Harfield RF Bridge types LE300/A and LE300/A1

Hatfield Instruments Ltd., Plymouth, Devon 1960 - 1966.

Version[1] 3.00, 19th March 2014.

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1 Based on manuals and brochures provided with the bridge. OCR and corrections; DWK, Jan. 2007.
Updated for standard electrical notation (c/s → Hz, K (kilo) → k, mho → S, etc.) + minor corrections + references added; March 2014.

LE300 Product Brochure

RF Bridge Type LE 300/A

The modern radio-frequency bridge is one of the most useful general purpose instruments in the electronic industry. It is the most versatile piece of test equipment available. Just how versatile in fact, is not generally realised. One reason for this is perhaps the idea that a bridge circuit is a rather academic approach to the measurement problem, and that it is out of place in industry. This is not true of the Hatfield Instrument's radio-frequency bridge, which was deliberately designed for use in Industry, as well as in research establishments.

The Hatfield RF Bridge, Type LE 300/A is the modern development of the basic transformer ratio-arm bridge proposed by Blumlein and others and later developed by C G Mayo[2] of the BBC Research Department for use at radio frequencies. Further development by Hatfield Instruments Ltd. results in an extended frequency range over which the accuracy is well maintained, plus exceptional ease of operation. These features, plus the rugged construction, ensure that the Hatfield bridge is equally suitable for industrial and laboratory use. Every effort has been made in placing the controls and providing comprehensive scaling to give direct and simple operation. To further this aim a legend plate is fitted to the top panel of the bridge to provide the user with instant information without the need to refer to the handbook. The Hatfield bridge is calibrated directly in conductance, resistance, capacitance, inductance and reactance. Thus, at a glance the components of a complex impedance can be determined for two or three terminal networks. Plug-in terminals are featured and components, jigs, adaptors, etc. can be fitted in a fraction of the time taken with conventional screw terminals.

2 **Improvements in AC bridge circuits**, C G Mayo, British Patent No. 566970, 1945.

A feature found only with the Hatfield bridge is the built-in source and detector unit, Type LE 302. The source is a 1.592 MHz crystal controlled oscillator ($2\pi f = 10^7$) and the detector is a tuned amplifier with AGC. The equipment is mains operated. The amplifier output is rectified and applied to the edgewise balance indicating meter on the front panel. The AGC log. characteristic clearly indicates the approach to balance, since the pointer is never off the scale. At the frequency of the source and detector unit the bridge is direct reading in terms of inductance and reactance. Where the source and detector has not been fitted as original equipment, it may be fitted by the customer at a later date. In this event the source and detector assembly, Type LE 302, is supplied complete with the balance indicating meter. This can be fitted to the front panel following removal of the blanking-off plate.

The Hatfield Bridge, Type LE 300/A can be supplied with or without source and detector equipment as required. The standard frequency is 1.592 MHz. Others can be supplied to order. Where the source and detector is not fitted, or where it is desired to work at frequencies other than 1.592 MHz, a signal generator with an output level of at least 100 mV and a receiver with a sensitivity of at least 5 µV should be used.

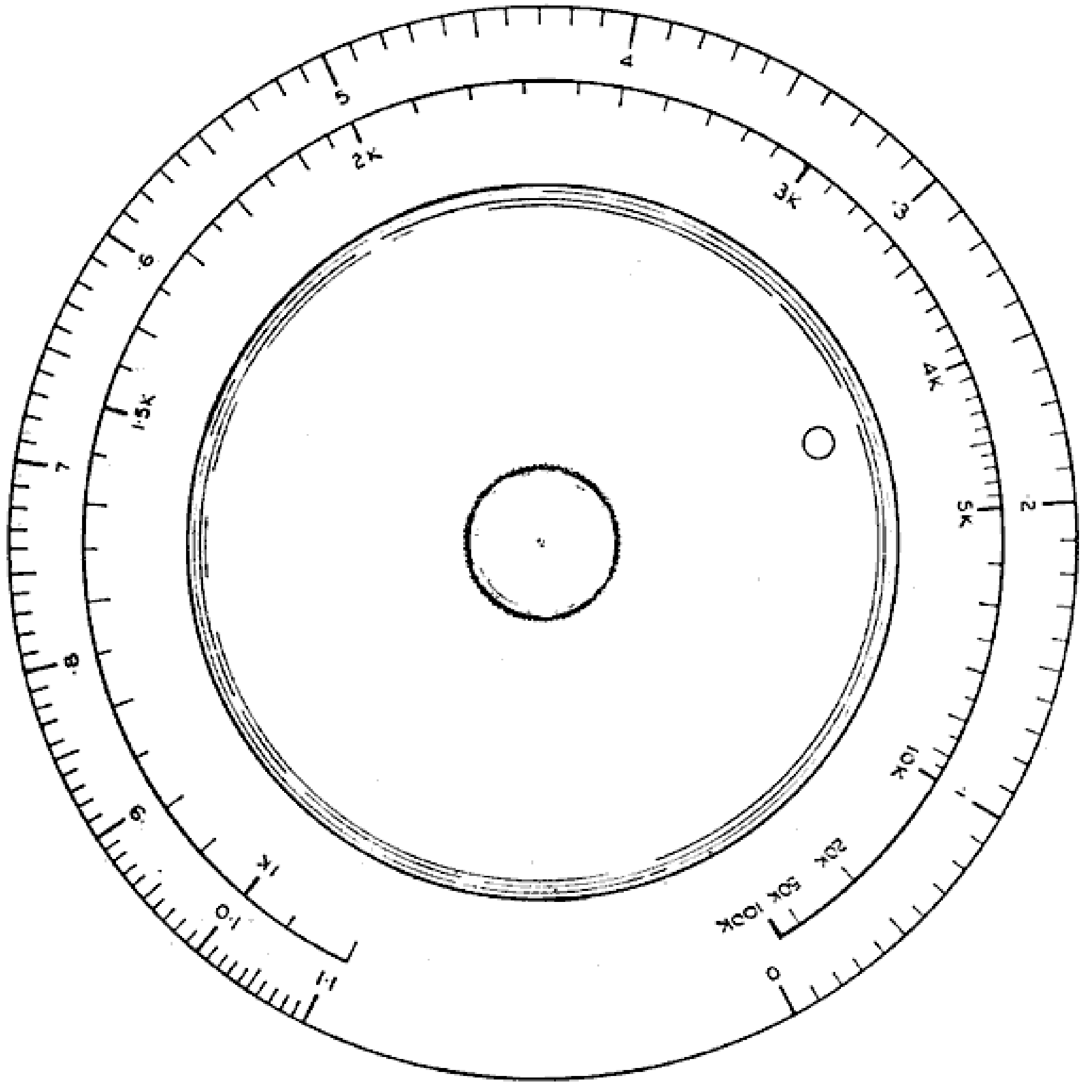
Specification: Type LE 300/A

Frequency Range: -	15 kHz to 15 MHz. (30 MHz with some restrictions).
Accuracy of Major Component: -	1% over major part of range up to 5 MHz, decreasing to 2% at 10 MHz and 5% at 15 MHz.
Accuracy of Power Factor: -	15 kHz to 2 MHz ± 5% ± 0.001. 2 MHz to 10 MHz ± 10% ± 0.0013. 10 MHz to 15 MHz ± 15% ± 0.002.

