Nov. 11, 1947. H. T. WILHELM 2,430,488

ADJUSTABLE COMPENSATED STANDARD

Filed Sept. 2, 1943 3 Sheets-Sheet 1

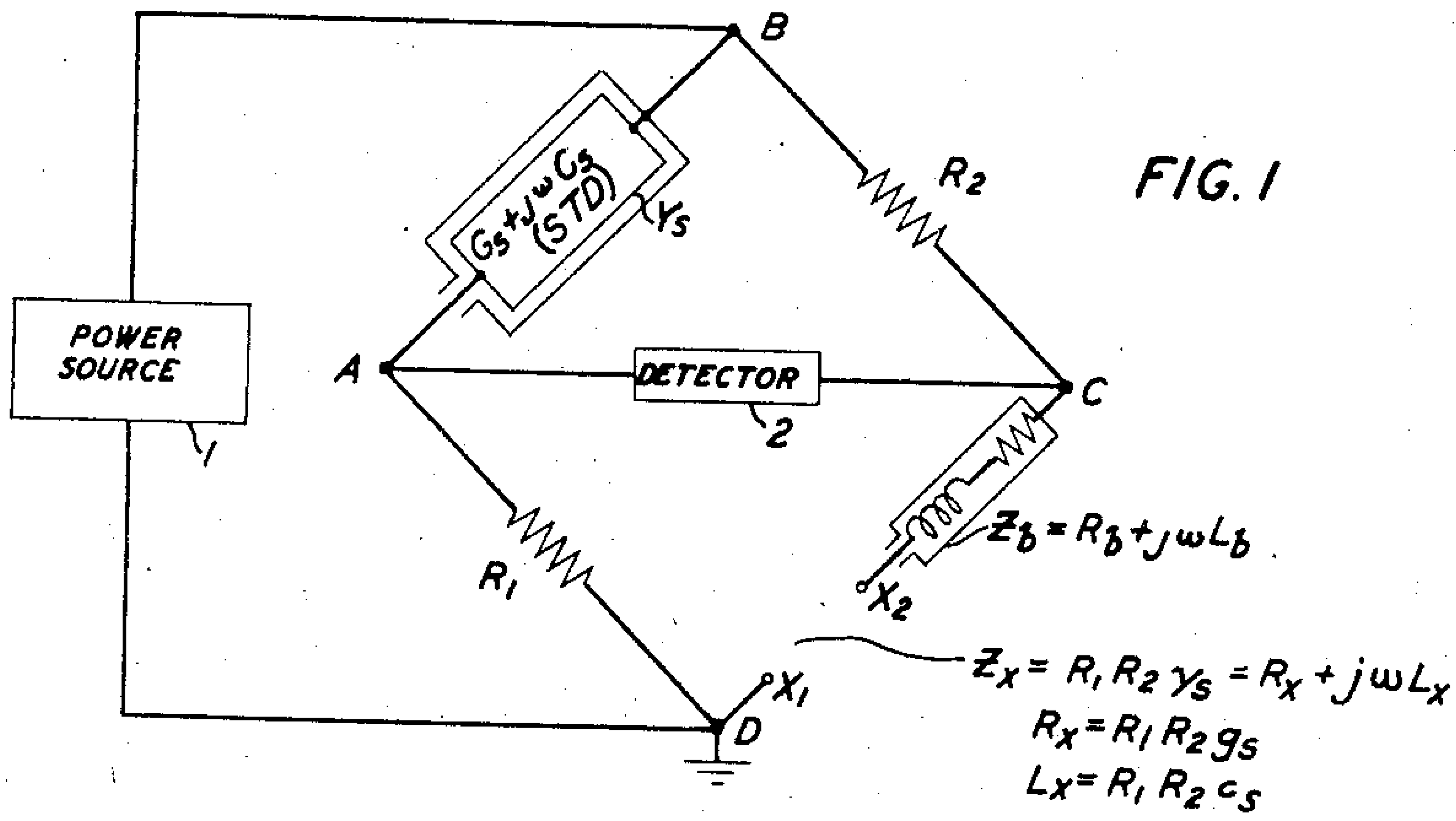

FIG. 1

FIG. 2

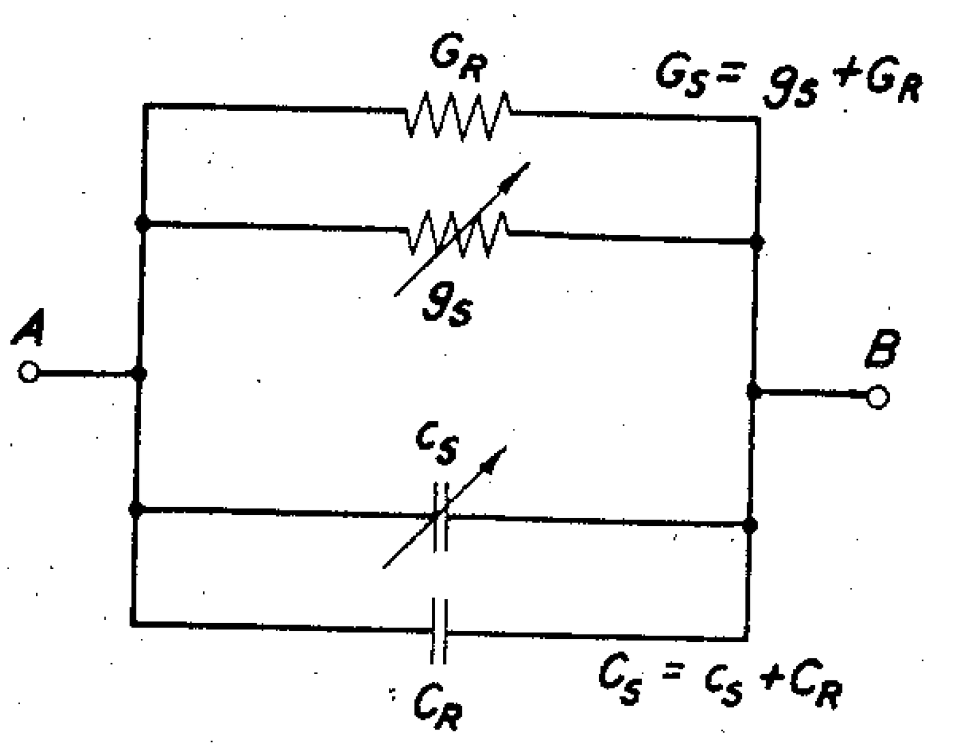

FIG. 3

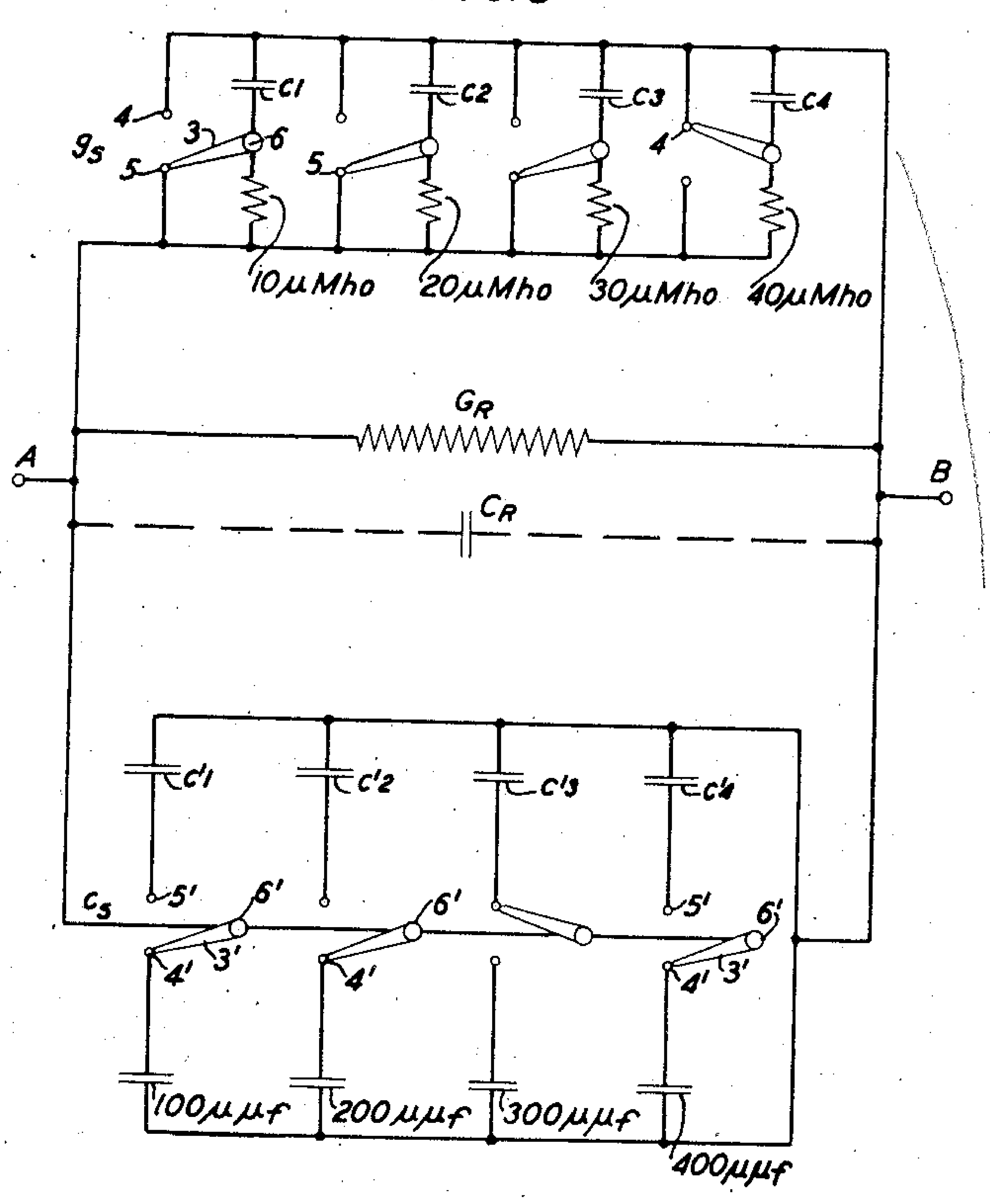

FIG. 4

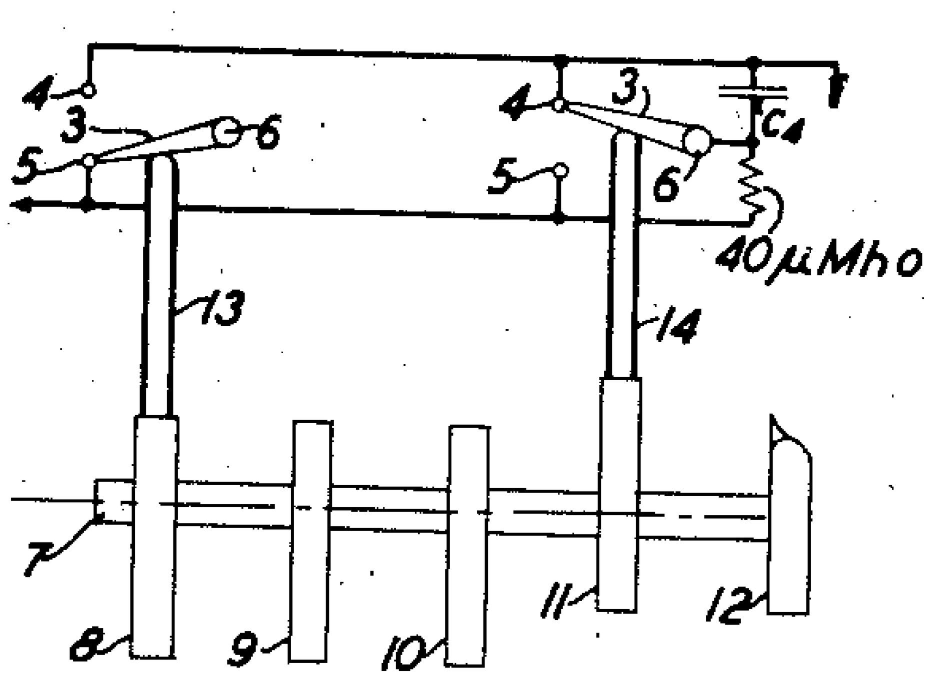

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FIG. 5

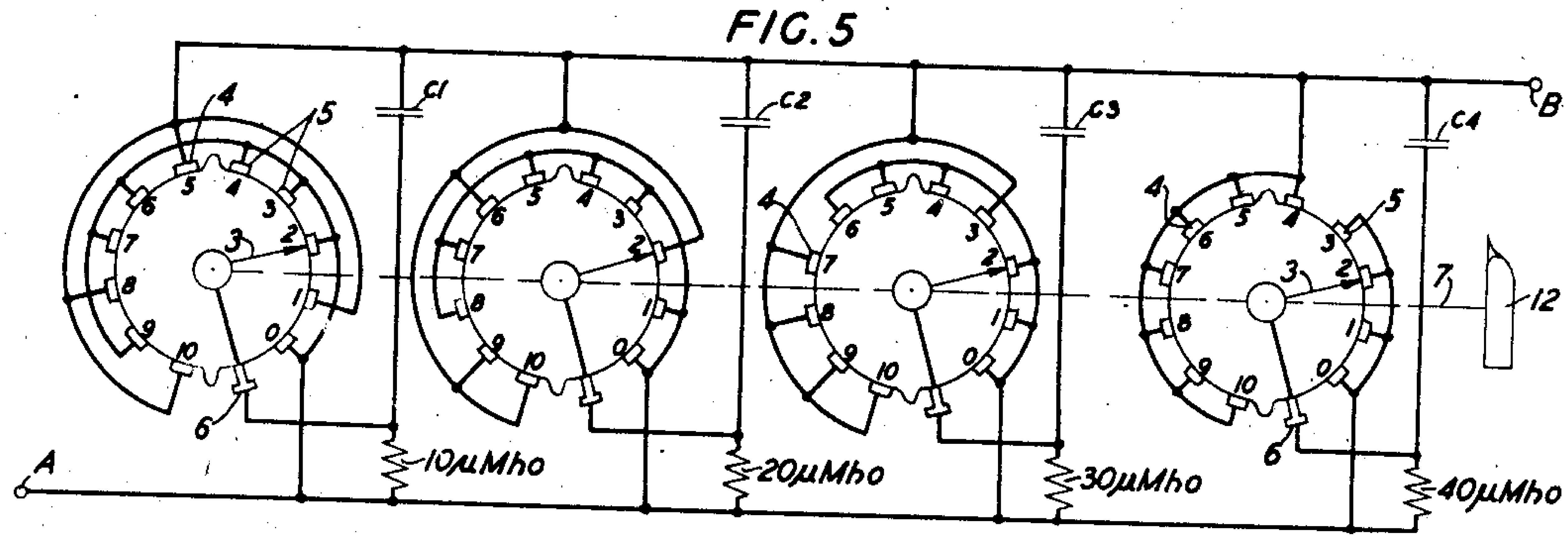

FIG. 6

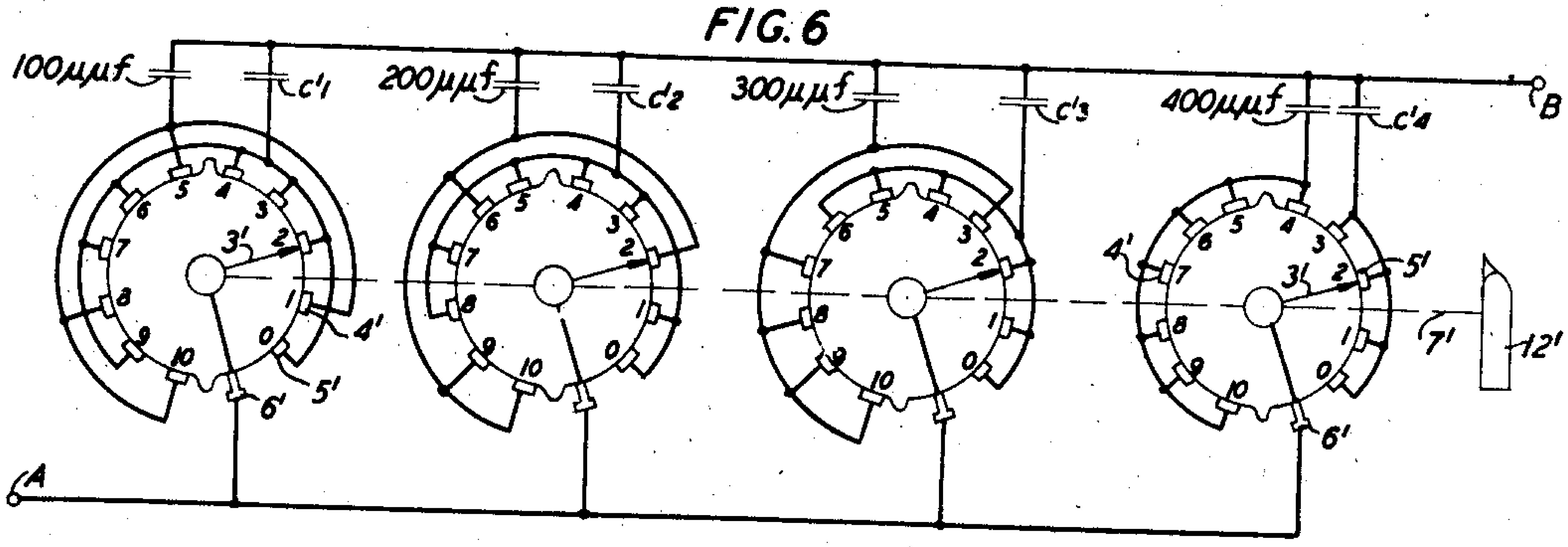

FIG. 9

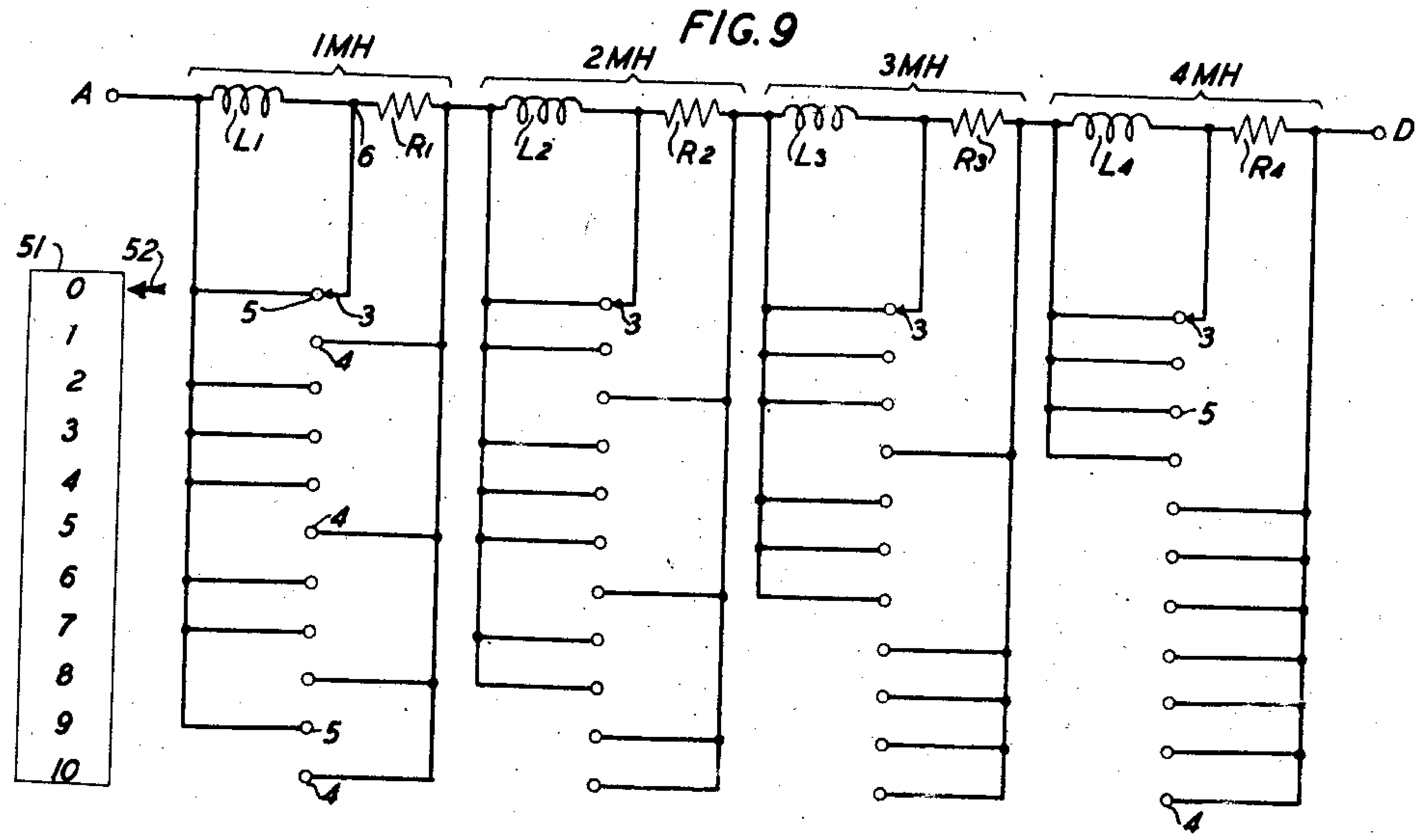

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FIG. 7

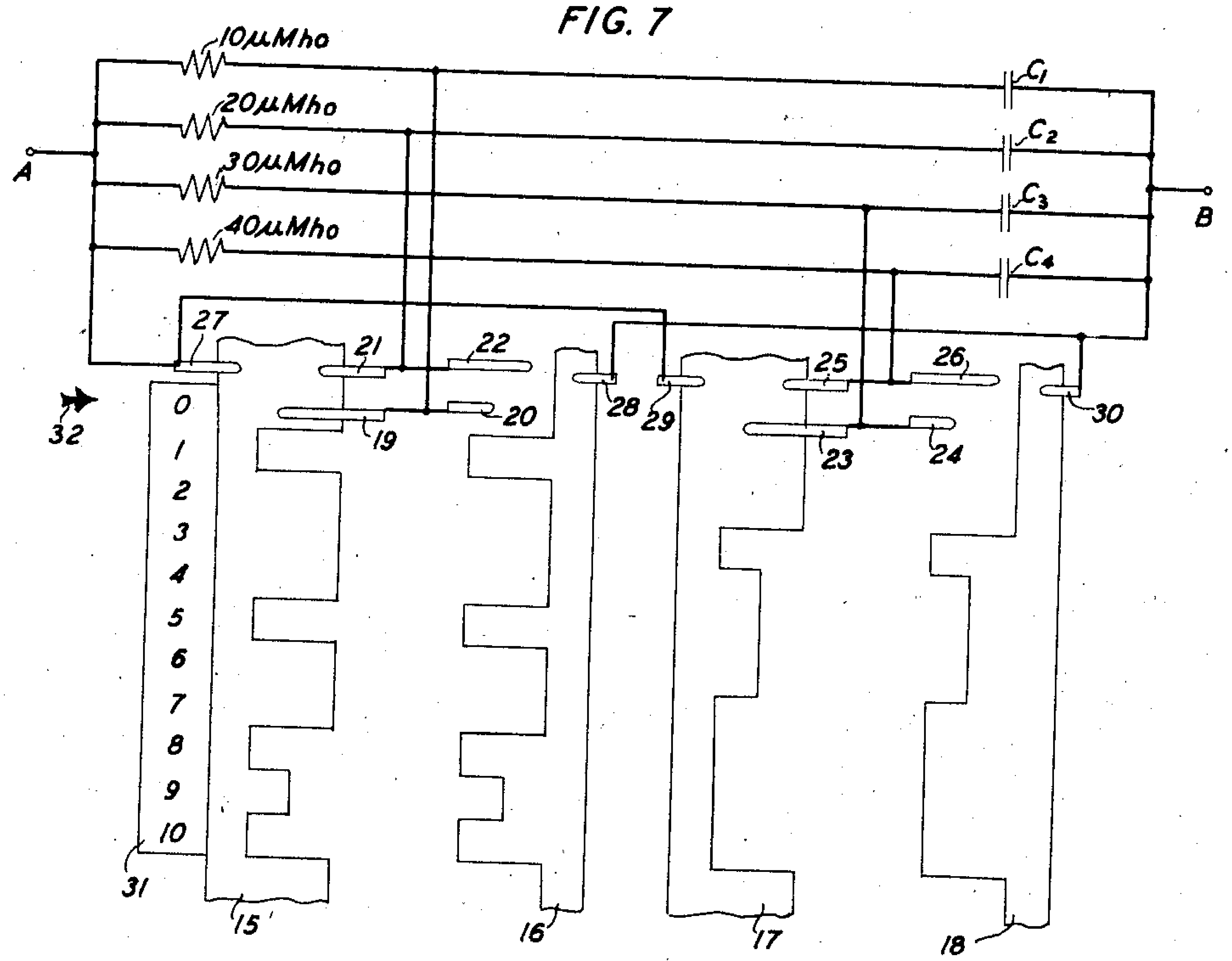
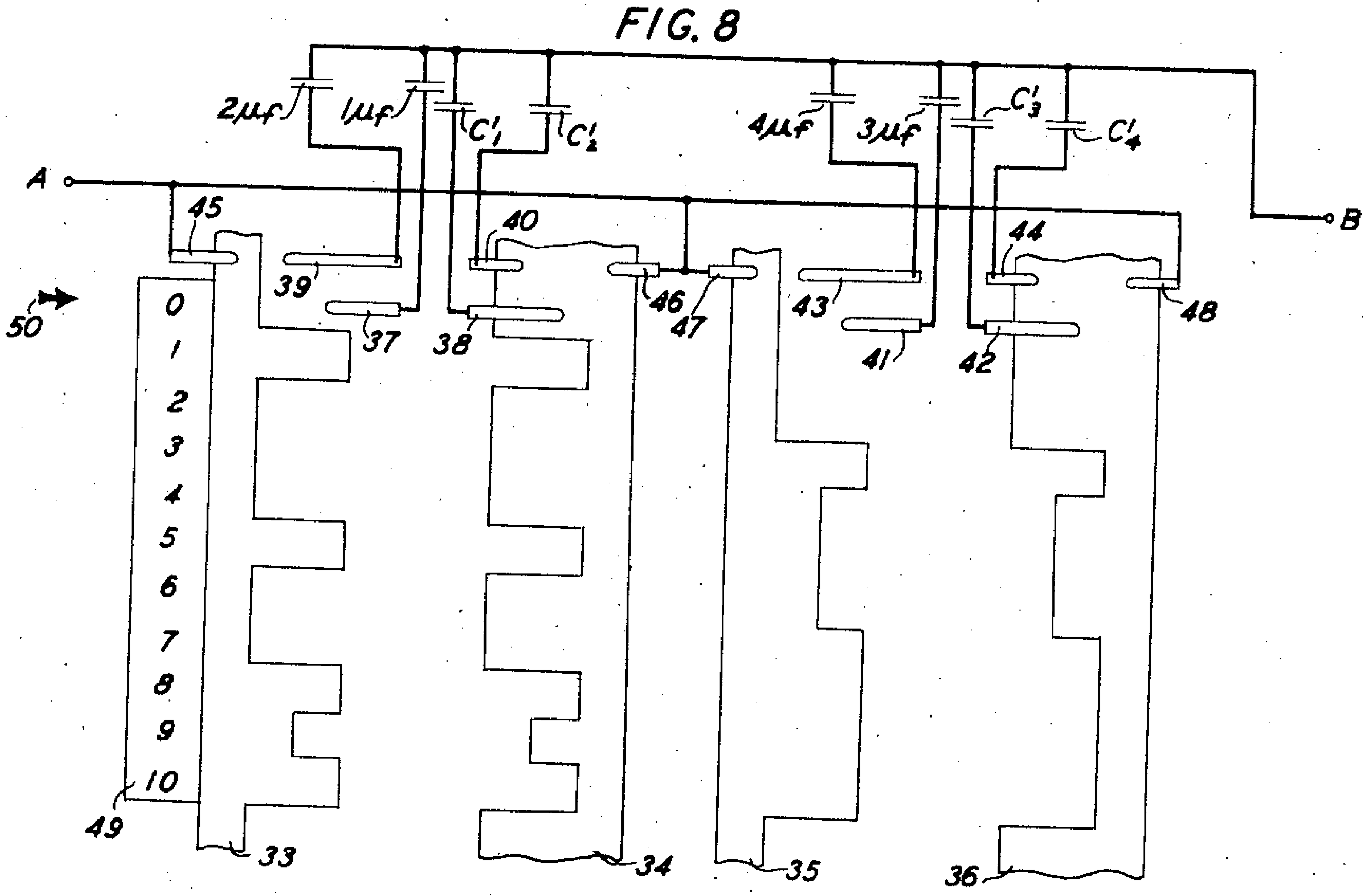


FIG. 8



