Spring April, 1964

A New Technique for the Recognition of Resistance in the Presnce of Reactance

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A New Technique for the Recognition of Resistance in the Presence of Reactance

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In this article a bridge type technique is described which enables resistance to be recognized and, if required, measured in the presence of reactance. The theoretical basis of the measurement is given in detail and a typical circuit illustrated.

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Zusammenfassung in deutscher Sprache auf Seite 288)

A 'BRIDGE-TYPE' technique for recognizing the resistive element, alone, of a 'lossy' reactance has been devised[1].

Conventional methods involve the measurements of reactance in addition to the resistance, and in consequence demand a frequency-stable signal-source. With both these complications eliminated the new technique becomes simple to apply and to use; the presence of resistance is

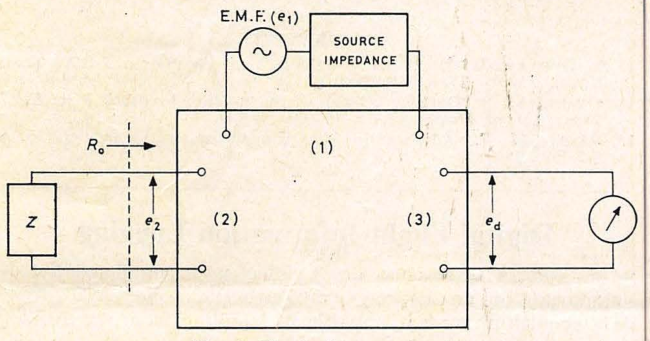

Fig. 1. The basic arrangement

The three-port resistive net is so proportional that (given $e_d = 0$ when $Z = R_b$) R_b is identical with R_o—the output impedance of the net measured at port (2)

recognized immediately the test-object is connected; measurement, if required, may take a few seconds.

Because the network involved has the form of a 'bridge' (see Fig. 1) the new technique can properly be so described; the usage of the bridge, however, is completely unconventional. For example, although the voltage e_d appearing at the 'detector' terminals becomes some measure of the loss-resistance r present in the unknown impedance Z, that voltage is never reduced to zero—as in conventional practice—but remains very nearly constant. Measurements of r are made in terms of the *departure from constancy of* e_d, or—speaking more strictly—of the ratio e_d/e_1, (e_1 being the supply e.m.f.).

When the (purely resistive) bridge network is properly proportioned, a short-circuit, or an open-circuit of the test-terminals (2) of the bridge, or the connexion of a completely loss-less reactance, all lead to the same e_d/e_1 ratio—phase-relation being ignored.

By adopting one of the many available artifices the constant magnitude of this ratio can be converted into a 'null' reading of the detector. This null is disturbed when the test-object contains resistance r: r will be treated as the 'equivalent series resistance'.

The meter reading then becomes nearly proportional to r, unless the r/X ratio is substantial. On the other hand, when X, alone, is present the deflexion remains at zero irrespective of the sign of the reactance. Such properties strongly recommend the device for mass-production testing, the tested item being rejected if the meter current exceeds a preset maximum.

The circuit conditions set out in the legend of Fig. 1 give all the essential information upon which an '*R*-Recognizing' bridge can be designed. Note, however, that the basic circuit elements are required to be purely resistive. If an '*X*-Recognizing' bridge were required the same theory—*mutatis mutandis*—will apply, the basic elements being purely reactive.

The Appendix deals with the basic circuit theory of the *R*-Recognizer but the practical embodiments, of which there exist an unlimited number, are not dealt with; equally

