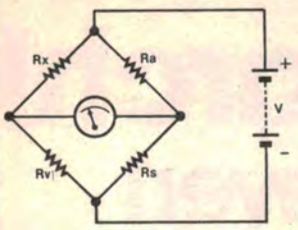


Fig. 1a

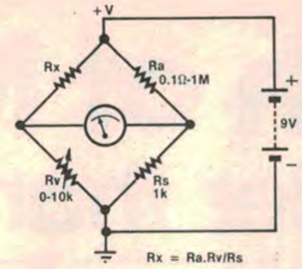


Fig. 1b

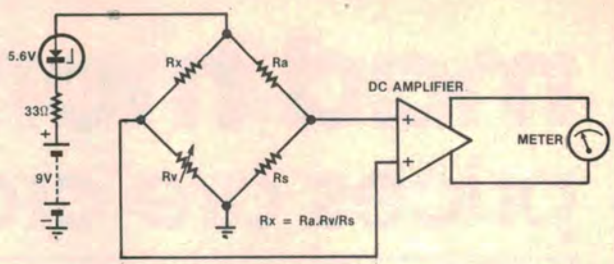


Fig. 1c

by JEFF SKEEN & LEO SIMPSON

A versatile LCR Bridge

– for laboratory & workshop

When it comes to measuring resistors, capacitors and inductors nothing can beat a good all-round LCR bridge, especially if it can cope with electrolytics and high and low-Q inductors.

So who needs an LCR bridge? The answer is everyone who is really interested in electronics, whether they be hobbyists, amateur radio operators, technicians or design engineers. Sure, if you only put one kit together in a year, you probably don't need a good LCR bridge but once you decide to become a little more venturesome, an LCR bridge becomes indispensable.

Once you acquire a good LCR bridge such as this new EA design you will wonder how you ever managed without it. It is very reassuring to be able to quickly check the value of any passive component before you solder it into circuit – at least you know that particular component won't give any trouble! And capacitors and other components with their values rubbed off cease to be a problem. Just whack 'em across the bridge, twiddle the dials and there's the value. Easy.

To a certain extent other instruments have encroached upon the need for a comprehensive LCR bridge. For example, most digital multimeters can measure resistance over a wide range of values with a high order of accuracy. And digital capacitance meters, two of which have been described in EA (March 1980 and March 1982), bring precise and convenient measurement to capacitors although the range of measurement is not as wide as it might be.

Paradoxically, resistors are probably the one component we have the least need to measure since their value is clearly marked (once you know the colour codes) and they are a readily available in close tolerances (1% or better). Still, it is often desirable to know the precise value of a resistor, regardless of its specified tolerance.

And even though digital capacitance meters can be very handy, they are usually unable to cope with large value electrolytics and do not have any facility for measuring dissipation factor of capacitors.

And of course, there is no instrument, other than that rare creation, the Q-meter, which can really do the job of an LCR bridge for quick and convenient measurement of inductors. If you have to work with inductors it is important to have a bridge that can measure them because they are rarely marked – once they're out of the packet you have no idea of their value.

So even though there are a number of alternatives to an LCR bridge which can measure resistors and capacitors, they are only a partial substitute for a good bridge.

In fact we have put a great deal of development into this new bridge, to the point where it puts any other bridge we have designed in the past well into the shade. If you presently have an elderly EA LCR bridge amongst your test equipment line-up now is the time to replace it with a high performance design which will cost much less than an equivalent imported commercial unit.

That is not to say the new design will be cheap to put together. We have not cut corners in this design and some of the components are quite expensive. The end result is a design which we think will be popular for many years and will pay back its purchase cost many times.

Features

The new EA LCR bridge will measure AC and DC resistance from one milliohm to 11 megohms; inductance from 0.1 microhenries to 1100 henries; and capacitance from one picofarad to 11,000 microfarads. In other words, for resistance, capacitance and inductance the overall measurement range is 1.1×10^{10}. No other measuring instrument can match that!

Minimum resolution is one milliohm for resistance measurements, 0.1 microhenry for inductance and one picofarad for capacitance although for any measurement range the resolution will be limited to four digits.