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2,430,488

UNITED STATES PATENT OFFICE

2,430,488

ADJUSTABLE COMPENSATED STANDARD

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Application September 2, 1943, Serial No. 500,936

13 Claims. (Cl. 171—119)

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This invention relates to alternating current bridge circuits and more particularly to compensated admittance and impedance standards finding special applications in alternating current bridges.

One of the difficulties which constantly face users of alternating current bridges is that while adjusting one particular admittance or impedance component, other components are also varied by reason of impurities inherent in the bridge standard, thereby complicating the balancing adjustment and greatly increasing the time required to make the measurement. A very desirable advantage would be realized by maintaining constant all components not being adjusted.

It is therefore the object of this invention to provide an alternating current bridge standard for an alternating current bridge which, while any one component thereof is being adjusted, maintains all others constant.

The foregoing object is achieved by this invention by providing in combination an adjustable compensated alternating current bridge standard comprising a pair of terminals for said standard, a multiple position switching means, a plurality of standard circuit elements having undesired circuit components inherent therein, one compensating element for each standard element having components of the same kinds and magnitudes as the undesired inherent circuit components of its standard element, circuits connecting the standard elements, the compensating elements and the switching means to the pair of terminals, said circuits and switching means being adapted to selectively connect the standard elements in a plurality of predetermined combinations between said pair of terminals and to automatically substitute between said terminals the compensating element for each standard element not so connected.

