United States Patent

Rozenson et al.

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[45] **Feb. 29, 1972**

[54] WHEATSTONE-THOMSON COMBINED ELECTRICAL MEASURING BRIDGE

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[22] Filed: **June 8, 1970**

[21] Appl. No.: **44,145**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 674,796, Oct. 12, 1967, abandoned.

[52] **U.S. Cl.** .... **324/62 B,** 324/62 C

[51] **Int. Cl.** **G01r 27/02**

[58] **Field of Search** .... 324/62 R, 62 B, 62 X

[56] **References Cited**

UNITED STATES PATENTS

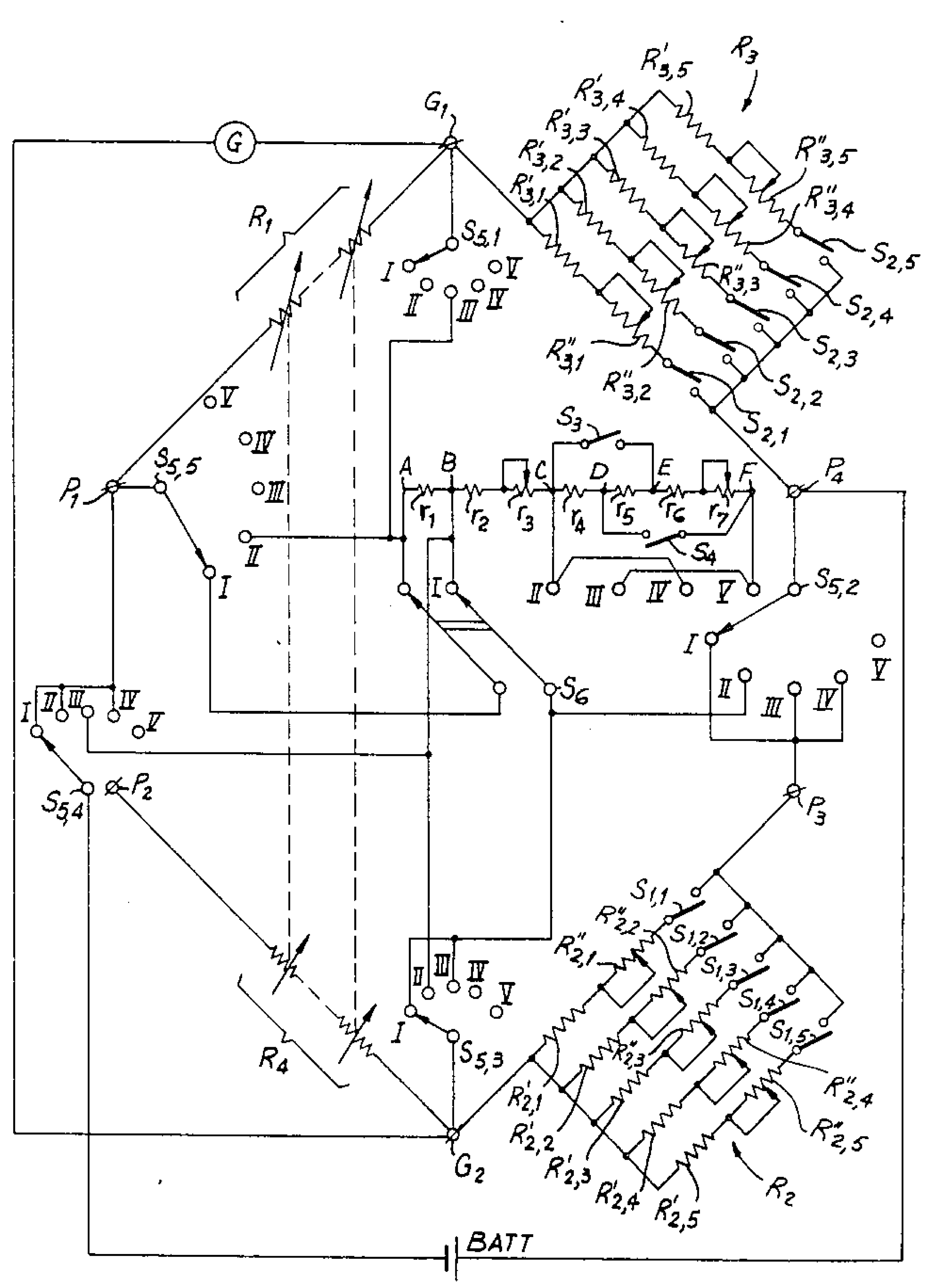
3,246,238 4/1966 Praglin et al. 324/62

Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Marvin Nussbaum
Attorney—Waters, Roditi, Schwartz & Nissen

[57] **ABSTRACT**

A Thomson-Wheatstone bridge including main and auxiliary adjustable arms comprising a number of decade units, the resistances of the ranks of different decade units having a relationship of 1:1, 1:10, 1:100, 1:1,000 and so forth and two adjustable ratio arms each of which consists of a plurality of parallel connected circuits each incorporating a nonadjustable resistor, an adjustable resistor and a switch, the resistors of the parallel circuits being in a relationship with the resistor of any decade unit of the adjustable bridge arms such as 1:1, 1:10, 1:100, 1:1,000, and so forth. With a view toward minimizing reading errors due to deviations of ambient temperature either from a narrow temperature, range or from a strictly fixed temperature, as well as due to instability of bridge arm resistors with time, comprises a standard of resistance ratio unit consisting of a plurality of series-connected sections incorporating nonadjustable and adjustable resistors, with the resistances of the sections being approximately in a relationship to one another such as $1:1:3:3:3:(3\cdot10):(3\cdot10):(3\cdot10):(3\cdot10^2):(3\cdot10^2):(3\cdot10^2):(3\cdot10^3):(3\cdot10^3):(3\cdot10^3):......:(3\cdot10^m):(3\cdot10^m):(3\cdot10^m)$, where m is a positive integer, switches are used which provide parallel connections between three of the above-mentioned sections whose resistances are in a relationship of 1:1:1 to obtain a reference ratio of the resistance of the first section of said standard of resistance ratio unit to total resistance of the other sections of said standard of resistance ratio unit, said reference ratio being equal to $1:10^n$, wherein n is an integer or zero. After tuning said standard of resistance ratio unit in the circuit of the Thomson-Wheatstone bridge whose component members are so interconnected as to form the Wheatstone bridge, the Thomson-Wheatstone bridge is reconstituted for measurement.