Five Directly Calibrated Ranges: -

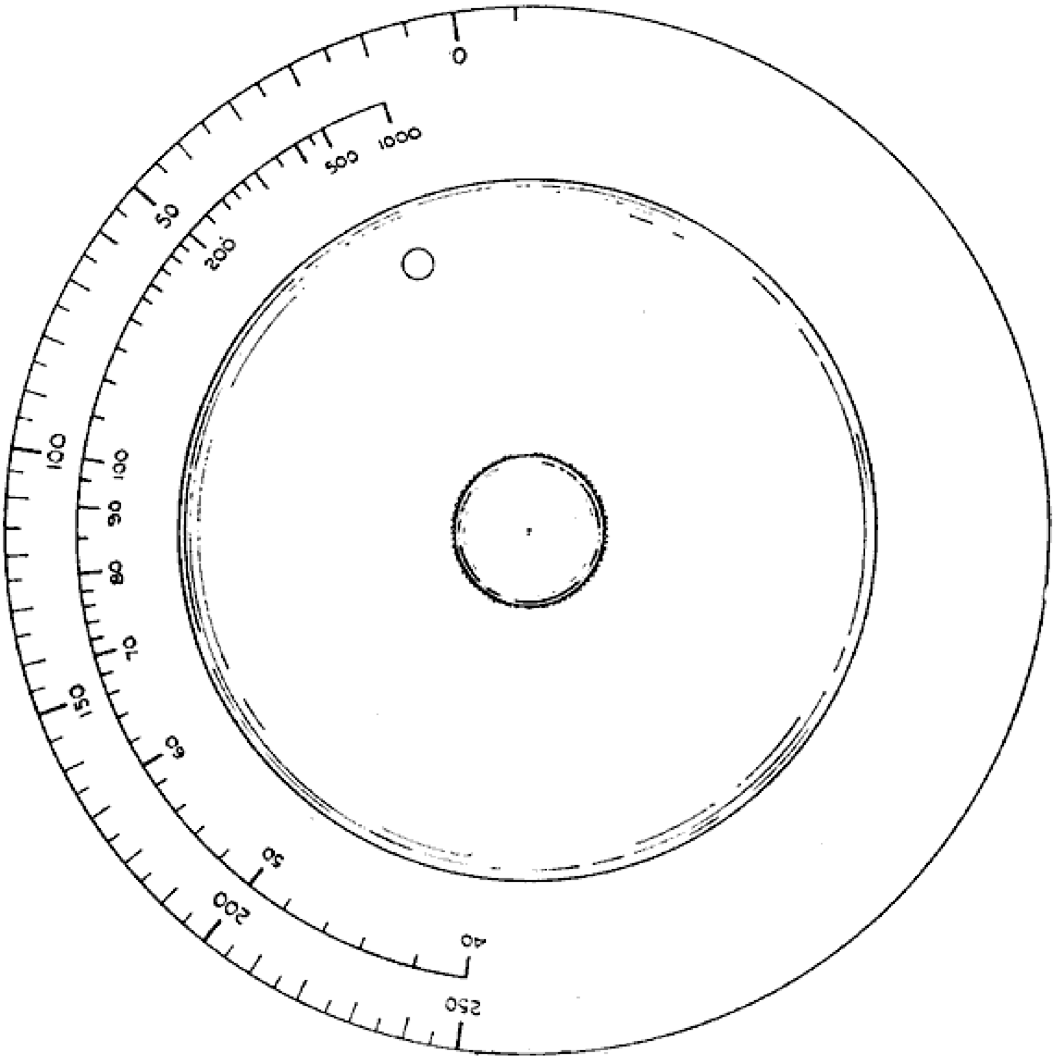
<table>
<tr><th>Resistance
Ω</th><th>Capacitance
pF</th><th>Conductance
mS</th><th>Reactance
Ω , $\omega = 10^7$</th><th>Inductance
$\omega = 10^7$</th></tr>
<tr><td>0.001 - 0.01</td><td>0 - 2.5</td><td>0 - 0.01</td><td>4 - 100</td><td>0.001 - 0.025 µH</td></tr>
<tr><td>0.01 - 0.1</td><td>0 - 25</td><td>0 - 0.1</td><td>40 - 1 k</td><td>0.01 - 0.25 µH</td></tr>
<tr><td>0.1 - 1.0</td><td>0 - 250</td><td>0 - 1.0</td><td>400 - 10 k</td><td>0.1 - 2.5 µH</td></tr>
<tr><td>1 - 10</td><td>0 - 2500</td><td>0 - 10</td><td>4 k - 100 k</td><td>1.0 - 25 µH</td></tr>
<tr><td>10 - 100</td><td>0 - 25 000</td><td>0 - 100</td><td>40 k - 1 M</td><td>0.4 - 10 µH</td></tr>
<tr><td>100 - 1 k</td><td>400 - 0.01 µF</td><td colspan="2" rowspan="4">Measurement ranges using low impedance adaptors types LE 305 and LE 306.</td><td>4.0 - 100 µH</td></tr>
<tr><td>1k - 10 k</td><td>4,000 - 0.1 µF</td><td>40 µH - 1.0 mH</td></tr>
<tr><td>10 k - 100 k</td><td>0.04 - 1.0 µF</td><td>400 µH - 10 mH</td></tr>
<tr><td>100 k - 1 M</td><td>0.4 - 10 µF</td><td>4 mH - 100 mH</td></tr>
</table>

Size:	Width 13" (33 cm), Height 10" (25.4 cm), Depth 9" (23 cm)
Weight:	15 lbs. (6.8 kg)



Left hand dial directly calibrated in both resistance and conductance.
The outer scale is engraved 0 - 1 mmho (mS) and inner scale its reciprocal 1000 Ω to 100 kΩ. The range switches and terminals extend the range of measurement to 0 - 100 mmho (mS) for conductance and 10 Ω to 10 MΩ for resistance.

With low impedance adaptors the outer scale reads in resistance and the inner scale in conductance. All scales are independent of frequency.

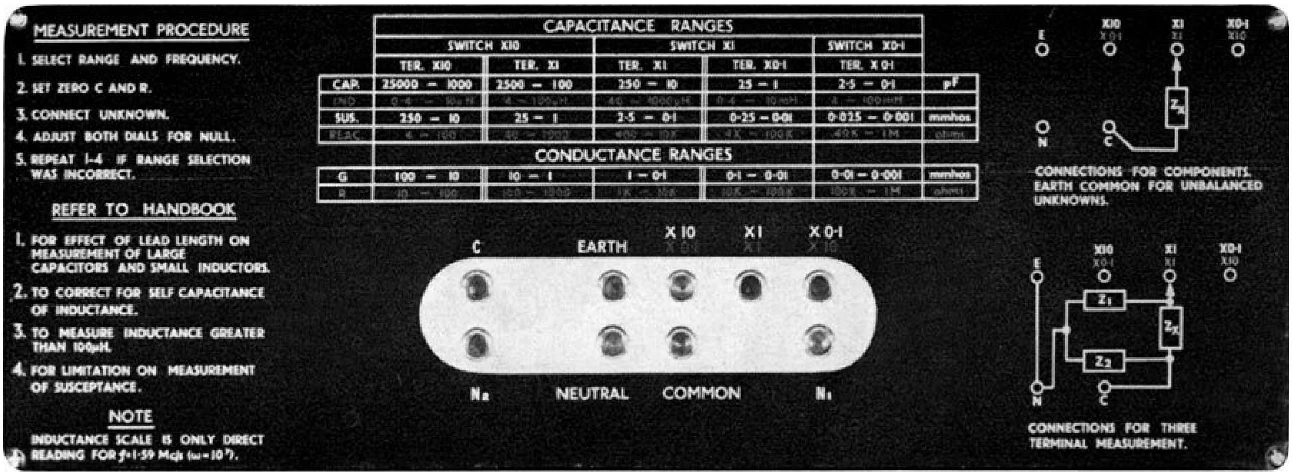


Right hand dial directly calibrated in both inductance and capacitance.

The outer scale is engraved 0 - 250 pF and the inner scale 40 to 1000 μH. The range switches and terminals extend the range of measurement from 0.01 pF to 25 nF for capacitance and from 0.4 μH to 100 mH for inductance. All ranges are independent of frequency with the exception of inductance where the calibration is for $\omega = 10^7$. For this value of ω the inductance scales are simply multiplied by ten to read directly in reactance.

With low impedance adaptors the outer scale reads directly in inductance and is independent of frequency. The inner scale reads capacitance but is dependent on frequency.

RF Bridge Type LE 300/A1



This new bridge is a further development of the type LE 300/A and has the great advantage that measurements can be made with or without direct current or voltage polarisation of the object being measured. Furthermore, the source of voltage or current polarisation is not in series with the measuring circuit. Thus, the impedance of the external polarising source is eliminated from the balance equation. This desirable feature has the great virtue that the RF characteristics of inductors, varactors, diodes, transistors, resistors, transformers, etc., can be measured and variations of parameters noted with the application of a wide variation of direct current or voltage. For instance, semiconductor diodes can be measured in the forward direction with current up to 500 mA and in the reverse direction with voltage up to 100 volts. Transistors PNP or NPN can be measured over a wide range of DC conditions. Since the bridge will measure negative resistance, even Y21' can be measured, and transistor adaptors are not necessarily required provided that the frequency of measurement is not too high.

The new bridge is physically similar to the type LE 300/A and the only external difference is the provision of two additional sockets on the terminal board to which is an external polarising power supply can be connected. For most purposes dry batteries, a milliammeter and a suitable rheostat are all that is required for passing direct current through the object being measured. For voltage polarisation, dry batteries can again be used. Where a capacitor or reversed biased diode is being measured, a voltmeter connected across the battery will indicate the voltage present across the component. Thus the component is free of any additional connections that could influence the measurement. The accuracy and range of measurements are the same as the type LE 300/A, but the frequency range is 100 kHz to 15 MHz.

Low Impedance Adaptors, Types LE 305 and LE 306

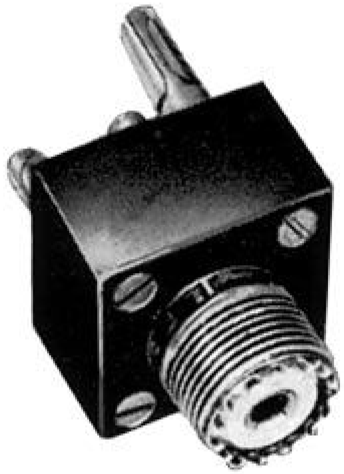
When used with the RF Bridges Types LE 300/A and LE 300A/1, these adaptors enable very low impedance measurements to be made[3]. All measurements are read directly from the scale with the exception of capacitance for which a simple calculation suffices. The adaptors plug into the socket panel of the Bridge and are provided with plug type 245 which selects either the ×1 or the ×0.1 terminal. This, in conjunction with the range switches, allows measurement of resistance, inductance, and capacitance over the range 15 kHz - 15 MHz.