The invention may be better understood by referring to the accompanying drawings, in which:

Fig. 1 discloses a Maxwell type bridge illustrative of one of the types of bridges which may utilize this invention;

Fig. 2 discloses a schematic of the essential elements of a practical standard admittance which may be used in the Maxwell bridge of Fig. 1;

Fig. 3 discloses how the standard admittance schematically disclosed in Fig. 2 may be constructed in accordance with this invention;

Fig. 4 discloses one form of switching mechanism which may be employed to practice this invention;

Fig. 5 discloses a decade type conductance standard employing commercially available radial type switches;

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Fig. 6 discloses a capacitance decade employing commercially available radial type switches;

Figs. 7 and 8 disclose conductance and capacitance decade units respectively, each employing a drum type switch; and

Fig. 9 discloses the invention applied to an inductance standard.

Fig. 1 shows how the invention may be embodied in a well-known Maxwell type inductance measuring bridge. A detail description of this bridge and its properties may be found in any standard work on electrical measurements, reference, however, being made to Bell Laboratories Record for November 1940, page 92, for a brief description of the principles of this bridge. In the simple form shown in Fig. 1 the bridge comprises four arms, two opposite arms comprising resistors R1 and R2, while one of the other two arms comprises the standard admittance Y_s and the fourth arm the unknown impedance Z_x in series with a balancing impedance Z_b. A suitable power source 1 is connected to the B and D corners of the bridge and a suitable detector to the A and C corners of the bridge. Except for the shielding shown on the standard admittance and the balancing impedance, all shielding is deleted for the sake of clarity. Shielding would, of course, be used and may be applied in accordance with established principles. An important advantage of the Maxwell bridge is that an unknown inductance L_x may be measured by using a capacitance standard which is more easily constructed with low losses and with accuracy than is a standard inductance. The unknown inductive impedance Z_x may contain an unknown resistive component R_x, the complex impedance being expressed in the familiar form $Rx+j\omega Lx$. The Maxwell bridge permits the standard to be expressed most conveniently in the form of a complex admittance y_s so that the balance equation is:

$$R_1R_2y_s=Rx+j\omega Lx=R_1R_2g_s+j\omega R_1R_2c_s \quad (1)$$

In a practical bridge structure the product R_1R_2 is made equal to some power of ten so that the resistance component R_x is measured by the standard conductance G_s and the inductance L_x by the capacitance c_s.

A schematic of the essential elements of a practical standard admittance for the Maxwell bridge is shown in Fig. 2. It is obvious that if the bridge is to balance for an unknown inductive impedance having a negligibly small resistive component R_x, the admittance standard must have a conductance component G_s which is also very small. For practical reasons the construction of such small conductances is not feasible and is avoided by including in the admittance standard a residual conductance G_R, usually in the form of a slide wire in series with a resistor which is balanced by the resistive component R_b of the balancing impedance Z_b. Also it is impossible to construct any practical alternating current standard admittance or impedance without incurring some spurious unwanted components usually in the form of capacitive susceptances for admittance standards and resistances for impedance standards. In this invention these components are utilized as a part of the residual components of the bridge and are automatically kept constant so as not to continuously upset the balancing adjustment for one component while adjusting another. In this way the undesired components are at all times completely compensated.

In Fig. 2 the residual conductance G_R and the residual capacitance C_R are each kept constant. In the practical decade standard the residual conductance comprises a fixed conductance element connected as shown schematically in Fig. 2. However, the residual capacitance C_R comprises not only physical capacitors but also the capacitance of the wiring and switch elements of the decade standard. The total admittance may then be expressed as

$$Y_s = G_s + j\omega C_s = (g_s + j\omega c_s) + (G_R + j\omega C_R) \quad (2)$$

In the above expression the quantity

$$(G_R + j\omega C_R)$$

is the residual admittance constant for any given test frequency, while the quantity $(g_s + j\omega c_s)$ is the variable admittance equal to y_s in Equation 1. It will be obvious to those skilled in the art that the constant quantity $(G_R + j\omega C_R)$ is not objectionable as it may be balanced by inserting in the C—D arm a balancing impedance Z_b. It is also clear that if this quantity is to be kept constant as is contemplated by this invention, the initial balance of the bridge is in no way upset and any variations which take place in the admittance standard are incurred by reason of the adjustment of the various variable components of the standard unit. The variable components, therefore, are a direct measure of the unknown impedance Z_x which is connected to the terminals X_1 and X_2 of the bridge of Fig. 1.

Referring now to Fig. 3 which discloses the schematic of a practical embodiment of this invention, illustrating how an admittance unit of the general form shown in Fig. 2 may be constructed, the two terminals of this standard admittance carry the reference characters A, B which correspond to the A, B terminals of the bridge in Fig. 1. Between these two terminals is shown permanently connected the constant conductance G_R and capacitance C_R. As previously stated, the constant conductance G_R in a practical structure usually comprises a physical conductance connected between these two terminals as well as the lumped leakage conductance. The constant capacitance C_R represents not only a physical capacitance which may be connected between the two terminals but also the total stray capacitance existing between the wiring and the switch terminals of both the conductance and capacitance standard component elements shown in Fig. 3. At this point it may be mentioned that in a practical structure it is preferable that the balancing impedance Z_b be made without adjustment in which event the constant capacitance C_R of the admittance standard shown in Fig. 3 may also include a variable condenser to aid in securing the initial balance with terminals X_1 and X_2 short-circuited. In any event after initial balance is secured the value of the capacitance C_R remains invariable.

It is a well-known fact that it is very difficult to construct standard circuit elements without including impurities which are herein termed undesirable components. Although various types of improved construction may be employed to reduce their magnitudes, no construction has been found to eliminate them entirely. In accordance with this invention they need not be eliminated but in so far as adjusting the standard elements is concerned their presence in no way disturbs the initial balance of the bridge. For the conductance decade g_s, shown in Fig. 3, this is accomplished by compensating the conductance elements by connecting in series therewith compensating capacitors such as C_1, C_2, C_3 and C_4, the capacitances of which are exactly equal to the spurious capacitances of their associated conductance elements. It is here assumed that all other spurious components are negligible but should they be appreciable, they may be compensated in exactly the same way. The function of the switching arrangement is then to either short-circuit the compensating capacitance or short-circuit the standard conductance element which inherently includes the stray capacitance to be compensated. For example, in Fig. 3 the ten-micromho conductance unit must be understood to have inherent therein a capacitance component equal to C_1. Therefore a compensating condenser C_1 is connected in series with this conductance unit. A two-position switch with a blade **3** is connected to terminal **6** joining this compensating capacitor C_1 and the ten-micromho conductance unit. The switch is caused to engage either switch point **4** or switch point **5**. When it is in engagement with point **5**, as shown in Fig. 3, the ten-micromho standard element is short-circuited thereby eliminating this conductance standard element from the circuit between the standard terminals A, B. It will be noted that in this position compensating capacitor C_1 is inserted between these two standard terminals A and B. The effect is to remove the ten-micromho standard element from the circuit while leaving intact between the two standard terminals the capacitance C_1 which corresponds to the undesired inherent capacitance component of the standard ten-micromho element. When this switch blade **3** is switched to point **4**, the compensating capacitance C_1 is switched out of the circuit and the ten-micromho element is connected to the terminals A and B along with its inherent capacitance component equal to the capacitance of capacitor C_1. Each of the two conductance elements also has a similar capacitor connected in series therewith which in each case is exactly equal in capacitance to the stray capacitance inherent in its associated conductance element. It will be understood that by switching switch blades **3** of these conductance units in various combinations, a complete compensated conductance decade may be achieved ranging from zero to 100 micromhos in ten micromho steps.