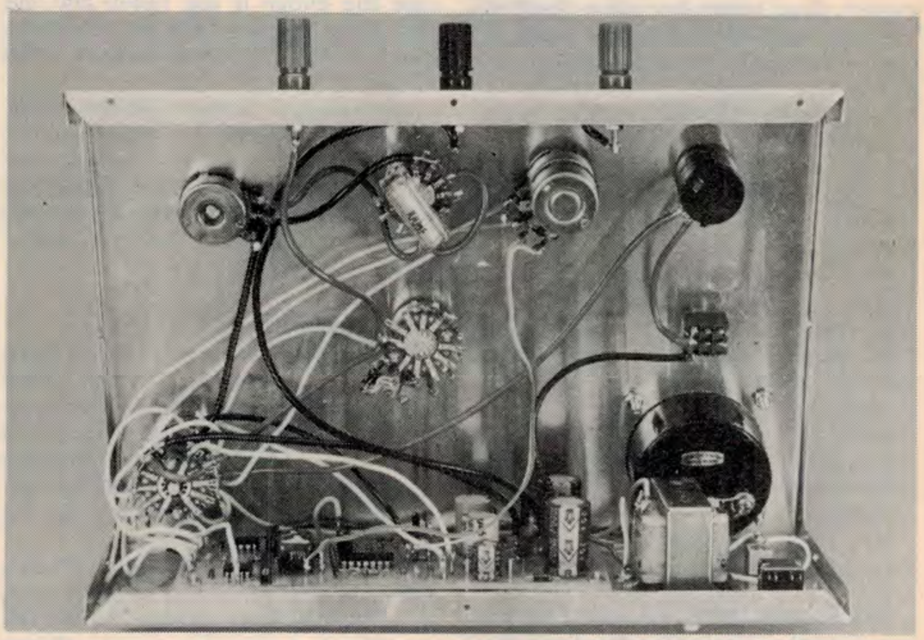
Basic accuracy is about ±1% for AC resistance, inductance and capacitance ranges and about ±0.3% for DC resistance measurements.

In addition, the quality factor, Q, of inductors and the dissipation factor, D, of capacitors under test is indicated for values lying in the range .01 to 31.

AC measurements (inductance, capacitance and AC resistance) are performed at a frequency of 1kHz which is supplied by an internal sinewave oscillator. A socket has been provided to allow connection of external AC signals in the range 20Hz to 20kHz so that measurement of component values may be done at frequencies other than 1kHz. This feature is useful for components which have values specified at particular frequencies.

A further useful feature is provision for applying a polarising voltage to electrolytic and tantalum capacitors under test. This is done via a front panel socket. In addition, the power supply may be derived from either a set of internal batteries or an external 12V AC plugpack. This means that the instrument is fully portable and that measurements can be made in places remote from mains power.

Above is a view of the new LCR Bridge in early prototype stage, with the front panel layout still to be finalised. Below is an interior view showing the PCB and general wiring details.



Controls

Perhaps the most important control on the new EA LCR Bridge is the main nulling control. Unlike previous EA designs this is not a single-turn pot with an attached dial. Instead it is a precision 10-turn potentiometer with a three-digit vernier readout. This, combined with the close tolerance internal standard capacitor and multiplier resistors, determines the high performance of the design.

The nulling indicator is a centre-reading meter which is electronically driven so that it provides very high sensitivity while still indicating the null "direction", even when the bridge is a long way from the null setting; ie, when the multiplier settings are quite wrong.

Two rotary switches are used to select the measurement mode (and whether DC or AC resistance measurement) and the range multiplier. Since the control settings may not be self-evident, an explanatory table is displayed on the front panel.

Other features will be explained in the next article.

Circuit concepts

For the remainder of this article we shall discuss the circuit methods used in the new EA LCR Bridge while next month's article will be devoted to the full circuit presentation and construction details.

The basic bridge circuit used in the instrument is shown in Fig. 1a. To most readers this will be familiar as the Wheatstone Bridge. While this was first developed for resistance measurements there are many variations on the basic theme and several are used in this new EA design.

The principle of operation of the Wheatstone Bridge is quite simple, the bridge basically consisting of two voltage dividers placed across a common power source. The first voltage divider consists of Rx and Rv while the second voltage divider consists of Ra and Rs.

