PATENT SPECIFICATION

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COMPLETE SPECIFICATION

Thermionic Voltmeter for Alternating Voltages

We, MUIRHEAD & Co. LIMITED, of Croydon Road, Elmers End, Beckenham, Kent, a British company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to thermionic voltmeters for indicating the value of alternating voltages.

The invention consists of a thermionic voltmeter for determining the values of alternating voltages comprising a voltage divider, an amplifier, an attenuator and a second amplifier connected in cascade, and a bridge connected to the output of the second amplifier, the bridge consisting of a four-element resistive network with four terminals, at least one of the elements being a non-linear resistor, the alternating voltage output of the second amplifier being applied to one pair of diagonally opposite terminals of the bridge, means for applying a direct voltage of adjustable magnitude to the said pair of diagonally opposite terminals of the bridge and a direct voltage null indicator connected to the other pair of diagonally opposite terminals of the bridge for indicating by a null reading when the alternating voltage output of the second amplifier is at a predetermined value, the value of the unknown voltage being determined from the scale readings of the voltage divider and the attenuator when adjusted to give a null reading on the direct voltage null indicator.

In order that the invention may be clearly understood it will be described in conjunction with the accompanying drawings in which:—

Figure 1 shows a bridge circuit for indicating when an alternating voltage is at a predetermined value.

Figure 2 is a circuit diagram similar to Figure 1 but showing an alternative method of feeding direct current to the bridge.

Figure 3 is a block diagram of a measuring instrument according to the invention.

Figure 4 is a graph showing the relationship between the current and voltage through a metal filament lamp.

Referring to Figure 1 there is shown a bridge circuit of which two opposite arms are formed by a pair of fixed resistors 10, 11. The third arm comprises an adjustable resistor 12 and the fourth arm comprises a non-linear resistor formed of two lamps 13 connected in series. The alternating current or voltage source under test is applied to two terminals 14, 15 from which the alternating signal is fed into one diagonal of the bridge through a condenser 16. Connected in shunt across the condenser is an adjustable potentiometer 17 fed by a battery 18 so that an adjustable direct current can be injected into the bridge across the same diagonal as that across which the alternating signal is applied. Connected across the second diagonal of the bridge circuit is a direct voltage indicator 19.

Figure 2 shows a modified form of the circuit of Figure 1 embodying, as before, a bridge with fixed resistors 10, 11, a variable resistor 12 and a non-linear resistor 13 formed of two lamps. The alternating input is applied to the terminals 14, 15 and fed to one diagonal of the bridge through the condenser 16. In Figure 2, however, the direct current bias is injected into the bridge from an adjustable potentiometer 20 fed by a battery 21 as a shunt voltage across the alternating signal input.

The choice of circuit for injecting the direct current into the network will, in general, depend on the manner in which the bridge is to be used.

Figure 3 shows a block diagram of a measuring instrument according to the invention incorporating a bridge similar to that of Figures 1 and 2 and illustrating a further method of injecting the direct current. An alternating input signal to be measured is applied to input terminals 30 and 31 which are connected to a potential divider 32. By means of the potential divider a known fraction of the input voltage may be picked off and this is applied to an amplifier 33. The amplifier design may be generally in accordance with the known art, including devices, such as negative feedback, to ensure that its gain is substantially constant. The output of amplifier 33 is fed to an adjustable attenuator 34 which may be of any suitable type. The output of attenuator 34 is fed to a further amplifier 35, also having a constant gain. Amplifier 35 may be generally similar to amplifier 33 but includes a cathode follower output circuit so that a direct voltage is developed between output terminals 36 and 37 in addition to an alternating voltage having a known relationship with the input signal. The two voltages are applied together to the bridge circuit 38 through adjustable resistance 41 and direct current meter 42 by which the direct current passing to the bridge may be adjusted and measured, the resistance and meter being shunted by condensers 39 and 40 respectively to provide a low impedance path for the alternating signal voltage. The amount of the direct current component can be adjusted by means of variable resistance 41 and measured by means of meter 42 without appreciably affecting the alternating current.

