	22pF
	R x1·0	1kΩ	20kΩ	100kΩ	C x1·0	1pF	10pF	220pF
	R x10	10kΩ	200kΩ	1MΩ	C x10	10pF	100pF	2200pF
x10 R & L x0·1 C	R x0·1	1kΩ	20kΩ	100kΩ	C x0·1	0·01pF	0·1pF	2·2pF
	R x1·0	10kΩ	200kΩ	1MΩ	C x1·0	0·1 pF	1pF	22pF
	R x10	100kΩ	2MΩ	10MΩ	C x10	1·0 pF	10pF	220pF

2 Find the value of inductance which, at this frequency, has the same reactance.

3 Multiply the inductance value so obtained by the range and terminal factors used.

The alternative procedure, if reactance charts are not available, is to calculate the inductance from the expression:

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

and multiply the value obtained by the range and terminal factors used.

Example:

R dial:	8·5kilohms
R multiplier:	R x10
C dial:	100picofarads
C-L multiplier:	L x0·1
Terminal:	x0·1 R & L
Measurement frequency:	100kc/s

Reactance of 100pF at 100kc/s: 15, 900ohms

Equivalent inductance at 100kc/s: (from $\omega L = 15,900$) 0·0253henrys

Scale factors for inductance:
Multiplier 0·1
Terminal 0·1

Value of inductance:
0·0253 x 0·1 x 0·1 = 253μH

Effective parallel resistance:
8500 x 0·1 x 10 = 8, 500 ohms.

The expressions for calculating the equivalent series components are given later in this section.

Measurement of Dielectric Loss

The bridge is not suitable for the direct measurement of dielectric losses in high-grade insulating materials, since the very small loss term becomes comparable with the series resistance of the bridge transformers and the internal wiring associated with the Standards. The effect of these internal losses can be minimised, however, by adopting a substitution procedure employing a 3-terminal variable air-dielectric capacitor of comparable value to the unknown. The procedure is to obtain a preliminary balance on the bridge with the unknown connected and then substitute the variable capacitor, connecting the third terminal to Neutral. Balance is restored by adjusting the external variable capacitor and the R BALANCE control only, with the main R dial at 'INF'. The variable capacitor is then replaced by the unknown and a normal balance obtained, using the main R and C dials. Their settings at balance, after the multiplier and terminal factors have been taken into account, provide an accurate measure of the capacitance value and the best measure of the loss term that can be obtained from the bridge.

Measurement of Lines and Aerials

The general procedure is as described in the foregoing sections but particular care must be taken to ensure that the detector is adequately screened against radiation from the line or aerial under test.

The primary constants of a cable can be derived from measurement of the input impedance (or admittance) of a length of line, the far end of which is short-circuited in one case and left open-circuited for a second measurement. To obtain the highest measurement accuracy it is advisable to use a length of cable which is an odd multiple of $\lambda/8$. Under such conditions the input impedances will be very near to the values:

$$Z_{in} = Z_o \pm jZ_o$$

Conversely, if the length of cable is fixed, it is advisable to select frequencies for measurement such that the length of the cable is an odd multiple of $\lambda/8$.

Lengths of cable such that they are multiples of $\lambda/4$ must be avoided, since the input impedance tends to zero or infinity and no bridge can provide useful readings.

The maximum capacitance reading of the B601 Bridge used without the Low Impedance Adaptor is 22,000pF. This determines the minimum reactance that can be measured directly, selected values being 160Ω at 50kc/s, 80Ω at 100kc/s and 16Ω at 0·5Mc/s.

There are no clearly-defined limits to the maximum reactance values which correspond to minimum capacitance settings.

An extension to the lower reactance limit can be achieved by the use of an external capacitor. If the line capacitance is negative and greater than 22,000 pF, the external capacitor is connected in parallel with the input to the cable. If the line capacitance is positive and greater then 22,000 pF, the external capacitor is connected in series with the input to the cable. When the measurement is completed, due allowance for the capacitor is made when calculating the input impedances. The value of the external capacitor can lie between 10,000 and 30,000pF.

