Sept. 24, 1946. K. S. JOHNSON 2,408,072

TELEPHONE REPEATER CIRCUIT

Filed Dec. 31, 1943 3 Sheets-Sheet 1

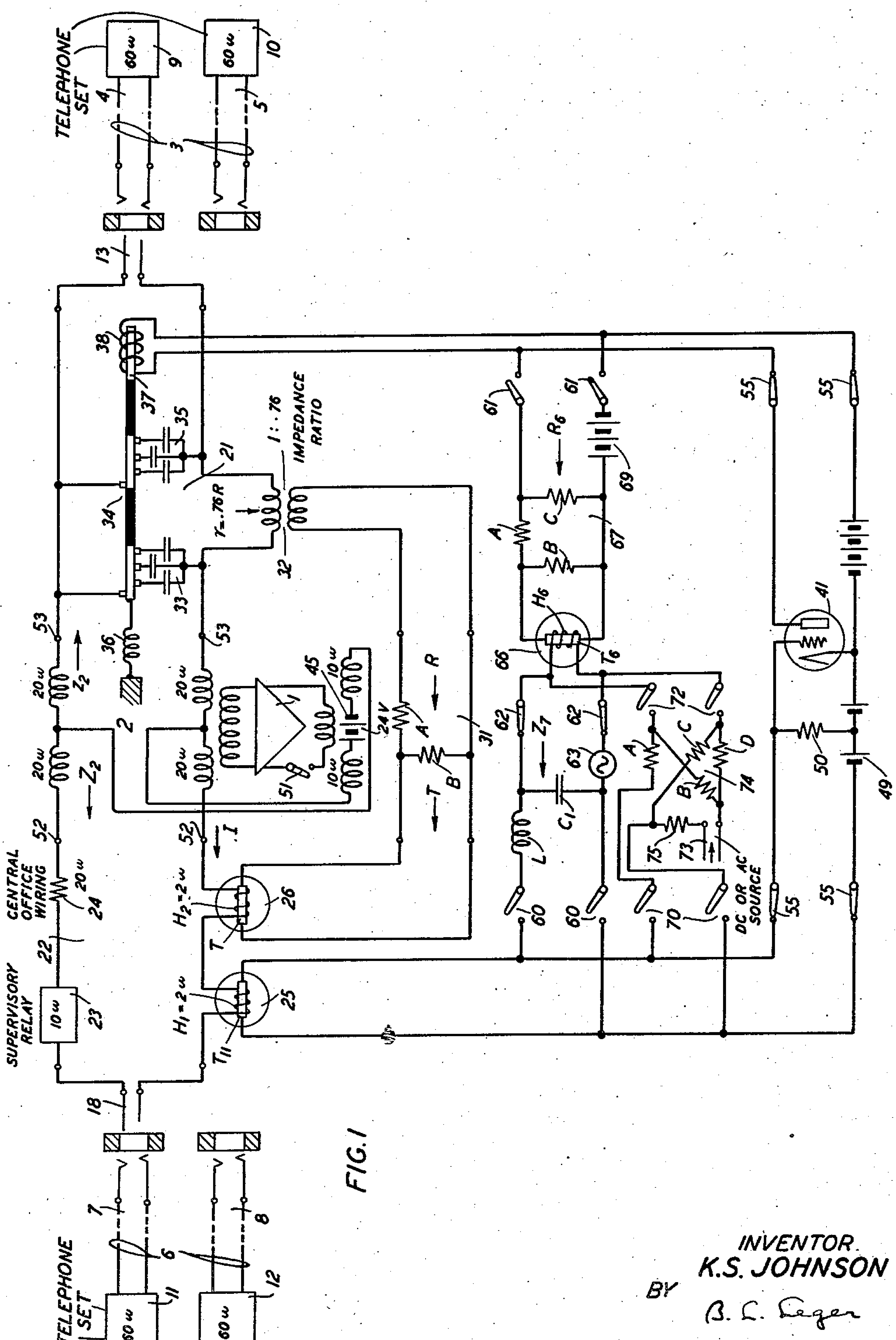


