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COMPLETE SPECIFICATION

Improvements in and relating to Voltage or Current Dividing Networks

I, Edmund Ramsay Wigan, of "Kerry," Barnham, in the County of Sussex, a British Subject, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electric impedance networks, which can be used as potential or current dividers to give known fractions of a given voltage or current. The invention can be used for direct currents; for convenience the invention will be described in relation to networks which are suited to direct current use, and employing resistive elements, but it is to be understood that such elements can be replaced with purely reactive elements, provided they are all of the same kind, in which case the invention can be applied to alternating current networks. Accordingly the use of the word resistance herein is to be considered as including, as the context permits, the corresponding reactive elements or quantities.

One object of the present invention is to provide a network of this class the output resistance of which is not affected by changes in the voltage or current dividing-ratio.

While the invention can be applied equally to both voltage and current-dividing networks, it is convenient to describe the invention in relation to voltage-dividing networks. Moreover, as will appear hereinafter, the current-dividing properties of the networks can be directly derived from the voltage formulae.

The invention consists broadly of a resistive network for establishing selectively a plurality of pre-determined ratios between the voltage or current at the input and output terminals of the network, whilst presenting a constant resistance or reactance as seen from the terminals at one end of the network with a short circuit across the terminals at the other end of the network, said network including series and shunt branches, or arms, and switching means for effectively transferring a conductance from a series to a shunt branch for varying said ratio.

Other features and advantages of the invention will appear from the following description of various embodiments of the invention, given by way of example, in conjunction with the drawings accompanying the provisional specification of application 18022/59, in which:

Figure 1 is a generalised form of a potential divider network in accordance with the invention;

Figures 2 to 5 are circuit diagrams of component parts of networks;

Figure 6 is a circuit diagram of the network with zero resistance load;

Figure 7 is a diagram of an arrangement for current measurements;

Figures 8 to 11 are fragmentary circuit diagrams of modifications of the arrangement of Figure 7, and

Figure 12 is a diagram of a switching arrangement, suitable for the main network; and in conjunction with the accompanying drawings, in which:

Figure 13 is a circuit diagram of a complete potential divider network.

Before proceeding with the description of these embodiments, the meaning of the expression "output resistance" as used in this specification will be made clear.

The output resistance is that resistance which would be measured at the output terminals of the network if the input terminals were short-circuited and any load-resistance removed, and is represented by R^1. The invention is concerned with networks in which the same value of R^1 appears despite changes of the output/input voltage or current-ratio of the network.

Hence the output voltage will always be related to the input voltage by this ratio; and this condition will be true for any constant load resistance, which can be identified as the load resistance, connected to the output terminals. In the special case where the load resistance is zero there will be no voltage, but there will be a load current which in this special case will be related to the input voltage by the dividing ratio of the network.

The object of the invention is achieved by the use of two variable resistive elements, serially connected, which can be identified as R_a and R_b, of resistance *a* and *b* respectively. The output voltage may be taken either from the terminals of R_a or of R_b; only the second case will be considered here: if the ratio of output to input voltage is N, where there is no load applied to the network, then

$$N=b/(a+b) \qquad (1)$$

and the output impedance will be R^1 where

$$1/R^1=1/a+1/b \qquad (2)$$

With the invention, the desired output ratio N is obtained by variation of the effective value of both *a* and *b*, so as to change N but leave R^1 unchanged.

From equation (2) it can be seen that the desired effect can be achieved by varying the value of R_a and R_b when a change of N is made by transferring conductance from one to the other. For example to provide ten steps of N each equal to 0.1, ten equal resistances each of $10R^1$ in value are used and a ten-position switch is arranged to include a number of these resistances in parallel, to provide R_a, and the remainder in parallel, to present R_b. The value of N will then be equal to the number of resistances in R_a, multiplied by 0.1. To vary N in ten steps of 0.01, resistances of $100R^1$ are required, and so on.

Decade or similar stages can be provided by using a switch for each stage, each switch giving successively smaller steps of N and the effective value of N being equal to the sum of the switch settings. For example two sets of switches can give steps of 0.1 and 0.01, two of the circuits described above being connected with their R_a and R_b branches respectively in parallel. In this case there will be, however, nine steps only in each successive stage, except the last, so that the total conductance shall be $1/R^1$.

A suitable switching arrangement for the purpose of the invention is shown in Figure 12. The network comprises input terminals 1, 2 and output terminals 3, 4, between which series of resistances r_1, r_2 etcetera are connected as described above. One end of each resistance is connected to terminals 3; the other ends of the resistances are connected to contacts F_1, F_2 etcetera engaging contact rings Z_1, Z_2, which are insulated from each other and move together when the switch control is operated. It will be seen that in the successive switch positions one of the resistance r_1 etcetera is moved from a series to a shunt position.

It is very desirable that a short circuit of terminals 1 and 2, or 3 and 4, or an open circuit between terminals 1 and 3 should be avoided if possible while the transfer of resistances is being made, and this is achieved with the switch described.

The switching arrangement shown in Figure 12 can be used with each of the decades of a decade potential divider. The switch is shown as set for the maximum value of N=0.9 if it is the *first* decade, the other decades producing the remaining 0.1 fraction. The switch is turned in the direction of the arrow to reduce N. Provision is made to keep contact Z_1 permanently connected to terminal 1, and contact Z_2 to terminal 2 and 4. The conductance measured at terminal 3—4, with 1 and 2 short circuited is constant; when all switches are connected similarly in parallel this conductance is equal to $1/R^1$. The conductance provided by this particular switch is equal to the sum of the conductances of all the resistances r_1, r_2, and so on, for as soon as the dial is turned one step to the right r_1 is disconnected from the series arm and transferred to the shunt arm, until all are eventually transferred to the shunt arm. Terminal 1 is then isolated, and terminals 3 and 4 carry the full conductance. This gives the required conductance transfer as explained above. Now if a suitable gap is left between the end of contact Z_2 and that of contact Z_1, a contact such as F_1 will for a moment be out of contact with either ring, and the output voltage will fall slightly because the conductance between 1 and 2 has fallen; a moment later the output voltage will fall further, and to its correct value, as F_1 contacts Z_2 when the step is completed. A dummy, isolated contact piece Z_3 can be provided upon which the contacts F_1, F_2 etcetera rest while in transit; it is of no importance that there will be temporary contact between Z_1 and Z_3 or between Z_2 and Z_3 as the switch moves from one position to the next, as Z_3 is isolated.

With such an arrangement, though the output resistance R^1 as defined remains constant, the input resistance presented by the network to the signal source, which can be called R_1, will vary when N varies. Since in the majority of practical cases the signal source will have a finite internal resistance, which can be called *r*, any change of N (and therefore of R_1) will cause a change of voltage at the input of the network; the presence of the resistance *r* cannot modify the *ratio* between the output and input voltages of the network per se, but it *can* affect their magnitudes. In some circumstances this may be undesirable; the effect is overcome in an embodiment of the invention to be described, by the inclusion of correcting resistances in the input of the network.