With these adaptors the bridge measures the series components of an impedance and the desired values are given directly.

Specification	**LE305**	**LE306**
Resistance	1 mΩ to 1 Ω	0.01 Ω to 10 Ω
Inductance	1 nH minimum. 0.1 µH maximum at 15 MHz. 100 µH maximum at 15 kHz	0.01 µH minimum. 0.3 µH maximum at 15 MHz 1 mH maximum at 15 kHz
Capacitance	0.3 µF minimum at 15 kHz 1 nF minimum at 15 MHz 10 nF maximum at 15 kHz 0.3 µF maximum at 15 MHz	0.1 µF minimum at 15 kHz 300 pF minimum at 15 MHz 30 nF maximum at l5kHz 0.1 µF maximum at 15 MHz
Accuracy	Generally better than 3% inclusive of bridge tolerance.	

3 see **'The transformer ratio-arm bridge'**, Ian Hickman. Electronics World + Wireless World, Aug 1994, p670-672. Also reprinted in expanded form in '**Hickman's Analog and RF Circuits**', ISBN 0 7506 3742 0. p182-.
'Ian Hickman' is a nom de plume of Dave May, one of the design engineers who worked at Hatfield Instruments when the LE300 series was in production. http://www.users.greenbee.net/~davedotmay/

Co-axial Adapter, Type LE 330/F



The adaptor type LE 330F is supplied fitted with a coaxial connection UHF type SO 239, as illustrated.

Adaptors to connect to type N and B.N.C. connectors are available as follows:

U.H.F. to B.N.C. Female 75 ohm -	Tranradio Cat No. ABS1/7
U.H.F. to N Female 75 ohm -	Tranradio Cat No. ABS5/7
U.H.F. to B.N.C. Female 50 ohm -	Tranradio Cat No. ABS/1
U.H.F. to N Female 50 ohm -	Tranradio Cat No. ABS/5
Plug, PL 284, cable type	P/No. 1682
Plug, PL 284, shorting type	P/No. 3794
Plug, spring loaded terminal type	P/No. 3983
Socket 7 Way, for transistor adaptors	P/No. 2643
Socket Hood	P/No. 2648
Selector Plug, for use with adaptors	P/No. 2848

Bridge Standards

The following standard resistances and capacitances can be obtained for checking the accuracy of the bridge. They are adjusted to better than 0.5 % and can be readily plugged into the top panel. This gives a ready means of checking the calibration at any time. The 1 Ω standard resistor can be used for checking low impedance adaptors.

The types available are as follows:-

Standard 1 Ω resistor P.N.4139.	For LE.305/6.
Standard 10 Ω resistor P.N.4I40.	For LE.300A and LE.300A/1
Standard 100 Ω resistor P.M. 4141.	For LE.300A and LE.300A/1
Standard 1 kΩ resistor P.N.4I42.	For LE.300A and LE.300A/1
Standard 200 pF Capacitor P.N. 4143.	For LE.300A and LE.300A/1

Three-Terminal Adaptor, Type LE 309

This special adaptor enables in-situ measurements to be made at frequencies up to about 1 MHz.

Transistor Adaptors, Types LE 311 - LE 322

A set of twelve plug-in adaptors is available for use with bridges type LE 300/A and LE 300/A1 to determine the performance of transistors at radio frequencies. The Transistor Adaptors will accurately measure the four-pole characteristics as a set of four admittances (G + jB) from which the radio frequency performance can be completely determined. The operating DC working point for all adaptors has a design centre of 1 mA, collector current for a collector voltage of 6 volts. Since the bridges measures negative conductance the Y21' parameter can be measured directly.

Parameters measured		Y11	Y11'	Y21	Y21'	Y22	Alpha.
Type Nos. Adaptors	PNP	LE 311	LE 312	LE 313	LE 314	LE 315	LE 316
Type Nos. Adaptors	NPN	LE 317	LE 318	LE 319	LE 320	LE 321	LE 322

The Bridge, Type LE-300/A1 will in addition measure transistors without adaptors. Thus, the DC operating conditions need not be tied to that of the adaptors listed above. Measurements can therefore, be made at collector voltages up to 100 volts and current up to 1 Amp PNP or NPN. It must be remembered however that the bridge will not measure below 10 Ω and some of the parameters shown above yield lower values than 10 Ω at higher collector currents. Although the low impedance adaptors will measure very low resistance, they are not suitable for transistor measurement.

(Leaflet C5/4/1966)

User Manual

Radio Frequency Bridge Type LE 300/A

1.0 General Principles

Most electronic engineers are familiar with the conventional universal impedance bridge, which will measure inductance, capacitance and resistance at an audio frequency, which is usually 1 kHz, or occasionally 1.592 kHz so that $\omega = 10^4$.

These bridges have resistive ratio arms, which are wire wound and it is this feature that limits the top frequency at which accurate measurements can be made. Furthermore, only two terminal measurements can be made. Various attempts have been made to design RF bridges using resistive ratio arms and one or two have appeared on the market. The first major step forward in design was made by the Research Department of the British Broadcasting Corporation during World War 2, when the transformer ratio arm admittance bridge was developed.

The principle of the tapped transformer ratio arm bridge is now well established and has been further developed by Hatfield Instruments Ltd. to a high degree of simplicity in use, combined with exceptionally wide range and accuracy.

2.0 Notes on design

Since the bridge measures the unknown as an admittance, the measured values will be given as a conductance in parallel with a susceptance, that is, $G + jB$, and the dials should be calibrated in millimhos (mS). However, this result is not in a form suitable for everyday use, particularly in the case of susceptance, which is dependent on frequency. For this reason the dial that measures the susceptance is actually calibrated directly in capacitance and can be switched to read either positive or negative values. It will readily be seen that a negative capacitance is in fact an inductance, and if the frequency of the source to the bridge is fixed at a suitable value the dial can also be calibrated in inductance and reactance. In order to further increase the usefulness of the bridge, the conductance dial is also calibrated in resistance. Thus, when an unknown is measured, the bridge directly gives at once the conductance, resistance, reactance and either capacitance or inductance according to whichever parameter obtains.

3.0 Additional equipment required

The bridge requires a signal source having an output of at least 100 mV into 75 Ω. It should be well screened and the stray field should be less than one microvolt. Good class signal generators fulfil this requirement. A well screened receiver can be used as a detector and it should have a sensitivity of better than five microvolts. The generator can be used with audio modulation, and headphones, loudspeaker, or output meter can be used to obtain a null balance.

Hatfield Instruments Limited can supply a compact source and detector having a crystal controlled fixed frequency of 1.592 MHz. An output meter is also supplied and the complete equipment is mains operated. The fixed frequency is so chosen that $\omega = 10^7$. The inductance calibration of the LE 300 bridge is correct for this frequency.