FIG. 1

INVENTOR
K.S. JOHNSON
BY B. C. Leger
ATTORNEY

FIG. 2

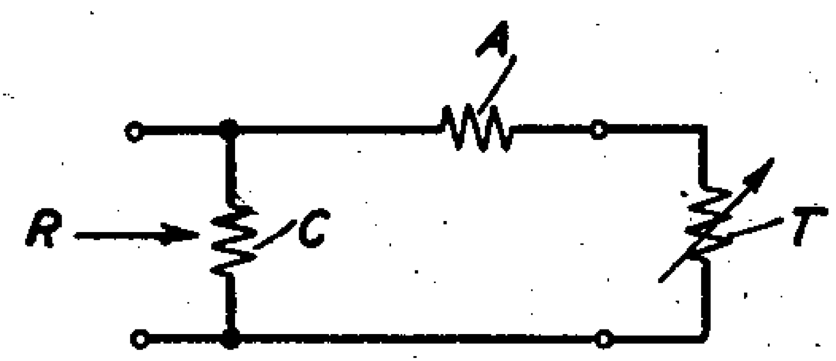


FIG. 3

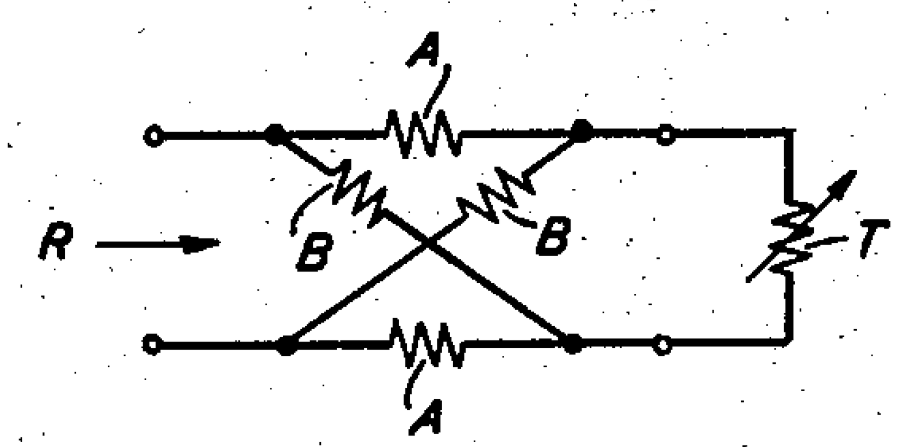