The general case of a network in accordance with the invention is shown in Figure 1. The input terminals 1, 2 are connected to the series-connected elements P, Q; the output voltage is derived from the terminals 3, 4 of element Q. Terminals 1, 2 are shunted by an input resistance correcting network R_s. The network is described as having an input resistance R_1 when R_s is infinity, and an input resistance R_2 when R_s is finite; the input voltage is E_i; terminals 3, 4 are shunted by the load impedance. The output voltage (measured across the load-resistance) is E_2, and the output resistance, as defined, is R^1. For the case where the load resistance is infinite $E_2 = E_2{}^1$ and $E_2{}^1/E_1$ is equal to N. The effective voltage ratio when the network is loaded will be E_2/E_1 and will always be less than N. If the load is equal to R^1, then $E_2/E_1 = N/2$.

In designing the shunt element R_s to give the desired constant input resistance, the case mentioned above will first be taken, where the load impedance is equal to R^1. The impedance R_1 shown in Figure 1 will then be given by

$$R_1 = R^1/(N—N^2/2) \qquad (3)$$

and its conductance

$$1/R_1 = (N—N^2/2)/R^1 \qquad (4)$$

If then it is required to make the input resistance R_2 constant for all values of N, and equal to R^1, it is necessary that the total conductance of R_1 and R_s shall be $1/R^1$;

i.e. that $R^1/R_s{}^1 = 1 - N + N^1/2$ (5)

In what follows the ideal value of R_s that satisfies equation 5 is written with a prime (^{1}) as above. It is the object of this part of the design to set out the arrangement and choice of values of the resistances which have to be switched into the R_s-branch of the network, by extra switch-contacts carried on the controlling means by which the dividing ratio is varied, so as to obtain a value of R_s which, for all possible settings of the dividing ratio N, agrees with equation 5 to the closest possible approximation.

Equations similar to equation 4, which applies only when the load is equal to R^1, can be set up for any other load conditions. Also, in the case to be examined the constant input resistance R_2 aimed at is arbitrarily set also at R^1 but this can be modified and a new form of equation 5 applied, subject however, to the limitation that the value of R_2 can never be greater than the " design-resistance " if it is required to keep R_2 constant for all values of N. The choice of R^1 both as the load and also as the input resistance in the circuits to be discussed has the advantage that the divider can then be connected into a transmission-line of characteristic resistance R^1 without introducing disturbances due to mismatch.

It is convenient to normalise all equations so that $R^1 = 1.0$; if R^1 is 1000 ohms conductances will then be in millimhos.

One form which the shunt impedance R_s can take consists of serially connected resistances to a total value of $R^1(1+N)$. For this case

$$1/R_s = 1/(1+N) \qquad (6)$$

Since N is less than 1, this can be expanded: —

$$1/R_s = (1 - N + N^2 - N^3 \text{ and...ad inf...}) \qquad (7)$$

This is a poor approximation to the ideal of equation 5, normalised:

$$1/R_s = (1 - N + N^2/2) \qquad (8)$$

except when N is zero or unity. At other values the departure of the input impedance from the ideal value may be as much as 5%.

As an example of an arrangement by which the ideal value of R_s can be more closely approximated the case will be taken of a three decade arangement, using three switches giving respectively steps of multiples of 0.1, 0.01 and 0.001. The two first switches, as mentioned above, have ten positions (an extra position being included for zero) and the third eleven.

These switches can be identified respectively as the Na, Nb, and Nc switches; the value N will be equal to the total setting (Na + Nb + Nc) of the switches.

An improved form of the shunt-element R_s can be made if the Na switch carries two extra contacts which are arranged to select, for each position of the switch, two resistances A and B connected as shown in Figure 2, and the Nb- and Nc-switches carry one contact each which together vary the resistance C. In one arrangement C varies from zero to a value $\hat{C}$ of 130 ohms, linearly in relation to variations of the Nb- and Nc-switch settings; then, writing for convenience B//C to represent the resistance of B when shunted by C, and putting C'_{eff} as equal to B//C, when the Nb- and Nc-switches are at maximum (Nb + Nc)=0.1; and $\hat{C}_{eff} = B//$ 130 ohms. It will be seen that when Nb and Nc are set at zero $R_s = A$.

If the divider has been set so that N = 0.1; this might have been achieved by Na=0.1, or by (Nb + Nc) = 0.1; the choice of elements A and B is decided by this fact.

First A is fixed by the value of Na: —

$$1/A = 1 - Na + Na^2/2; \qquad (9)$$

then B is chosen so that B//130 ohms, $(=\hat{C}_{eff})$ is such that:

$$1/(A + \hat{C}_{eff}) = 1 - (Na + 0.1) + (Na + 0.1)^2/2. \qquad (10)$$

In this case the value of $\hat{C}$ has been chosen so that B becomes infinite when Na=0.4; this is not essential, but $\hat{C}$ cannot be made less than 130 ohms to fulfil the given conditions. The values of A and B calculated as above will hold R_2 to within about 0.4% of the ideal value for all values of N.

For convenience, equation (7) above can be rewritten, putting $M=(1-N)$:

$$1/R_s{}^1=(1+M^2)/2 \qquad (11)$$

Figure 3 shows another network element that can be used, consisting of resistance A, with resistances B and C in parallel.

The elements A and B are selected by contacts on the Na-switch, and element C is varied by the Nb and Nc-switches. It is possible to choose different designs, depending upon the resistance chosen for element C. A convenient value is 200 ohms, each Nb step contributing 20 ohms and each Nc step 2 ohms. Higher values of resistance can be used if desired, but a minimum seems to exist at about 105 ohms. Design proceeds from the fact that change of conductance of the shunt element R_s due to the operation of the Nb and Nc-switches, once Na is chosen, depends only upon the branch B—C. The value of B has to be such that the introduction of 200 ohms at C in the example taken, i.e. the increase of N by 0.1, shall change the conductance of $(B+\hat{C})$ by the amount appropriate to the setting of Na.

From equation (11), this means that the change shall be from $(1+M_a{}^2)/2$, when C is zero, to $(1+(M_a+0.1)^2)/2$ when C is equal to $\hat{C}$.

Writing this change of conductance as $\Delta\, 1/R_s$:

$$1/A-1/(B+\hat{C})=\Delta\, 1/R_s \qquad (12)$$

Since $\hat{C}$ is fixed at 200 ohms, the value of B can be ascertained. Further, since

$$1/A+1/B=(1+M_a{}^2)/2 \qquad (13)$$

A can be derived.