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Example:

Measurement frequency: 60kc/s

Length of line: 1km (assuming a dielectric permittivity of 3·5, this corresponds to approximately 3λ/8)

Cable connected between 'Common' and 'x0·1 R & L, x10 C' terminals

(a) Far end short-circuited:

Range Multipliers: R x1·0 and C x10

Dial Readings: 4·15 kilohms and 133 picofarads

$\therefore R_p = 415\Omega$ and $C_p = 13,300\text{pF}$

(b) Far end open-circuited:

In order to obtain a balance, a capacitor of 22,000pF was connected in parallel with the line at the measurement terminals.

Range Multipliers: R x1·0 and L x0·1

Dial Readings: 1·033 kilohms and 105 picofarads

$\therefore R_p = 103{\cdot}3\Omega$

As L x0·1 is equivalent to -ve C x10,

$C_p = -10,500-22,000 = -32,500\text{pF}.$

(i) Short-circuited impedance $Z_{s.c.}$

$$-jXp = -j\frac{1}{\omega C_p} = -j200$$

$$Q = \frac{R_p}{X_p} = \frac{415}{200} = 2{\cdot}075$$

$$Q^2 = 4{\cdot}3$$

$$\frac{1}{Q^2} = 0{\cdot}233$$

$$\therefore Z_{s.c.} = r_{s.c.} + jX_{s.c.} = \frac{R_p}{1+Q^2} - j\frac{X_p}{1+\frac{1}{Q^2}}$$

$$= \frac{415}{5{\cdot}3} - j\frac{200}{1{\cdot}233}$$

$$= 78{\cdot}2 - j162 = 180\,\underline{/-64{\cdot}2^\circ} \qquad \ldots\ldots\ldots (1)$$

(ii) Open-circuited impedance $Z_{o.c.}$

$$jX_p = j\frac{1}{\omega C_p} = j\,81{\cdot}6\Omega$$

$$Q = \frac{R_p}{X_p} = \frac{103{\cdot}3}{81{\cdot}6} = 1{\cdot}26$$

$$Q^2 = 1{\cdot}6$$

$$\frac{1}{Q^2} = 0{\cdot}625$$

$$\therefore Z_{o.c.} = \frac{103{\cdot}3}{2{\cdot}6} + j\frac{81{\cdot}6}{1{\cdot}625}$$

$$= 39{\cdot}7 + j\,50 = 63{\cdot}8 \;\underline{/+51{\cdot}6^{\circ}} \quad \cdots\cdots \quad (2)$$

(iii) Characteristic impedance

$$Z_o = \sqrt{Z_{s.c.} \cdot Z_{o.c.}} = 106{\cdot}3 \;\underline{/-6{\cdot}3^{\circ}} \quad \cdots\cdots \quad (3)$$

(iv) Propagation Constant

$$Pl = (\alpha + j\beta)\,l = \tanh^{-1}\sqrt{Z_{s.c.}/Z_{o.c.}}$$

$$\text{i.e.}\quad \tanh Pl = A + jB = 1{\cdot}68 \;\underline{/-57{\cdot}9^{\circ}}$$

$$= 0{\cdot}892 - j\,1{\cdot}42$$

$A = 0{\cdot}892 \qquad A^2 = 0{\cdot}8$

$B = -1{\cdot}42 \qquad B^2 = 2{\cdot}02$

$A^2 + B^2 = 2{\cdot}82$

(v) Attenuation α

$$\tanh 2\alpha l = \frac{2A}{1 + A^2 + B^2} = 0{\cdot}468$$

$$2\alpha l = 0{\cdot}507$$

$$\alpha l = 0{\cdot}2535 \text{ nepers}$$

Assuming exact length of cable was 975 metres,

$$\alpha = 0{\cdot}26 \text{ neper/km}$$
$$= 2{\cdot}26 \text{ dB/km}$$
$$= 3{\cdot}61 \text{ dB/mile}$$