FIG. 4

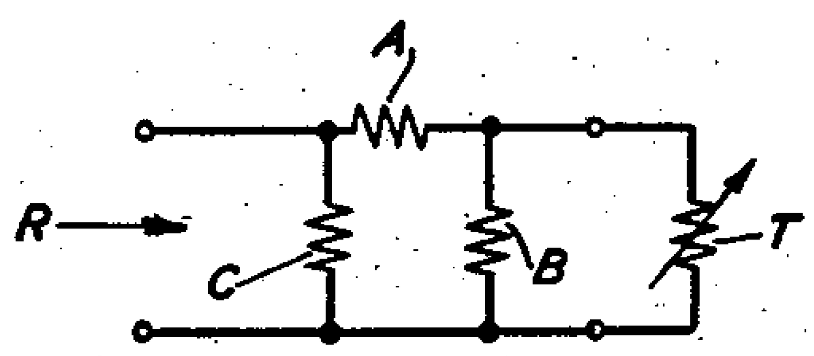


FIG. 5

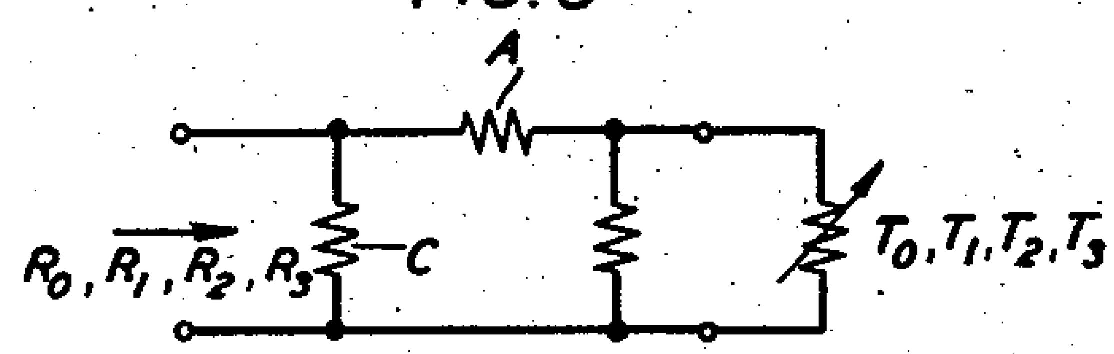
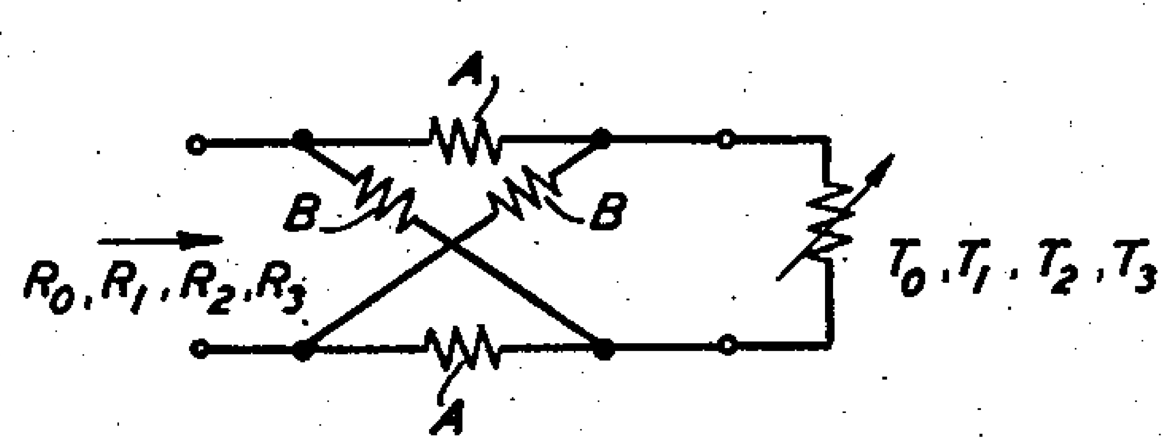