The sum of the capacitances of the compensating condensers C_1, C_2, C_3 and C_4 is symbolically indicated as being a part of the constant capacitance C_R, it being understood that these compensating capacitances together with the wiring capacitances are included in this constant capacitance C_R along with any variable capacitance which may be connected between the terminals A and B for initial balance purposes. In the event that any one of the conductance elements is inductive instead of capacitive the compensating capacitor will be omitted and compensation provided by bridging the standard conductance element with a capacitor of suitable size in accordance with well-known principles.

In the past the capacitance standard has been a somewhat simpler problem. Standard capacitors can be constructed quite easily with very low impurities. However, in order to secure precise adjustment for an inexpensive bridge standard by employing commercially available capacitors, it has been necessary to select capacitors which are slightly less than the nominal value and then pad them out with shunting capacitors to bring them to the exact nominal value. This means that on the average about half of the condensers commercially available have not been used for the construction of this type of standard. In accordance with this invention, however, these oversize capacitors may easily be employed to construct such a standard. For example, in Fig. 3, the capacitance standard c_s comprises a plurality of standard capacitors nominally indicated as having the values of 100 micromicrofarads, 200 micromicrofarads, 300 micromicrofarads, and 400 micromicrofarads, respectively. Each of these standard capacitors is assumed to be oversize by an amount equal to the capacitance of its associated compensating capacitor. As an example, the 100-micromicrofarad standard capacitor is assumed to be oversize by an amount equal to the capacitance C_1'. In the circuit arrangement shown in Fig. 3, one side of all of the standard capacitors as well as one side of all of the compensating capacitors is connected to the B terminal of the standard, while the terminals **6'** of the switch blades **3'** are all connected together to the A terminal of the standard. Switch blades **3'** are caused to operate between switch points **4'** and **5'** connected to the standard capacitors and the compensating capacitors, respectively. It will be obvious that when any one of the switch blades **3'** is moved between points **4'** and **5'** the net change in capacitance will be equal to the difference between the capacitance of the standard capacitor and that of its associated compensating capacitor. The standard capacitor in each case may be regarded as having inherently therein an admittance component which is undesired and which is eliminated in effect from the standard circuit by reason of the switching arrangement and the compensating capacitor. As in the case of the conductance standard, the sum of all of the compensating capacitors C_1', C_2', C_3' and C_4' together with the wiring capacitance is included as part of the constant capacitance C_R, schematically shown in Fig. 3. In alternating current bridge practice, the constant conductance and capacitance G_R and C_R, respectively, are referred to as the residual conductance and capacitance of the standard. As previously stated, this residual conductance and capacitance are balanced out in the Maxwell type bridge by the balancing impedance Z_b in the C—D arm of the bridge as shown in Fig. 1.

In using the standard shown in Fig. 3, the switch blades **3** of the conductance standard and **3'** of the capacitance standard may be manually switched in various combinations to suit the conductance and capacitance desired. For convenience it is desired to have them vary progressively in one-unit steps from zero to ten for each of the decade units employed. One form of switching arrangement suitable for this purpose is shown in Fig. 4.

In Fig. 4 a part of the conductance standard of Fig. 3 is shown with two of the switch blades **3**, their associated terminals **6** and their switch points **4** and **5**. One of the conductance standard elements, the 40-micromho element, with its associated compensating capacitor C_4 is also shown. The various switch blades **3** are shown actuated by suitable push-rods **13**, **14** which are preferably made of insulating material. These push-rods rise on a series of properly cut cams **8**, **9**, **10** and **11** which are in turn mounted to a shaft **7** which may be turned by an index knob **12**. As the index knob **12** is turned to the required conductance, the cams **8**, **9**, **10** and **11** are rotated to actuate their associated push-rods **13** and **14**. In Fig. 4 the push-rods and the switch blades associated with cams **9** and **10** have been deleted. Also in Fig. 4 the position of the switch is such as to set the standard for 40 micromhos which corresponds to the schematic arrangement shown in Fig. 3. It will be noted that this is achieved by causing the switch blade **3** to contact switch point **4** which is caused by push-rod **14** being lifted by a swell on cam **11**.

It will be understood that each of the cams have eleven positions corresponding to the conductance settings zero to ten, inclusive. The positions on the respective cams which contain swells are more fully disclosed by the following table:

Table

Position or Setting (g_s)	Cam Swells on Cam Numbers	Conductance Elements in Circuit
0	None	None.
1	8	10μ mho.
2	9	20μ mho.
3	10	30μ mho.
4	11	40μ mho.
5	8, 11	10, 40μ mho.
6	9, 11	20, 40μ mho.
7	10, 11	30, 40μ mho.
8	8, 10, 11	10, 30, 40μ mho.
9	9, 10, 11	20, 30, 40μ mho.
10	8, 9, 10, 11	10, 20, 30, 40μ mho.

Fig. 5 discloses how the conductance decade standard elements together with their associated compensating capacitors may be connected between the A, B standard terminals with a radial type switch commercially available. When using such radial type switches, it is preferable that the switch be of the non-shorting type, that is, the switch blade **3** does not bridge adjacent switch points. Should it bridge these points, it is obvious that certain positions would cause the blade to momentarily short-circuit the A and B terminals of the standard thereby greatly unbalancing the bridge and increasing the difficulty of balancing the bridge. It will be noted that as in Fig. 3, the conductance elements are connected in series with their compensating capacitors between the A and B terminals of the standard. The switch acts merely to short-circuit either the conductance element or the compensating capacitor, it being understood that the conductance element contains an undesired capacitance component equal to the capacitance of its corresponding compensating capacitor. As in Fig. 3 all the switch points 4 of the various switches are connected to the B terminal of the standard while all the switch points 5 of the various switches are connected to the A terminal of the standard. When using this type of switch, instead of having only one No. 4 and one No. 5 switch point for each switch as in Fig. 3 and Fig. 4, a plurality of such points must be provided. All the No. 4 points of each switch must be strapped together and all the No. 5 points must be strapped together as shown schematically in Fig. 5. As all of the standard elements and the compensating elements as well as the various switch elements bear reference characters and numerals corresponding to those shown in Fig. 3, the operation of this switch is obvious from the previous description. It need only be remembered that these four switches are ganged together on a common shaft 7 so that their brush rotors 3 all rotate simultaneously under control of a single knob 12 in a manner similar to the four cams in Fig. 4.

A capacitance decade switching arrangement for a capacitance decade standard is shown in Fig. 6. The same general type of switch structure is employed here as is employed for the circuit of Fig. 5. As in Fig. 3 one side of each of the standard capacitors as well as the compensating capacitors is connected permanently to the B terminal of the standard. All of the switch blades 3 are connected permanently to the A terminal of the standard. For each position of the switch either the standard capacitance or the compensating capacitance is connected directly across the A and B terminals of the standard in just the same manner as previously described for Fig. 3. The reference numerals and characters employed in this figure also correspond with the corresponding parts of Fig. 3. While in the case of the conductance standard of Fig. 5 it was preferable that a non-shorting type switch be used, either a non-shorting or a shorting type may be used for the capacitance standard of Fig. 6. Because of the better contact features of the shorting type switch it is preferred.

Two types of switch structures have already been described as suitable for the practice of this invention. Figs. 7 and 8 disclose still another familiar type of switch structure which may be employed. In Fig. 7, for example, a conductance decade standard is shown utilizing a drum type switch. As in the previous figures the conductance standards are connected in series with their respective compensating capacitors and each of these series connections is permanently connected between the A and B terminals of the standard. As is well known either the drum may rotate relative to stationary brushes or the brushes may be moved with respect to stationary drums. In Fig. 7 it is intended that the drum strips 15, 16, 17 and 18, which are developments of strips which may be mounted on an insulating cylinder, are caused to rotate and thereby move past their contacting brushes 19, 20, 21, 22, 23, 24, 25 and 26. Brushes 27 and 29 maintain connections between strips 15 and 17 and the A terminal of the standard while brushes 28 and 30 maintain connection between strips 16 and 18 to the B terminal of the standard. It will be noted that the brushes 19 to 26, inclusive, are offset with respect to their associated brushes. For example, brush 19 is offset so as to break connection with strip 15 before brush 20 will make contact with drum 16. This provides the non-shorting feature previously mentioned with respect to the other switches. A suitable index strip 31 integrally mounted to drum strip 15 carries numerals 0 to 10, inclusive, which correspond to the various settings of the decade units zero to 100 micromhos, inclusive. This index strip 31 rotates with the drum past a stationary index 32 schematically illustrated in Fig. 7 as an arrow. Except for the different type of switch structure, the switching operation is identical with those previously described for the other type switches and further description is therefore unnecessary.