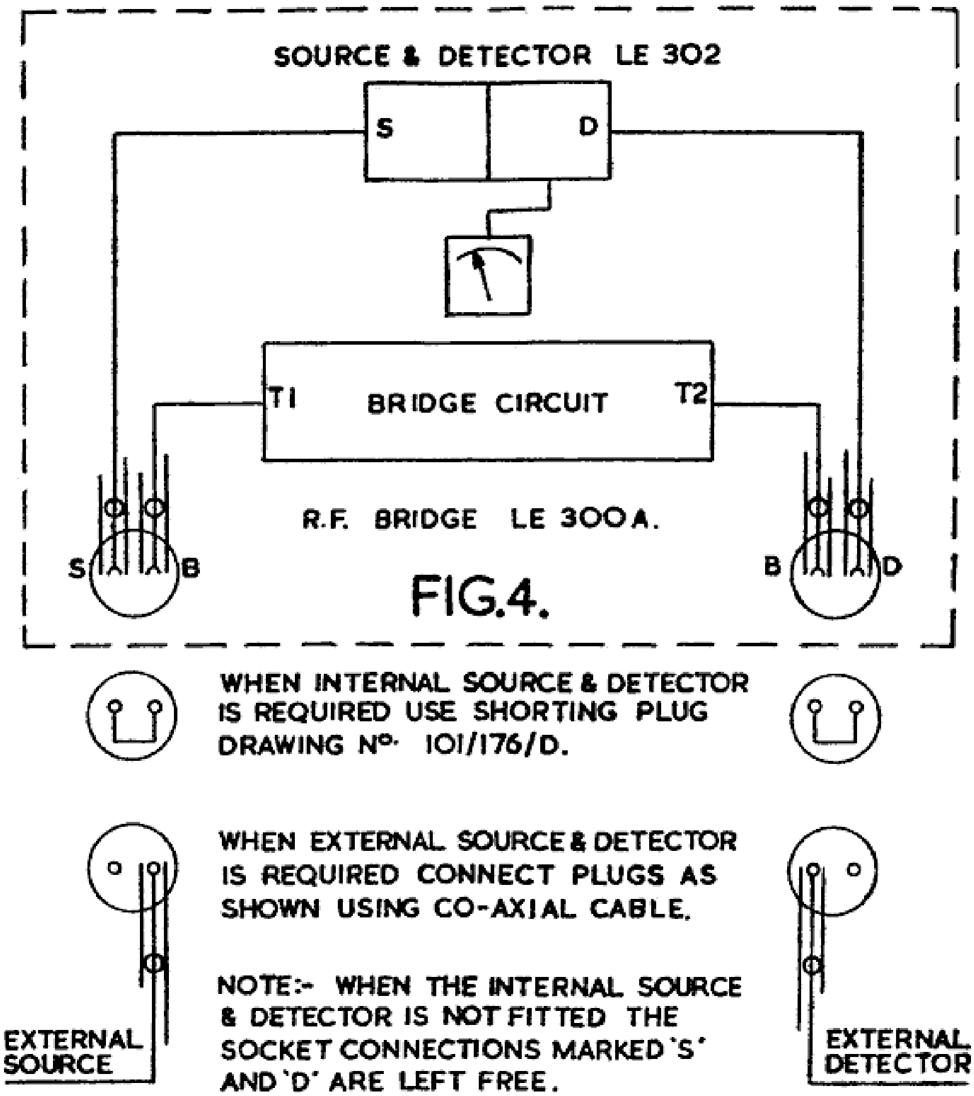
4.0 Controls

The large dial on the left of the instrument is directly calibrated in conductance in black and resistance in red. Adjacent to it at the edge of the panel is its associated set zero control. Above and to the right of this dial is its associated range change switch, which has six positions marked ×0.1, ×1, ×10 positive, and ×0.1, ×1, ×10 negative. These factors multiply the conductance dial reading. ***It should be noted that for resistance these factors must be reversed***, that is, for ×0.1 read ×10 and for ×10 read ×0.1

The large dial on the right on the instrument is directly calibrated in capacitance, in black, and inductance in red. Adjacent to it are its associated set zero and range change control. The latter is a six position switch, with three positions marked ×0.1, ×1, ×10 in each of two groups marked positive and negative. This arrangement allows both capacitance and inductance to be measured.

Two twin sockets are provided to connect the source and detector. Because the bridge circuit is a linear passive network their function can be interchanged without loss of accuracy, when measuring passive unknowns.

The left hand socket is engraved S and B and the right hand socket is engraved B and D. The sockets marked B are connected to the bridge. When the bridge is supplied with the built-in source and detector, Type LE 302, the sockets marked S and D are connected to the source and detector respectively. In this event two twin plugs having internal shorting links are also provided. When these plugs are inserted into the sockets the internal source and detector is automatically connected to the bridge.



5.0 Terminals

The terminal panel is conveniently located on the upper face of the bridge panel, and has six sockets built into it. Three of the sockets are connected to intermediate tappings on the transformer ratio arms and provide additional multiplying factors of ×0.1, ×1 and ×10 for conductance and capacitance. ***For resistance and inductance, these factors must be reversed***, i.e., , read ×10 for ×0.1 and ×0.1 for ×10. The other three sockets are marked N for Neutral, C for Common and E for Earth. Their use will be described in later sections. Into these sockets are plugged the special spring loaded terminals supplied with the bridge. A peg is also supplied, which is intended for use with the ×0.1 terminals when switched to read 0 - 2.5 pF full scale. On this range, the metal body of the plug, which has capacitance to earth, causes the dial to read about 0.7 pF. The peg, which is an insulator, has a tapered flat on one side and will, therefore, lock a wire into the socket. The socket panel is very well suited for special plug-in jigs adapted for production testing. Additional plugs modified for such jigs are available on request.

6.0 Range of Measurement

6.1 The conductance dial is calibrated from 0 to 1 millimhos (mS). By means of the range switch the reading can be divided or multiplied by a factor of ten. A further factor of 10 in both directions is obtained by the use of the appropriate terminal. Thus conductance can be measured from 0 - 0.01 mS full-scale to 0 - 100 mS full-scale. Where resistance is being measured the switch and terminal factors are reversed. Thus resistance can be measured from 10 Ω to 10 MΩ.

Table **1** shows the switch and terminal positions for measuring conductance:

Conductance Range Switch

Terminal	× 10	× 1	× 0.1
× 10	0 - 100 mS	0 - 10 mS	
× 1		0 - 1 mS	0 - 0.1 mS
× 0.1			0 - 0.01 mS

6.2 Table **2** shows the switch and terminal positions for measuring resistance:

Conductance Range Switch

Terminal	× 10	× 1	× 0.1
× 10	10 Ω - 1 kΩ	100 - 10 kΩ	
× 1		1 kΩ - 100 kΩ	10 kΩ - 1 MΩ
× 0.1			100 kΩ - 10 MΩ

6.3 It will be observed that in both of the tables above and in tables **3**, **4** and **5** to follow, there are other combinations of terminals and switch positions that can be used.

For instance, where terminal ×1 is used with switch position ×1, it would be possible to use terminal ×10 in conjunction with switch position ×0.1 to obtain the same range of measurement. However, in such a case the accuracy of the minor component would be reduced. This is explained more fully in section **9**.

6.4 The capacitance dial is calibrated 0 to 250 pF. The associated range switch multiplies or divide the reading by a factor of 10. Again a further factor of 10 in both directions is obtained by the use of the appropriate terminal. Thus capacitance can be measured from 0 - 2.5 pF full-scale to 0 - 25 nF full-scale; either positive or negative.

Table **3** shows the switch and terminal positions for measuring capacitance:

Range Switch Positive

Terminal	× 10	× 1	× 0.1
× 10	0 - 25 nF	0 - 2.5 nF	
× 1		0 - 250 pF	0 - 25 pF
× 0.1			0 - 2.5 pF

For other combinations of terminals and switch positions see section **6.3**

It will be remembered, however, that the upper limit of susceptance that the bridge will measure, is nominally fixed at 100 mS. A capacitance of 25 nF reaches this value at a frequency of approximately 670 kHz. Therefore, above that frequency the capacitance that can be measured is proportionately reduced. There is a further restriction in measurement above 1.5 MHz and this is explained more fully in section **9** (Measurement of Capacitance).

6.5 Adjacent to the capacitance calibration is the red scale calibrated 0 to 1000. This scale is used for the measurement of both inductance and reactance. It will be observed that the product of the two scales anywhere under the cursor is always 10^4. Thus $40 \times 250 = 10^4$. This value is for microhenries and picofarads and for fundamental units is 10^{-14}. Since $\omega^2 LC = 1$ and we have seen that $LC = 10^{-14}$ it follows that ω^2 must be 10^{14} or $\omega = 10^7$. This value of ω gives a frequency of 1.592 MHz and, therefore, if the frequency of the source is adjusted to this value the red scale will read directly in inductance.

Table **4** shows the switch and terminal positions for measuring inductance:

Range Switch Negative

Terminal	× 10	× 1	× 0.1
× 10	0.4 - 10 µH	4 - 100 µH	
× 1		40 - 1000 µH	400 µH - 10 mH
× 0..1			4 - 100 mH

For other combinations of terminals and switch positions, see section **6.3.**

6.6 Since reactance is equal to ωL and ω has been fixed at 10^7, the reactance, where the inductance is in microhenries, is ωL or $10^7 \times 10^{-6}$ L which is 10L. Thus if the red scale is multiplied by ten it will read directly in reactance. Furthermore, since ωL = 1/ωC , the reactance scales read directly for either inductance or capacitance.

Table **5** shows the switch and terminal positions for measuring reactance:

Range Switch Positive or Negative

Terminal	× 10	× 1	× 0.1
× 10	4 Ω - 100 Ω	40 Ω - 1 kΩ	
× 1		400 Ω - 10 kΩ	4 kΩ - 100 kΩ
× 0.1			40 kΩ - 10 MΩ

For other combinations of terminals and switch positions, see section **6.3**.

It will be observed from table **5** that reactance can be measured down to 4 Ω for ω = 10^7. This value of reactance corresponds to a susceptance of 250 mS and will have an error of approximately 5%. This error can be corrected, as is explained in section **11** (Measurement of Reactance).

7.0 Operating Instructions

7.1 Choice of Terminal

The value of the unknown being measured is obtained by multiplying the dial reading at balanced by the appropriate switch range and the terminal factor. The errors in the bridge are a minimum when using the ×1 terminal and the range switches are set to ×1. It will be obvious that a ×1 factor could be obtained by using the 0.1 terminal and setting the range switch ×10. Generally the 0.1 terminal should be used for high impedance, and the ×10 terminals for low impedance. When complex impedances are being measured the major component should determine the terminals to be used.

7.2 Earth Terminal

The earth terminal is connected internally to the chassis and case. Where unbalanced impedances, having appreciable capacitance to earth, are being measured the earth terminal should be connected to the common terminal. The unknown should then have the earthy side connected to the common terminal.