This design of shunt element can be made precisely correct when N has any value which is a multiple of 0.1, whether switch Na or switches Nb and Nc together are used. It is possible to make R_s precisely correct whenever Na has one specific value, preferably 0.0, and Nb has any setting from 0.00 to 0.09 but Nc must be zero. The reason for the last limitation is that the increments of resistance required of the Nc-switch are not the same as between Nb=0.00 to 0.01 and Nb=0.08 and 0.09, and so on; it follows that one specific set of ten resistances will not serve for the Nc-switch without introducing errors at some settings of the Nb-switch. The errors introduced by the Nc-switch when acting alone may reach 0.1%; there is an additional error which passes through a maximum when the Nb-setting reaches 0.05, its amount depends upon Na and is zero by design when Na-0.0 and about 0.15% at Na=0.9.

As there are applications where precision of this order are adequate, the values of resistance required are set out below. Table I gives the values of C, and a few typical values of A and B are given in Table II. In Table I figures are given for C to sufficient accuracy to permit the error to be seen. The figures are normalised, so that for $R_s=1000$, a value of C of 0.2 represents a resistance value of 200 ohms.

TABLE I

Na	Nb	Nc	C (normalised resistance)
0.0	0.01	0.0	0.018,501,46
0.0	0.02	0.0	0.037,321,69
0.0	0.03	0.0	0.056,465,99
0.0	0.04	0.0	0.075,939,72
0.0	0.05	0.0	0.095,748,23
0.0	0.06	0.0	0.115,896,89
0.0	0.07	0.0	0.136,391,06
0.0	0.08	0.0	0.157,236,10
0.0	0.09	0.0	0.178,437,35
0.0	0.09	0.01	0.200,000,00 (increment due to Nc-switch at maximum)

In Table II, the figures are given to a less accuracy than in Table I and indicate an order of magnitude only.

TABLE II

Na	$1/R_S{}^1$	$\Delta 1/R_S{}^1$	1/B	1/A	
0.00	1.00	0.095	0.73835	0.26165	
0.10	0.905	0.085	0.69578	0.20921	
0.20	0.820	0.075	0.65105	0.16895	Units are
0.30	0.745	0.065	0.60350	0.14150	millimhos.
..	..	..	..	..	..
0.70	0.545	0.025	0.36628	0.17872	
0.80	0.520	0.015	0.28148	0.23852	
0.90	0.505	0.005	0.16065	0.34435	

To improve further the precision of the shunt structure R_s the element S can be added as in Figure 4. In the example now to be calculated $S=\infty$ when Na=0.0, so that A, B, and C in Figure 4 are identical with the values calculated above and given above but only for the case of Na=0.0; for all other values of Na the A and B values will be different; the C value remains unchanged.

The object of this shunt structure is to reduce to zero all errors in $1/R_s$ whenever N is a multiple of 0.05, at which value of N the Figure 3 shunt has a maximum error. The resistance of C shown in Table I against Nb=0.05, will be called C_5 ($C_5 =$ 0.09574823 . .), and the change in $1/R_s{}^1$ when Nb changes from 0.00 to 0.05 will be called ${}_0\Delta_5 1/R_s$; similarly, the change Nb of from 0.00 to 0.01 will be called ${}_0\Delta_{10} 1/R_s{}^1$. Both quantities are directly calculable from equation

(11) by differences; their magnitude will depend upon the setting of the Na-switch. Since changes of $1/R_s$ appear directly as any change of conductance of the branch B—S—C:—

$$B^2/C_5 + B^2/S + B = 1/{}_0\Delta_5 1/R_s^1 \quad (14)$$

and $$B^2/\hat{C} + B^2/S + B = 1/{}_0\Delta_{10} 1/R_s^1 \quad (15)$$

which by subtraction gives B in terms of $\hat{C}$ and C_5, and then S in terms of B. As an approximate example, Table III gives value for $S = \infty$, when Na=0, and C is 200 ohms. In each case the value of 1/A is found by subtracting 1/B from $1/R_s^1$.

TABLE III

Na	1/A	B	S
0.0	0.26166	1.3544	∞
0.1	0.20808	1.4349	14.332
0.2	0.15935	1.5137	6.295
0.3	0.12680	1.6176	3.825
....	....	....	....
0.7	0.13714	2.4518	0.8026
0.8	0.18188	2.9575	0.4379

If Table III is calculated to a greater degree of accuracy, it can be shown that the errors of the shunt do not exceed 2 parts in 10^5, but error of up to .1% can occur when the Nc switch is operated.

Figure 5 shows an arrangement by which this error can be largely removed, though small errors of the order of 1 part in 10^5 can occur when Nc=0.005. In Figure 5, element C is supplemented by elements F and D.

In this arrangement, the element C has the values given in Table I, the element D representing the resistance provided by the Nc-switch. The shunt F is selected by the Nb-switch and adjusts the contribution made by the Nc-resistance D so that when Nc is at its maximum value of 0.01,

$$F /\!/ \hat{D} = 21.57 \text{ ohms when } Nb = 0.09$$
$$21.20 \text{ ohms when } Nb = 0.08$$

down to

$$18.50 \text{ ohms when } Nb = 0.00$$

It is convenient to make F and $\check{D}$ of the same order of resistance and, in the example given, about 40 ohms.

Figure 13 of the accompanying drawings gives an example of a practical potential divider network with three stages, each giving ten positions, the first of step of 0.1, the second 0.01 and the third 0.001. The networks present an input impedance of 1000 ohms an output impedance of 1000 ohms, and is intended to operate into a load of 1000 ohms. That part of the network which lies within the broken line is concerned principally with change of the ratio N, whilst the parts outside the line are for ensuring that R_s, the shunt impedance, is adjusted to give the desired constant input impedance.

The switch section Na includes an eleven position switch with 6 sections S1A to S1F. Similarly; section Nb includes an eleven position switch with 5 sections S2A to S2E, and the section Nc includes 5 sections S3A to S3E; the switches are ganged, as indicated by the dotted line.

A bank of resistors R_1 to R_{29} are associated with switch S1; for clarity the actual connections are omitted, the connecting points being indicated by symbols. Thus, the function of resistors R_1 and R_2 is shown as being connected to point S1E/10, meaning the tenth contact of switch section S1E.

Resistors R_{30} to R_{33}, R_{43} to R_{46} and R_{56} to R_{55}, are associated with the switch sections for varying the ratio N; resistors R_{34} to R_{42} and R_{47} to R_{61} form part of the variable shunt R_s. The values of the individual resistors are as marked in the Figure, though the values of R_1 to R_{29} are marked to a greater accuracy than would normally be used.

The potential (or current) dividers described can be used for calibrating voltage or current meters, and for the measurement of externally applied voltage or current.

The networks already described can operate into any value of load resistance without compromising the dividing ratio $N = E_2/E_1$; the magnitude of the load determines the load current for a given E_1. If the special shunt element R_s is used there is the additional advantage that the input resistance R_2 remains constant for all values of N provided that the load resistance and the shunt R_s are selected appropriately. It is to be noticed that since all the calculations made above have been normalised the design data serve equally well for any value of R^1. For the applications now to be considered there is an advantage in choosing a round number of ohms for R^1 and for making the load equal to R^1, but this is not essential.