A preferred method of using the voltmeter is to "standardize" the bridge by means of a direct voltage which is accurately known by comparison with a standard cell incorporated in the instrument, to apply a direct voltage of a known lower level (which may be derived from the same direct voltage source) so that a predetermined alternating voltage will balance the bridge, to adjust the total gain of the amplifiers to a predetermined level and then to adjust the attenuation until the input voltage produces a balance of the bridge. The input voltage may then be determined from the index scales of the voltage divider and attenuator.

The direct current component injected into the bridge is preferably made smaller than the alternating component. In practice it is found desirable to make the magnitude of the direct component through the non-linear resistor 13 one quarter or less than that of the alternating component. The reason for this is as follows:—

If a metal filament lamp is used as the resistor 13, its resistance depends upon the filament temperature and thus upon the r.m.s. value of the total current through the lamp. If A is the r.m.s. value of the alternating component and B the value of the direct component then the lamp resistance is controlled by A^2+B^2. Suppose the bridge is balanced with a current of r.m.s. value I and writing n for $\frac{B}{A}$, then $I=A(1+n^2)^{\frac{1}{2}}$.

If we take the case of $n=\frac{1}{4}$, it will be seen that the contribution of the direct current to the heating of the lamp is of the order of 1/32, i.e., only 3%. If the direct current can be read off a meter with a precision of say plus/minus 2% the heating value of the combined alternating and direct components of current in the lamp is known with a precision of 0.06%.

Taking the case of a lamp rated at 6 volts, 40 milliamperes (at full brilliance) which is conveniently used in a lamp-bridge with a heating current of 14 mA r.m.s., the bridge might be proportioned so that it was balanced when the alternating current in the lamp was 14 mA r.m.s. and the direct current was 3.5 mA. The latter could be observed on a robust and relatively inaccurate meter, and so long as the reading lay between 3.5 plus/minus 2% when the bridge was balanced, the input alternating current would be known to lie between 14 mA plus 0.06% and minus 0.06%.

It is quite practicable, therefore, to employ a direct current supply the value of which is imperfectly known, in a bridge intended for very high precision measurements of alternating inputs.

The precision with which measurement can be made depends only on the precision with which the direct voltage is known, and the difference between the impedance of the bridge arms to alternating and direct components. Since the phase-angle of the impedances of the bridge parts is of no concern, only the *magnitude* of the current passing through the lamp matters and quite large residual reactances can be tolerated without seriously affecting the precision of the measurement. It follows, therefore that an instrument incorporating a bridge of this kind can be used to make measurements of alternating signals over a very wide frequency range.

It is possible to increase the sensitivity of the bridge by using two non-linear elements and two linear elements instead of one non-linear element and three linear elements. Two non-linear elements of the same kind, that is both having positive or both having negative co-efficients of resistance change with current, may be connected in opposite arms of the bridge or, alternatively, non-linear elements of the opposite kind may be connected in adjacent arms. If the two non-linear elements have the same co-efficient of resistance change with current, the sensitivity of the bridge will be doubled compared with that of a bridge using only one non-linear element.

The disadvantage of two non-linear elements is that if one or both of these elements have to be replaced it is not possible to restore the input impedance of the bridge to its previous value, and at the same time to retain the same value of the critical voltage (at which the bridge balances), without making an adjustment to both the fixed linear resistors in the bridge.

For the purpose of the invention it is desirable to restore the bridge always to the same value of input impedance when a lamp is replaced. Assuming that fixed resistances 10 and 11 are equal then it can be shown that when the bridge is balanced its input resistance is equal to the magnitude of either resistance 10 or 11 if the product of the resistances 12 and 13 is equal to the square of either the resistance 10 or 11. Thus the input impedance may be restored to its original level by adjustment of variable resistance 12. It follows that when the bridge is balanced its input impedance is exactly known, being equal to resistance 10 or 11.