7.3 Neutral Terminal

The bridge network is centred on a neutral plane, which has no DC connection to earth. The neutral plane is brought out to the neutral terminal. For many purposes it is convenient to earth the neutral terminal. This will occur when measurements are desired on three terminal networks, for which see section **12.1**.

7.4 Common Terminal

For all measurements, one side of the unknown must be connected to the common terminal, whether the measurement be on a two or three terminal network. When measuring an unbalanced two terminal unknown, connect the common terminal to the earth terminal. When measuring a balanced two terminal unknown, neither the common or neutral terminal is earthed.

7.5 Initial Balance

Before any measurements are made and before the unknown is connected, the bridge must first be balanced. The correct procedure is as follows:-

(a) Connect earth terminal to neutral or common terminal if required.

(b) Adjust range switches to appropriate settings.

(c) Set both dials to zero

(d) Now, by using the set zero controls, balance the bridge for a null. It will be found an advantage to reduce the output from the source (or reduce the RF gain of the detector), while searching for the null, since it is easily masked by overload of the detector.

(e) Connect the unknown and adjust the main dials for balance.

If it is found that the choice of switched range was incorrect and that the range has to be changed, disconnect the unknown and rebalance the bridge again before making the final measurement. For a given position of the range switches, the set zero controls will not change appreciably with the frequency from 15 kHz to 5 MHz and only slightly up to 15 MHz.

8.0 Measurement of Resistance and Conductance

8.1 Where the resistor to be measured is a small component the earth terminal is not used. As an example consider the measurement of a small carbon resistor known to be somewhere between 50 Ω and 100 Ω at a frequency of 1 MHz.

8.2 After balancing the bridge and making measurements, the dials in conjunction with the range switches, give a direct reading of the unknown. In our example let the conductance range switch be set to ×10, the ×10 terminal is used and the conductance dial reads 0.14 millimhos (mS). The combined range factor of the related switch position and terminal will be one hundred. Thus 100 × 0.14 = 14 mS. Since the dial is also calibrated in resistance the reciprocal can be instantly read which in this case is 71.5 Ω. In order to obtain balance, the reactance dial will have been adjusted and since such a small resistor would have a capacitance of only 0.5 pF approximately, the reactance switch will have been set to ×1 capacitive and the capacitance dial will read very nearly zero.

8.3 Small carbon resistors from about 50 Ω to 2 kΩ do not change appreciably with frequency and have sensibly constant values up to approximately 15 MHz. Higher values will decrease as the frequency rises. This is characteristic of carbon resistors and is greater for moulded types than for film types. A moulded resistor of 470 kΩ may only measure about 300 kΩ at 15 MHz, whereas a 470 kΩ high stability resistor will measure about 400 - 420 kΩ. On the other hand wire wound resistors increase in value with frequency. Some vitreous enamelled wire wound resistors increase over three times in value between 1 MHz and 15 MHz. Most resistors will exhibit a minor component which is capacitive and usually only 0.5 to 2 pF. When measuring a resistive component that is lower than 20 Ω at frequencies in excess of 10 MHz, the residual inductance of the bridge at the ×10 terminal will begin to become noticeable. A ten ohm resistor measured at 15 MHz will appear inductive and connecting leads of only ⅛" will add to the error.

9.0 Measurement of Capacitance

9.1 Since the measurement of capacitance will always be associated with resistance, it will be necessary to choose a suitable range factor for the resistive component. In the measurement of capacitance it will usually suffice to set the conductance range switch at ×1. The switch and terminal positions, to obtain a desired range of capacitance, have been shown in table **3** (section **6.4)**. It will be observed that there are other combinations of terminals and switch positions that can be used. For instance, where terminal ×1 is used with switch position ×1 it would be possible to use terminal ×10 in conjunction with switch position ×0.1 to obtain the same range of measurement. This can be done if so desired at frequencies up to approximately 1.5 MHz, depending on the magnitude of the capacitance. However, above this frequency the accuracy of the minor component (resistive) rapidly decreases.

9.2 When the unknown is a low loss capacitor such as a silver-mica or air type, the power factor will be better than 0.001, which is nearly the limit of the measurement in the bridge. A power factor of 0.001 corresponds to a phase shift of only 3 seconds of arc, an exceedingly small angle of measurement. Furthermore, the difference in magnitude between the sine and cosine flux in the output transformer would then be only one part in two million. For an air capacitor having a power factor of, say, 0.0001, the difference would only be one part in two hundred million. When using the combination of range and terminal referred to earlier in this handbook, the phase shift varies from two to three seconds, which can be positive or negative. Other combinations of range and terminal cause much larger phase shifts both positive and negative and are not recommended where the measurement of the minor components is important.

The specified limit on Tanδ is ±0.0015. This value corresponds to a shunt resistance of ±75 kΩ across a capacitor of 0.01 µF at 300 kHz, or a similar shunt resistance across as capacitor of 200 pF at 15 MHz.

When measuring low loss capacitors it may be necessary to adjust the set zero conductance control to obtain a null, should the conductance appear to be slightly negative.

9.3 In section **6.3** it was pointed out that the upper limit of susceptance that the bridge will measure is nominally fixed at 100 mS. A capacitance of 25 nF reaches this value at 670 kHz. Therefore, above this frequency the capacitance that can be measured is proportionately reduced. Ideally the maximum value that could then be measured would decrease with frequency until at 15 MHz the capacitance is 1 nF.

However, there are further limitations due to (a) the self inductance of the unknown and (b) the residual inductance of the bridge. Looking in at the common and ×10 terminal this residual is 0.02 µH. At the ×1 and ×0.1 terminals the values are slightly higher but produce no significant error because the capacitance to be measured on them should not exceed those shown in table **3** (section **6.4**). When using the ×10 terminal, the-measured values of capacitance will be high by a fractional amount ω^2LC, where L = 0.02 µH.

It is convenient to rearrange this expression to read percentage error = $8 f^2 C/10^5$ where f is the measurement frequency in MHz and C = the measured capacitance in pF. A few examples will now illustrate the order of correction. For f = 5 MHz and C = 400 pF, deduct 0.8%. For f = 15 MHz and C = 100 pF deduct 1.8%. Thus for a susceptance of 100 mS (1 nF) at 15 MHz one must deduct 18%. These corrections do not take into account the self inductance in the measured specimen, which can be significant at the higher frequencies.

10.0 Measurement of Inductance

10.1 Since the bridge measures the unknown as an admittance, an inductor will be presented as a conductance in parallel with a negative capacitance, i.e. a value of capacitance that has an equal reactance to the unknown at the frequency of measurement. In order to arrive at the value of inductance, the frequency must be known. If the frequency is so adjusted that $\omega = 10^7$ the red scale on the capacitance dial will read directly in microhenries. This is fully explained in section **6.4**. Reference to Table **4** in that section will show-the switch and terminal positions for the desired range of measurement.

10.2 The measurement of inductance is straightforward and the only corrections to be made are (a) when using the ×10 terminal and (b) the correction for self capacitance of the unknown. When using the ×10 terminal it is only necessary to deduct 0.02 µH from the measured value (for $\omega = 10^7$). The correction for the self capacitance will be found at the end of this book. Where the self capacitance is known, the true inductance can quickly be found from the dial reading as follows: for $\omega = 10^7$ the frequency of measurement is 1.592 MHz. At this frequency the capacitance that tunes the inductor to resonance is clearly the sum of the self capacitance and the reading on the capacitance dial immediately above the value of inductance. An example will make this clear. Let the measured value of inductance be 80 µH. Above this value read 125 pF. Now assuming that the self capacitance is10 pF, the total tuning capacitance is 125 + 10 = 135 pF. Below this value on the capacitance dial read 74 µH, which is the true inductance of the unknown. It will now be obvious that the self capacitance must be a small fraction of the tuning capacitance to prevent serious error if there is no correction. Single layer solenoids do not usually have a self capacitance greater than about 1 pF. Small wave wound coils might have 3 to 10 pF. Where the self capacitance is an appreciable fraction of the tuning capacitance, greater accuracy can be obtained by measurement at a lower frequency. In this event it will be convenient to make the frequency of measurement either 502 kHz or 159.2 kHz. In the former case the inductance calibration is multiplied by 10 and in the latter case it is multiplied by 100. Thus the scales are still direct reading. At any other frequency f_2, the inductance calibration is adjusted by the factor $(f_1/f_2)^2$ where f_1 = 1.5922 MHz. Alternatively, the inductance can be computed from the equation $L = 1/(\omega^2 C)$, where C is the measured value of negative capacitance. It must be emphasized again that the value of inductance measured is the parallel value, which is substantially the same as the series value provided that Q is greater than 10.