7 Claims, 15 Drawing Figures



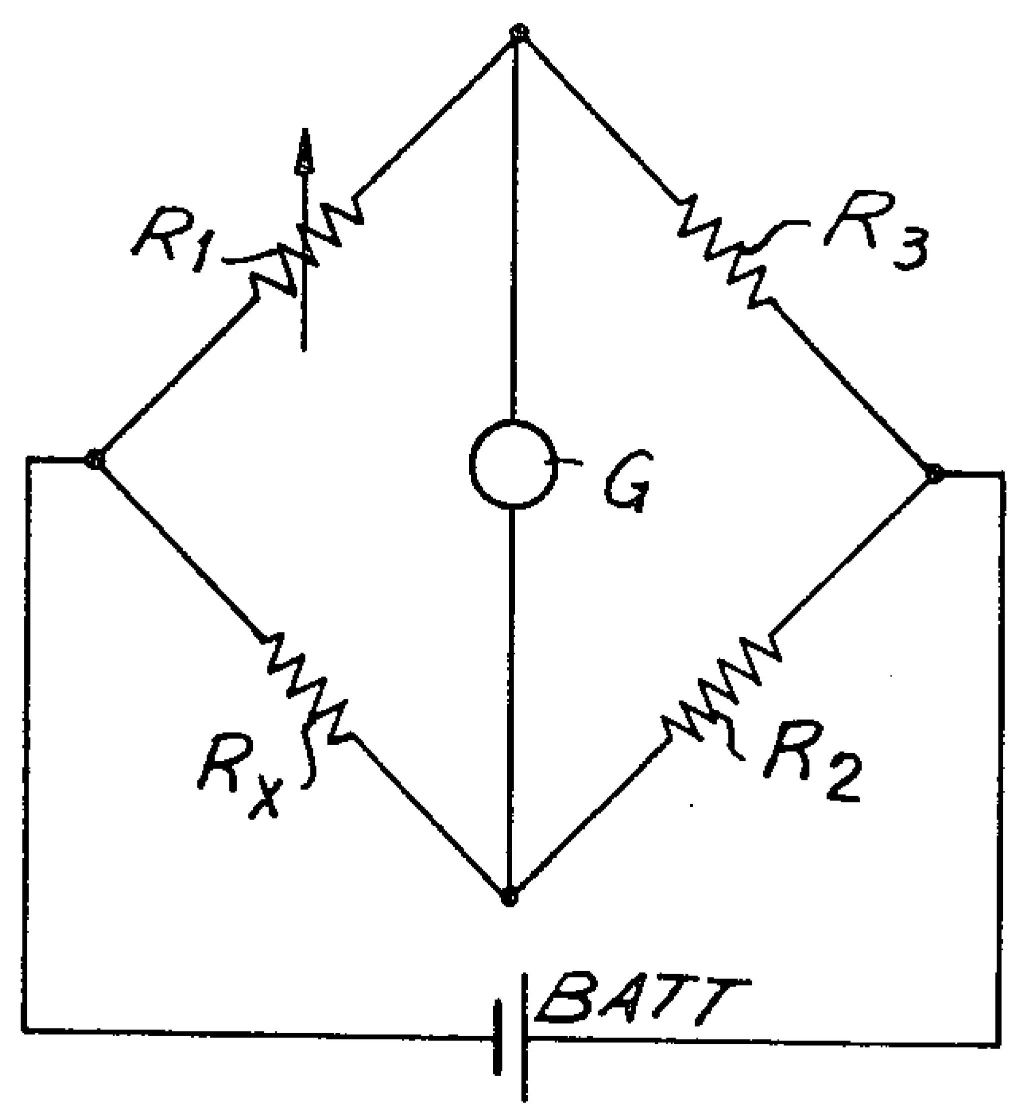


FIG. 1

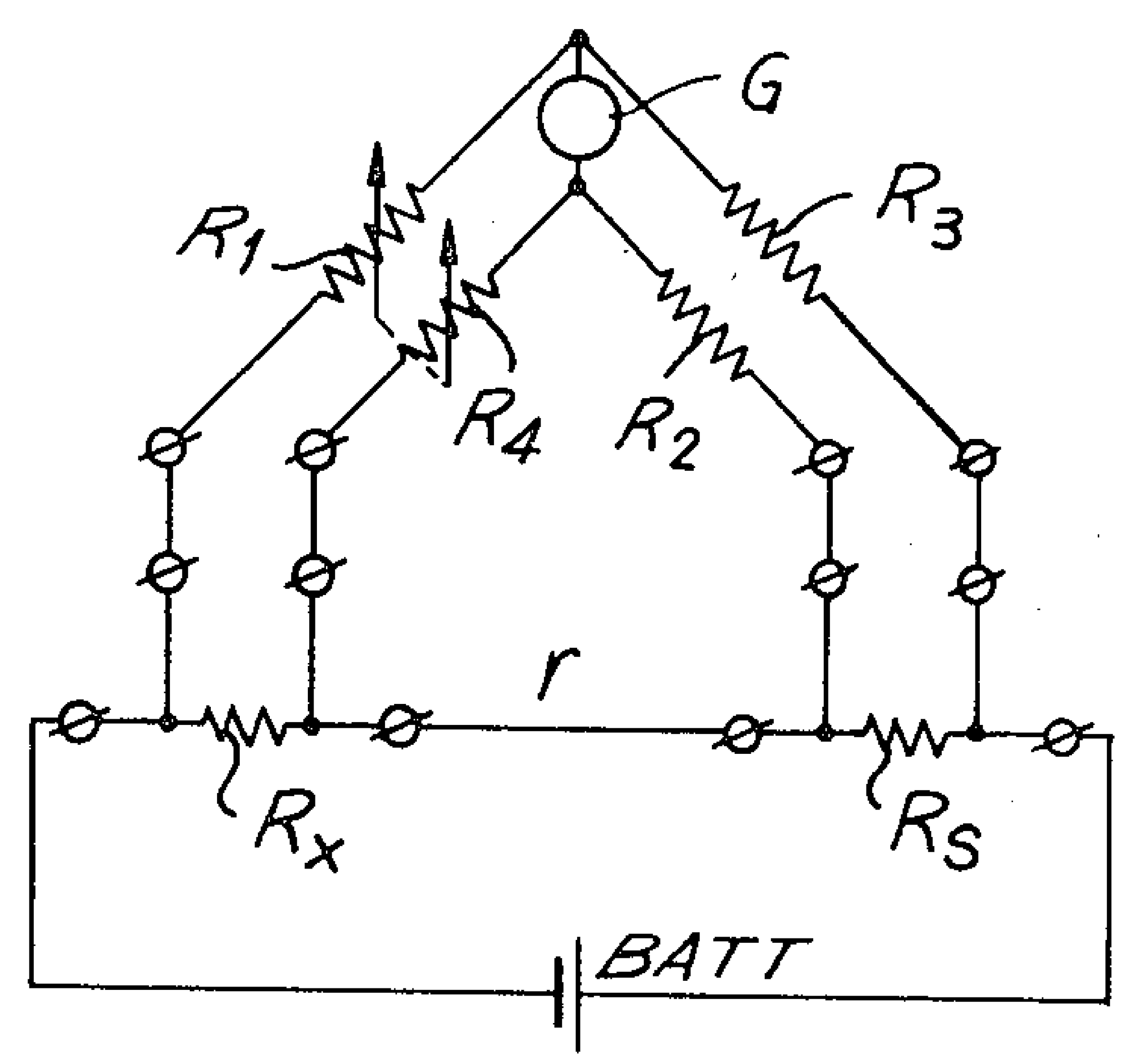


FIG. 2

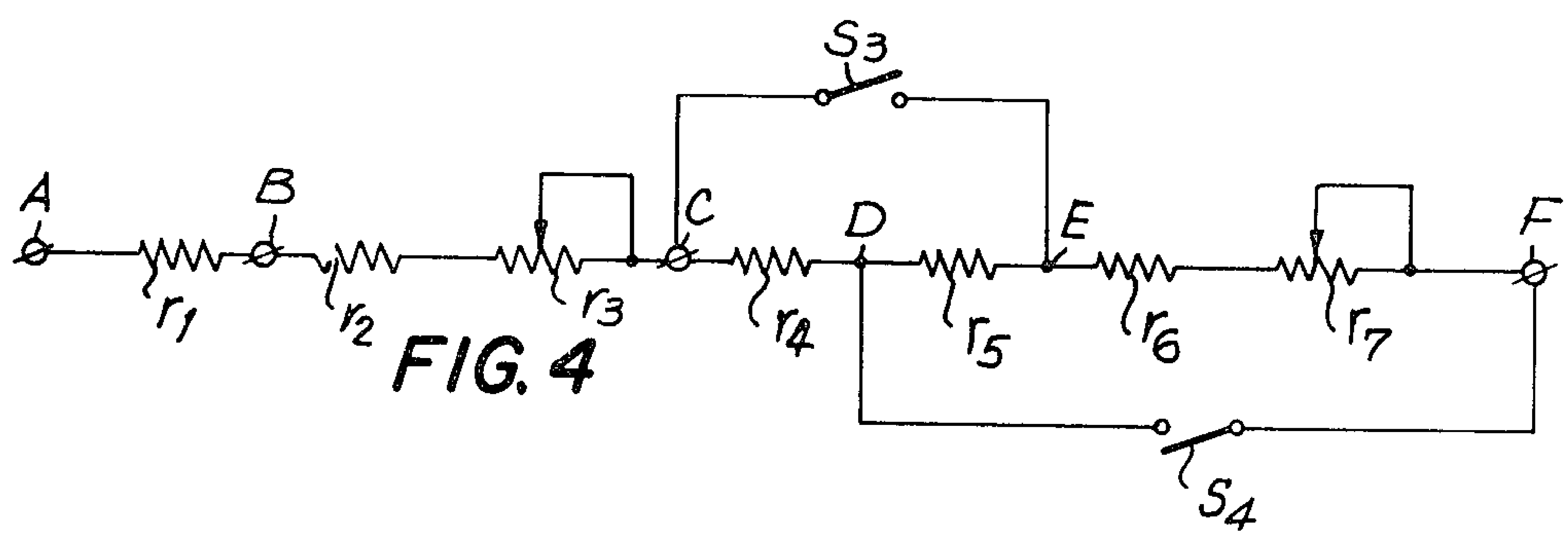


FIG. 4

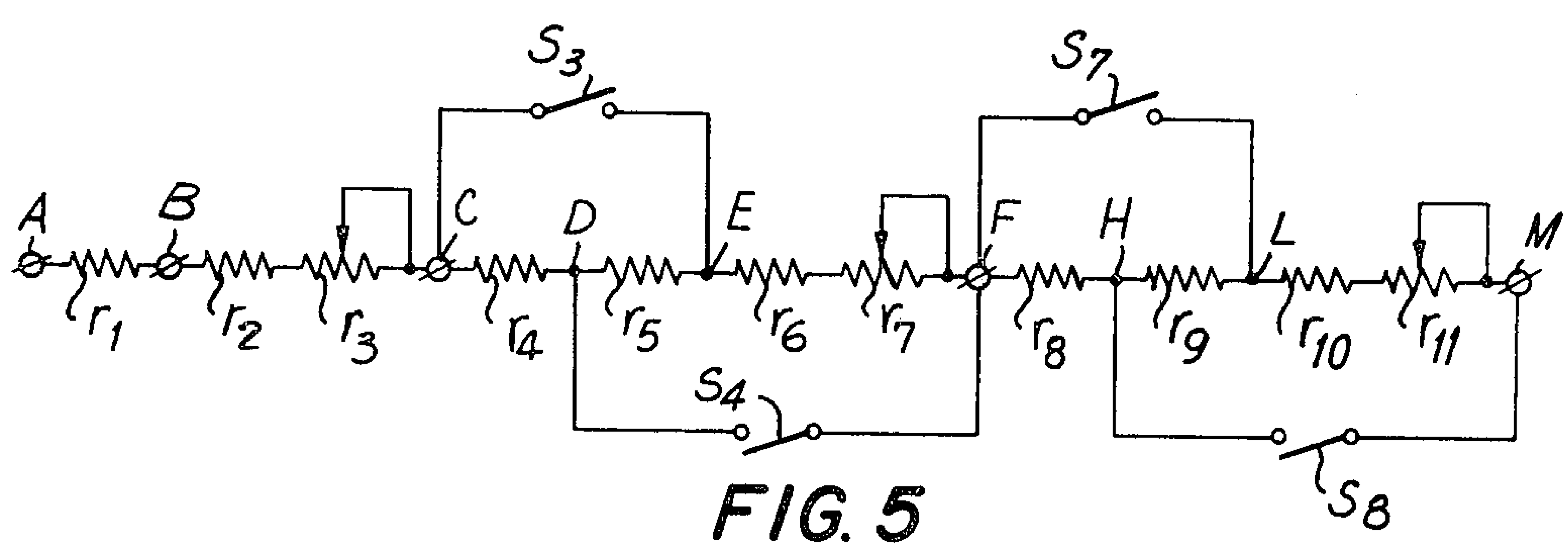
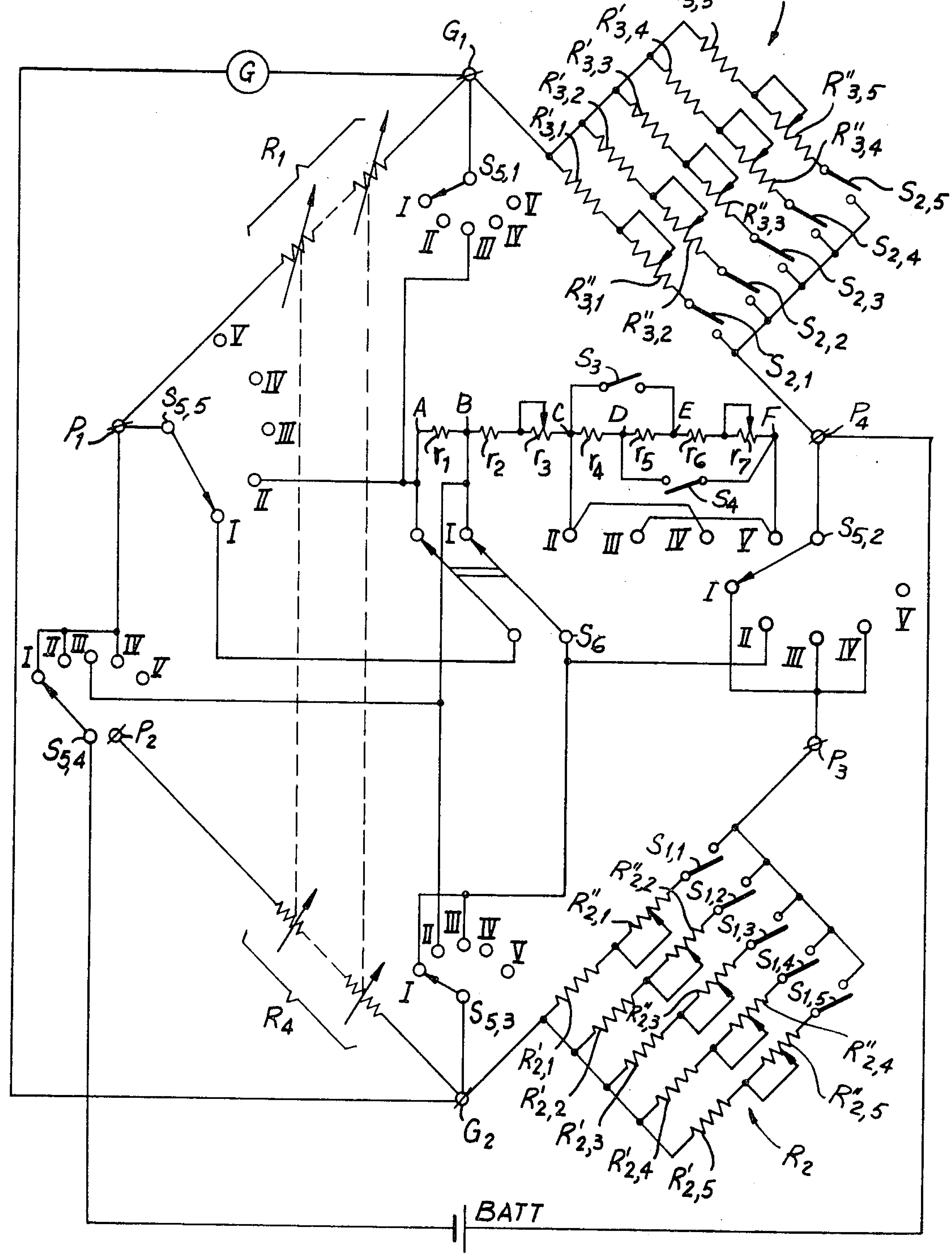


FIG. 5

FIG. 3


G
G1
G2
R1
R2
R3
R4
P1
P2
P3
P4
S5,1
S5,2
S5,3
S5,4
S5,5
S6
S3
S4
S1,1
S1,2
S1,3
S1,4
S1,5
S2,1
S2,2
S2,3
S2,4
S2,5
A
B
C
D
E
F
r1
r2
r3
r4
r5
r6
r7
BATT