(vi) Phase Constant β

$$\tan 2\beta l = \frac{2B}{1 - (A^2 + B^2)} = 1{\cdot}56$$

$$\therefore \quad 2\beta l = 57{\cdot}3^{\circ} + 180^{\circ} = 237{\cdot}3^{\circ} \text{ (since } \lambda_c \simeq 3300\text{m)}$$

$$\therefore \quad \beta l = 118{\cdot}6^{\circ}$$

Exact length of cable: 975 metres

$$\therefore \quad \beta = 121^{\circ} \text{ per km}$$
$$= 2{\cdot}1 \text{ rads/km}$$
$$= 3{\cdot}38 \text{ rads/mile}$$

(vii) Resistance and Inductance/unit length

$$R + j\omega L = Z_o \times P$$
$$= 224\underline{/\ 76{\cdot}7^o}$$
$$= 51{\cdot}5 + j\,218$$

Thus

$$R = 51{\cdot}5\Omega/km = 83\Omega/mile$$
$$L = \frac{218}{2\pi \times 60}\ mH/km = 58mH/km = 93mH/mile$$

(viii) Conductance and Capacitance/unit length

$$G + j\omega C = \frac{P}{Z_o}$$
$$= 0{\cdot}0198\ \underline{/\ 89{\cdot}3^o}$$
$$= 0{\cdot}00024 + j\,0{\cdot}0198$$

G is negligible (240μmho/km)

$$C = \frac{0{\cdot}0198}{2\pi \times 60 \times 10^3} \times 10^6\ \mu F/km$$
$$= 0{\cdot}053\mu F/km = 0{\cdot}085\mu F/mile$$

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Capacitance Correction

In order to provide fine discrimination, the main R potentiometer is of large physical size. The capacitance between the potentiometer wiper and earth (chassis) can affect the measured capacitance value when an R-C or R-L combination is being examined. There is no effect when resistance alone or capacitance alone is measured.

The effect of the stray capacitance can usually be neglected but, when accurate values are required for R and C (or R & L) simultaneously, the following procedure can be adopted to check the readings and to correct the C value when necessary.

From a preliminary bridge balance, obtain an approximate value for the resistance of the unknown. Remove the unknown from the bridge terminals and substitute a carbon resistor whose nominal value is within 20 per cent of the resistance measured previously. Balance the bridge and note the reading of the main C dial. Disconnect the resistor and re-connect the unknown. Balance the bridge and note the settings of both main dials. The corrected capacitance (or inductance) value is the difference between the final C dial reading and that obtained for the resistor.

It should be noted that the correction required depends on the multiplier range in use, the frequency of measurement and on the setting of the main R dial, and can be positive or negative. Even when R and C values are to be measured simultaneously, the checking procedure described will often indicate that the capacitance reading error is negligible.

Equivalent Series Circuit

If the constants of the unknown are required in terms of equivalent series components, they can be calculated from the relations:

$$R_s = \frac{R}{1 + (R^2/X^2)}$$

$$= \frac{R}{1 + \omega^2 C^2 R^2} = \frac{R}{1 + Q^2}$$

$$C_s = C + \frac{1}{\omega^2 C R^2}$$

$$X_s = \frac{X}{1 + (X^2/R^2)} = \frac{X}{1 + (1/Q^2)}$$

$$L_s = \frac{L}{1 + (\omega^2 L^2/R^2)} = \frac{L}{1 + (1/Q^2)}$$

where R, X and L are the values of the parallel components obtained from the bridge.

It should be noted that for values of Q greater than 10 the difference between the equivalent series and parallel capacitance (or inductance) is less than 1 per cent.

Z601 OPERATING INSTRUCTIONS

General

As stated in the Introduction, the Low Impedance Adaptor is essentially a T-network. The two ranges are provided by alternative pairs of series resistors contained in a reversible plug-in moulding. The printed-circuit board has six holes for the terminal screws of the B601 to pass through, and the clearance is such that no electrical contact takes place until the appropriate bridge terminals are screwed down. Two additional terminals are provided on the adaptor itself for connection of the unknown, which forms the shunt arm of the T-network.