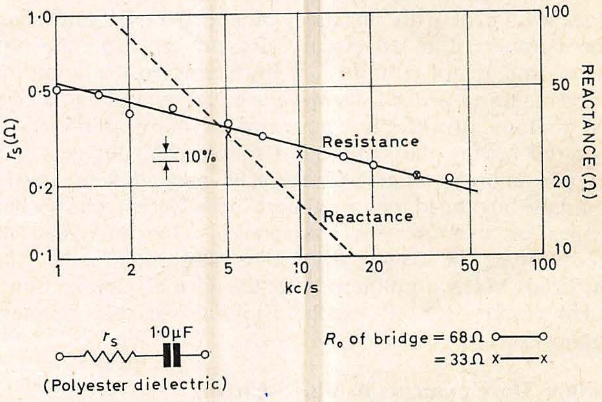

Fig. 2. Measurements made using polyester dielectric capacitor

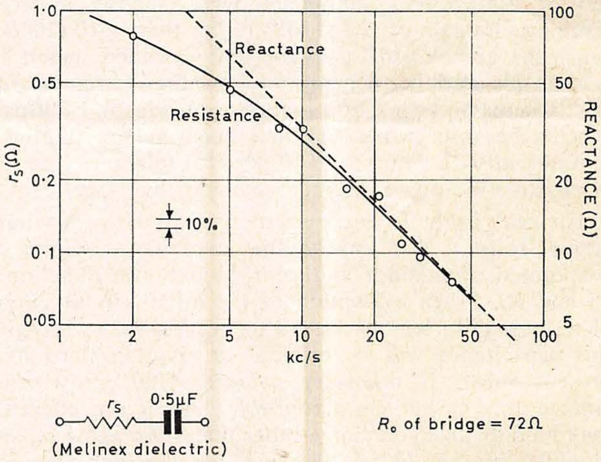

Fig. 3. Measurements made using Melinex dielectric capacitor

the various artifices for generating a 'null' detector reading from a constant value of e_d/e_1 are left to the ingenuity of the designer.

For various technical reasons the 'ratio arms' of the resistive bridge are best replaced by a tapped transformer-winding. The residual imperfections of the transformer can then be swamped by using resistive attenuating networks to ensure that the essentially resistive elements of the network operate in an effectively resistive milieu. A practical circuit uses a centre-tapped transformer associated with five auxiliary resistors—if the transformer was perfect, three resistors would suffice.

Such an assembly, capable of operating from audio to radio frequencies was demonstrated by Messrs. Hatfield Instruments Ltd at the recent Exhibition of the Physical Society. Some graphs illustrating measurements made with an earlier, low-frequency, model are shown in Figs. 2

and 3. The following circuit information applies to this model.

The idealized network of Fig. 4 illustrates the proportions of the bridge used for tests with $R_o = 33{\cdot}3\Omega$. Here the two idealized sources E_1 have zero impedance and the instrument observing E_3 takes no current; elements A, C and D are pure resistances and T is the impedance of the test-object.

Then the conditions called for (see legend of Fig. 1) are met if: $A = K . C$ and $D = C . (K - 2)(K + 1)/(K + 2)$, which leads to $R_o = C . (K - 2)(K + 1)/2K$. (Notice that $K > 2$, or D and R_o become negative).

Then when $T = 0$, $E_3 = +E_1/(1 + K)$

when $T = \infty$, $E_3 = -E_1/(1 + K)$

while when $T = \pm jX$, $|E_3|$ is unchanged.

(if $K = 3$, $|E_3| = E_1/4$.)

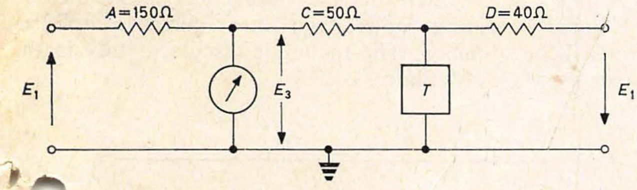

Fig. 4. Ideal network

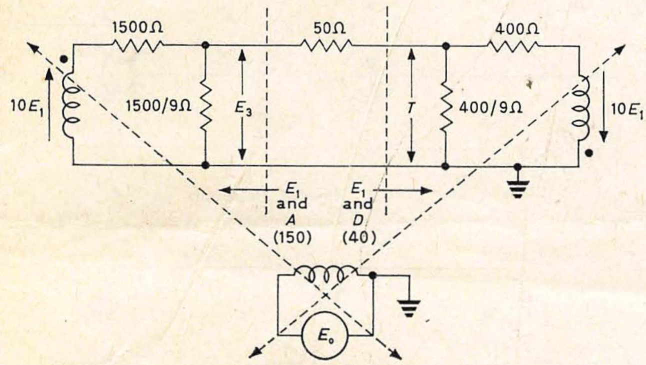

Fig. 5. Practical network

In practice the e.m.f's E_1 are generated by a transformer (Fig. 5); at the same time attenuating pads (in the figure 10/1 voltage ratio) are used as explained above to 'hold off', from the A-C-D net, any unwanted impedance contributed by the transformer.