FIG. 6



INVENTOR
K. S. JOHNSON
BY
B. C. Feger
ATTORNEY

Sept. 24, 1946. K. S. JOHNSON **2,408,072**

TELEPHONE REPEATER CIRCUIT

Filed Dec. 31, 1943 3 Sheets-Sheet 3

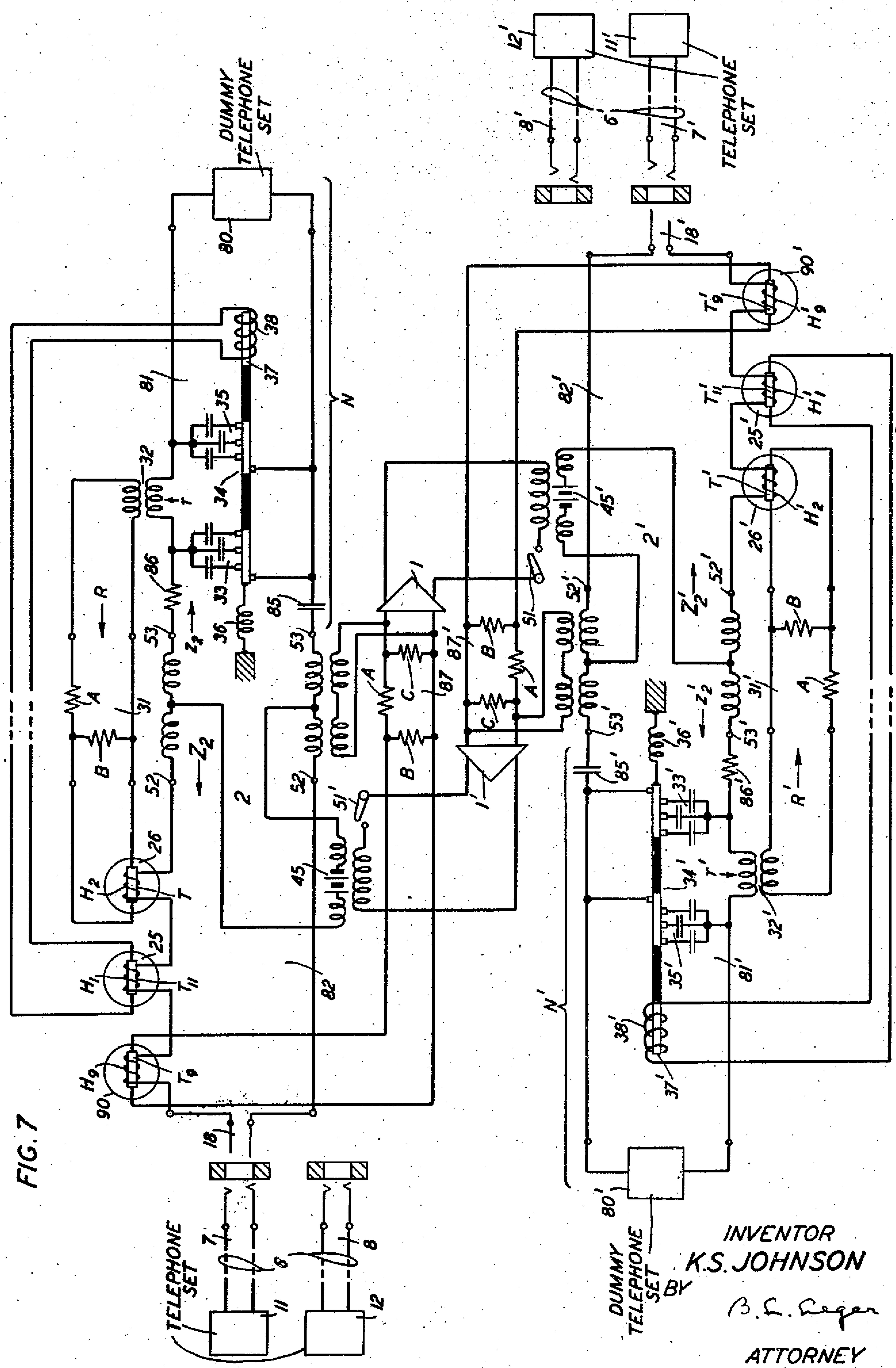


FIG. 7

INVENTOR
K. S. JOHNSON
BY
B. C. Seger
ATTORNEY

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UNITED STATES PATENT OFFICE

2,408,072

TELEPHONE REPEATER CIRCUIT

Kenneth S. Johnson, South Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application December 31, 1943, Serial No. 516,464

16 Claims. (Cl. 179—170)

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This application is in part a continuation of my copending application Serial No. 509,056, filed November 5, 1943, for Telephone repeater circuits.

This invention relates to systems, as for example, telephone repeater systems, involving networks that include conjugate circuits and have a branch subject to impedance variation that disturbs the conjugacy.

An object of the invention is to maintain conjugacy in such networks.

In one specific aspect the invention is a system comprising a cord circuit repeater for connection to any chosen one of a group of subscriber loops of various impedances, and having direct current supplied from the cord circuit over the connected loop for talking or supervisory purposes, the cord circuit repeater including thermistor means responsive to the direct current to so adjust the impedance of a balancing circuit for the loop as to establish impedance balance between the loop and the balancing circuit.