It will be noticed that the power-loss in the bridge as described can be relatively large. Thermisters could be substituted to reduce this, but several practical merits of the lamp type of network would then be lost; it is very cheap, has a long time constant (1—3 seconds), a high "overload capacity" since a lamp rated at 6V can be run at about 0.6V and, having a positive temperature coefficient, it tends to protect itself from overload.

The lamp characteristic is shown in Figure 4 in which the ordinate represents the current i and the abscissa the voltage e. The characteristic represented by the solid line 50 has a straight part of slope equal to $\frac{1}{r}$ and this straight part, if extended backwards, cuts the abscissa at $-V$ volts. The straight part begins at e_0 volts. If the impedance of the bridge at balance is R and if the total r.m.s. input is E volts, then it can be shown that:—

$$F = \frac{V}{E} \cdot \frac{R}{r+R}$$

or

$$F = \frac{1 - \frac{e}{E}}{1 + \frac{E}{V}}$$

where F is a Merit Factor, being the ratio:

$$\frac{\text{percentage change in bridge ratio}}{\text{percentage change in alternating r.m.s. input}}$$

It is at once obvious that E should be a minimum for several reasons: If the watts lost are written as E^2/R it is found that F varies as $1/E^3$ at constant loss, and in fact there is no advantage in raising the voltage on the lamps above e_0 (about 1.0 Volts for the lamps of this example) unless E has to be increased because $nE_1 = E_2$ is too small to give a useful value of i_M where i_M is the unbalance current and the suffixes 1 and 2 are used for alternating and direct components respectively.

The lamps used in the examples quoted just begin to glow when $e = e_0 = 1$ volt. The temperature is therefore about 400 Degs. C or so above ambient. Since the filament temperature is largely controlled by radiation adjacent sources of heat only slightly higher than ambient will have little influence upon the lamp characteristics. However, even if shielded from direct illumination, there is a small effect produced by local temperature changes. In a lamp bridge required for the highest precision measurements this can be compensated in various ways.

A negative-coefficient non-linear element in the adjustable arm can be arranged to be influenced by the local temperature but, though carrying current, be substantially uninfluenced by the current changes, e.g. a carbon filament lamp of high current rating. By series and shunt connections of linear resistors the compensating element may be given the right coefficient of resistance due to temperature changes.

Such an arrangement is preferred to one in which a positive coefficient element is connected in series with one of the fixed arms. Although temperature compensation will be obtained the input impedance of the bridge (when balanced) will no longer be a constant.

Alternatively a thermo-junction may be connected in series with the meter so that the E.M.F. it generates opposes the E.M.F. caused by ambient temperature changes in the lamps. This has the same objections as the former method, and cannot be used where the maintenance of the input impedance at a strictly constant value is of primary importance.

Unless specially designed lamps are used which reach the "e_0" point on their characteristics at a very low voltage it is unlikely that "E" in the above equations will fall below 2.0V or so (although this is always possible by sacrificing the Merit Factor "F"). In practical cases where cheap commercially available lamps are employed, E will be of the order of 3—4V and the watts loss of the order of 30—60 mwatts. Except for the measurement of relatively large powers or currents the bridge needs therefore to be preceded by an amplifier, as shown in Figure 3.

It is of great importance to notice that an amplifier-bridge combination of this type will register the true r.m.s. value of the input signal. Moreover the time period over which the r.m.s. value is estimated can be made of the order of a second or so.

If it is desired to increase the time period beyond the value obtainable with, for instance, two lamps in series, eight lamps connected, for instance, in two parallel paths of 4 each, can be substituted. The current carried by each lamp is now reduced and the rate at which the resistance rises to its final stable value will be decreased.