If a centre zero meter is placed between the junctions of the two resistive dividers as shown, and Rv is varied, a point will be found where no current flows through the meter and the bridge is said to be "nulled". At this point the voltages on either side of the meter are equal and so:

$$V.Rv/(Rv + Rx) = V.Rs/(Ra + Rs)$$

Cancelling the "V" terms and cross multiplying gives:

$$Rv.Ra + Rv.Rs = Rv.Rs + Rs.Rx$$

Subtracting Rv.Rs from both sides leaves:

$$Rv.Ra = Rs.Rx$$

This expression may be rewritten as a ratio of the divider resistors to give:

$$Rx/Rv = Ra/Rs$$

which could have been written down by inspection directly from Fig. 1a.

We can now express Rx in terms of the other resistors by writing:

$$Rx = Rv.Ra/Rs$$

So providing we know the values of Ra, Rv and Rs, we can find out the value of our unknown resistor, Rx.

In our bridge, Ra and Rs are fixed resistors of known value, while Rv is a 10-turn variable resistor with a matching vernier drive attached. A "digital" readout on the vernier drive indicates the resistance of Rv and so the three resistors on the right hand side of the expression for Rx are known. Therefore

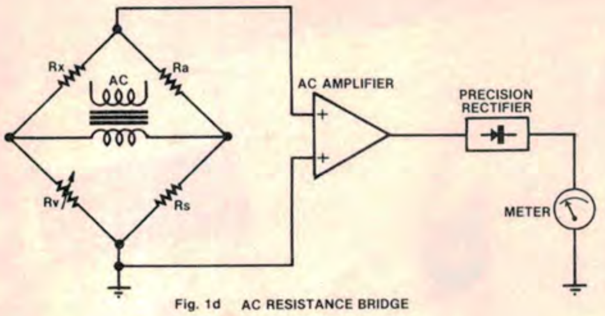


Fig. 1d AC RESISTANCE BRIDGE

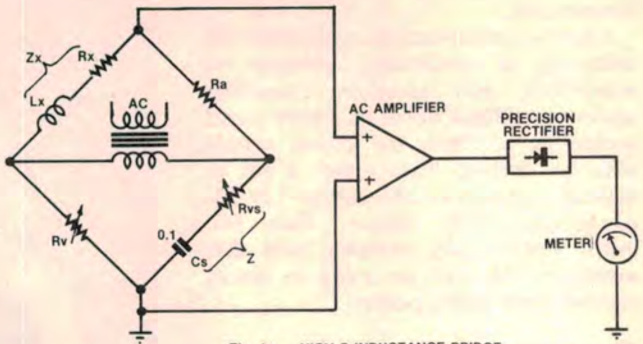


Fig. 1e HIGH Q INDUCTANCE BRIDGE

A versatile LCR Bridge

we can work out Rx. In practice, the values of Ra, Rv and Rs are all multiples of 10 and the unknown value may be read directly from the vernier scale.

Fig. 1b shows the Wheatstone Bridge with values shown for three of the four arms.

There are several practical problems associated with this form of bridge. The first and most obvious is the excessive current drain when low value resistors are measured. The extreme practical case occurs when we wish to measure the residual resistance of the bridge. In this instance we have a value for Rx of around 3mΩ and a corresponding value for Rv of around 3Ω. This calls for a current of 3A from the power supply which is not really possible using small batteries.

Also, if the short circuit used in measuring the residual resistance is removed, about 3A will pass through the 0.1Ω range resistor, Ra. The range resistors are rated at ¼W, 0.1% and should not be overloaded otherwise their value may change. Since passing 3A would dissipate 0.9W in the resistor, it is obvious some form of current limiting is necessary.

This problem is overcome by the variant shown in Fig. 1c. Current limiting is achieved by placing a 33Ω resistor and a 5.6V zener diode in series in the power supply lead of the bridge. This limits the maximum current which can flow through the bridge to around 100mA. The 5.6V zener diode is not really necessary for current limiting, since increasing the 33Ω resistor to 100Ω would achieve the same result. However, it helps solve another problem that we will discuss shortly.