There is one special case in which the load resistance is zero and this has application to the circuits now to be mentioned. Figure 6 shows a dividing network which has a series branch P which is identical with P in Figure 1 and has a resistance R^1/N, and two shunt branches Q identical with Q in Figure 1, and each equal to $R^1/(1—N)$. It is easily shown that the input impedance R_2 is equal to R^1 and so also the output impedance. The load current is therefore $N . E_1/R^1$. At first sight it would seem impossible to make use of the output current in Figure 6 for any useful purpose since it appears in a circuit of zero impedance, also it would seem that the right-hand shunt element Q is superfluous being short circuited. In practice neither statement is true if power is supplied to both ends of the divider. The technique adopted here has been described elsewhere, for example by the applicant in an article in " Wireless Engineer " 1952 at page 195. Such an arrangement is shown in Figure 7. The divider network is indicated at 7*a* with input and output currents I_1 and I_2. The output current is withdrawn from output terminals 3, 4 by means of a source E_x of opposite polarity and adjustable resistance R_x, shown in Figure 7*b*. When E_x and R_x are appropriately chosen, the potential difference across terminals 3, 4 can be reduced to zero, so that the divider has effectively zero load, whilst the output, short-circuit, current I_2 becomes available in the external circuit.

The simple network R_x, E_x of Figure 7*b* can be replaced by the corresponding arrangements of Figures 7*c* or 7*d*. Figure 7*c* shows a valve T_1, arranged as a cathode follower, to which is applied an unknown AC or DC signal *x*. The output voltage appearing across the cathode load resistance R_k, in series with a source of voltage E_c, is applied to terminals 3, 4.

Figure 7*d* shows a simple half wave rectifier circuit including rectifier W, with a load circuit including resistance R_{10} and by-pass capacitor C_{10}. An unknown voltage *x* is applied to the rectifier input; the rectified output is applied to terminals 3, 4. The circuit of Figure 7*b* is useful when voltmeters or ammeters are being calibrated.

The generalised form of the output circuit associated with terminals 3, 4 is shown in Figure 8. To the terminals 3, 4 is connected a resistance R_4, which is the load resistance of the network, in series with a sensitive current indicator G_2; the sensitivity of indicator G_2 can be varied by shunt R_5. For the case in which the divider has the form of Figure 6, where the load resistance is zero, R_4 can be ignored.

One of the external circuits shown in Figures 7*b*, 7*c* or 7*d*, or an equivalent circuit, is connected to terminals 5, 6; a meter M_1 is provided for measuring the current I_3.

With suitable adjustment of the external circuit connected to terminals 5, 6; the current in G_2 can be brought to zero, current I_3 is then equal to I_2, that is, to the current that the network would supply to a load equal to R_4. Current I_3 can be measured on the instrument M_1, which can then be calibrated in terms of E_1, N, R^1 and R_4. If E_1 is made 1 volt, R_4 is zero and R^1 is 1000 ohms, I_3 can be read in milliamperes from the N-switch settings Na, Nb and Nc. Similarly, if R_4 and R^1 are both 1000 ohms, I_3 will be equal to N/2 milliamperes.

For this operation, E_1 has to be standardised in some way before calibration can be effected, for example by potentiometric comparison with a standard cell. A somewhat simpler arrangement for this purpose is shown in Figure 9, where the input terminals 1, 2 of the network are shunted by the standard cell C_1 in series with a current indicator G_1. If the potential divider S_1 is set so that the indicator indicates zero, then E_1 will be equal to the e.m.f. of the standard cell.

The voltage of the standard cell, 1.0185, is inconvenient in use, and to avoid the need to use this figure, the circuit of Figure 10 can be used, connected to terminals 5, 6 as indicated. A series resistance R_6 and shunt resistance R_7 are used, and a meter M_3 is connected in the connection to the " power sink " element of Figures 7*b*, 7*c* or 7*d*. If conditions are established so that the indication given by G_2 is zero, then the potential differences across R_6 and R_7 must be equal. The current in R_6 is I_3; that in R_7 is I_7, so that

$$R_6/R_7 = I_3/I_7 \qquad (16)$$

and the meter current I_4 is given by

$$I_4/I_3 = (R_7 + R_6)/R_7 \qquad (17)$$

The circuit of Figure 10 can be replaced by the arrangement of Figure 11, where resistance R_6 is replaced by the fixed resistance R_5 and part R_{10} of resistance having a slider S_2 on it. By this means the slider S_2 can be used to adjust the ratio R_6/R_7. Resistance R_7 is replaced by R_9 and that part R_{11} the resistance below slider S_2. This circuit provides the constant resistance $(R_7 + R_6)$ called for in equation (17), the slider S_2 permitting variation of the ratio R_6/R_7 by altering both R_6 and R_7. The ratio I_4/I_3 will be directly controlled by S_2, which can have an associated scale marked in accordance with the variation of e.m.f. with temperature of the cell C_1. By making R_6 much larger than R_7, readings in units of current 10,000 or more times I_3 can be made.

The potential difference across the resistance R_7, once the conditions have been established to bring the current through the indicator G_2 to zero, is independent of the value of R_7, so that if a voltmeter M_2, of unspecified resistance is used in place of R_7 the potential difference due to the current I_3 through resistance R_6 can be ascertained.

It will be apparent that there is a practical advantage in designing the divider-network to have an input impedance which is constant irrespective of the setting of N, for if it varied as N is varied it would be necessary to observe continuously not only the indicator G_2 but also the indicator G_1, Figure 9, for both must read zero simultaneously before a measurement can be made. With resistance R_2 held constant, by using either the network of Figure 6 with resistance R_4 set to zero, or by the network of Figure 1 with the load set to R^1 the voltage E_1 can be stabilised at the outset of a measurement by bringing G_1 to zero, and thereafter no changes of N will disturb this null setting; attention can therefore be concentrated upon indicator G_2.

The use of a 3-decade network for calibration implies that the current or voltage will be expressible by a simple decimal running to not more than three figures. The divider of Figure 1 will provide such a calibration since it has three decimal dials; however, if an externally supplied current is merely to be measured in terms of N, it will nearly always happen that the indicator G_2 cannot be brought to zero. The shunt R_5 is then adjusted so that, when the last dial of the divider is advanced one step the meter pointer moves over, say, ten divisions. Although a rough estimate of the true "null" point can be made from the indications of G_2, the estimate cannot be accurate unless the output resistance of the divider is independent of N, a fact which can most easily be checked when N is small. This is one reason why the divider network of Figure 6 is provided with shunt elements Q at both input and output, even though the load resistance is zero.

There is a second reason for making input and output resistance constant; the procedure of adjusting the shunt R_5 can then be made once and for all. If the output resistances were not constant, resistance R_5 would have to be readjusted every time a new null-balance was attempted, since the steps of the final decade-switch would lead to different current increments in indicator G_2 depending upon the output resistance, that is to say, upon the setting of N and therefore upon the magnitude of the unknown voltage or current. For various reasons it is desirable to make the resistance of indicator G_2 as small as possible.