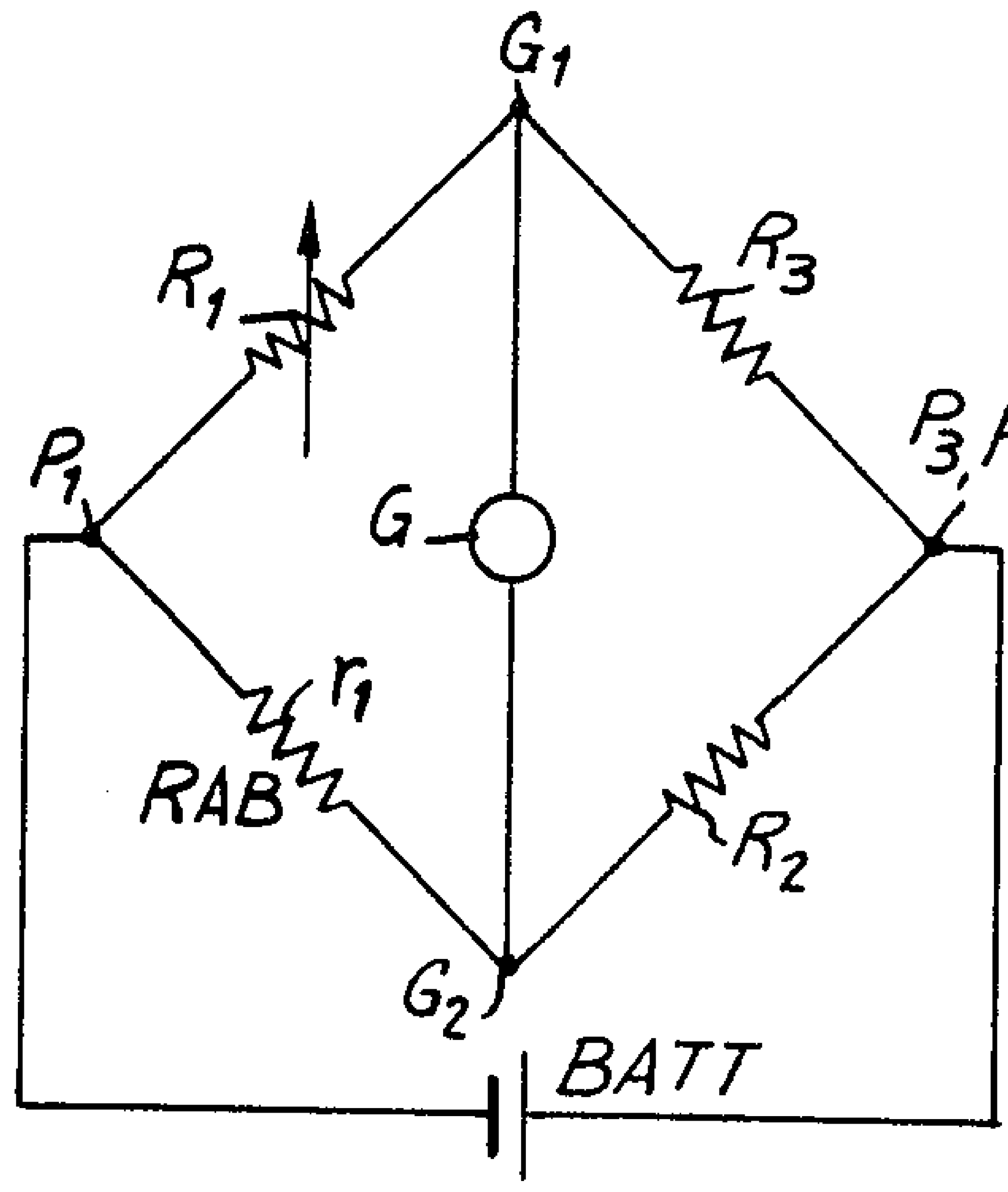


FIG. 6a

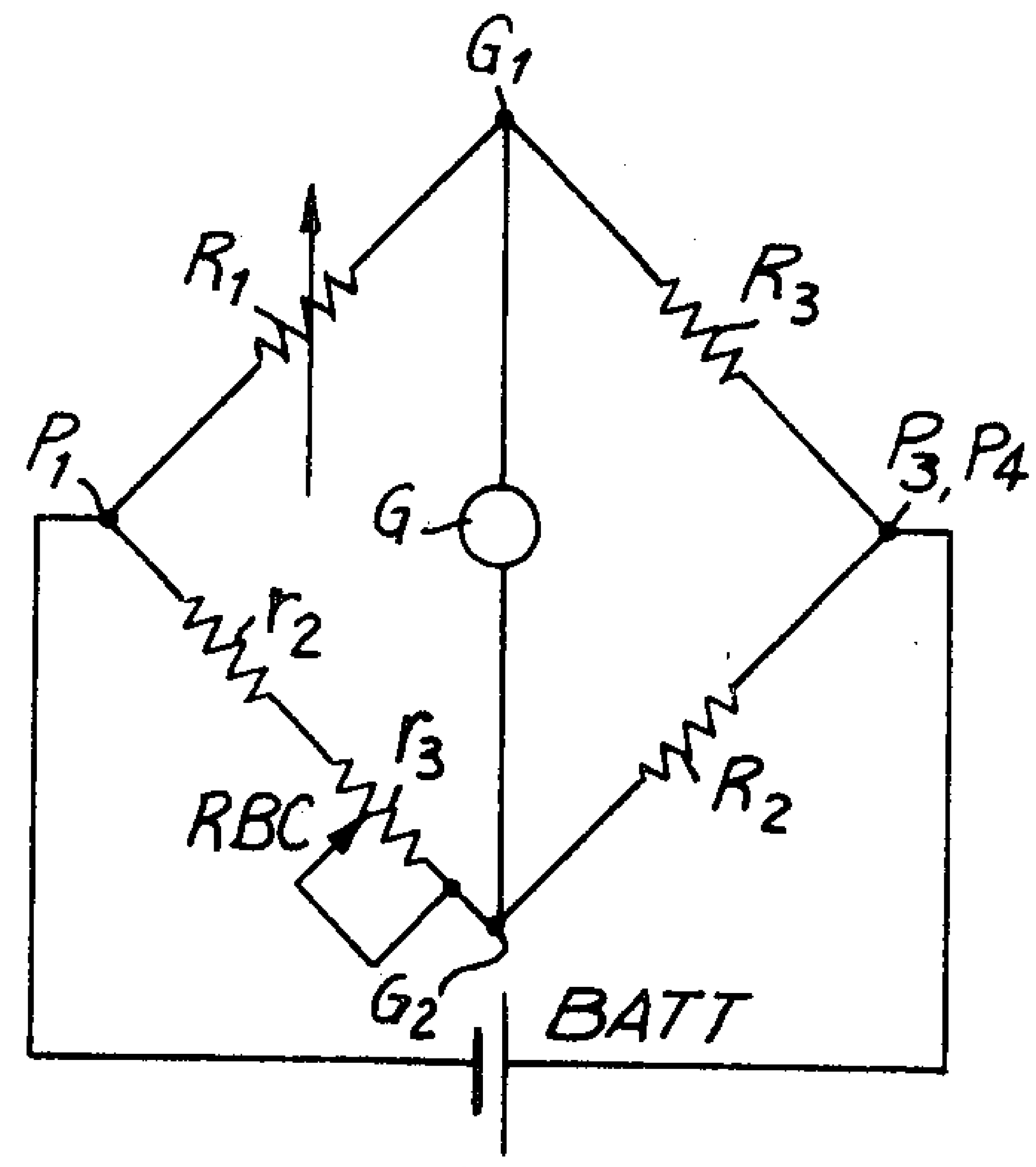


FIG. 6b