10.3 The measurement and effect of the resistance of an inductor will now be described. Two quite different cases will be illustrated; the first, a small RF coil and the second, the admittance of a loaded transformer. Let the frequency of measurement be 1.592 MHz. The conductance switch is set to ×0.1, the capacitance range switch to ×1 negative and the ×1 terminal is used. The RF coil is measured and the conductance dial reads 0.055 millimhos (mS). Below this value read 18 kΩ. Since the range factor for conductance is ×0.1, the conductance is 0.0055 mS. Conversely the range factor for resistance is ×10. Hence the resistance is 180 kΩ. The capacitance dial reads 110 pF. Below this value read 90 µH. It is assumed that the coil self capacitance is not greater than 1 pF. Thus the RF coil is measured as 90 µH in parallel with 180 kΩ. The series values can easily be obtained from the equation in Fig, **3**. To find these values the reactance must be known. This is easily done since the reactance can be read directly from the inductance scale. For f = 1.592 MHz, the reactance is ten times the inductance. Hence, 90 µH has a reactance of 900 Ω. Further, since

$$Q = R_p/X_p$$

we have 180 000 / 900 and the Q of the measured coil is 200.

10.4 Now consider the admittance of a loaded transformer. Let the frequency of measurement be 10 MHz. The conductance switch is set to ×10, the capacitance switch to ×1 negative and the ×10 terminal is used. The transformer is bulky and unbalanced, so will have appreciable capacitance to earth. Therefore, it is necessary to connect the common terminal to the earth terminal before taking-measurements. The bridge is balanced and the conductance dial reads 0.14 millimhos (mS). Since the range factor is 100 the conductance is 14 mS and the resistance is 71.5 Ω. The capacitance dial reads 10 pF negative. Since the capacitance range factor is ×10 the capacitance is 100 pF negative. The value of inductance is calculated from the expression $L = 1/(\omega^2 C)$ and is found to be 2.55 µH. In this case the Q is very low and the series values can be obtained from the expressions in Fig **3** (serial to parallel conversions). These have been calculated and are as follows: R_s = 59.5 Ω and X_s = 26.5 Ω. At 10 MHz this reactance is 0.424 µH. Thus, the transformer has an admittance comprising a conductance of 14 mS shunted by a negative capacitance of 100 pF. Alternatively, it can be considered as an inductance of 0.424 µH in series with 59.5 Ω. All these values of course only obtain at the frequency of 10 MHz.

11.0 Measurement of Reactance

11.1 It has already been explained in section **6.5** and subsequently in section **6.6** that if the frequency of measurement is so adjusted that $\omega = 10^7$, the red scale on the capacitance dial will read directly in inductance and reactance. It will be remembered that the inductance scale is multiplied by ten to give the value of reactance and further that the values of reactance are identical for either capacitance or inductance. This very useful feature is further amplified and clarified by the following example: With the range switch positive a capacitor is measured and found to be 150 pF. The inductance that will resonate with it at 1.592 MHz is on the red scale immediately below i.e. 66.5 μH. Multiply this value by ten and we have also the reactance of the inductance and the capacitor i.e. 665 Ω. The reactance will be directly proportional to f_l / f_2 where $f_l = 1.592$ kHz. Note, however, that if the range switch had been set at negative, an inductance would have been measured and the reactance at any other frequency f_2 would be proportional to f_2 / f_l .

11.2 In table **5**, it will be noticed that on the ×10 terminal the reactance scale reads 4 to 100 Ω. Since the bridge has a residual inductance of 0.02 μH on the ×10 terminal, it has a residual reactance of 0.2 Ω at $\omega = 10^7$. Where positive capacitive reactance is being measured add 0.2 Ω to the value read on the dial. Thus to a dial reading of 5 Ω reactance add 0.2 making the true value 5.2 Ω. However, where negative capacitive reactance (inductive) is being measured deduct 0.2 Ω from the dial reading to obtain the true value. It will be obvious that for reactance greater than 20 Ω the correction need not be applied since the error is then less than 1%.

12.0 Measurement of a Three-terminal Network

12.1 To illustrate the measurement of a three terminal impedance consider the common case of a capacitor in a metal box. Reference to Fig. **2a** shows such a capacitor where it is desired to measure C_1 at terminals t_1 and t_2. It will be obvious that without use of the neutral terminal, the result will be $C_1 + C_2 C_3 / (C_2 + C_3)$.

If, however, the case is connected to neutral as at Fig. **2b**, C_2 and C_3 do not enter into the measurement. Fig **2c** shows that C2 shunts the input transformer, and C_3 shunts the output transformer. Since both transformers are of a very low impedance, these shunt capacitors are of no significance and do not affect the balance of the bridge.

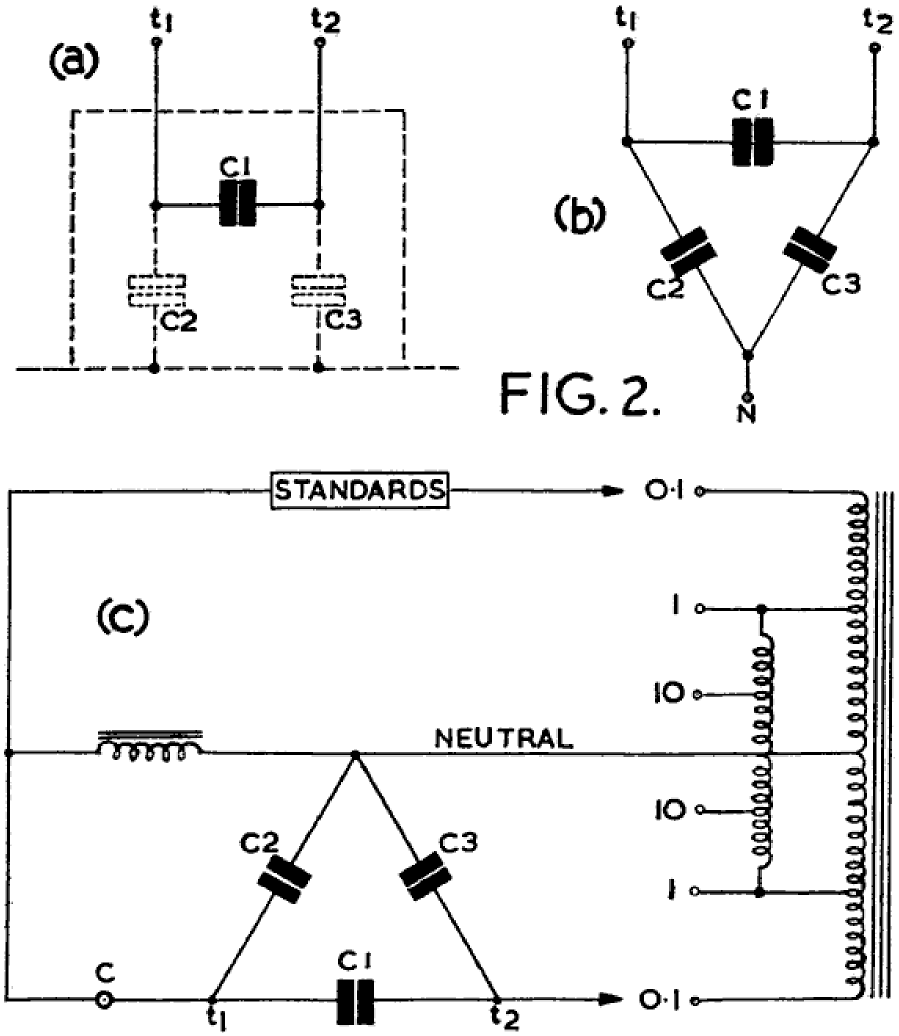


FIG. 2.

RF Bridge Type LE 300/A1

This new RF bridge has the great advantage that measurements can be made with or without direct current or voltage polarisation of the object being measured. Furthermore, the source of voltage or current polarisation is not in series with the measuring circuit. Thus, the impedance of the external polarising source is eliminated from the balance equation. This desirable feature has the great virtue that the RF characteristics of inductors, varactors, diodes resistors, transformers, etc. can be measured and variations of parameters noted with the application of a wide variation of direct current or voltage. For instance, semiconductor diodes can be measured in the forward direction with current up to 500 mA and in the reverse direction with voltage up to 100 volts.

The new bridge has the same specification and range of measurements as Type LE 300/A. The only external difference is the provision of two additional sockets on the terminal board to which is connected the external polarising power supply. For most purposes dry batteries, a milliammeter and a suitable rheostat, are all that is required for passing direct current through the object being measured. For voltage polarisation, dry batteries can again be used. Where a capacitor or reverse-biased diode is being measured, a voltmeter connected across the battery will indicate the voltage present across the component. Thus, the component is free of any additional connections that could influence the measurement.

It will be appreciated that it is a serious disadvantage to insert DC into the unknown from an external source. The series impedance of the supply will, in such a case, be in series with the unknown. At radio frequencies, a capacitor can be placed in parallel with the source resistance, but its impedance is not likely to be less than a few Ω, and in the measurement of semi conductors this could well be prohibitive. It will be observed from the circuit diagram supplied with this Handbook that the direct current or voltage is introduced in the neutral line. Therefore, no external connections have to be made to the unknown to introduce polarisation. By the use of blocking capacitors, the polarising current can only flow through the unknown and therefore, the polarising current supplied by the DC source is, in fact, the current flowing through the object under test. Since the unknown is directly connected to the bridge and the polarising source is injected to the neutral line, the balance equation is not in any way affected.