Assume that a bridge has been designed to balance at 4 volts r.m.s. precisely, then, when the bridge-amplifier combination is used as a voltmeter the ratio of output to input voltage of the combination will have to be as follows:—

input	Gain Ratio
1 mV	4000
2	2000
3	1333.3
etc	etc
etc	etc
1 Volt	4.0
100 Volts	0.04

It will be seen that the gain must vary as the inverse of the input voltage. In practice the instrument may be provided with two sets of controls; one which acts as a "multiplier" of 1, 10, 100 etc or "divider" 1/10, 1/100 etc, and one which reads from 1 to 10, being capable of providing any factor in this range to several decimal points.

There are two different ways of setting up the absolute calibration of the instrument. The first is the obvious one of applying an exactly known input. The second way is to set up an exactly known direct voltage by comparison with a standard cell, apply this voltage to the bridge and adjust resistance 12 for balance. A lower direct voltage (which may be derived from the same source) is then applied, such that a convenient value of alternating voltage will produce balance of the bridge. An alternating voltage from a convenient source is then applied and adjusted until the bridge is balanced.

The voltage divider 32 and attenuator 34 are adjusted until the total attenuation equals the desired total gain of the two amplifiers. The preset alternating voltage is now applied to terminals 30 and 31 and the gain of one or both of the amplifiers is adjusted until the bridge is again balance. The overall gain of the two amplifiers is then accurately known, being equal to the total attenuation.

Provision for adjusting the amplifier gain may conveniently consist of small trimmer resistances in the feedback path of one or both of the amplifiers to vary the negative feedback and hence the overall gain.

The standard cell is conveniently embodied in the instrument.

It is to be observed that, should one of the lamps in the bridge have to be replaced, the amplifier will be restored to exactly the same accuracy as before by this procedure, for the load presented to the second amplifier, will, after the lamp bridge has been balanced by readjusting the resistance 12, be exactly the value of the fixed resistors 10, 11. The only change which will occur is that the merit factor of the bridge may change very slightly if the new lamp has unusual characteristics. Since the bridge is always used as a "null" device this is of no importance.

Since the time constant of the lamps in the bridge is a second or so, low-frequency surges of mains voltage may be registered as error signals. The H.T. supply for the amplifiers will therefore include a stabiliser which is effective at these frequencies.

What we claim is:—

1. A thermionic voltmeter for determining the values of alternating voltages comprising a voltage divider, an amplifier, an attenuator and a second amplifier connected in cascade, and a bridge connected to the output of the second amplifier, the bridge consisting of a four-element resistive network with four terminals, at least one of the elements being a non-linear resistor, the alternating voltage output of the second amplifier being applied to one pair of diagonally opposite terminals of the bridge, means for applying a direct voltage of adjustable magnitude to the said pair of diagonally opposite terminals of the bridge and a direct voltage null indicator connected to the other pair of diagonally opposite terminals of the bridge for indicating by a null reading when the alternating voltage output of the second amplifier is at a predetermined value, the value of the unknown voltage being determined from the scale readings of the voltage divider and the attenuator when adjusted to give a null reading on the direct voltage null indicator.

2. A thermionic voltmeter, as claimed in Claim 1, in which the bridge is connected in the cathode circuit of the output valve of the second amplifier whereby the direct voltage for the bridge is derived from the high tension supply of the said output valve.

3. A thermionic voltmeter, as claimed in Claim 2, in which a variable resistance and a direct current meter are connected in series between the cathode of the output valve and the bridge for the purpose of adjusting and measuring the direct current, the variable resistance and the meter being shunted by a capacitor to provide a parallel low impedance path for the alternating current.

4. A thermionic voltmeter, as claimed in any preceding claim, in which an adjustable resistance is included in the negative feedback path of at least one of the amplifiers whereby the total gain of the amplifiers may be adjusted to a desired value.

5. A thermionic voltmeter, as claimed in any preceding claims, in which one element of the bridge is a non-linear resistor and the other three elements are linear resistors.