If the divider is designed to operate into a load resistance R_4 which is finite, it can be arranged that the current which flows in resistance R_4, Figure 8, is less than the current output from terminals 3—4 of the divider. For instance, it may be convenient to reduce it in the ratio 1/10 or in some small ratio such as 1/1.0185. This can be achieved by connecting a combination of shunt and series elements between resistance R_4 and the output terminals 3, 4 for instance in the form of a star-or delta-network, symmetrical or otherwise, the elements being so chosen that when R_4 is connected across the terminals of the said network remote from terminals 3—4, the resistance presented to these terminals is equal to R^1, the design-resistance of the divider. In these circumstances resistance R_4 can be unequal to R^1.

WHAT I CLAIM IS:—

1. A resistive network for establishing selectively a plurality of predetermined ratios between the voltage or current at the input and output terminals of the network, whilst presenting a constant resistance, or reactance, as seen from the terminals at one end of the network with a short circuit across the terminals at the other end of the network, said network including series and shunt branches, and switching means for effectively transferring a conductance from a series to a shunt branch, for varying said ratio.

2. A resistive network for establishing selectively a plurality of predetermined ratios, between the voltage or current of the input and output terminals of the network, whilst presenting a constant resistance of reactance, as seen from the output terminals with no load across said output terminals and with a short circuit across said input terminals, when different ratios are established, the network including first switching means for effectively transferring conductances each from a series to a shunt branch, for varying said ratio.

3. A network in accordance with claim 2, and comprising second switching means for maintaining a constant input impedance of the network at different ratios, when a suitable load-resistance is connected to the network.

4. A network in accordance with claim 3, wherein said further switching means is coupled to the first switch means.

5. A network in accordance with any preceding claim, wherein said switching means is or are adapted to vary said ratios in steps affording equal increments of ratios.

6. A network in accordance with claim 5, wherein said switching means is or are arranged to vary said ratios in greater and lesser steps.

7. A network in accordance with claim 5, wherein the lesser steps are decimally related to the greater.

8. A network in accordance with any preceding claim, wherein said network includes at least as many equal resistances as there are possible selectable ratios, said switching means

being effective to connect said resistances in parallel in a first, series arm, group and the remainder in parallel in a second, shunt arm, group, and to transfer resistances from one group to the other.

9. A network in accordance with claim 8, and comprising a plurality of switching means so arranged, effectively in parallel and affording different increments of ratio.

10. A network in accordance with claim 3, said network including an input section the impedance of which is varied by said second switching means.

11. A network in accordance with claims 2, 3 and 10, wherein said impedance includes a shunt section comprising serially connected resistance each of value $R^1(1+N)$ where R^1 is the output impedance of the network and N is the desired ratio.

12. A network in accordance with claims 2, 3 and 10, including a shunt section comprising two serially connected resistances the second of which is shunted by a third, and wherein the values of the first two resistances are varied by the first switching means and that of the third resistance by the second switching means.

13. A network in accordance with claims 2, 3 and 10, including a shunt section comprising a first shunt resistance and second and third serially connected resistances in parallel with the first, said first switching means effectively varying the value of the first and second resistances, and the second switching means effectively varying that of the third resistance.

14. A network in accordance with claim 13, said network having three switching means for effecting change of the said ratio in steps, affording different increments of ratio, the third of said switching means being arranged to vary the effective value of said third resistance.

15. A network in accordance with claim 14, said third resistance being shunted by a fourth resistance, the value of which is effectively varied by the first switching means.

16. A network in accordance with claim 14, in which the third resistance is supplemented by the connection in series with it of a fifth and a sixth resistance connected in parallel, the third switching means varying the effective value of said fifth resistance.

17. A resistive network for establishing selectively a plurality of predetermined ratios between the voltage at the input and the current at the output terminals of the network, where the output impedance is zero, whilst presenting a constant input resistance, said network comprising series and shunt branches, and switching means for effectively transferring conductance from a series to a branch arm, for varying said ratio, and for effectively maintaining the input impedance at a constant value.

18. A resistive network in accordance with claim 17, wherein the means for varying the said ratio is in accordance with any of claims 1, 2 or 4 to 16.

19. A resistive network in accordance with claim 18, wherein the means for maintaining the input at a constant value is a branch of the same or corresponding character as one used for varying the said ratio.

20. An improved network substantially as described with reference to the drawing accompanying the Provisional Specification.