In Fig. 8, the capacitance decade type of standard is disclosed utilizing a drum type switch similar to the drum type switch previously described for the conductance standard of Fig. 7 except that the non-shorting feature which is unnecessary for the capacitance standard is not shown. As in the case of the previously described capacitance standard, one side of each of the standard and compensating capacitors is permanently connected to the B terminal of the standard, while each of the drum strips 33, 34, 35 and 36 is permanently connected to the A terminal of the standard through brushes 45, 46, 47 and 48, respectively. Each of the capacitors whether standard or compensating has connected to its free terminal a brush 37 to 44, inclusive. The switching action of this drum type switch is identical with the switching action of the other types previously described. As in Fig. 7, so also in Fig. 8, an index strip 49 is integrally attached to drum strip 33 and carries the numerals 0 to 10, inclusive. This index strip is caused to move past a stationary index schematically illustrated as an arrow 50.

In all of the previous figures the invention has been applied exclusively to the construction of an admittance standard. However, the invention is equally applicable to an impedance standard which may contain unwanted or undesired impedance components. This is illustrated for an inductance standard in Fig. 9. When an inductance standard is constructed for measuring inductance, it is usually used in a bridge of the comparison type in which case the standard would ordinarily be connected between the A and D corners, while the A—B and B—C arms would be employed as ratio arms of the bridge. The unknown as in Fig. 1 would be between the C and D corners of the bridge. In Fig. 9 the switching is accomplished by means of radial type switches of the type previously illustrated in Fig. 5. In Fig. 9 this type of switch is shown in a developed form. All the switch blades 3 are ganged together and caused to move around the switch simultaneously as previously described for Fig. 5. These are actuated manually through a knob (not shown) which carries with it an index 52. This index 52 moves adjacent to a stationary scale 51 inscribed from 0 to 10, inclusive. While this index strip 51 is shown developed straight in Fig. 9 it will be understood that for a radial type switch it is necessary that it be curved or arcuate in form.

The standard inductance elements L_1, L_2, L_3 and L_4 are shown connected in series with their respective compensating resistors R_1, R_2, R_3 and R_4, between the A and D terminals of the standard. It will be understood that each of these standard inductance units has inherent therein an undesired resistance component. For example, the inductance element L_1 may be expressed as having the complex form $R_1+j\omega L_1$. For each of the inductance elements the switch blade 3 is caused to either short-circuit the standard inductance element or its compensating resistor. If the inductance element is to be included in the circuit between terminals A and D, the blade **3** is caused to short-circuit the compensating resistor. On the other hand, if the inductance element is to be switched out of the circuit, the blade **3** is caused to short-circuit the inductance element leaving in the circuit the compensating resistor. Referring to Fig. 9 it will be seen that this will take place each time a switch blade **3** engages a switch point **5**, while each time the blade **3** engages a switch point **4**, the associated inductance element is switched into the circuit.

As in the previous figures it will be observed that with only four standard elements of 1-millihenry, 2-millihenry, 3-millihenry and 4-millihenry inductance, a complete decade with 1-millihenry steps from 0 to 10 millihenries may be achieved. Also it will be observed that the total resistance component of the standard inductance will always be equal to the sum of the four compensating resistors R_1, R_2, R_3 and R_4. In this manner whether or not any particular inductance element is switched in or out of the circuit, the total resistance component of the entire standard is always the same.

It will be obvious that while several different types of specific switching structures have been disclosed embodying the invention, the same principle is used in every case, that is to say, either the standard element containing the undesired components is switched into the circuit while its corresponding compensating element is switched out or the standard element is switched out while the compensating element is switched into the standard circuit. It will be appreciated by all those skilled in the use of this type of alternating current bridge that this invention greatly increases the speed with which measurements may be made. It will also be appreciated that various other specific types of switching structures may be employed to accomplish the same switching scheme and therefore may be used to practice this invention. Each of these switching schemes should be regarded as equivalent to those specifically herein disclosed. It may also be pointed out that the switching circuit disclosed in Fig. 3 for the conductance component g_s may be interchanged with the circuit disclosed for the capacitance component C_s but the circuits as selected for these two components in Fig. 3 are preferred. For low frequencies there would be little advantage in either circuit but at higher frequencies there is a real advantage in selecting them as illustrated schematically in Fig. 3. Should the circuit shown for the capacitance component in Fig. 3 be used for the conductance component, the conductance elements would be open when switched out of the circuit instead of being short-circuited. Nevertheless, at higher frequencies the stray capacitance between the free terminal of the conductance element and various switch parts would couple the conductance element into the standard circuit which, without extra shielding, would introduce an uncontrollable error rendering the standard useless for accurate measurements. For this reason the short-circuiting arrangement for the conductance component g_s is preferred as shown in Fig. 3, using non-shorting type switches as previously described.

For the capacitance component C_s a similar objection arises. Should the circuit shown for the conductance component be used for the capacitance component and the measurements be made at higher frequencies the contact resistance of the shorting switches may become an uncontrollable factor which would again render the standard useless for accurate measurements. Therefore, the switching scheme as shown in Fig. 3 for the capacitance component is preferred.

Attention is also called to the obvious fact that this invention may be applied to compensating a standard element for more than the one undesired component specifically disclosed herein, the additional compensating elements being connected in the same manner as the ones illustrated. This, however, is ordinarily unnecessary.

What is claimed is:

1. An adjustable compensated alternating current bridge standard of the decade type comprising a pair of terminals for said standard, a multiple position switching means, a plurality of standard circuit elements less than ten in number and having undesired circuit components inherent therein, one compensating element for each standard element having components of the same kinds and magnitudes as the undesired inherent circuit components of its standard element, circuits connecting the standard elements, the compensating elements and the switching means to the pair of terminals, said circuits and switching means being adapted to selectively connect the standard elements in a plurality of predetermined and arbitrary combinations between said pair of terminals and to automatically substitute between said terminals the compensating element for each standard element not so connected.

2. An adjustable compensated alternating current bridge standard of the decade type comprising a pair of terminals for said standard, a plurality of standard circuit elements less than ten in number and each having undesired circuit components inherent therein, one compensating element for each standard element, said compensating element having components of the same kinds and magnitudes as the undesired inherent circuit components of its standard element, a multiple-position switch for each standard circuit element and its associated compensating element, circuits connecting the standard elements, the compensating elements and the switches to the pair of terminals, said circuits for each switch being adapted to alternately connect either the standard element or its associated compensating element in circuit between said pair of terminals, control means for operating all of said switches in a predetermined and arbitrary sequence whereby said standard elements are selectively connected in predetermined and arbitrary combinations between said pair of terminals and said compensating elements are caused to replace between said terminals any corresponding standard element not so connected.

3. An adjustable compensated admittance standard of the decade type comprising a pair of terminals for said standard, a multiple-position switching means, a plurality of standard admittance elements less than ten in number and having undesired admittance components inherent therein, one compensating admittance element for each standard, said compensating element having components of the same kinds and magnitudes as the undesired inherent components of its standard element, circuits connecting the standard elements, the compensating elements and the switching means to the pair of terminals, said circuits and switching means being adapted to selectively connect the standard elements in a plurality of predetermined and arbitrary combinations between said pair of termi-

nals and to automatically substitute between said terminals the compensating element for each standard element not so connected.