Initial Setting-up

1 Connect the source and detector to the bridge, set the switch to Transistor and remove the bridge terminals. Locate the adaptor over the terminal studs and replace the Earth, Common and Neutral terminals. If one side of the component to be measured is already connected to earth, this connection must be taken to the right-hand adaptor terminal.

2 The most suitable adaptor range can be selected according to the following rules:

Impedances less than 1ohm:	range A
Impedances from 1 to 10ohms:	range B

The range in use is that indicated on the upper edge of the reversible block.

When the impedance exceeds 10ohms the measurement should be made on the bridge itself, without an adaptor. It should be remembered when changing over that the bridge alone provides values for the unknown impedance in terms of the equivalent parallel components whereas, with the Adaptor in use, the results obtained are of the equivalent series components.

3 Because the adaptor introduces a phase reversal on the reactive component of the unknown, it is necessary to set the window multiplier of the bridge to one of the settings for capacitance measurements.

4 To select the most suitable multiplier terminal and range, the order of the impedance to be measured must be known approximately, or be estimated. The bridge readings (R_b and C_b) corresponding to these values can be obtained from the simplified expressions which follow, enabling the correct terminal and range to be selected.

$$R_b = R^2/r_s, \quad C_b = L_s/R^2 \text{ or } 1/\omega^2 R^2 C_s$$

where

$R^2 = 10^4$ for Adaptor range A

$\quad = 10^5$ for Adaptor range B

and r_s, L_s and C_s are the equivalent series components of the unknown. Screw on the terminal head for the selected range.

Example:

Assume a coil of approximately 3 microhenrys and 0·4ohm is to be measured.

Then the order of the bridge readings, for adaptor range A, will be:

$$R_b = R^2/r_s = 10^4/0{\cdot}4 = 25k\Omega$$

$$C_b = L_s/R^2 = (3\times10^{12})/(10^6\times10^4)\mu\mu F$$

$$= 300\mu\mu F$$

Thus the multiplier terminal to be used is x1·0 R & L, x1·0 C and the window multipliers should be set to R x10 and C x10 respectively.

5 Connect the short-circuiting link (supplied) across the two unknown terminals and screw it securely in position.

6 Set the source and detector to the required frequency and tune the detector for maximum sensitivity.

7 Set the bridge resistance dial to infinity and the capacitance dial to zero. Adjust the R and C-L Balance controls for a null.

8 Remove the short-circuiting link: the adaptor is now ready for use.

Measurement Procedure

1 Connect the unknown across the adaptor terminals.

2 Using the main R and C dials of the bridge, balance for a null. It will help during this operation to start with reduced detector sensitivity to find an approximate balance and to increase the sensitivity as final balance is approached. Record the bridge dial readings R_b and C_b and calculate the values of resistance (r_s) and inductance (L_s) or capacitance (C_s) using simplified formulae. The measurement gives the series combination of the above values i. e. the impedance.

The simplified formulae are:

$$r_s = \frac{R^2}{R_b} \quad\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$L_s = R^2\ C_b \quad\ldots\ldots\ldots\ldots (2)$$

$$C_s = \frac{1}{\omega^2 R^2 C_b} \quad\ldots\ldots\ldots\ldots (3)$$

where $R^2 = 10^4$ for adaptor range A ($R = 100\Omega$)

$= 10^5$ for adaptor range B ($R = 316\Omega$)

R_b is the resistance

and C_b is the capacitance, as obtained from the brdige after the multiplying factors have been taken into account.

For the range of impedance below 1ohm (for range A) and below 3ohms (for range B) no corrections are necessary. The accuracy of measurement will be better than ± 5 per cent.

3 If the impedance value obtained from the simplified formulae is more than 1ohm or 3ohms (for adaptor ranges A and B respectively) the full formulae will have to be used to obtain an accuracy of measured impedance to better than 5 per cent.