Other objects, aspects and features of the invention will be apparent from the following description and claims.

Fig. 1 shows a system in which the invention is applied to a cord circuit repeater of the 21-type;

Figs. 2 to 6 show four-terminal networks useful in systems such, for example, as those of Figs. 1 and 7; and

Fig. 7 shows a system in which the invention is applied to a cord circuit repeater of the 22-type.

In Fig. 1 is shown a cord circuit or connecting circuit, comprising a 21-type repeater including amplifier 1 and bridge transformer (hybrid coil) 2, for connecting any chosen one of a group 3 of a considerable number of subscribers' loops such as the two indicated at 4 and 5 with any chosen one of a group 6 of a considerable number of subscribers' loops such as the two indicated at 7 and 8. The loops are shown terminated in substation sets 9, 10, 11 and 12, which may each have an impedance of 60 ohms, for example.

Switching means of any suitable type, as for example plug 13 for cooperation with jacks of loops 3 and plug 18 for cooperation with jacks of lines 6, may serve to connect the cord circuit with loops 3 and 6.

The loops 3 have their impedances facing the cord circuit approximately equal. For example, they may be private branch exchange loops of negligible length, or may be loops in a congested business area, all of substantially the same length.

The loops 6 may have various lengths, or substantially different impedances facing the cord

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circuit; and, indeed, any one may be considered to include one or more interoffice trunks of considerable lengths (switched in at times in extending the talking connection from the cord circuit to a desired subscriber station) so that its impedance facing the cord circuit suffers substantial variation.

The cord circuit includes a link 21 connecting hybrid coil 2 with plug 13, and a link 22 connecting the hybrid coil with plug 18. The link 22 includes supervisory relay 23 and central office wiring represented by its equivalent resistance 24. Two thermistors 25 and 26 comprise temperature-dependent resistances T_{11} and T (which may have negative temperatures coefficients of resistance) and heater elements H_1 and H_2 electrically insulated from T_{11} and T. (Thermistors are described in an article by G. L. Pearson at page 106 of the Bell Laboratories Record for December 1940.) The elements H_1 and H_2 are in series in the link 22. Resistance T is connected in series in the link 21 through an impedance-modifying network 31 and an impedance transformer 32. The (variable) resistance of element T is designated T and that of T_{11} is designated T_{11}. The resistance presented to the transformer 32 by the network 31 terminated by T is designated R. The resistance inserted in the link 21 by the transformer 32 is designated r. This resistance forms the series arm of a π-network in the link 21, one of the shunt arms including a group of condensers 33 adapted to be connected in parallel by a sliding switch 34, and the other shunt arm including a group of condensers 35 adapted to be connected in parallel by the switch 34.

The switch 34 is shown drawn to its extreme right-hand position against the tension of the spring 36, by action, on its soft iron plunger 37, of flux due to current in its operating coil 38. This current may be space current of a tube 41, controlled by temperature-responsive resistance T_{11}. As described hereinafter, this current can be reduced by heating T_{11}. Then spring 36 can draw switch 34 to the left. The switch in this movement to the left, can remove from circuit the condensers 33 successively, and simultaneously remove from circuit the condensers 35 successively. In the extreme left-hand position of the switch, all of the condensers 33 and 35 will be out of circuit.

Direct current is supplied to the substation telephone sets connected to the cord circuit from battery 45 (of 24 volts, for example) through the connecting loops. This direct current applied over the loops to the substations may be either for talking and supervisory purposes, if the substation is of the common battery type with its transmitter energized from battery 45, or for supervisory purposes only, if the substation is of the local battery type with common battery supervision. For the sets connected to loops 3, this direct current can be supplied via link 21 and the loop 3 to which plug 13 is connected. For the sets connected to loops 6, the direct current can be supplied via link 22 and the loop 6 to which plug 18 is connected. This direct current in link 22 flows through heaters H_2 and H_1 and is the current for heating them and thereby controlling the temperatures of T and T_{11} and consequently the resistances of T and T_{11}. (The heating effects of the voice currents or alternating currents flowing in H_2 and H_1 upon T and T_{11} are negligibly small.)