Apart from the facility for DC polarisation, the bridge is used and set up exactly as described in the Handbook for the Type LE 300/A.

Measurement of Inductors with DC polarisation

Connect the inductor to the bridge and connect a suitable DC source, which is metered, to the sockets marked DC. In many cases a simple rheostat, battery and meter, is all that is required. The inductor is then measured in the usual way. The DC supply can then be switched on, and as the current is increased, any change in inductance is immediately noted when the bridge is re-balanced.

Measurement of Semiconductor Diodes with forward or reverse bias

If it is desired to measure a diode in the forward direction, connect the metered DC source to the DC sockets. Connect the diode to the bridge in the usual way and make the measurement. Switch on the DC supply and set the desired current. The bridge is re-balanced and the measurements noted. If it is desired to measure the characteristics in the reverse direction, connect a suitable voltage source to the DC sockets. It should be noted here that the sockets have no polarity. The source can be connected either way, and swapping the connections will change the sign of the voltage applied to the diode. Successive measurements can then be made for different voltages. The maximum permitted voltage is 100 V. This facility is particularly useful in the measurement of varactors. The maximum current that can be passed into the DC sockets depends on the sockets used on the terminal panel (which is located on the top of the bridge). The maximum permissible currents are detailed below:-

Maximum Permissible Voltage 100 V

Maximum Permissible DC:

Terminal			
×10	×1	×0.1	
2 A	1.5 A	150 mA	Greater currents than these will damage the internal transformers.
1.5 A	1 A	50 mA	Safe current but bridge error increases to 2%
1 A	0.5 A	30 mA	Safe, current with no effect in calibration.

General

Measurements can be conducted over the full frequency range, i.e., 15 kHz to 15 MHz with or without the application of DC. At any time during RF measurements the effect of polarisation can be determined by applying a polarising source to the DC sockets. It will also be appreciated that it is possible, if required, to measure the unknown at one frequency, say 1 MHz, and inject AC to the DC sockets at some other frequency. It might be required for instance, to measure the inductance of a ferrous-cored inductor at 1 MHz with 1 Amp at 50 Hz also flowing through the inductor. This can easily be done, since it is only necessary to apply an external 50 Hz source to the DC sockets. In such cases the non-linearity due to the ferrous core can cause the inductance to change as a function of the 50 Hz AC field. This will tend, in some measure, to obscure the balance. In the case of ferrite materials, the non-linearity does not cause the balance to be unduly flat.

Measurement of Negative Resistance

In order to further increase the versatility of the RF bridge Type LE 300/A, the design now incorporates a provision for the measurement of negative resistance. The conductance range switch now has six positions, three of which are positive, and three of which are negative. The instructions in the Handbook from **6.0** to **6.3** now apply for both negative and positive values of either resistance or conductance.

It will be found that when using the Transistor Adaptors, particularly for the measurement of Y21', the measurement of negative resistance is essential, and it was this requirement in particular that prompted the re-design of the RF Bridge Type LE 300/A.

Circuit Diagrams

LE 300 A/1

Switching Sequence (refer to circuit diagram - next page)

	Conductance	
	Positive	Negative
× 0.1	B → (c)	B → (d)
	C → (d)	C → (c)
× 1	B → (b)	B → (e)
	C → (e)	C → (b)
× 10	B → (a)	B → (f)
	C → (f)	C → (a)

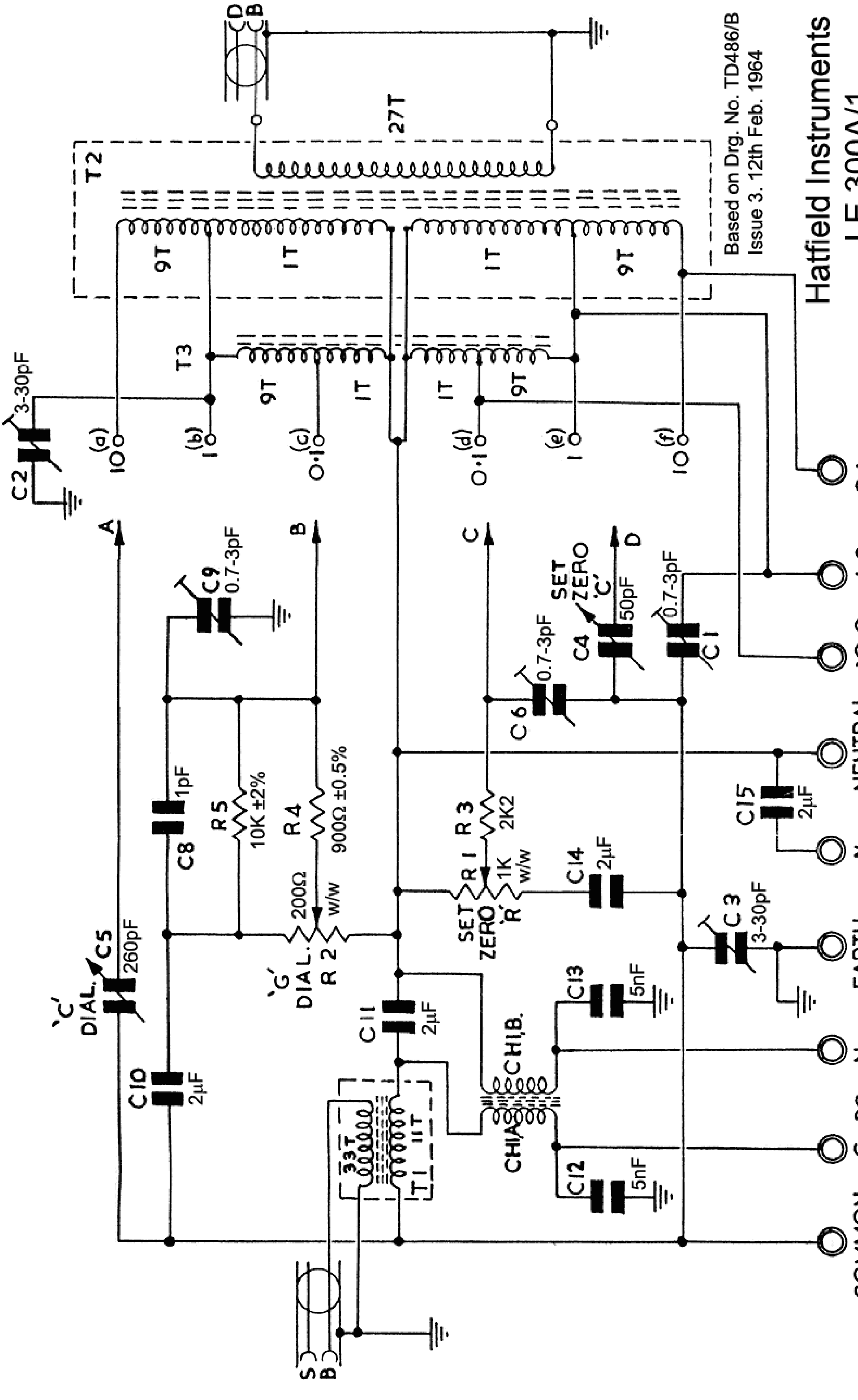
	Capacitance	
	Positive	Negative
× 0.1	A → (c)	A → (d)
	D → (d)	D → (c)
× 1	A → (b)	A → (e)
	D → (e)	D → (b)
× 10	A → (a)	A → (f)
	D → (f)	D → (a)

LE 300/A1 Circuit. (Fig. 1) Based on Drg. No. TD486/B. Issue 3. 12th Feb. 1964.

Issue	Date	Changes
1	11th July 1963	
2	13th Dec. 1963	C15 Added. DCN 124
3	12th Feb. 1964	Common Earth, Neutral N_1 and N_2 added.

Parts List.