21. An improved network substantially as described with reference to the accompanying drawings.

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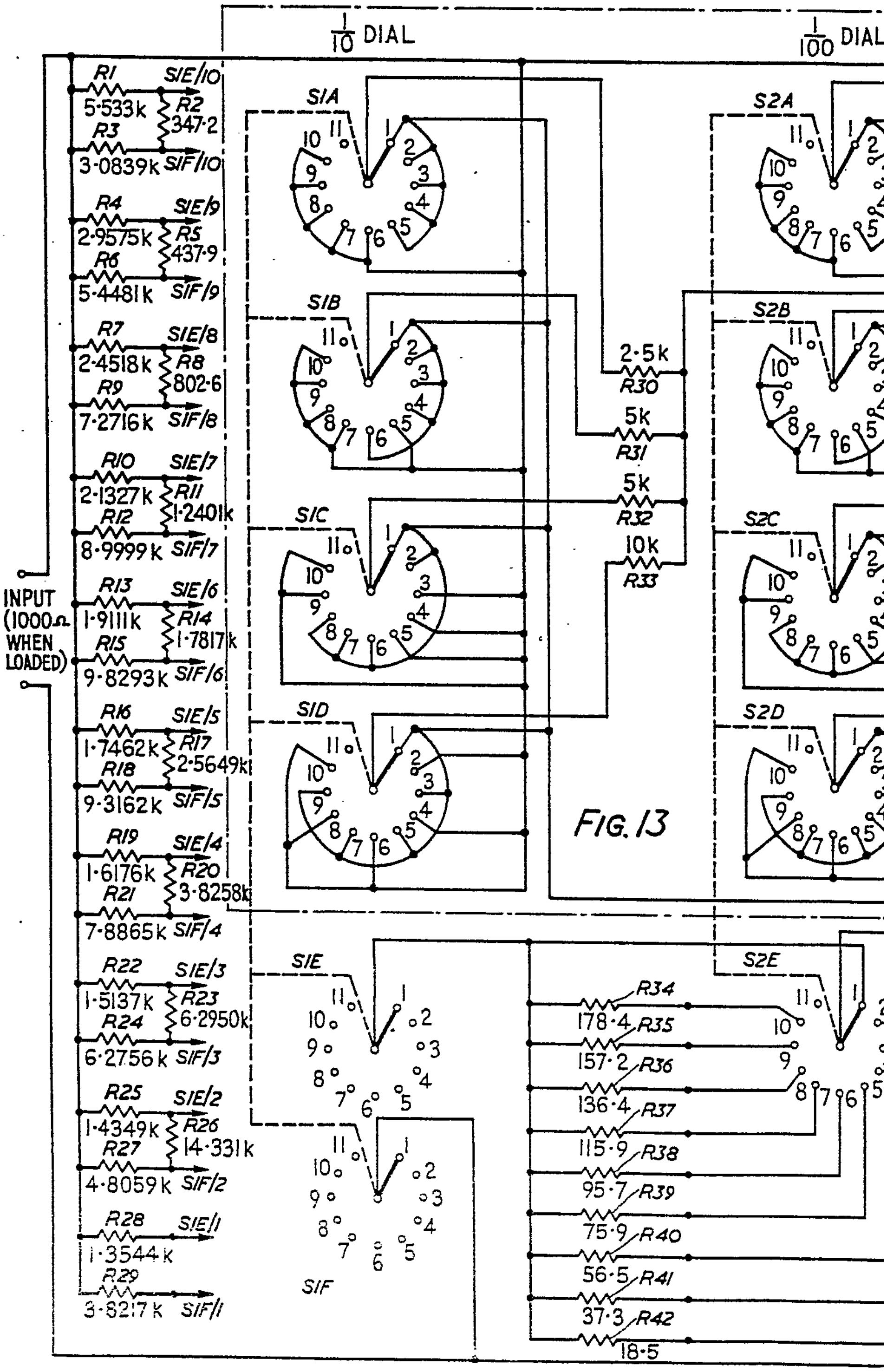
1/10 DIAL
1/100 DIAL
INPUT (1000Ω WHEN LOADED)
R1 5·533k
R2 347·2
R3 3·0839k
S/E/10
S/F/10
R4 2·9575k
R5 437·9
R6 5·4481k
S/E/9
S/F/9
R7 2·4518k
R8 802·6
R9 7·2716k
S/E/8
S/F/8
R10 2·1327k
R11 1·2401k
R12 8·9999k
S/E/7
S/F/7
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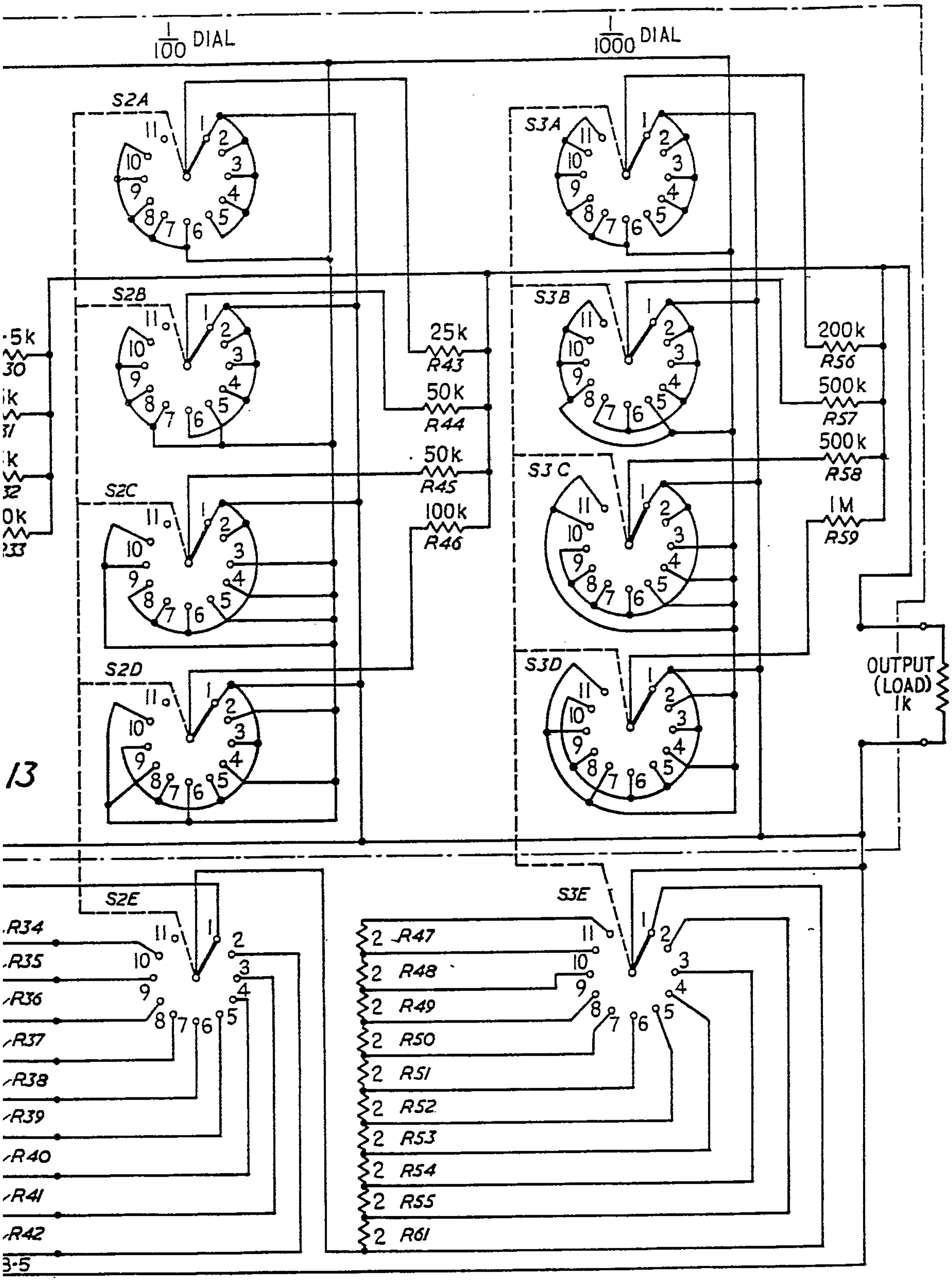
R17 2·5649k
R18 9·3162k
S/E/5
S/F/5
R19 1·6176k
R20 3·8258k
R21 7·8865k
S/E/4
S/F/4
R22 1·5137k
R23 6·2950k
R24 6·2756k
S/E/3
S/F/3
R25 1·4349k
R26 14·331k
R27 4·8059k
S/E/2
S/F/2
R28 1·3544k
S/E/1
R29 3·8217k
S/F/1
S/A
S/B
S/C
S/D
S/E
S/F
S2A
S2B
S2C
S2D
S2E
2·5k R30
5k R31
5k R32
10k R33
R34 178·4
R35 157·2
R36 136·4
R37 115·9
R38 95·7
R39 75·9
R40 56·5
R41 37·3
R42 18·5
1 2 3 4 5 6 7 8 9 10 11