The full formulae are as follows:

$$r_s = \frac{R^2}{R_b}\,\frac{1 - 2\frac{R}{R_b} - 2\,RR_b\,\omega^2 C_b{}^2}{(1 - 2\frac{R}{R_b})^2 + 4\,R^2.\,\omega^2 C_b{}^2} \quad\ldots\ldots\ldots\ldots (4)$$

$$L_s = R^2 \times C_b \times \frac{1}{(1 - 2\frac{R}{R_b})^2 + 4\,R^2\omega^2 C_b{}^2} \quad\ldots (5)$$

$$C_s = \frac{1}{\omega^2 R^2 C_b}\left[(1 - 2\frac{R}{R_b})^2 + 4\,R^2\omega^2 C_b{}^2\right] \ldots\ldots\ldots (6)$$

4 If the impedance measured (greater than 1 or 3ohms) is predominantly resistive (i. e. $x_s < r_s/5$) then the correction is necessary only for the resistance r_s. The correct value of r_s is then given by:

$$r_s = \frac{R^2}{R_b} \times \frac{1}{1 - 2\frac{R}{R_b}} \quad\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

5 If the impedance measured (greater than 1 or 3ohms) is predominantly reactive (i. e. $r_s < x_s/5$) then the full formulae - (5) or (6) - need be used for values of L_s or C_s only.

6 It must be remembered that the system is most suitable for the measurement of low-Q circuits. If both the reactance and resistance are to be known accurately, formulae (4) and (5) or (6) must be used.

Example:

Suppose at 300kc/s a small inductor was measured, using adaptor range A (R = 100Ω), and the following bridge readings were obtained:

$$C_b = 332\mu\mu F$$

$$R_b = 10,000\Omega$$

Values calculated from the simplified formulae are:

$$L_s = R^2 \times C_b = 10^4 \times \frac{332}{10^{12}} \times 10^6 \mu H$$

$$= 3{\cdot}32\mu H$$

$$r_s = \frac{R^2}{R_b} = \frac{10^4}{1 \times 10^4} = 1\Omega$$

At 300kc/s,

reactance $X_s = \omega L_s$

$$= 2\pi \times 0{\cdot}3 \times 10^6 \times 3{\cdot}32 \times 10^{-6}$$

$$= 6{\cdot}25\Omega$$

Since the impedance exceeds 1ohm, the measurement should have been made using adaptor range B, in which case the results obtained, again using the simplified formulae, would have been:

$$r_s \simeq \underline{0{\cdot}2\Omega} \quad \text{and} \quad L_s = \underline{3{\cdot}45\mu H}$$

Assuming that the only results available were obtained on range A, a good approximation to the correct values can be obtained by employing the full formulae:

$$L_s = 3{\cdot}32 \times 10^{-6} \times \frac{1}{(1 - \frac{200}{10000})^2 + 4.\,10^4.\,4.\,\pi^2 \cdot 09.\,10^{12} \times (\frac{332}{10^{12}})^2}$$

$$= 3{\cdot}32 \times 10^{-6} \times \frac{1}{0{\cdot}96 + 0{\cdot}016} = 3{\cdot}42\,\mu H$$

$$r_s = 1{\cdot}00 \times \frac{0{\cdot}98 - 200.\,10^4.\,4.\,\pi^2 \times (0{\cdot}3.\,10^6)^2 \times (\frac{332}{10^{12}})^2}{0{\cdot}96 + 0{\cdot}016}$$

$$= 1{\cdot}00 \times \frac{0{\cdot}98 - 0{\cdot}78}{0{\cdot}976} = \underline{0{\cdot}2\Omega}$$

Note: If the value of the impedance to be measured is completely unknown (except that it is less than 10ohms), the quickest method of obtaining a first balance is to use adaptor range A, the x1 terminal and range multipliers R x10 and C x10 (or L x0·1). With very much reduced detector sensitivity an approximate value can be found. The most suitable range and multiplier can then be selected, as described in the Initial Setting-up procedure for the adaptor.