This arrangement has the great practical advantage that a measuring 'meter' of quite low input impedance (provided it is resistive) can be used; the resistor across which it is shunted is increased to restore the value of A.

To observe that $|E_3|$ remains constant when $T = 0$ or ∞, and is therefore insensitive to anything except resistance in T, E_3 is amplified, rectified, and a d.c. voltage V_1 stored on a capacitor; meanwhile a second alternating voltage (equivalent to $E_1/(1 + K)$ is taken from the source E_o and similarly stored as V_2. The difference between V_1 and V_2 operates the final indicating meter in the test-equipment; this meter stands at zero unless T contains resistance.

Appendix

(1) Consider the influence of Z upon e_2 and e_d under the conditions listed below:

Condition	Z	(e_2)	(e_d)
(a)	∞	E_1	D_1
(b)	R_b	E_2	zero
(c)	zero	E_3	D_3
(d)	$(r + jX)$	E_4	D_4

(2) Then, because $R_b = R_o$,

$$E_2 = (E_1)/2$$

while clearly E_3 = zero.

(3) The argument turns on the *changes* in e_d due to changes of Z. The change in e_d, Δ_1, due to altering Z from R_b to ∞ is:

$$\Delta_1 = E_1 - E_2 = +E_1/2$$

Again the change in e_d due to short-circuiting R_b is:

$$\Delta_2 = E_2 - E_1 = -E_1/2$$

(4) The corresponding changes in the 'detector' p.d. e_d must—by the principle of superposition—inevitably reflect (in some fixed proportion) the p.d. changes Δ_1 and Δ_2 which have occurred at terminals (2).

The changes were all relative to the condition that $Z = R_b$, and under that condition (b) e_d = zero.

It immediately follows that:

$$D_1 = -(D_3)$$

(5) It is then easily deduced that when $Z = (r + jX)$, (Condition (d)):

$$D_4/D_1 = M, \text{ (say)} = (1 - (r+jX)/R_o)/(1+(r+jX)/R_o) \quad \text{(see footnote)} \ldots\ldots\ldots\ldots (1)$$

or:

$$M = (1 - \alpha - j\beta)/(1 + \alpha + j\beta) \ldots\ldots\ldots (2)$$

where $\alpha = r/R_o$ and $\beta = X/R_o$.

Thus if α (i.e. r) is absent $|M|$, the magnitude of the ratio M, is unity and is unaffected by X. On the other hand $|M| = 1$ again if $\alpha = \infty$.

If α is present, but β vanishingly small:

$$|M| = 1 - 2\alpha \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Or if, as is most common, α and β are both finite:

$$|M| \simeq 1 - 2\alpha/(1 + \beta^2) \ldots\ldots\ldots\ldots (4)$$

From these equations it is to be seen that $|M|$ will never *exceed* unity and will *fall* from this value only if α (that is r) is finite.

By the artifices mentioned this fall in voltage can be converted into a meter deflexion, N, which stays at zero unless r is finite.

Thus in the general case of equation (4), N is proportional to $2\alpha/(1 + \beta^2)$. Because of the term in β^2, the reading N is *reduced* by the reactance X; nevertheless N remains *proportional* to α and r, if β (or X) is fixed. In consequence the ohmic value of r can be deduced by inserting—in series with the unknown—a known resistance R_k which reduces N to $N/2$. R_k then equals r.

The elegance of this substitution technique is that the effect of β (or X) is completely eliminated except insofar as it reduces the 'sensitivity' of the measurement—see equation (4).

A slightly more sophisticated, direct-reading version of this measurement technique was used in collecting the data plotted in Figs. 2 and 3. The 'spread' of the data around the mean smooth curve shows up the loss of sensitivity as X or R_o were varied. (Two separate bridge networks were used; two resistors only have to be changed to alter R_o).

REFERENCE

1. Patent Application 43704/63.

This formula indicates that, when $r = 0$, the network has 'all pass' transmission characteristics. A note on the design and application of such networks is in preparation.