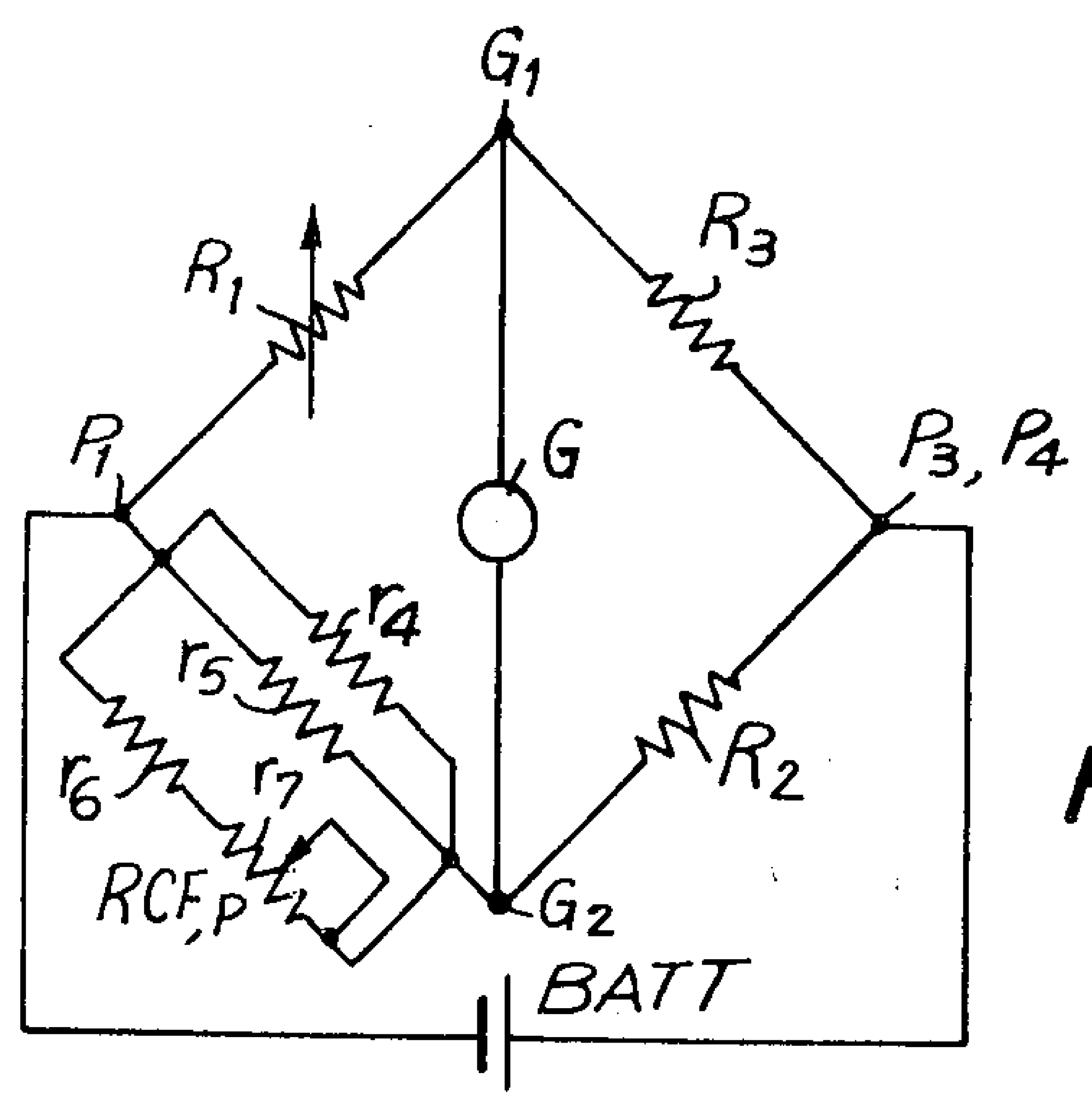


FIG. 6c

FIG. 7a

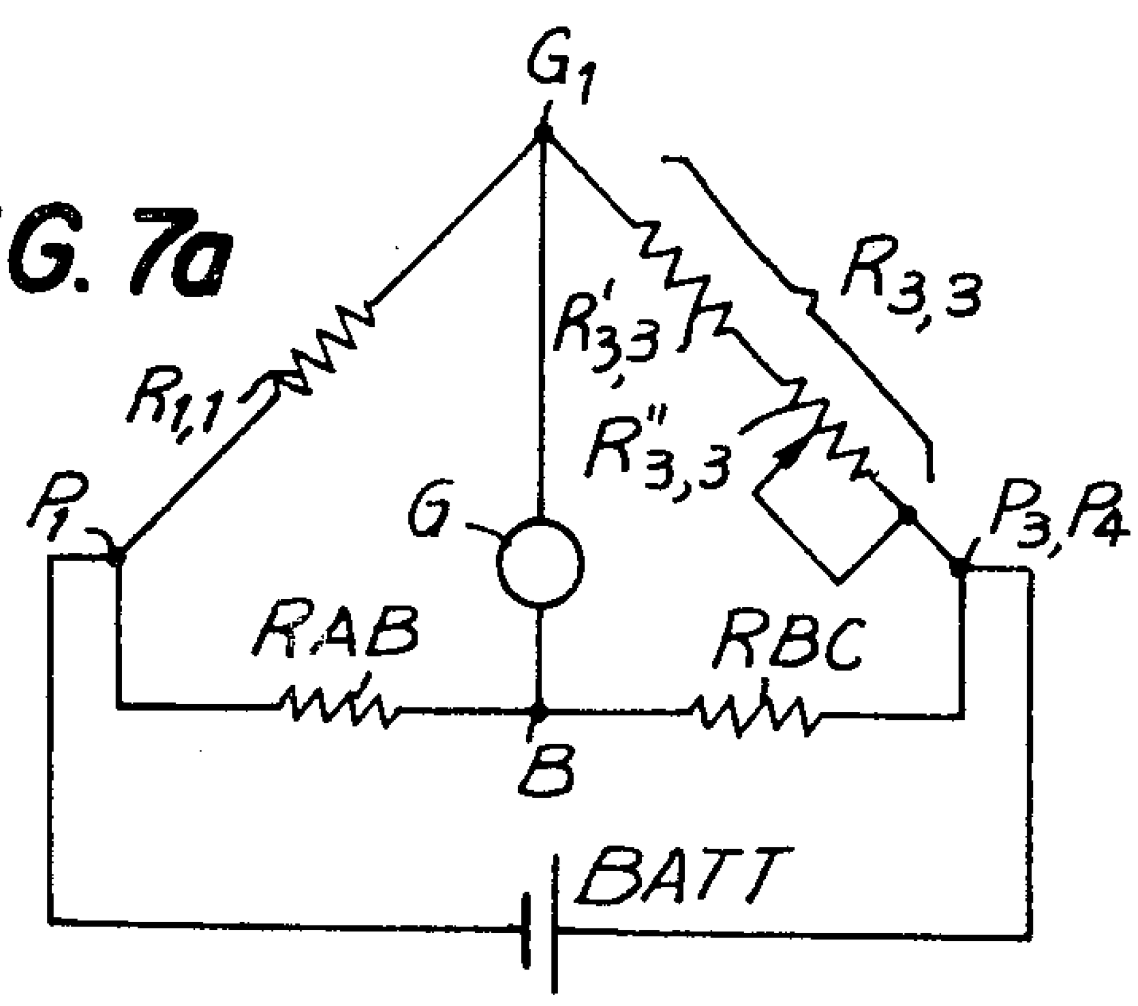
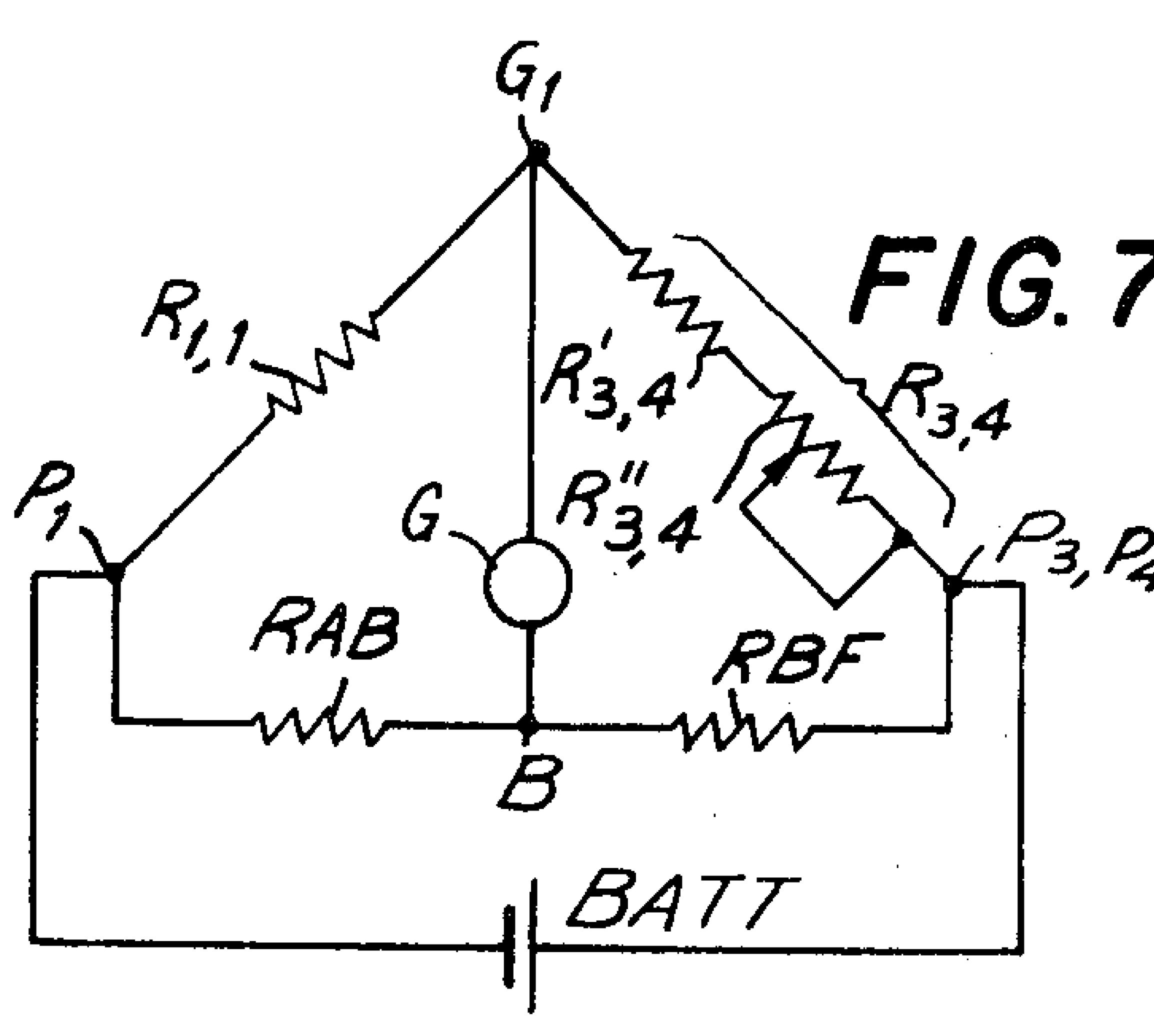