FIG. 13

923373 COMPLETE SPECIFICATION

1 SHEET

This drawing is a reproduction of the Original on a reduced scale



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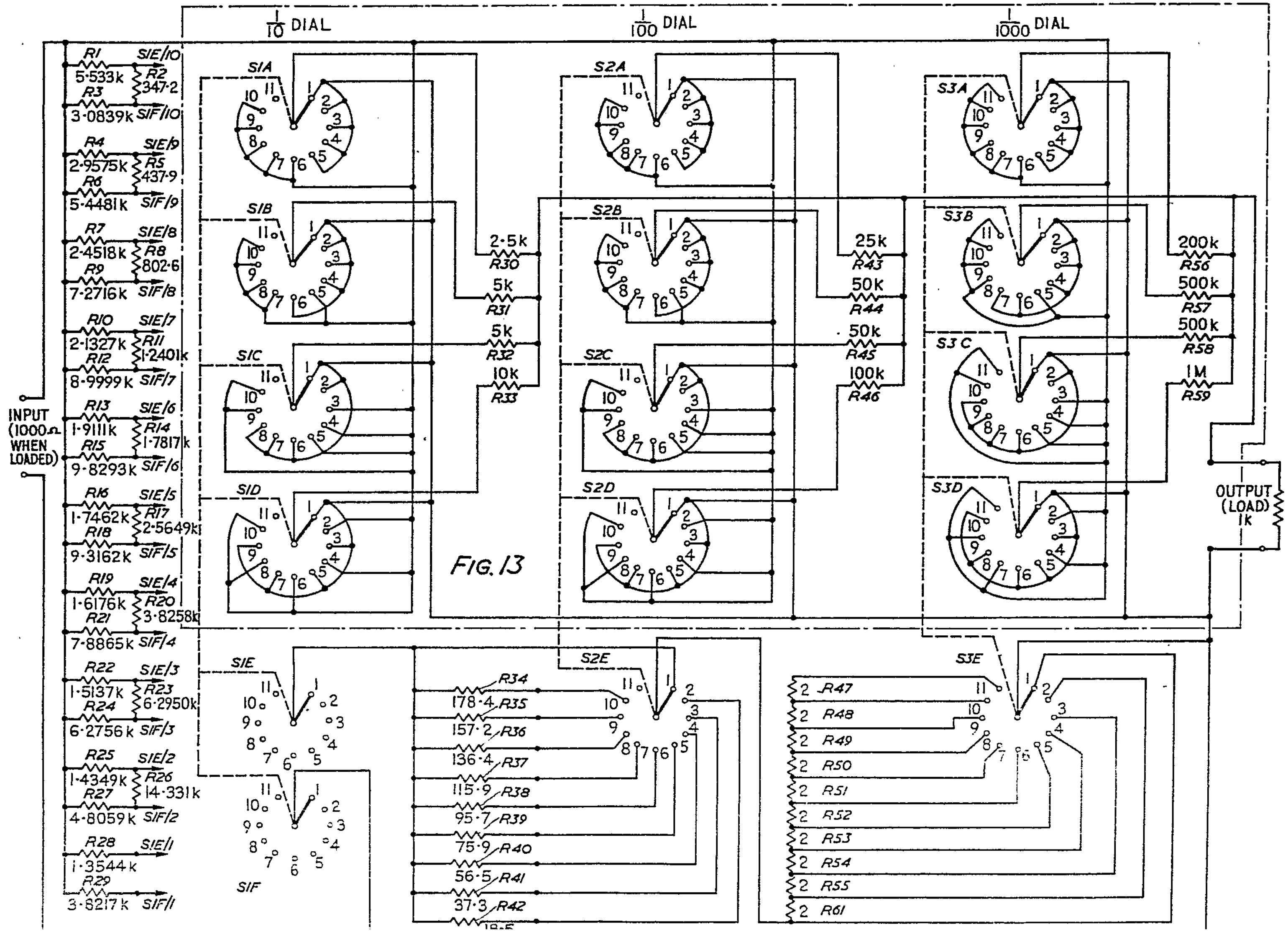