4. An adjustable compensated admittance standard of the decade type comprising a pair of terminals for said standard, a plurality of standard admittance elements less than ten in number and each having undesired admittance components inherent therein, one compensating admittance element for each standard element, said compensating element having components of the same kinds and magnitudes as the undesired inherent components of its standard element, a multiple-position switch for each standard element and its associated compensating element, circuits connecting the standard elements, the compensating elements and the switches to the pair of terminals, said circuits for each switch being adapted to alternately connect either the standard element or its associated compensating element in circuit between said pair of terminals, control means for operating all of said switches in a predetermined and arbitrary sequence whereby said standard elements are selectively connected in predetermined and arbitrary combinations between said pair of terminals and said compensating elements are caused to replace between said terminals any corresponding standard element not so connected.

5. An adjustable compensated conductance standard of the decade type comprising a pair of terminals for said standard, a multiple-position switching means, a plurality of standard conductance elements less than ten in number and having undesired admittance components inherent therein, one compensating element for each standard element having components of the same kinds and magnitudes as the undesired inherent components of its standard element, circuits connecting the standard conductance elements, the compensating elements and the switching means to the pair of terminals, said circuits and switching means being adapted to selectively connect the standard conductance elements in a plurality of predetermined and arbitrary combinations between said pair of terminals and to automatically substitute between said terminals the compensating element for each standard conductance element not so connected.

6. An adjustable compensated conductance standard of the decade type comprising a pair of terminals for said standard, a plurality of standard conductance elements less than ten in number and each having undesired admittance components inherent therein, one compensating element for each standard element, said compensating element having components of the same kinds and magnitudes as the undesired inherent components of its standard element, a multiple-position switch for each standard element and its associated compensating element, circuits connecting the standard elements, the compensating elements and the switches to the pair of terminals, said circuits for each switch being adapted to alternately connect either the standard element or its associated compensating element in circuit between said pair of terminals, control means for operating all of said switches in a predetermined and arbitrary sequence, whereby said standard conductance elements are selectively connected in predetermined and arbitrary combinations between said pair of terminals and said compensating elements are caused to replace between said terminals any corresponding standard element not so connected.

7. An adjustable compensated conductance standard of the decade type comprising a pair of terminals for said standard, a plurality of standard conductance elements less than ten in number and each having undesired admittance components inherent therein, one compensating element for each standard element, said compensating element having components of the same kinds and magnitudes as the undesired inherent components of its standard element, a multiple-position switch for each standard element and its associated compensating element, circuits connecting each standard element in a series circuit with its corresponding compensating element, other circuits connecting each of said series circuits to its corresponding multiple-position switch, said switch and said other circuits being such as to alternately short-circuit either the standard conductance element or its associated compensating element, a circuit connecting all of said series circuits in parallel between said pair of terminals, control means for simultaneously operating all of said switches in a predetermined and arbitrary sequence, whereby said standard elements are selectively connected in predetermined and arbitrary combinations between said pair of terminals and said compensating elements are caused to replace between said terminals any corresponding standard element not so connected.

8. An adjustable compensated capacitance standard of the decade type comprising a pair of terminals for said standard, a multiple-position switching means, a plurality of standard capacitance elements less than ten in number and having undesired admittance components inherent therein, one compensating element for each standard element having components of the same kinds and magnitudes as the undesired inherent admittance components of its standard element, circuits connecting the standard elements, the compensating elements and the switching means to the pair of terminals, said circuits and switching means being adapted to selectively connect the standard elements in a plurality of predetermined and arbitrary combinations between said pair of terminals and to automatically substitute between said terminals the compensating element for each standard element not so connected.

9. An adjustable compensated capacitance standard of the decade type comprising a pair of terminals for said standard, a plurality of standard capacitance elements less than ten in number and each having undesired admittance components inherent therein, one compensating element for each standard element, said compensating element having components of the same kinds and magnitudes as the undesired inherent admittance components of its standard element, a multiple-position switch for each standard capacitance element and its associated compensating element, circuits connecting the standard elements, the compensating elements and the switches to the pair of terminals, said circuits for each switch being adapted to alternately connect either the standard element or its associated compensating element in circuit between said pair of terminals, control means for operating all of said switches in a predetermined and arbitrary sequence, whereby said standard elements are selectively connected in predetermined and arbitrary combinations between said pair of terminals and said compensating elements are caused

to replace between said terminals any corresponding standard element not so connected.

10. An adjustable compensated capacitance standard of the decade type comprising a pair of terminals for said standard, a plurality of standard capacitance elements less than ten in number and each having undesired admittance components inherent therein, one compensating element for each standard element, said compensating element having components of the same kinds and magnitudes as the undesired inherent admittance components of its standard element, a two-position switch for each standard element and its associated compensating element, said two-position switch comprising two switch points and a blade, a connection from each standard capacitance element to one of the switch points of its associated two-position switch, a similar connection from each compensating element to the other switch point of its associated two-position switch, a circuit connecting all of said switch blades to one of the terminals of said pair of terminals, another circuit connecting all of said standard and compensating elements to the other terminal of said pair of terminals, said switches and said connections to each standard and compensating element being adapted to alternately connect either the standard element or its associated compensating element in circuit between said pair of terminals, control means for operating all of said switches in a predetermined and arbitrary sequence whereby said standard elements are selectively connected in predetermined and arbitrary combinations between said pair of terminals and said compensating elements are caused to replace between said terminals any corresponding standard element not so connected.

11. An adjustable compensated inductance standard of the decade type comprising a pair of terminals for said standard, a multiple-position switching means, a plurality of standard inductance elements less than ten in number and having undesired circuit components inherent therein, one compensating element for each standard element having components of the same kinds and magnitudes as the undesired inherent circuit components of its standard element, circuits connecting the standard elements, the compensating elements and the switching means to the pair of terminals, said circuits and switching means being adapted to selectively connect the standard elements in a plurality of predetermined and arbitrary combinations between said pair of terminals and to automatically substitute between said terminals the compensating element for each standard element not so connected.

12. An adjustable compensated inductance standard of the decade type comprising a pair of terminals for said standard, a plurality of standard inductance elements less than ten in number and each having undesired circuit components inherent therein, one compensating element for each standard element, said compensating element having components of the same kinds and magnitudes as the undesired inherent circuit components of its standard element, a two-position switch for each standard circuit element and its associated compensating element, circuits connecting the standard elements, the compensating elements and the switches to the pair of terminals, said circuits for each switch being adapted to alternately connect either the standard element or its associated compensating element in circuit between said pair of terminals, control means for operating all of said switches in a predetermined and arbitrary sequence whereby said standard elements are selectively connected in predetermined and arbitrary combinations between said pair of terminals and said compensating elements are caused to replace between said terminals any corresponding standard element not so connected.

13. An adjustable compensated inductance standard of the decade type comprising a pair of terminals for said standard, a plurality of standard inductance elements less than ten in number and each having undesired circuit components inherent therein, one compensating element for each standard element, said compensating element having components of the same kinds and magnitudes as the undesired inherent circuit components of its standard element, a two-position switch for each standard element and its associated compensating element, a circuit connecting the standard elements and the compensating elements in series between said pair of terminals, circuits connecting each two-position switch to its associated standard inductance and compensating element, said circuits for each switch being adapted to alternately short-circuit either the standard element or its associated compensating element in circuit between said pair of terminals, control means for operating all of said switches in a predetermined and arbitrary sequence whereby said standard elements are selectively connected in predetermined and arbitrary combinations between said pair of terminals and said compensating elements are caused to replace between said terminals any corresponding standard element not so connected.

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