FIG. 7b



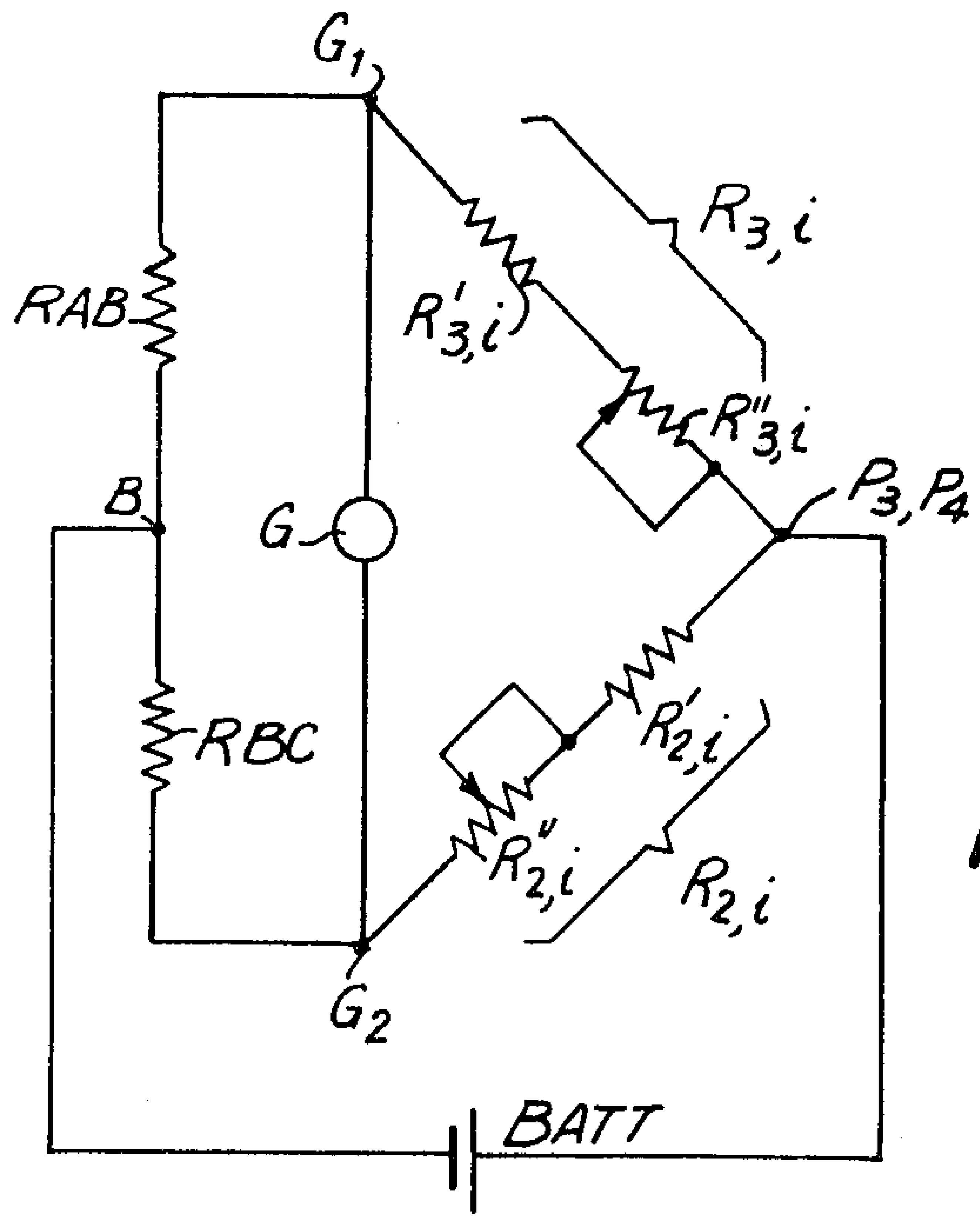

G1
R3,i
RAB
R'3,i
R''3,i
B
G
P3,P4
RBC
R'2,i
R''2,i
R2,i
G2
BATT

FIG. 8a

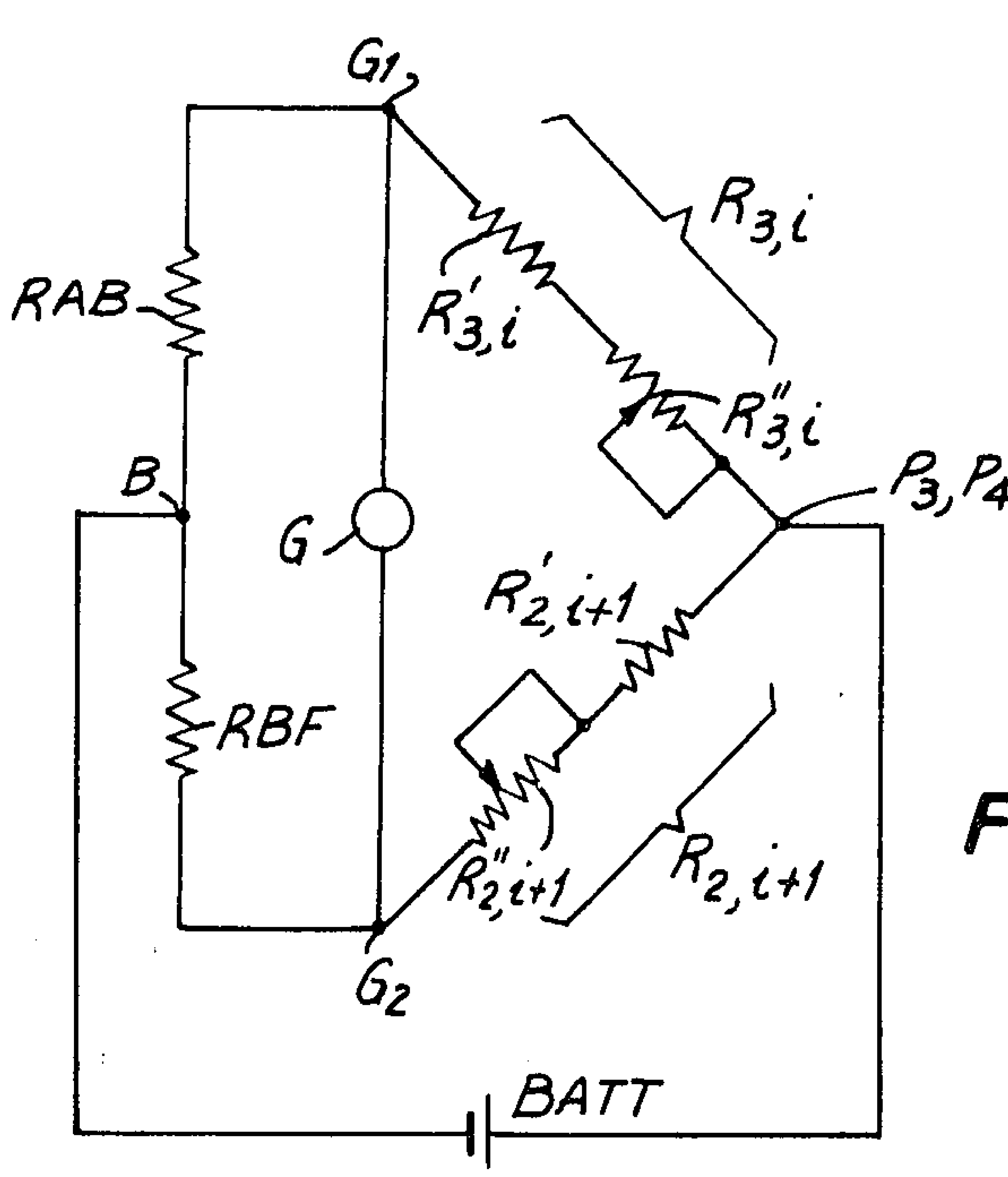
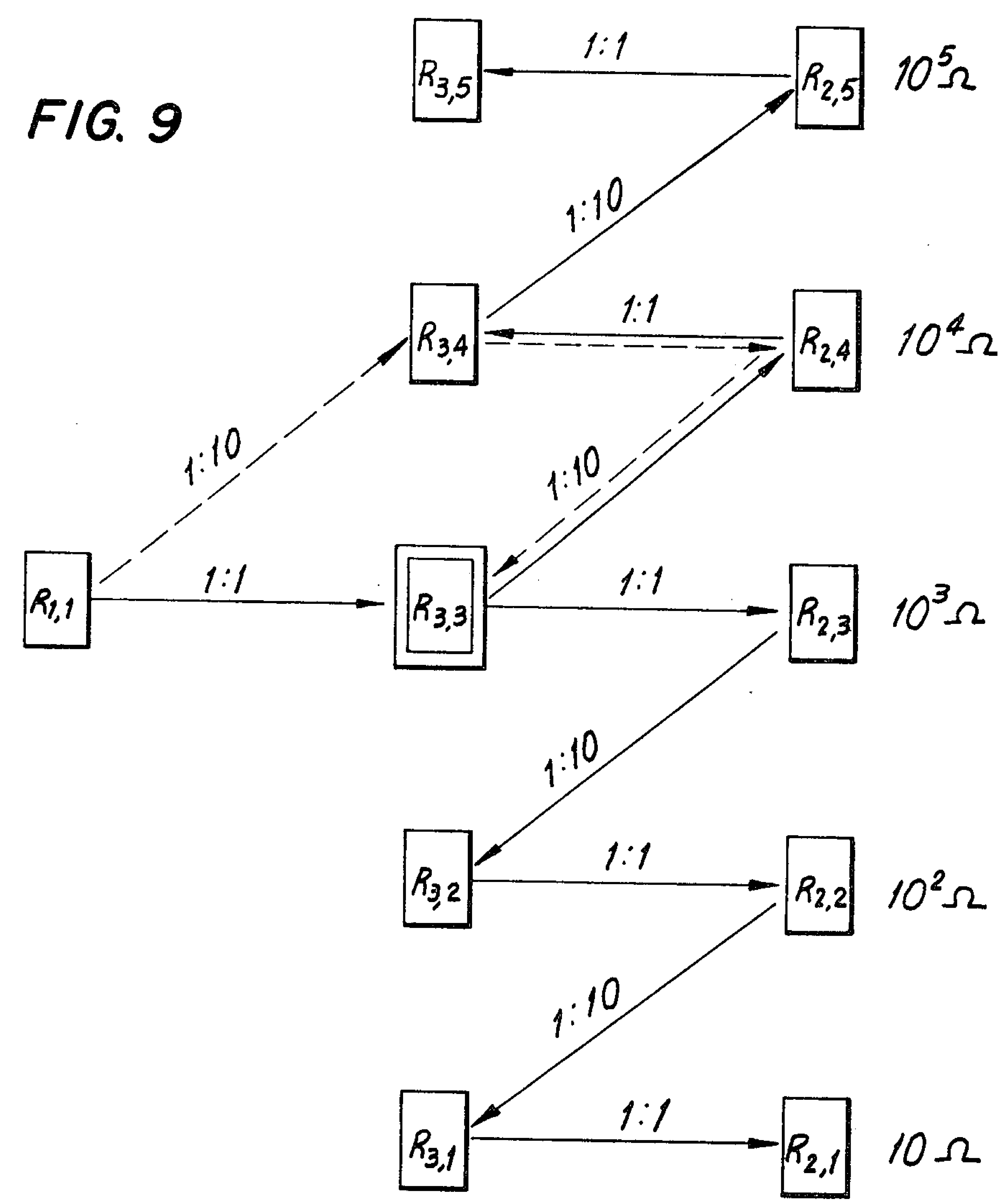

G1
R3,i
RAB
R'3,i
R''3,i
B
G
P3,P4
R'2,i+1
RBF
R''2,i+1
R2,i+1
G2
BATT

FIG. 8b

FIG. 9


$R_{3,5}$
1:1
$R_{2,5}$
$10^5 \Omega$
1:10
$R_{3,4}$
1:1
$R_{2,4}$
$10^4 \Omega$
1:10
1:10
$R_{1,1}$
1:1
$R_{3,3}$
1:1
$R_{2,3}$
$10^3 \Omega$
1:10
$R_{3,2}$
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1:10
$R_{3,1}$
1:1
$R_{2,1}$
10Ω