T1	Input Transformer.
T2	Output Transformer.
C1. C6. C9	0.7 - 3 pF Mullard Trimmer.
C2. C3.	3 - 30 pF Phillips Trimmer.
C4	0 - 50 pF. Set Zero Capacitance Trimmer.
C5	0 - 260 pF Standard Capacitance. Philips dual 520pF air-spaced variable capacitor with gangs operated in series to eliminate brush resistance.
C8	1.0 pF Capacitor.
C10. C11. C14	2 μF Capacitor
C12. C13	5000 pF Capacitor.
C15	2 μF Capacitor (Marked on original circuit as 2 pF)
R1	1 kΩ Potentiometer w/w
R2	200 Ω Potentiometer w/w (Ayrton-Perry wound, non inductive)
R3	2.2 kΩ ±10% Resistor
R4	900 Ω ±0.5% Resistor HS.
R5	10 kΩ ±2% Resistor

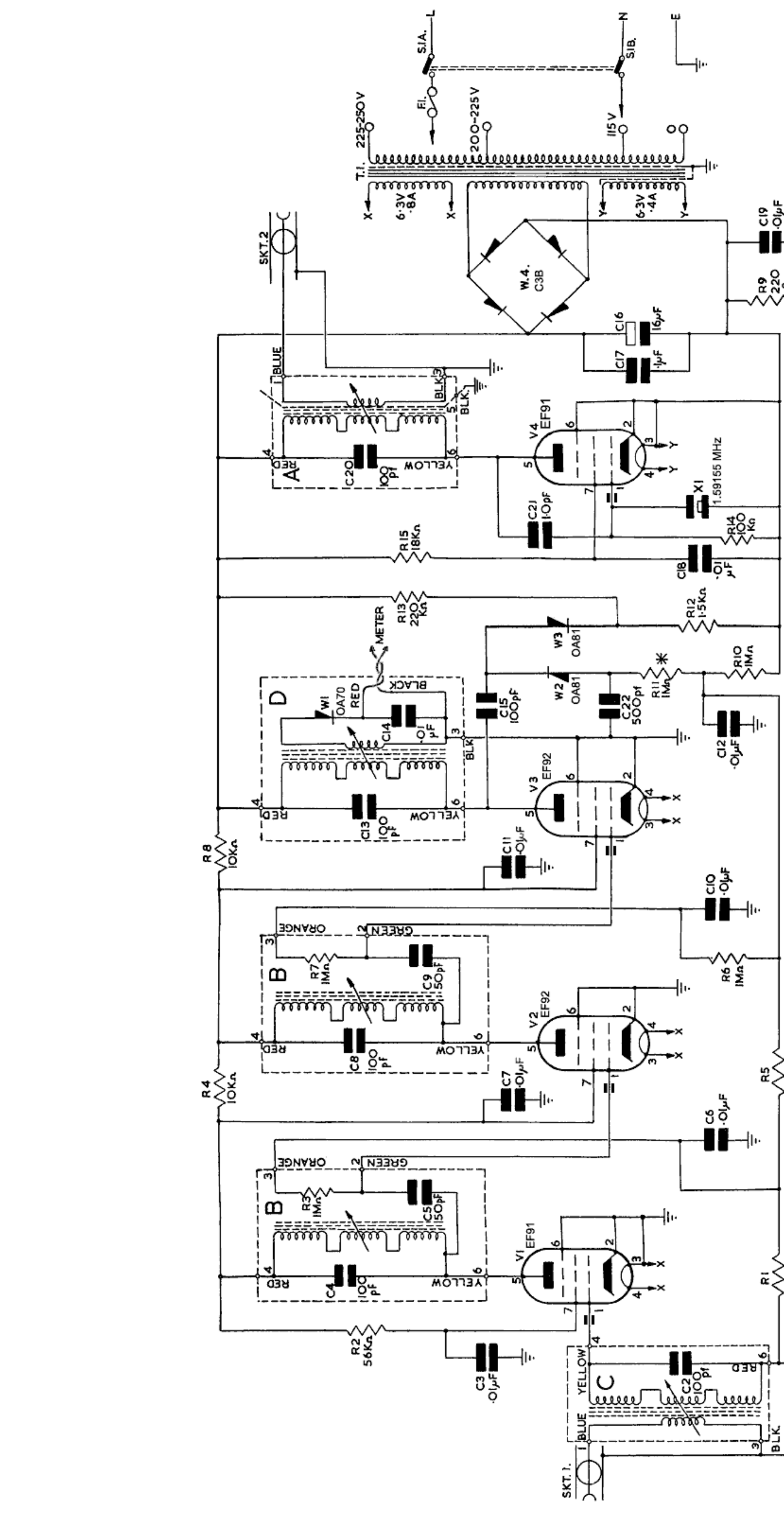

Based on Drg. No. TD486/B
Issue 3. 12th Feb. 1964
Hatfield Instruments
LE 300A/1
T2
27T
9T
1T
T3
C2
3-30pF
(a) 10
(b) 1
(c) 0·1
(d) 0·1
(e) 1
(f) 10
A
B
C
D
C9
0.7-3pF
C8
1pF
R5
10K ±2%
R4
900Ω ±0.5%
'C' DIAL.
C5
260pF
C10
2µF
'G' DIAL.
R2
200Ω
w/w
C11
2µF
T1
33T
11T
CH1A
CH1B
R3
2K2
SET ZERO 'R'
R1
1K
w/w
C14
2µF
C6
0.7-3pF
SET ZERO 'C'
C4
50pF
C1
0.7-3pF
C15
2µF
C3
3-30pF
C13
5nF
C12
5nF
S
B
COMMON
C
DC
N2
EARTH
N1
NEUTRAL
10·0
1·0
0·1

Bridge Source & Detector SA 28. (LE 302)

Issue	Date	Changes
1	20th Oct. 1960	
2	15th July 1960	* (select in test) Added to R11
3	27th July 1960	C22 Added.
4	20th Oct. 1960	Redrawn. No mods.
5	16th ???. 1962	W1 was GEX66 GEC.
6	18th July 1963	Circuit changed to DCN 112

Parts List.

A	Coil Assy. A. Drg. No. A1/132/B
B	Coil Assy. B. Drg. No. A2/132/B
C	Coil Assy. C. Drg. No. A3/132/B
D	Coil Assy. D. Drg. No. A4/132/B
T.1.	Transformer M.49
S.1	Switch Arrow DP/DT 81058-BT-13
F.1.	Fuse 0.25 Amp. L562. Size 00. Belling & Lee.
W.1.	Diode OA70 Mullard.
W2. W3.	Diodes OA81 Mullard.
W4	Rectifier C3B. ST & C.
V1. V4.	Valves EF91 Mullard.
V2. V3.	Valves EF92 Mullard.



— DENOTES FERROXCUBE BEADS, ✳ — SELECT IN TEST.

Hatfield Instruments 1.592 MHz Bridge Source & Detector. SA 28

Based on Drg. No. TD/132/A
Issue 6. 18th July 1963

Series - Parallel Conversions

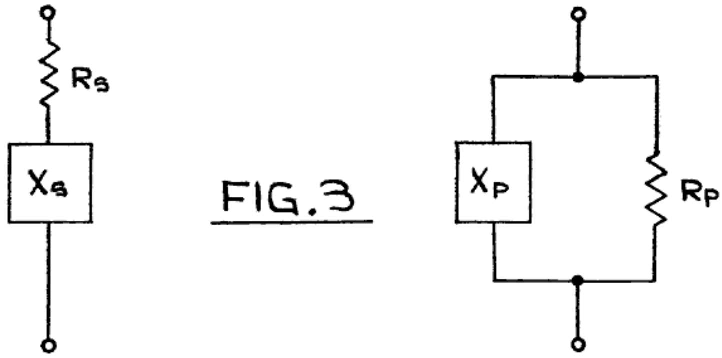


FIG.3

Parallel to series:

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

$$X_s = \frac{X_p}{1 + (X_p / R_p)^2} = \frac{X_p}{1 + 1/Q^2}$$

Series to parallel:

$$R_p = R_s\,[\,1 + (X_s / R_s)^2\,] = R_s\,[\,1 + Q^2\,]$$

$$X_p = X_s\,[\,1 + (R_s / X_s)^2\,] = X_s\,[\,1 + 1/Q^2\,]$$

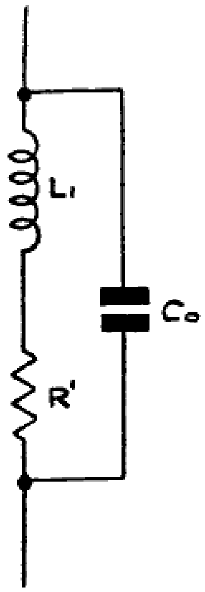
Where:

$$Q = X_s / R_s = R_p / X_p$$

When $Q > 10$

$R_s \approx X_p^2 / R_p$	$R_p \approx X_s^2 / R_s$
$X_s \approx X_p$	$X_p \approx X_s$

Corrections for inductor self capacitance



True inductance: $L' = L / [1 - f_1 / f_0]$
Where
L is the measured value
f_0 is the resonant frequency of L and C_0 , and $f_1 < f_0$.

When f_0 is $\geq 10 f_1$, L' is within 1% of L.

True resistance: $R' = R / [1 - (f_1 / f_0)^2]^2$
Where
R is the measured value.
f_1 and f_0 are as above.

When f_0 is $\geq 10 f_1$, R' is within 1% of R.

To find self capacitance

$$C_0 = \frac{C_1 - N C_2}{N - 1} \quad \text{where} \quad N = \frac{\omega_1^2}{\omega_2^2}$$

$$C_1 = \frac{1}{\omega_2^2 L} \quad \text{and} \quad C_2 = \frac{1}{\omega_1^2 L}$$

If $f_1 = 10 f_2$ then $C_0 = C_1 - 100 C_2$ to within 1%.