MAINTENANCE

The bridge is a carefully adjusted laboratory instrument and is not proof against rough handling or hard mechanical shock. This may have the effect of upsetting the calibration by disturbing the leads or the trimming capacitors.

To check the Bridge at the highest frequency, if the accuracy of calibration is suspected, the following procedure should be adopted.

1 Set the frequency of the source and detector to approximately 5Mc/s and the multiplier switches to R x1·0 and C x1·0.

2 Select two high-quality fixed capacitors of exactly equal values about 100pF and connect them in series between the terminals marked COMMON and C x0·1, leaving the junction free.

3 Set the main C dial at 50 and the main R dial at 'Infinity'. Adjust the R and C-L balance controls for a null, if necessary moving the main dial slightly off the '50' mark. When this has been obtained, connecting the junction of the two fixed capacitors to the EARTH terminal should not unbalance the bridge by more than 10 divisions (1pF on this scale), although it may be necessary to re-balance on the 'Balance R' control.

4 Repeat this procedure with the range switch set to L x1. Connecting the junction of the fixed capacitors to the EARTH terminal should not unbalance the bridge by more than 5pF (10 divisions = 1pF on this scale).

5 If the bridge is unbalanced by more than this amount, adjust the trimming capacitor TC_1, which will be found mounted adjacent to the EARTH terminal. The sealing compound on the trimmer can be softened by applying heat from a soldering iron near it.

6 Check the resistance side of the bridge with the source and frequency setting as before. Set the resistance multiplier switch to R x0·1, the capacitance switch to C x0·1, and connect together the EARTH and COMMON terminals.

7 Balance the bridge as before.

8 Connect a fixed carbon resistor of approximately 25ohms across the terminals COMMON and x0·1 R & L, x10C. Note the reading obtained on the R dial at balance.

9 Remove the fixed resistor and disconnect the EARTH terminal from the COMMON terminal.

10 Rebalance the bridge and remeasure the resistor. The reading on the R dial should not differ by more than 2 per cent from that obtained previously (see 8).