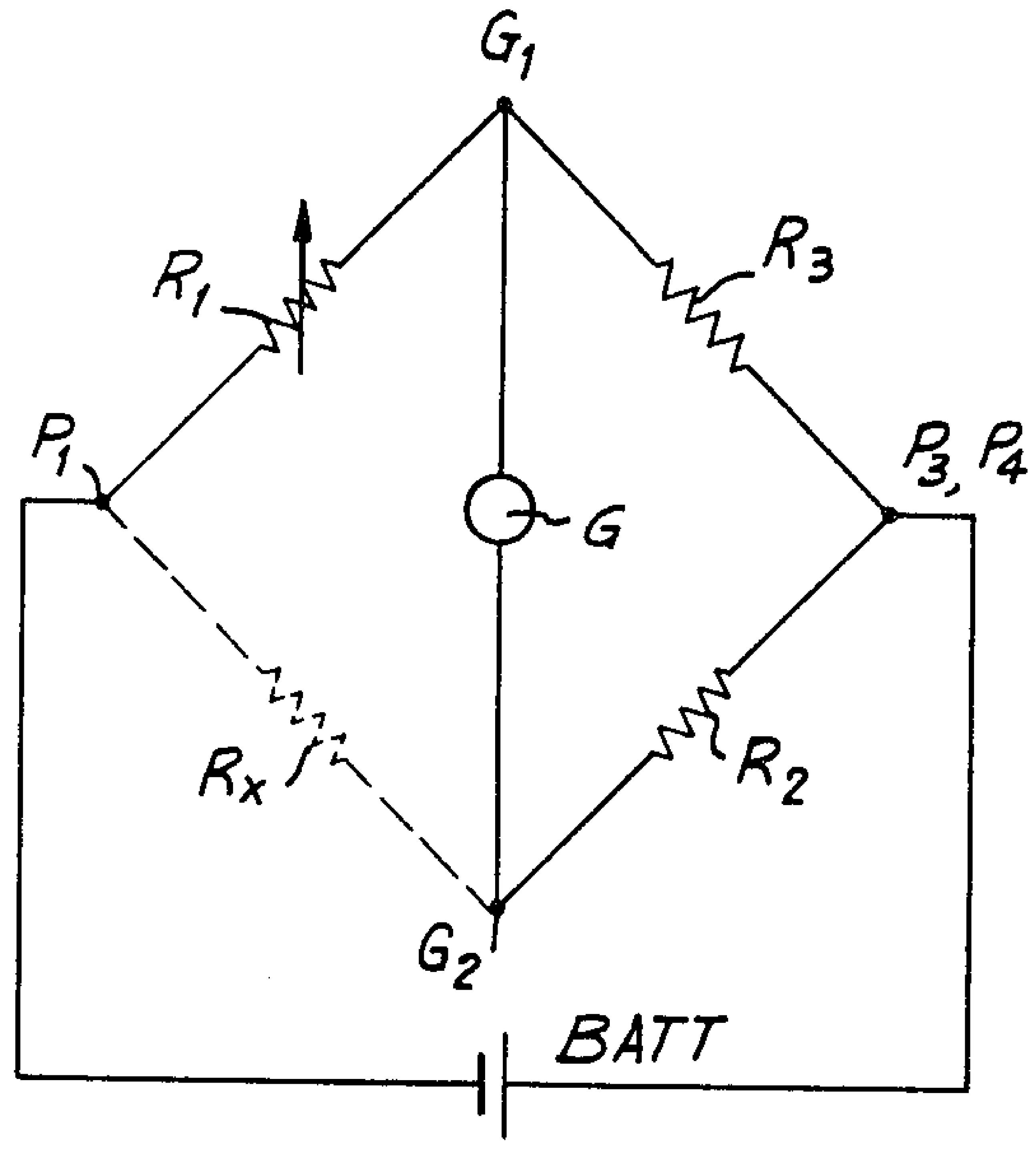
G1
R1
R3
P1
P3, P4
G
Rx
R2
G2
BATT

FIG. 10

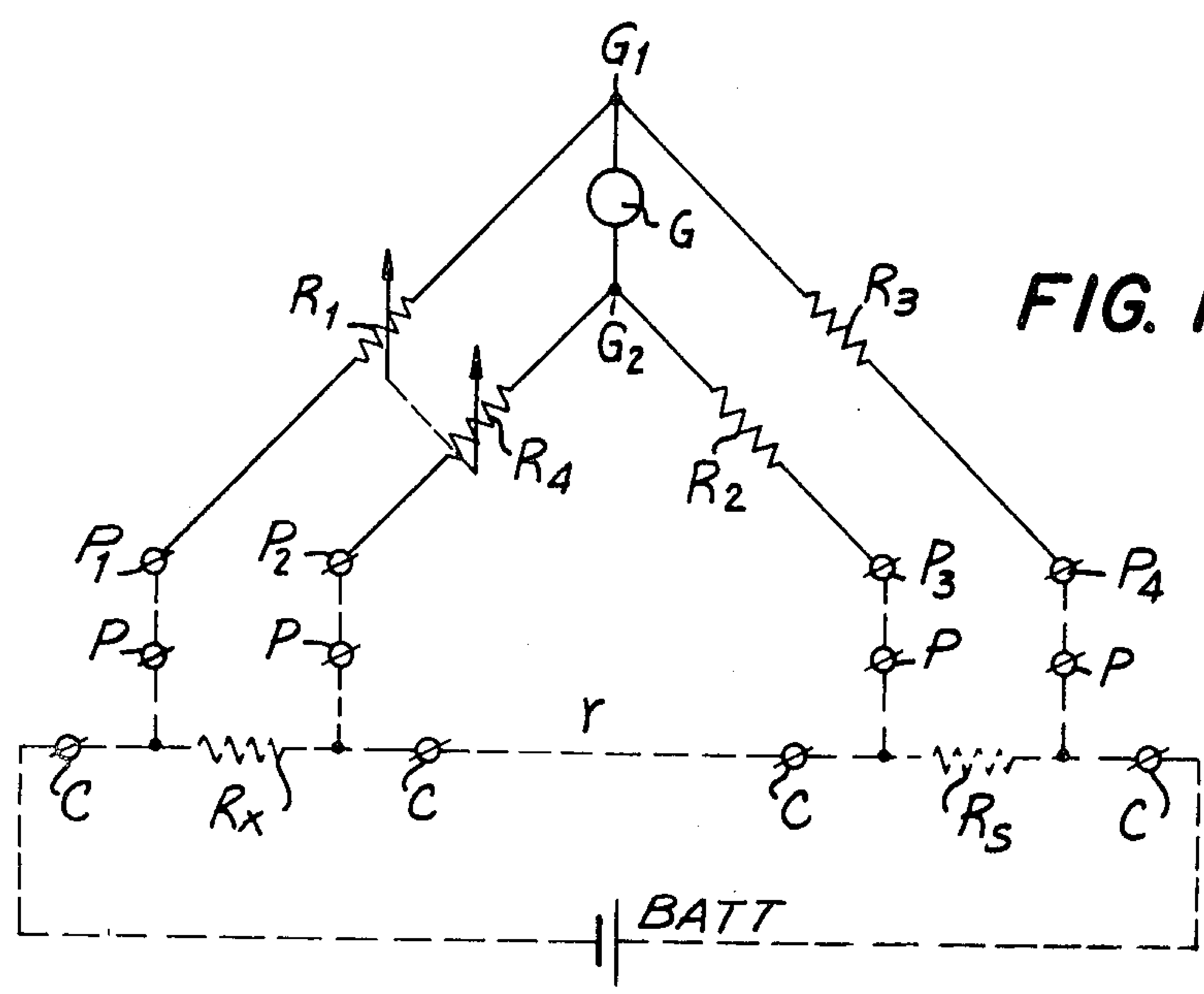
G1
G
R1
R3
G2
R4
R2
P1
P2
P3
P4
P
P
P
P
r
C
Rx
C
C
Rs
C
BATT

FIG. 11

WHEATSTONE-THOMSON COMBINED ELECTRICAL MEASURING BRIDGE

This is a continuation-in-part of Ser. No. 674,796 filed Oct. 12, 1967, now abandoned.

The present invention relates generally to bridge-type, measuring circuits, and more particularly to Thomson-Wheatstone bridges.

In Thomson-Wheatstone bridges, which are in themselves well known, the accuracy of readings is set either for a narrow range of temperatures or for a strictly fixed temperature. In case of temperature variations, an additional error in the bridge reading may occur which is due to different temperature resistance characteristics of the bridge arms. Moreover, the accuracy of readings also depends upon the adjustment and stability of the bridge arm resistances throughout the life of the apparatus.

It is an object of the present invention to provide a Thomson-Wheatstone bridge having improved accuracy of readings despite deviations of temperature from the aforementioned narrow temperature range or from said fixed temperature.

It is another object of the present invention to provide an improved bridge which is not characterized by instability with the passage of time.

According to the invention, a Thomson-Wheatstone bridge will incorporate main and auxiliary adjustable arms which comprise a plurality of decade units, with the resistances thereof having a relationship with one another such as 1:1, 1:10, 1:100; 1:1,000 and so forth. Two adjustable ratio arms are also employed, each of which consists of a number of parallel circuits each incorporating a nonadjustable resistor, an adjustable resistor and a switch. The resistances of the aforementioned circuits being have relationships with the resistances of the decade units such as 1:1, 1:10, 1:100, 1:1,000 and so forth.

According to the present invention, use is made of a plurality of series-connected sections incorporating both nonadjustable and adjustable resistors with the resistances of the sections being approximately in a relationship such as 1:1:3:3:3:(3·10):):((3·10a);(3⁾: ⁽3·10):(.10):(3^2):$(.10^2)$:(3^2):$(.10^2)$:(3^2):... $(.10^2)$:...(3^m):$(.10^m)$:(3^m):$(.10^m)$:$(3\cdot 10^m$), wherein m is a positive integer.

Switches serve to effect parallel connection of three of the sections whose resistances have a relationship of 1:1:1. There is obtained, on adjustment of the above-mentioned sections, which constitute a standard of resistance ratio means in the aforementioned Thomson-Wheatstone bridge and whose component members are introduced into the circuit of the Wheatstone bridge, a standard resistance ratio between the first section and the total resistances of the remaining sections of the standard of resistance ratio. Said remaining sections are series-connected to the first section. The standard resistance ratio equals $1:10^n$, wherein n is an integer or zero.

Also included are multiposition switches which help to form 3,4 of the bridge arm R_3, its resistance ratio with the resistor $R_{1,1}$ being the Wheatstone bridge by the use of the sections of the aforementioned standard of =ratio means and the arms of said Thomson-Wheatstone bridge, for adjusting said standard of resistance ratio and adjustable arms of the bridge ratio, as well as for forming the Wheatstone bridge circuit and the Thomson bridge circuit from the arms of the said Thomson-Wheatstone bridge. The aforementioned standard of resistance ratio means is switched out when measuring an unknown resistor.

With a view toward obtaining standard ratios such as 1:1 and 1:10 between the resistances of the sections in the above-mentioned standard of resistance ratio means the latter can be made of five series-connected sections in which the first section incorporates a nonadjustable resistor r_1 and the second section comprises a nonadjustable resistor r_2 and an adjustable resistor r_3. The resistance of said section with $r_3 \approx 0.5 : r_{3max}$ approximately equals that of the aforementioned first section, with r_{3max} being the maximum value of the adjustable resistor r_3. The third section incorporates a nonadjustable resistor r_4 whose nominal value is 3 times as high as the nominal value of the resistance of the aforementioned first section. The fourth section incorporates a nonadjustable resistor r_5 whose nominal value is 3 times as high as the nominal value of the resistance of the aforementioned first section. The fifth section incorporates a nonadjustable resistor r_6 and an adjustable resistor r_7, with the resistances of said section being 3 times as high as the resistance of the aforementioned first section with $r_7 \approx 0.5\ r_{7max}$, wherein r_{7max} is the maximum value of the adjustable resistor r_7.

A switching arrangement is employed by which the aforementioned third, fourth and fifth sections may be connected in parallel. Said switching arrangement incorporates both a first switch adapted to short-circuit a junction, where the aforementioned second and third sections are connected, to a junction connecting the aforementioned fourth and fifth sections, and a second switch adapted to short-circuit a junction, where the aforementioned third and forth sections are connected, to the end of the aforementioned fifth section.

A multiposition switch is adapted to form a circuit arrangement of the main adjustable arm and both tuned bridge arms and sections of the aforementioned standard of resistance ratio means. This obtains the circuit of the Wheatstone bridge for adjusting the aforementioned standard of resistance ratio means. The above-mentioned multiposition switch is adapted to connect the main adjustable arm, a tuned arm adjacent thereto and the other sections of the aforementioned standard of resistance ratio means to obtain the circuit of the Wheatstone bridge for adjusting one or two circuits of the arm undergoing tuning.

The multiposition switch is further adapted to connect both said arms being tuned and the sections of the aforementioned standard of resistance ratio means to form the circuit of the Wheatstone bridge for adjusting the resistances of said circuits of the arms involved. The above-mentioned multiposition switch is also adapted to connect to the circuit of the Wheatstone bridge the aforementioned main adjustable arm and both arms being tuned with the external resistance being measured and which is used as a fourth arm of said bridge. Said switch is additionally adapted to switch out said standard of resistance ratio means when measuring the unknown resistance. The above-mentioned multiposition switch is still further adapted to connect to the circuit of the Thomson bridge all the aforementioned arms together with the external resistance being measured and the standard resistance, which is introduced into the circuit as fifth and sixth arms of the Thomson bridge. A second multiposition switch connects the terminals of the aforementioned standard of resistance ratio means to said first multiposition switch.

Other objects and advantages of the present invention will be more apparent from a detailed consideration of exemplary embodiments thereof and the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic circuit diagram of a Wheatstone bridge;

FIG. 2 is a schematic circuit diagram of a Thomson bridge;

FIG. 3 is a schematic circuit diagram of a Thomson-Wheatstone bridge according to the invention;

FIG. 4 is a schematic circuit diagram of a standard of resistance ratio means, according to the invention;

FIG. 5 illustrates another embodiment of a standard of resistance ratio means, according to the invention;

FIGS. 6*a*, *b* and *c* are equivalent circuit diagrams of the Wheatstone bridge wherein the standard of resistance ratio means is tuned, according to the present invention;

FIGS. 7 a and b are equivalent circuit diagrams of the Wheatstone bridge, wherein one arm resistance is tuned according to the invention;

FIGS. 8 a and b are equivalent circuit diagrams of the Wheatstone bridge, wherein the resistances of two arms are tuned according to the invention;

FIG. 9 is a block diagram of a circuit used for the tuning of bridge arms;

FIG. 10 is an equivalent circuit diagram of the Wheatstone bridge with a resistance being measured in one of the arms according to the invention; and

FIG. 11 is a circuit diagram of the Wheatstone bridge with a standard resistances being measured according to the invention.

DETAILED DESCRIPTION

With a view toward elucidating the objects of the invention, let there be first considered the heretofore known circuit arrangements of Wheatstone and Thomson bridges.

In FIG. 1, a Wheatstone bridge is shown to comprise a resistance R_x, which is to be measured, an adjustable arm R_1, ratio arms R_2 and R_3, a null indicator G and a power supply Batt. The balance equation for the bridge is as follows:

$$R_x=R_1\,R_2/R_3$$

The equation to determine a relative error δR_x of the bridge readings may be written in the following form:

$$\delta R_x=\delta R_1+\delta R_2/\,R_3=\delta R_1+\delta R_2-\delta R_3\,,$$

wherein, δR_1, δR_2, δR_3 are relative errors which may occur in arm resistances R_1 and R_2 and in bridge resistance R_3, respectively.

The value of the error δR_x may be considerably diminished if δR_2 is made equal to δR_3, i.e., $\delta R_2=\delta R_3$. Then, $\delta R_x=\delta R_1$, i.e., the error in the bridge readings will depend upon the error of the bridge arm resistance R_1 only.

The Thomson bridge (FIG. 2) comprises a resistance R_x, which is to be measured, and a standard resistance R_s interconnected by a link r, as well as main adjustable arm R_1 and an auxiliary adjustable arm R_4, arms R_2 and R_3, a null indicator G and a power supply Batt.

The balance equation of the bridge is as follows:

$$R_x=R_sR_1/\,R_3+d,$$

wherein

$$d=\frac{r\cdot R_2}{r+R_2+R_4}\left(\frac{R_1}{R_3}-\frac{R_4}{R_2}\right)$$

The Thomson bridge is made so that the condition

$$R_1/R_3=R_4/R_2$$

holds true.

The link r features a very small resistance.

If $d=0$, then

$$R_x=R_s\,R_1/R_3\,,$$

and the equation to determine the relative error δR_x of the bridge readings may be written as follows:

$$\delta R_x=\delta R_s+\delta R_1/R_3=\delta R_s=\delta R_1-\delta R_3,$$

wherein δR_s is the relative error which may occur in the standard resistance R_s; δR_1 and δR_3 are relative errors which may occur in the resistances of the bridge arms R_1 and R_3, respectively.

The value of the error δR_x may be considerably diminished if δR_1 is made equal to δR_3, i.e., $\delta R_1=\delta R_3$. Then, $\delta R_x=\delta R_s$, and consequently, the error of the bridge readings will depend upon the error in the standard resistance R_s only.