If you examine the component values in each leg of Fig. 1b on the 0.1Ω and 1Ω ranges, you can see that the bridge is "bottom heavy"; ie, the component values on the bottom arms of the bridge are many times those on the top arms. The effect is that the two connection points for the meter are virtually short circuited to the supply point and so the voltage across the meter (and the current through it) is almost zero.

Consequently, the meter shows virtually no deflection (about three pointer-widths) over the entire range of Rv adjustment. The same situation applies to the 1MΩ range except in this case the bridge is top heavy and the high value resistors limit the maximum meter current (for resistors above 1MΩ) to 9μA.

Most simple bridges dodge these sensitivity problems by requiring that measurements on the highest and lowest ranges be done using an external power supply which can deliver enough voltage or current to obtain a usable meter deflection.

DC amplifier

Our solution to these problems is to include a DC amplifier in the meter circuit so that the sensivitity of the meter is increased. Maximum amplification is 290 times which ensures adequate meter sensitivity even on the 0.1Ω range. Fig. 1c shows the connection of the amplifier to the bridge circuit.

The DC amplifier consists of two operational amplifiers (op amps) sharing a common gain control. The DC amplifier is designed to reject voltages common to both corners of the bridge (called the common mode voltage) and amplify only the voltage difference between the corners (called the differential voltage).

The common mode range of the op amps does not extend to the positive supply rail so some form of voltage limiting is necessary on low resistance ranges so that the measurement points remain within the common mode range of the DC amplifier. This is the reason for the 5.6V zener diode mentioned earlier. It limits the maximum input voltage on the lower resistance ranges to 3.4V.

On the highest resistance ranges, very little current flows through the zener and it comes out of regulation, the voltage drop across it reducing to around 3V. This makes more voltage available to the bridge resistors, increasing the sensitivity by a factor of nearly two.

AC energisation

For the DC resistance method just discussed it was necessary to arrange for the detector circuitry to "float" so that a single power supply could power both the detector circuitry and the bridge itself. For AC measurements, however, it is desirable to swap the bridge around so that the null detector can use an unbalanced input amplifier. This means that the bridge source must "float". This condition is met by using a transformer, as in Fig. 1d.

Surprisingly, swapping the position of the power source and null detector does not alter the mathematical relationship given earlier, even though the circuit has now been turned on its side, as it were. You can prove this to your own satisfaction by starting with the basic relationship,

$V. Ra/(Ra + Rx) = V. Rs/(Rv + Rs)$

which reduces to

$Rx = Ra.Rv/Rs$

as before.

In fact, compared to the previous configuration, Fig. 1d produces a greater difference in measurement point potential for a given change in Rv, meaning that the bridge is more sensitive.

The amplifier circuit is changed slightly, an extra stage of amplification being added followed by a precision rectifier. The extra stage of amplification, together with the increased bridge sensitivity, compensates for the lower drive voltage produced by the transformer. The precision rectifier is necessary since the meter cannot respond to AC.

Fig. 1e shows the bridge connected to measure high-Q inductors. This configuration is sometimes referred to as a Hay bridge.