FIG. 13

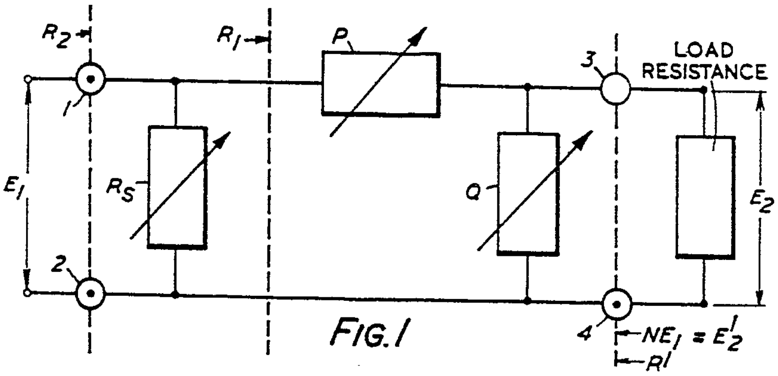

FIG. 1

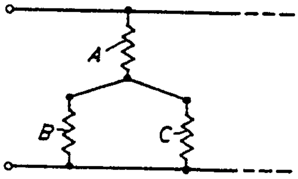

FIG. 2

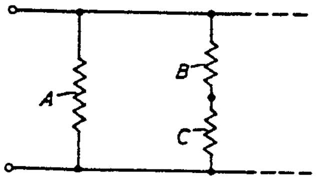

FIG. 3

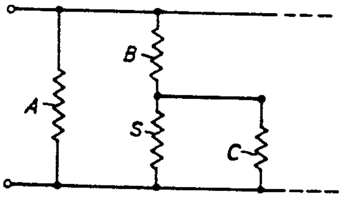

FIG. 4

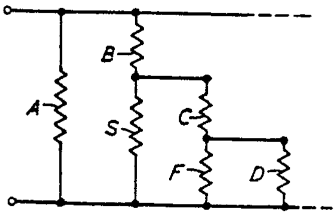

FIG. 5

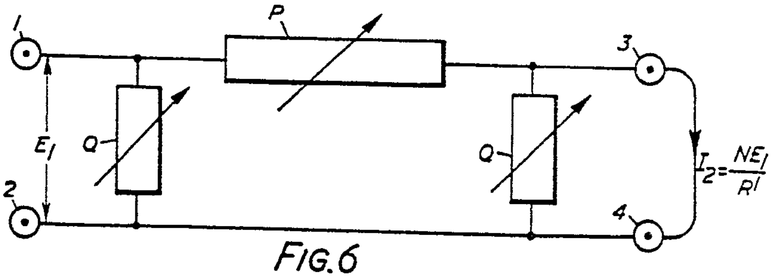

FIG. 6

923373 PROVISIONAL SPECIFICATION No. 18022^{59}

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Sheets 1 & 2

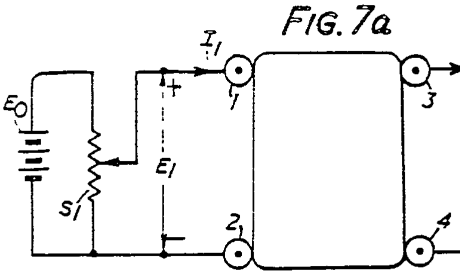

FIG. 7a

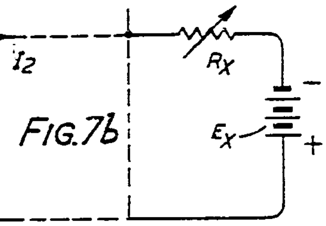

FIG. 7b

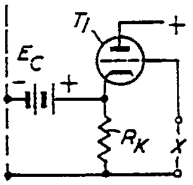

FIG. 7c

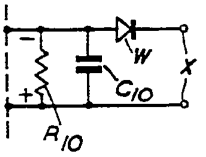

FIG. 7d

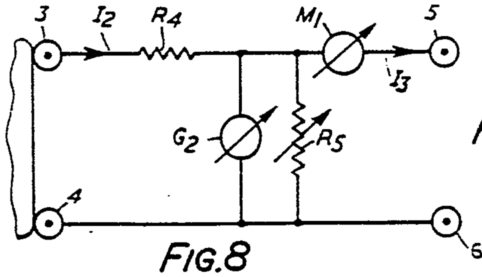

FIG. 8

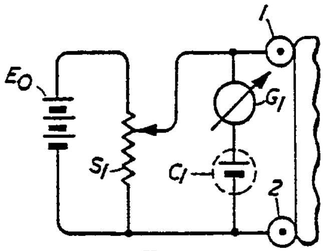

FIG. 9

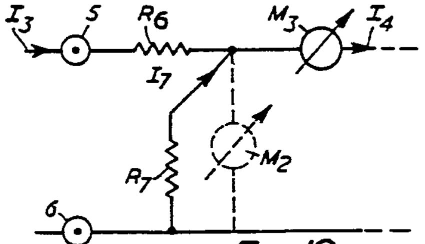

FIG. 10

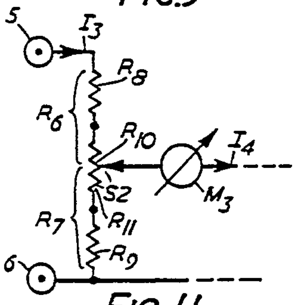

FIG. 11

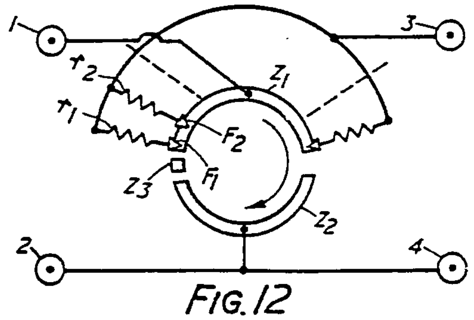

FIG. 12

923373 PROVISIONAL SPECIFICATION No. 18022/59

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

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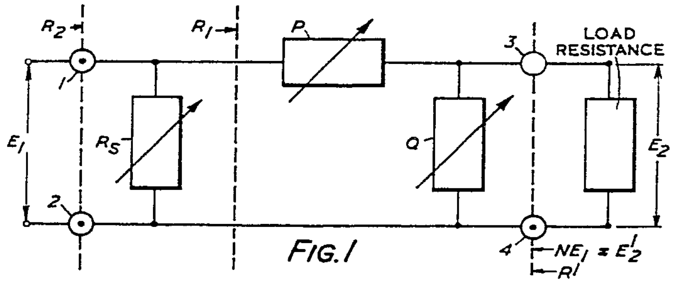

FIG. 1

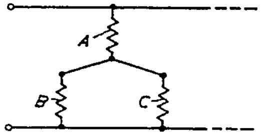

FIG. 2

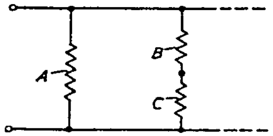

FIG. 3

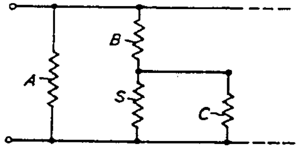

FIG. 4

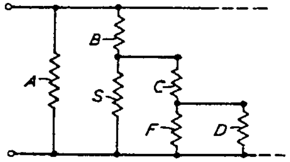

FIG. 5

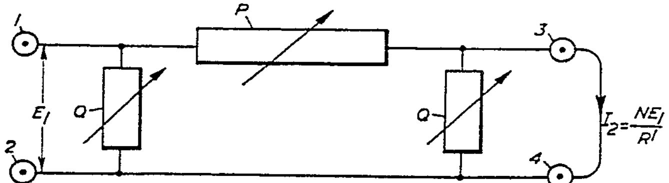

FIG. 6

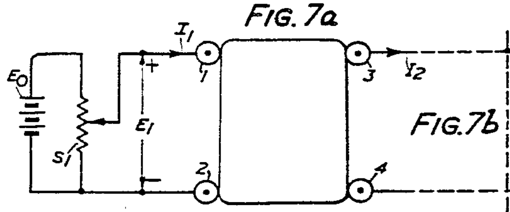

FIG. 7a

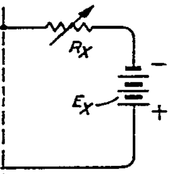

FIG. 7b

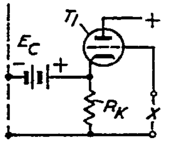

FIG. 7c

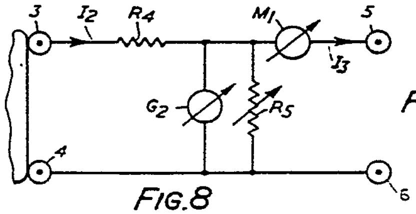

FIG. 8

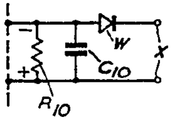

FIG. 7d

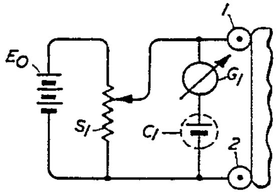

FIG. 9

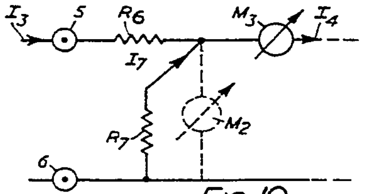

FIG. 10

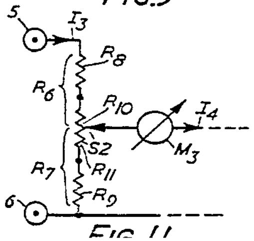

FIG. 11

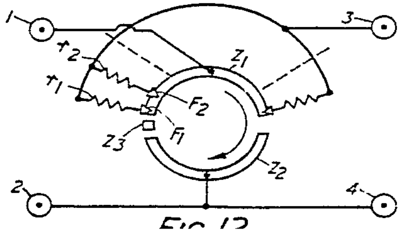

FIG. 12