When plug 18 is disconnected from all of the loops 6, no direct current flows through heaters H_2 and H_1. Then T, R, and r have their maximum values. T_{11} also has its maximum value, so the current flowing from battery 49 through resistor 50 has its minimum value. Consequently, the component of negative grid bias then furnished for tube 41 by the voltage drop across resistor 50 due to this current in 50, has its minimum value; and the space current of tube 41 flowing in coil 38 has its maximum value, so switch 34 is in its extreme right-hand position, as shown.

When the cord circuit is connected between two loops, it is desired that before switch 51 is closed to complete the repeater circuit, the link 21 automatically be given any adjustment required for building out the impedance of the connected loops 3 to make the impedance z_2 presented to terminals 53 of the hybrid coil equal the impedance Z_2 presented to terminals 52 of the hybrid coil or balance the impedance Z_2 sufficiently well to prevent the repeater from having any undue singing tendency.

This automatic adjustment is effected by response of thermistor 26 and network 31 to give r the proper value, and response of thermistor 25, tube 41 and switch 34 to properly adjust the capacities 33 and 35 connected in circuit.

The longer the loop 6 to which plug 18 is connected, the greater will be its resistance, the less will be the current in H_2, and the greater will be T, R and r; and the shorter the loop, the less will be its resistance, the greater will be the current in H_2, and the less will be T, R and r. The responsiveness of T and 31 must, by proper design, be made such as to always establish and maintain within the limits of tolerance the balance between the resistance component of Z_2 and that of z_2.

In some systems, as for example, where the variation of length of the loops 6, or the range of impedance variation of the loops 6, does not exceed certain limits, the adjustment of resistance balance may be adequate for preventing singing, without necessity for provision of capacities 33 and 35; and then switches 55 may be opened, or capacities 33 and 35 and switch 34 and its control circuits may be omitted. However, their provision enables closer impedance balance between z_2 and Z_2 to be obtained, especially in systems in which the variations in length or impedance of loops 6 are great.

If plug 18 be connected, for example, to a loop 6 that is so long or has such high resistance and effective shunt capacity (distributed capacity) that, with switch 34 in its extreme right-hand position, the degree of balance between Z_2 and z_2 is within the limits of tolerance, then the response of T_{11}, 41 and 34 should be insufficient to disconnect any of the capacities 33 or 35; whereas, if plug 18 be connected to a loop 6 so short as to require a given reduction of the capacities 33 and 35 in circuit in order to bring the degree of balance between Z_2 and z_2 within the limits of tolerance, then the response of T_{11}, 41 and 34 should be such as to effect such reduction.

Network 31 may be referred to as a shaping network. It controls the shape of the characteristic (not shown) of R versus T, as discussed hereinafter. In the specific form shown in Fig. 1, it consists of resistances A and B; but other forms may be used, as will be made apparent hereinafter.

Any suitable number of condensers 33 and 35 in link 21 may be used, to obtain any desired number of steps in the capacity variation. The individual condensers 33 and 35 may have any suitable values, either the same or different, to obtain equal or different steps of any desired magnitudes; or any suitable form of condensers may be used as for example, well-known types of ganged air condensers (not shown) with sets of fixed and movable plates shaped to continuously vary the capacity as desired upon relative motion of the plates.

Opening switches 55 and closing switches 60 and 61 (with switches 62 closed) replaces the circuit of tube 41 by a circuit comprising series inductance L and shunt capacity C_1, an oscillator or other alternating current source 63 of frequency f, thermistor 66, network 67, and source of electromotive force 69. Thermistor 66 comprises a temperature-dependent resistance T_6 with temperature coefficient of resistance of the same sign as that of temperature dependent resistance T_{11}, and heater H_6 electrically insulated from resistance T_6. Heater H_6 is in series with source 63 and condenser C_1, which is shunted across elements L and T_{11} in series. Element T_6 terminates network 67. Network 67 is shown as a π network of resistances A, B and C. It is a shaping network for controlling the shape of the characteristic of R_6 versus T_6, where R_6 designates the impedance or resistance that coil 38 faces (with switches 55 open) and T_6 designates the impedance or resistance of thermistor element T_6.