FIG. 3 is a schematic circuit diagram of a Thomson-Wheatstone bridge, provided in accordance with the invention, which has neither the resistance R_x, which is to be measured, nor the standard resistance R_s. There resistances are not used for calibration of the bridge, which is provided with an external null indicator G and a power supply Batt which is adapted to supply power both to the circuit of the Wheatstone bridge wherein the calibration of the bridge is accomplished and to the circuit of the Wheatstone bridge to effect measurement of the resistance to be measured.

The bridge comprises a main adjustable arm R_1 and an auxiliary adjustable arm R_4 both consisting of a plurality of decade units, the resistances of the ranks of the different decade units having a relationship such as 1:1, 1:10,1:100; 1:1,000, and so forth.

The ratio arms R_2 and R_3 comprise a number of parallel circuits. Each parallel circuit of the arm R_2 consists of a nonadjustable resistor $R'_{2,i}$, and adjustable resistor $R''_{2,i}$ and a switch $S_{1,i}$, wherein the number of the circuit i=1,2,3,4,. . . m.

Each parallel circuit of the arm R_3 comprises a nonadjustable resistor $R'_{3,i}$, an adjustable resistor $R''_{3,i}$ and a switch $S_{2,i}$, wherein i again indicates the number of the circuit.

The resistances of the circuits of each arm R_2 and R_3 have a relationship approximately such as $1:10:10^2:10^3 10^4:.....10^m$

For example,

$R_{2,1}\approx R_{3,1}\approx 10\Omega$
$R_{2,2}\approx R_{3,2}\approx 100\Omega$
$R_{2,3}\approx R_{3,3}\approx 1{,}000\Omega$
$R_{2,4}\approx R_{3,4}\approx 10{,}000\Omega$
$R_{2,5}\approx R_{5,5}\approx 1000{,}000\Omega$

The resistances of the parallel circuits of the arms R_2 and R_3 have a relationship with the resistances of the decade units of the above-mentioned arms R_1 and R_4 such as 1:1, 1:10, 1:100, 1:1000, and so forth.

The bridge incorporates a standard of resistance ratio unit consisting of five series-connected sections AB, DC, CD, DE and EF, whose resistances are approximately in a relationship such as 1:1:3:3:3. The first section (AB), which is assumed to be a reference section, consists of a nonadjustable resistor r_1; the second section (BC) comprises a nonadjustable resistor r_2 and an adjustable resistor r_3, the resistance of the section BC approximately equaling the resistance of the aforementioned section AB with $r_3\approx 0.5\ r_{3max}$, wherein r_{3max} is the maximum value of the resistor r_3.

The third section (CD) and the fourth section (DE) incorporate the nonadjustable resistors r_4 and r_5, respectively, the resistance of the sections CD and DE being approximately three times the resistance of the aforementioned section AB.

The fifth section (EF) comprises the nonadjustable resistor r_6 and adjustable resistor r_7 the resistance of this section being approximately 3 times the resistance of the aforementioned section AB with $r_7\approx 0.5r_{7max}$, wherein r_{7max} is the maximum value of the resistor r_7.

The standard of resistance ratio unit incorporates a switch S_3 adapted to short circuit the junction "C," where the sections BC and CD are interconnected, to the junction E where the sections DE and EF are interconnected, and a switch S_4 adapted to short circuit the junction D, where the sections CD and DE are interconnected, to the point F of the section EF.

Switches $S_{5,1}$–$S_{5,2}$–$S_{5,3}$–$S_{5,4}$–$S_{5,5}$ and S_6 provide for connection of the above-mentioned component members of the bridge to form the circuit of the Wheatstone bridge for adjusting both the standard of resistance ratio unit and the arms R_2 and R_3 of the aforementioned Thomson-Wheatstone bridge, as well as to form the circuit of the Wheatstone bridge and that of the Thomson bridge to measure unknown resistances. In the latter two cases, the standard of resistance ratio unit is switched out of the bridge circuit.

FIG. 4 is a schematic diagram of the standard resistance ratio unit of FIG. 3 arranged to obtain a standard resistance ratio of 1:1 and 1:10.

It follows from the abovesaid that

$$r_2+r_{3,min}<r_1<r_2+r_{3,max}$$
$$r_4\approx r_5\approx 3r_1$$
$$r_6+r_{7,min}<3r_1<r_6+r_{7,max}$$

wherein $r_{3\ min}$ and $r_{7\ min}$ are the minimum values of resistors r_3 and r_7, respectively.

On closing of the switches S_3 and S_4, the sections CD, DE and EF are connected in parallel due to which the equivalent resistance of the portion CF ($R_{CF\ p}$) will be approximately equal to the resistance of the aforementioned section AB, i.e.,

$$R_{CF\ p}\approx R_{AB}.$$

By adjusting the resistor R_3, the condition $R_{BC}=R_{AB}$ may be accomplished with a high degree of accuracy, due to which fact the ratio of the resistances R_{AB} and R_{BC} is equal to:

$$K_1=R_{AB}:R_{BC}=1:1$$

By adjusting the resistor r_7, the condition $R_{CF\ p}=R_{AB}$ may likewise be accomplished with a high degree of accuracy. On opening of the switches S_3 and S_4 the resistance of the portion CF is equal to:

$$R_{CF}=R_{CD}+R_{DE}+R_{EF}=9R_{AB}$$

while the resistance of the circuit between the points B and F is equal to:

$$R_{BF}=R_{BC}+R_{CF}=10R_{AB}.$$

Consequently, the resistance ratio of R_{AB} and R_{BF} is equal to:

$$K_{10}=R_{AB}:R_{BF}=1:10.$$

Thus, the arrangement implemented according to the circuit diagram of FIG. 4 provides the possibility of obtaining with a high degree of accuracy the resistance ratios of 1:1 and 1:10, and may serve as a standard resistance ratio unit which is employed to adjust the arms R_2 and R_3 used in the aforementioned Thomsom-Wheatstone bridge.

The standard of resistance ratio unit may provide the possibility of obtaining a standard resistance ratio $1:10^n$, wherein r is an integer or zero.

With this purpose in view, the standard of resistance ratio unit is made of a group of series-connected nonadjustable and adjustable resistors which form the various sections, their resistances being approximately in a relationship such as $1:1:3:3:3:(3\cdot10):(3\cdot10):(3\cdot10^2):(3\cdot10^2):(3\cdot10^2)\ldots\ldots:(3\cdot10^m):(3\cdot10^m):(3\cdot10^m)$, wherein m is a positive integer.

Shown as an example in FIG. 5 is a circuit diagram of a standard of resistance ratio unit that provides the possibility of obtaining the reference ratios 1:1, 1:10, and 1:100.

This standard of resistance ratio unit features a sixth section (FH) and a seventh section (HL) which are adapted to switch in the nonadjustable resistors r_8 and r_9, respectively, with the resistances of the sections FH and HL being approximately 30 times the resistance of the aforementioned section AB. An eighth section LM which incorporates the nonadjustable resistor r_{10} and adjustable resistor r_{11} has a resistance approximately 30 times that of the section AB with $r\approx0.5r_{11max}$ where r_{11max} is the maximum value of the resistor r_{11}.

The sections FH, HL and LM incorporate switches S_7 and S_8 , the former being adapted to short circuit the junction F, whereat the sections EF and FH are interconnected, to the junction L whereat the sections HL and LM are interconnected. The switch S_8 is adapted to short circuit the junction H, whereat the sections FH and HI are interconnected, to the junction H of the section LM.

On closing of the switches S_7 and S_8, the sections FH, HL and LM are connected in parallel due to which fact the equivalent resistance of the portion FM ($R_{FM,p}$) will approximately equal the resistance of the portion BF with the switches S_3 and S_4 being open.

Let it be assumed that the adjustment of the section BC and the portion CF has been completed as described above. By adjusting the resistance r_{11}, the condition $R_{FM,p}=R_{BF}$ may be accomplished with a high degree of accuracy. On opening of the switches S_7 and S_8, the resistance of the portion FM is equal to:

$$R_{FM}=R_{FH}+R_{HL}+R_{LM}=9R_{BF}$$

It has been proved hereinabove that $R_{BF}=10R_{AB}$

Consequently $R_{FM}=90R_{AB}$.

The resistance in the circuit between the points B and M is equal to

$$R_{BM}=R_{BF}+R_{FM}=10R_{AB}+90R_{AB}=100R_{AB}.$$

Consequently, the resistance ratio between R_{AB} and R_{BM} is

$$K_{100}=R_{AB}:R_{BM}=1:100.$$

Analoqously, a standard of resistance ratio can be obtained which has addition additional reference ratios of 1:1,000, 1;10,000, and so forth.

The Thomson-Wheatstone bridge disclosed herein operates as follows.

The adjustment of the sections of the standard of resistance ratio unit is effected in the circuit arrangement of the Wheatstone bridge, its equivalent circuits being shown in FIGS. 6*a*, *b* and *c*, which is formed of the aforementioned component members of the bridge in the following way:

1. The multiposition switch $S_{5,1}$–$S_{5,2}$–$S_{5,3}$–$S_{5,4}$–$S_{5,5}$ (FIG. 3) and the multiposition switch S_6 are set in position I (FIG. 3) and the resistor of the section AB of the standard of resistance ratio unit is connected to the bridge apices P_1 and G_2.

The arms R_2 and R_3 (FIG. 6*a*) feature the required values of the resistances and the bridge is balanced by the adjustment of the Bridge arm R_1. 2. The switch $S_{5,1}$–$S_{5,2}$–$S_{5,3}$–$S_{5,4}$–$S_{t,5}$ (FIG. 3) is in position I, the switch S_6 is set in position II and the resistor of the section BC of the standard of resistance ratio is connected to the aforementioned apices R_1 and G_2; the equivalent circuit arrangement of the Wheatstone bridge thus formed is shown in FIG. 6*b*. With the values of the resistances of the arms R_1, and R_2 and R_3 set earlier, the bridge is balanced by the adjustment of the resistor r_3 of the standard of resistance ratio unit. As a result of tuning, there is obtained $R_{BC}=R_{AB}$. 3. The aforementioned switch $S_{5,1}$—$S_{5,2}$–$S_{5,3}$–$S_{5,4}$–$S_{5,5}$ FIG. 3 remains in position I, the switch S_6 is set in position III and the above-mentioned switches S_3 and S_4 of the standard of resistance ratio unit are closed; in the case, the parallel resistors of the sections CD, DE and EF are connected to the bridge apices P_1 and G_2; the equivalent circuit arrangement of the Wheatstone bridge thus formed is shown in FIG. 6*c*. With the earlier set values of the resistances of the aforementioned arms R_1, R_2 and R_3, the bridge is balanced by adjustment of the resistor r_7. As a result of tuning, there is obtained

$$R_{CF,p}=R_{AB}.$$

Then, the resistor of one of the above-mentioned circuits of the arm R_3, say $R''_{3\ 3}$ (FIG. 3) is tuned to obtain a ratio, between its resistance and the resistance of one rank or ten ranks of the decade unit of the arm R_1, equal to either 1:1, or 10:1.

To obtain the ratio of 1:1, the tuning is accomplished by the circuit arrangement of the Wheatstone bridge (cf.FIG.7*a*) formed by the bridge arms R_1 and R_3 and the sections AB and BC of the standard of resistance ratio unit.

With this purpose in view, the switch $S_{5,1}$–$S_{5,2}$–$S_{5,3}$–$S_{5,4}$–$S_{5,5}$ (FIG. 3) is set in position II, while the switch S_6 is set in position IV. In this case, the arm R_1 has values of resistance equal to that of the bridge arm R_3. For example, switched into the circuit is the first stage $R_{1,1}$ of the first (highest-order) decade unit. The bridge thus formed (cf.FIG.7*a*) is balanced by adjustment of the above-mentioned resistor $R''_{3,3}$ of the bridge circuit $R_{3,3}$. Since the standard of resistance ratio unit is already tuned, $R_{AB}:R_{BC}=1:1$. Consequently, upon balancing of the bridge, the resistance of the aforementioned circuit $R_{3\ 3}$ of the bridge arm R_3 equals, with a high degree of accuracy, the resistance $R_{1\ 1}$ introduced into the arm R_1.