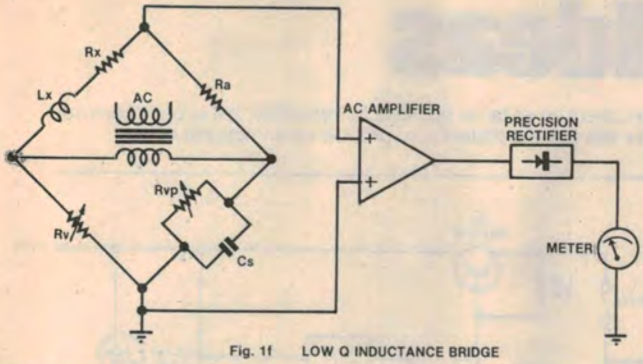


Fig. 1f LOW Q INDUCTANCE BRIDGE

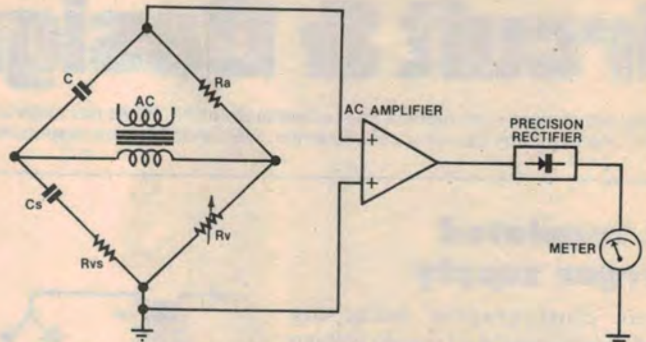


Fig. 1g CAPACITANCE BRIDGE CONFIGURATION

The "Q" or "quality factor" of an inductor is defined as the ratio of its imaginary component of impedance to its real component. Or, in other words, $2\pi fL/R$. The high-Q bridge functions in much the same manner as the AC resistance bridge except that Rs is replaced by a capacitor Cs with a variable resistor Rvs in series.

Rvs is used to balance out the series resistance which is found in all practical inductors. An understanding of the bridge operation can be obtained by considering the measurement of an ideal inductor. Since an ideal inductor has zero series resistance, the variable resistor, Rvs, has nothing to balance out and so will be set to zero ohms. This corresponds to an inductor with infinite Q.

The ratio of the impedances in the arms of the bridge can be written by inspection as:

$Z_L/Ra = Rv/Zc$

By substituting $Z_L = jwL$ and $Zc = 1/jwCs$ and rearranging we obtain:

$jwL = Rv.Ra.jwCs$

which simplifies to

$L = Rv.Ra.Cs$

When the inductor being measured is not ideal and has some series resistance, the expression for inductance becomes more complicated and is given by:

$L = Rv.\ Ra.Cs/(1 + 1/Q^2)$

where $Q = 1/w.Cs.Rvs$

Our bridge uses this measurement configuration for inductors with a Q greater than 30 so less than 0.11% error will be introduced if the inductance is approximated as $L = Rv.Ra.Cs$.

Low Q inductors (ie inductors with a Q under 30) are measured using the bridge configuration shown in Fig. 1f. This configuration is sometimes called a Maxwell bridge. The bridge is essentially the same as the high Q bridge but this time the inductor losses are balanced via a resistor in parallel with the standard capacitor.

Expressions for the inductance and Q of the unknown inductor are:

$L = Rv.Ra.\ Cs$ and

$Q = w.Cs.Rvp$

Note that the expressions for the high and low Q inductances are the same over the respective measurement ranges and therefore one scale can be used to read both.

Capacitance measurement is very similar to inductance measurement except that the arm containing the standard capacitor and its loss balancing resistor is swapped with the arm containing Rv. The swap corrects for the fact that capacitor impedances are the inverse of resistor and inductor impedances, ie a large value capacitor has a small impedance while a large value resistor or inductor has a large impedance.

The term "Q" is not used for capacitors; instead the term "D" or dissipation factor is used as an indication of the capacitor quality. D is the ratio of the real component of capacitor impedance to the imaginary part and is written as:

$D = w.R.C$

Typically, D is almost zero for high quality polystyrene and polycarbonate capacitors, while electrolytic capacitors often have D values of around 0.2 to 0.3.

In Fig. 1g the bridge configuration used in the measurement of capacitance is shown. This form of the bridge circuit is known as a De Sauty configuration.

In the usual manner we can write down the expression for the bridge impedance ratios (assuming the unknown capacitor, C is ideal) as:

$$\frac{Ra}{\frac{1}{jwC}} = \frac{Rv}{\frac{1}{jwCs}}$$

or, $$C = \frac{Rv.Cs}{Ra}$$

and, $D = w.Rvs.Cs$ from before.

The normal range of capacitor D values is covered quite well by the De Sauty bridge configuration and there is no real need to switch to a parallel loss resistor. It can be done, if required, by switching the Q ranges and finding the values of C and D from the expressions:

$C = Rv.Cs/Ra(1 + 1/Q^2)$

$D = 1/w.Rvp.Cs$

This completes our article on basic theory of LCR bridge operation. In the following article we will provide the circuit diagram and full details of the bridge construction.