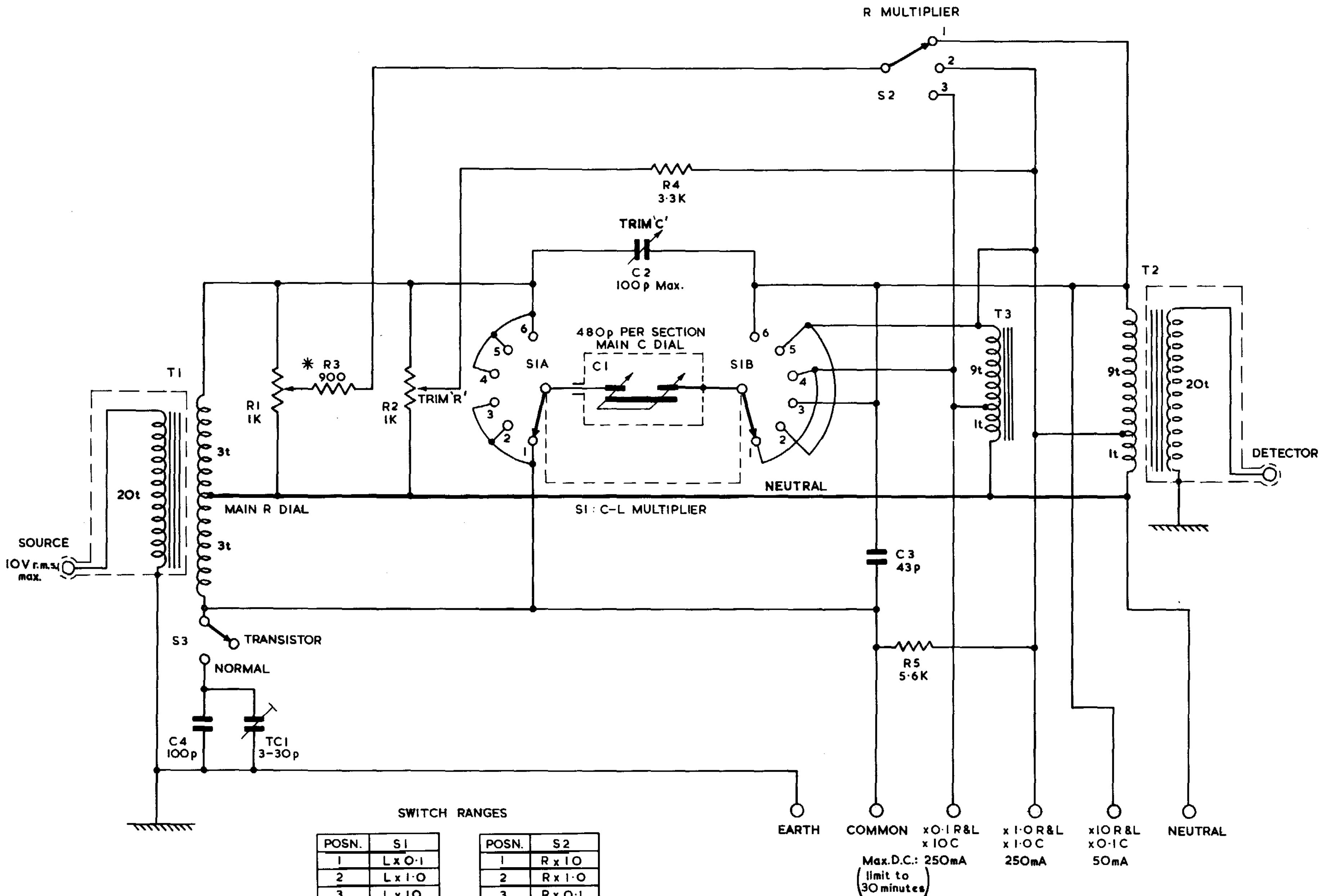
If the Low Impedance Adaptor is suspected of being faulty, the values of the resistors in the reversible block should be checked.

Z601A: 100 + 100 ohms ± 0·5 per cent (1/4 W)
Z601B: 316 + 316 ohms ± 0·5 per cent (1/4 W)

COMPONENTS LIST

Ref.	Value	Tolerance	Rating	Type
R1	1kΩ	± 10 per cent	10 W	Reliance PIW/B601 A. P. Wound
R2	1kΩ	Linear Law	-	Carbon, Linear. AB Metals type 37 special D7786/1.
R3	900Ω	± 1 per cent	1/4 W	Welwyn C21
R4	3·3kΩ	± 5 per cent	1/4 W	High stab. Welwyn C22
R5	5·6kΩ	± 20 per cent	1/4 W	Erie RMA9
C1	2 x 480pF ganged			Wingrove and Rogers C16 02/264
C2	3·3 - 100pF			Wingrove and Rogers C18/02
C3	43pF	± 10 per cent		Ceramic, Erie N750K
C4	100pF	± 20 per cent		Ceramic, Erie N750L
TC1	3 - 30pF			Concentric trimmer, Mullard 7864/01
S1	2-pole, 6-way			W. K. Type D9674 (AB Metals)
S2	1-pole, 3-way			W. K. Type D9675 (AB Metals)
S3	1-pole, on/off			Arcolectric 2-T216 SP/ON/OFF
T1	Input (voltage) Transformer			W. K. Type D9631
T2	Output (current) Transformer			W. K. Type D9630
T3	Auto Transformer			W. K. Type D9608

Plug amphenol BNC type 31/212



SWITCH RANGES

POSN.	S1
1	L x 0·1
2	L x 1·0
3	L x 10
4	C x 10
5	C x 1·0
6	C x 0·1

POSN.	S2
1	R x 10
2	R x 1·0
3	R x 0·1

✳ FITTED INSIDE R1

B601 CIRCUIT DIAGRAM (D 9676/C)