6. A thermionic voltmeter, as claimed in Claim 5, in which at least one of the linear resistors is adjustable.

7. A thermionic voltmeter, as claimed in Claim 6, in which the bridge comprises one non-linear resistor and one adjustable linear

resistor together with two fixed resistors of equal magnitude, the four elements being arranged in the bridge network with the fixed resistors in non-adjacent arms of the bridge.

8. A thermionic voltmeter, as claimed in any preceding claim, in which two non-adjacent arms of the bridge contain non-linear resistors having temperature coefficients of resistance which are both positive or both negative.

9. A thermionic voltmeter, as claimed in any preceding claim, in which two adjacent arms of the bridge contain non-linear resistors respectively having positive and negative temperature coefficients of resistance.

10. A thermionic voltmeter, as claimed in any of Claims 1 to 8, in which each non-linear resistor consists of one of more electric lamps.

11. A thermionic voltmeter, as claimed in Claim 10, wherein each lamp is a metal filament lamp.

12. A thermionic voltmeter, as claimed in any preceding claim, wherein means responsive to the ambient temperature are incorporated in the bridge circuit for compensating any alteration in the resistance of the non-linear resistor or resistors due to changes in the ambient temperature.

13. A thermionic voltmeter, as claimed in Claim 12, in which the means responsive to the ambient temperature comprise a thermo-junction connected in series with the direct voltage indicator.

14. A thermionic voltmeter, as claimed in Claim 12, in which one arm of the bridge contains a metal filament lamp forming the non-linear resistor and the means responsive to ambient temperature changes comprise a carbon filament lamp of high current rating in the non-adjacent arm.

15. A thermionic voltmeter for indicating the value of alternating voltages substantially as described with reference to the accompanying drawings.

MARKS & CLERK.

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783,967 COMPLETE SPECIFICATION
1 SHEET
This drawing is a reproduction of the Original on a reduced scale.

Fig.1.

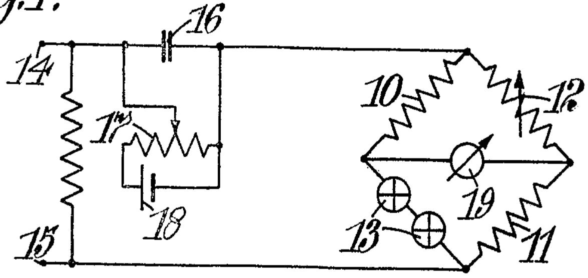

Fig.2.

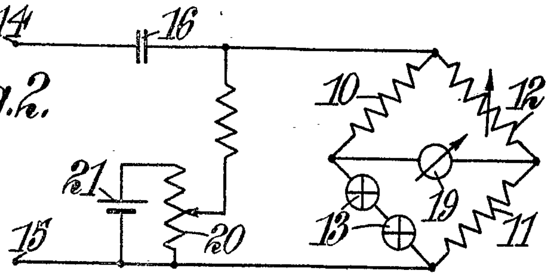

Fig.3.

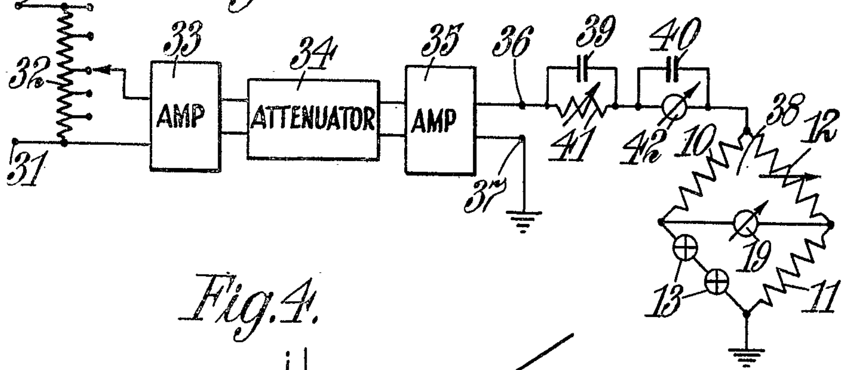

Fig.4.