To tune the resistance of the circuit $R_{3,4}$ of the bridge arm R_3, its resistance ratio with the resistor $R_{1,1}$ being 10:1, it is necessary to set the relationship of $K_{10}=1:10$ in the standard of resistance ratio unit for which purpose the switch S_6 is set in the position V and the switches S_3 and S_4 are opened. The equivalent circuit arrangement of the Wheatstone The equivalent circuit arrangement of the Wheatstone bridge is shown in FIG. 7*b*. The bridge is balanced by the adjustment of the resistor $R''_{3,4}$ of the bridge circuit $R_{3,4}$.

Since the standard of resistance ratio unit is already tuned, $R_{AB}:R_{BF}\times1:10$. Consequently, after bridge balancing, the resistance of the circuit $R_{3,4}$ of the bridge arm R_3 relates with a high degree of accuracy to the resistor $R_{1,1}$ as ten to one, i.e., $R_{3,4}:R_{1,1}=10:1$.

Tuning of the resistances of the bridge arms R_2 and R_3 is effected in the Wheatstone bridge formed by said bridge arms and the sections of the standard of resistance ratios. With this purpose in view the aforementioned switch $S_{5,1}$–$S_{5,2}$–$S_{5,3}$–$S_{5,4}$–$S_{5,5}$, is set in the position III, whereas the switch S_6 is set in the position IV for the case when it is necessary to provide the ratio of the sections of the standard of resistance ratio equal to $K_1=1:1$, and in the position V, when it is necessary to provide the ratio of $K_{10}=1:10$, in the latter case the switches S_3 and S_4 must be switched out. The equivalent circuit arrangements of the Wheatstone bridge for both cases are shown in FIG. 8*a* ($K_1=1:1$) and in FIG. 8*b* ($K_{10}=1:10$).

An example of the sequence of operations to tune the resistors of the bridge ratio arms R_2 and R_3 is graphically shown in FIG. 9.

The resistance of the above-mentioned circuit $R_{3,3}$ of the arm R_3 tuned by the above-described method to provide the relationship between its resistance and the resistance $R_{1,1}$ of the arm R_1 as equal to 1:1, is assumed as a standard resistance (in FIG. 9 it is outlined with a two-line frame).

The arrow indicates the direction of transmission when tuning the value of the resistance of the standard resistance to the resistance to be tuned. Each tuned resistor is in fact a standard resistor for the resistor to be tuned next. Shown near the arrow is the value of resistance ratio set for the standard of resistance ratio unit.

Tuning is accomplished as follows:

a. Tuning of the resistor $R_{2,3}$ is effected by use of the resistor $R_{3,3}$. In the bridge arm R_2 (FIG. 3), the circuit resistor $R_{2,3}$ is switched into the circuit by the switch $S_{1,3}$, while in the bridge arm R_3 the circuit resistor $R_{3,3}$ is switched into the circuit by the switch $S_{2,3}$. The switches $S_{5,1}$–$S_{5,2}$–$S_{5,3}$–$S_{5,4}$–$S_{5,5}$ and S_6 are set to form the circuit arrangement of FIG. 8*a* in positions III and IV, respectively. The bridge is balanced by adjustment of the resistor $R''_{2,3}$, whereupon $R_{2,3}=R_{3,3}$.

b. Tuning of the resistor $R_{2,4}$ is effected by use of the resistor $R_{3,3}$. In the bridge arm R_2, the circuit resistor $R_{2,4}$ is switched into the circuit by the switch $S_{1,4}$ and the resistor $R_{3,3}$ remains connected in the circuit in the arm R_3. Since $R_{2,4} \approx 10R_{3a,3}$, the switch S_6 is set into the position V thereby switching in the standard of resistance ratio unit for the ratio of K_{10}=1:10. The switch $S_{5,1}$–$S_{5,2}$–$S_{5,4}$–$S_{5,5}$ remains in position III. As a result, the Wheatstone bridge circuit is formed which is shown in FIG. 8*b*. The bridge is balanced by adjustment of the resistor $R''_{2,4}$, whereupon $R_{2,4}=10R_{3,3}$.

c. Tuning of the circuit resistor $R_{3,4}$ of the arm R_3 is effected by use of the resistor $R_{2,4}$ of the arm R_2. A standard resistor assumed to be constituted by the tuned circuit resistor $R_{2,4}$. In the arm R_3, the circuit resistor $R_{3,4}$ is switched into the circuit by the switch $S_{2,4}$; the switch S_6 is set in position IV thereby switching in the standard of resistance ratio unit for K_1=1:1. As a result, the Wheatstone bridge is in the form of the circuit of FIG. 8*a*. The bridge is balanced by adjustment of the resistor R''_3 , whereupon $R_{3,4}=R_{2,4}=10R_{3,3}$.

d. The tuned circuit resistor $R_{3,4}$ of the arm R_3 is a standard resistance for the case of tuning the circuit resistor $R_{2,5}$ of the arm R_2 with K_{10}=1:10 in the standard of resistance ratio unit (FIG. 8*b*). After bridge balancing the the adjustable resistor $R''_{2,5}$

$$R_{2,5}=10R_{3,4}=100R_{3,3}.$$

(e) The tuned circuit resistor $R_{2,5}$ of the arm R_2 is a standard resistance when tuning the circuit resistor $R_{3,5}$ of the arm R_3 with K_1=1:1 in the standard of resistance ratio unit (FIG. 8*a*). After bridge balancing by the adjustable resistor $R''_{3,5}$, $R_{3,5}=R_{2,5}=100R_{3,3}$.

f. Tuning of the circuit resistor $R_{3,2}$ of the arm R_3 is effected by use of the previously tuned circuit resistor $R_{2,3}$ of the arm R_2. In the bridge arm R_3, the switch $S_{2,2}$ switches in the circuit resistor $R_{3,2}$ whereas, in the arm R_2, the switch $S_{1,3}$ switches in the circuit resistor $R_{2,3}$. Since $R_{3,2} \approx 0.1R_{2,3}$, the switch S_6 is set in position V, thereby switching in the standard of resistance ratio unit for the ratio of K_{10}=1:10 As a result, the Wheatstone bridge circuit (FIG. 8*b*) is formed. The bridge is balanced by adjustment of the resistor $R''_{3\ 2}$, whereupon

$$R_{3,2}=0.1\ R_{2,3}=0.1\ R_{3,3}.$$

g. The tuned circuit resistor $R_{3,2}$ of the arm R_3 is a standard resistor when tuning the circuit resistor $R_{2,2}$ of the arm R_2 with the ratio of K=1:1 in the standard of resistance ratio unit (FIG. 8*a*). After bridge balancing by the adjustable resistor $R''_{2,2}$:

$$R_{2,2}=R_{3,2}=0.1\ R_{3,3}.$$

h. The tuned circuit resistor $R_{2,2}$ of the arm R_2 is a standard resistor when tuning the circuit resistor $R_{3,1}$ of the arm R_3 with the ratio of K=1:10 in the standard of resistance ratio unit (FIG. 8*b*). After bridge balancing by the adjustable resistor $R''_{3,1}$, $R_{3,1}=0.1R_{2,2}=0.01\ R_{3,3}$.

k. The tuned circuit resistor $R_{3,1}$ of the arm R_3 is a standard resistor when tuning the circuit resistor $R_{2,1}$ of the arm R_2 with the ratio of K_1=1:1 in the standard of resistance ratios (FIG. 8*a*). After bridge balancing by the adjustable resistor $R''_{2,1}$.

$$R_{2,1}=R_{3,1}=0.01R_{3,3}.$$

Substituting the obtained values of the tuned resistances of the bridge arms R_2 and R_3 in the ratios of R_2/R_3 (for the Wheatstone bridge) and R_1/R_3 (for the Thomson bridge) there is obtained the values of said ratios with the compensated errors.

To measure unknown resistances, use is made of the Wheatstone bridge circuit arrangement which is formed when the switch $S_{5,1}$–$S_{5,2}$–$S_{5,3}$–$S_{5,4}$–$S_{5,5}$ is set in position IV. In this case, the standard of resistance ratio unit is disconnected from the bridge circuit. The equivalent Wheatstone bridge circuit is shown in FIG. 10. The resistor R_x being measured which is connected to the terminals P_1 and G_2, is an external resistance and is indicated by a broken line.

The Thomson bridge circuit to measure the unknown resistor R_x is formed when the switch $S_{5,1}$–$S_{5,2}$–$S_{5,3}$–$S_{5,4}$–$S_{5,5}$ is set in position V; in this case, the standard of resistance ratio unit is disconnected from the bridge circuit.

The resistor R_x being measured is connected by its potential terminals and through the use of conductors to the bridge terminal R_1 and P_2. The standard of resistance ratio unit is connected to the bridge terminals P_3 and P_4. The resistor R_x and R_s are external resistors.

The equivalent circuit arrangement of the Thomson bridge in shown in FIG. 11. The external resistors (R_x,R_s and r) and external conductors are indicated by a broken line).

The hereinabove considered Thomson-Wheatstone measuring bridge according to the present invention provides for minimizing the reading errors of the bridge irrespective of their causes which may include deviation of ambient temperature from the aforementioned narrow range of temperatures or from a strictly fixed temperature, unstability of bridge arm resistances doing life of the apparatus, or various other factors.

What is claimed is:

1. A Thomson-Wheatstone bridge for measuring the value of an unknown resistor, said bridge comprising main and auxiliary arms each being of adjustable resistance, first and second adjustable ratio arms each including a plurality of parallel circuits, each parallel circuit including a fixed resistor, an adjustable resistor and a switch connected in series, a standard of resistance ratio means including a plurality of serially connected sections inclusive of a first section and other said sections, said sections including resistors at least one of which is adjustable and is included in one of said other sections, said ratio means further including switch means for selectively connecting said other sections in parallel relationship with each other, said other sections being adapted to have substantially equal resistances, a voltage source, a null indicator, and selector switch means, first and second terminals respectively connecting said main to said first ratio arm and said auxiliary to said second ratio arm and across which terminals is connected said indicator, said arms including further terminals at ends remote from the first said terminals, said selector switch means being connected between said further terminals and to said ratio means and said first and second terminals, said source being connected to the further terminal of said first ratio arm and to said selector switch means, said selector switch means being adapted to connect said source, indicator, arms and ratio means in Wheatstone bridge arrangement for a tuning of said ratio means and ratio arms, said selector switch means being further adapted to connect said source, indicator and arms in Thomson-Wheatstone bridge arrangement while disconnecting the ratio means therefrom, said unknown resistor being connected for measurement between said second terminal and the further terminal of said main arm.

2. A bridge as claimed in claim 1, wherein said main and auxiliary arms comprise decade units.

3. A bridge as claimed in claim 2, wherein the ratio of the resistance of said first section to the total resistance of said

other sections is a reference ratio equal to $1:10^n$ wherein n is an integer or zero.

4. A bridge as claimed in claim **3**, wherein the decade units of said main and said auxiliary units include ranks of resistances with a relationship of 1:1, $1:10...1:10^m$ wherein m is an integer and wherein the resistances of said parallel circuits have the same relationship.

5. A bridge as claimed in claim **4**, wherein said other sections of the ratio means include second, third, fourth and fifth sections connected in series with said first section, said first section including a fixed resistor, said second section including fixed and adjustable resistors in series, said second section having a resistance substantially equal to that of said first section, the latter said adjustable resistor having a resistance $r_3 \approx 0.5 r_{3max}$ wherein 5_{3max} is the maximum value of r_3.

6. A bridge as claimed in claim **5**, wherein said third and fourth sections include fixed resistors each having a resistance equal to three times the resistance of the first section.

7. A bridge as claimed in claim **6**, wherein said fifth section includes fixed and adjustable resistors the total resistance of which is about three times that of the first section, the latter said adjustable resistor having a resistance $r_7 \approx 0.5 r_{7max}$ wherein r_{7max} equals the maximum value of r_7.

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