With L and C_1 given such values that

$$LC_1\,(2\pi f)^2 \doteq 1$$

thermistor 66, source 63 and elements L and C_1 make it possible to have the sign of the resistance variation of T_{11} opposite to the sign of the consequent resistance variation of T_6, though elements T_{11} and T_6 be alike as regards the signs of their temperature coefficients of resistance. Assuming, for example, that the temperature coefficient of resistance of T_{11} is negative, as T_{11} gets smaller due to increased current in H_1

$$|Z_7| \doteq \left(\frac{L}{C_1}\right)\left(\frac{1}{T_{11}}\right)$$

at the oscillator frequency f or $|Z_7|$ becomes proportional to the reciprocal of T_{11}. That is, at the frequency of anti-resonance the network consisting of resistance T_{11} and inductance L in series, shunted by capacity C_1, has its impedance increase in magnitude as the resistance T_{11} decreases. Thus, increase of the heating current in H_1 causes decrease of the resistance T_{11}, with consequent increase of $|Z_7|$, decrease of heater current in H_6, increase of resistance T_6, increase of resistance R_6, and decrease of the current flowing from battery **69** through coil **38**.

Opening switches **60** and **62** and closing switches **70** and **72** replaces the source **63** and the network L, C_1 by a source **73** with resistance **75** and a lattice or bridge network **74** comprising resistances A, B, C and D proportioned so that A/B=C/D. Then, as the heating current in H_1 increases, the resistance T_{11} becomes smaller—as compared with A—and the lattice or bridge network **74** becomes more nearly balanced, so the current flowing from source **73** in heater H_6 decreases and consequently the resistance T_6 increases. The source **73** may be either a direct current source or an alternating current source.

The shaping networks **31** and **67** are typical of four-terminal networks designed so that if terminated in a variable resistance, for example a varistor or a thermistor, the input resistance has a plurality of preassigned values, (within the limits of physical realization), one for each of a plurality of specified values of the terminating resistance. For example, two preassigned values of input resistance, which may be designated R_1 and R_2, can be obtained with a two-element ladder network (such for instance as network **31** of Fig. 1 or the network of Fig. 2) or with a lattice network such for instance as that of Fig. 3, and three preassigned values, which may be designated R_1, R_2 and R_3 can be obtained with a three-element ladder network such, for instance, as network **67** of Fig. 1 or the network of Fig. 4.

The design formulae for a network of the configuration of network **31** can be shown to be:

$$A=\frac{R_1+R_2}{2}\pm\sqrt{\left(\frac{R_1+R_2}{2}\right)^2+\frac{T_1T_2(R_2-R_1)}{T_2-T_1}-R_1R_2} \quad (1)$$

and

$$B=\frac{R_1T_1-R_2T_2+A(T_2-T_1)}{T_1+R_2-T_2-R_1} \quad (2)$$

The formulae for a network of the form shown in Fig. 2 may be given as:

$$C=\frac{(R_1+R_2)\pm\sqrt{(R_1+R_2)^2-2R_1R_2\left[2\left(\frac{T_2+R_1-T_1-R_2}{T_2-T_1}\right)\right]}}{2\left(\frac{T_2+R_1-T_1-R_2}{T_2-T_1}\right)} \quad (3)$$

and

$$A=\frac{C(T_2+R_1-T_1-R_2)+R_1T_1-R_2T_2}{R_2-R_1} \quad (4)$$

The formulae for a lattice network of the configuration shown in Fig. 3 are:

$$x\equiv\frac{R_2T_2(T_1-R_1)+R_1T_1(R_2-T_2)}{R_1T_1-R_2T_2} \quad (5)$$

$$y\equiv\frac{T_1+R_2-T_2-R_1}{R_1T_1-R_2T_2} \quad (6)$$

$$B=\frac{1}{y}\pm\sqrt{\left(\frac{1}{y}\right)^2-\left(\frac{x}{y}\right)} \quad (7)$$

and

$$A=\frac{1}{B}\left(\frac{x}{y}\right) \quad (8)$$

It may be noted that

$$R=\frac{\frac{2AB}{A+B}+T}{1+\frac{2T}{A+B}} \quad (9)$$

The formulae for a ladder network of the form shown in Fig. 4 (a π-network) are:

$$x\equiv\frac{T_2R_2(R_3-R_1)+T_3R_3(R_1-R_2)+T_1R_1(R_2-R_3)}{T_1R_2R_3(T_3-T_2)+T_2R_1R_3(T_1-T_3)+T_3R_1R_2(T_2-T_1)} \quad (10)$$

$$y\equiv\frac{T_2T_3(R_2-R_3)+T_1T_3(R_3-R_1)+T_1T_2(R_1-R_2)}{T_1R_2R_3(T_3-T_2)+T_2R_1R_3(T_1-T_3)+T_3R_1R_2(T_2-T_1)} \quad (11)$$

$$y\equiv\frac{T_3(R_1-R_2)+T_2(R_3-R_1)+T_1(R_2-R_3)}{T_1R_2R_3(T_3-T_2)+T_2R_1R_3(T_1-T_3)+T_3R_1R_2(T_2-T_1)} \quad (12)$$

$$A=\frac{1}{\sqrt{xy-z}} \quad (13)$$

$$B=\frac{A}{Ax-1}=\frac{1}{x-\sqrt{xy-z}} \quad (14)$$

and

$$C=\frac{A}{Ay-1}=\frac{1}{y-\sqrt{xy-z}} \quad (15)$$

The π-network may be replaced by its equivalent T-network with the conversion relations of Figs. 28A and 28B of Appendix D of my book "Transmission Circuits for Telephonic Communication," published by the D. Van Nostrand Company, New York.

It may be noted that although Formulae 1 to 15 were derived on the assumption that all of the circuit elements involved were pure resistances, these formulae are also valid if all of the circuit elements are pure reactances of the same sign. Consequently, if A, B, C, R and T in the formulae were all replaced by corresponding inductances, (L_A, L_B, L_C, L_R, and L_T), or by the reciprocal of capacitances, ($1/C_A$, $1/C_B$, $1/C_C$, $1/C_R$, and $1/C_T$), the formulae would still be valid. For example, Formulae 10 to 15 would serve if, with a variable terminating inductance L_T (instead of a variable resistance T), it were desired to design a network composed of pure inductances L_A, L_B and L_C such that the inductance at the input terminals, L_R, would have any three desired preassigned values.

Specific numerical examples of designs for networks of the ladder and lattice types shown in Figs. 5 and 6 are given in the following table:

Fig.	R_0	R_1	R_2	R_3	T_0	T_1	T_2	T_3	A	B	C
5	48	100	342	642	0	43	300	860	43	262	−395
5	91	133	342	642	0	43	300	860	91	1530	∞
6	101	140	342	642	0	43	300	860	51	3400	------
5	102	142	342	642	0	43	300	860	106	4260	2880
5	115	152	342	642	0	43	300	860	122	∞	1870
5	227	242	342	642	0	43	300	860	386	−718	551

All the circuits of the table were designed such that (1) when 860 ohms resistance (=T_3) was connected across the output terminals, the input resistance (≡R_3) would be 642 ohms, and (2) when 300 ohms resistance (=T_2) was connected across the output terminals, the input resistance (≡R_2) would be 342 ohms. For the cases in which A, B and C are all finite, the design also assumed T_1=43 ohms and R_1 was preassigned to have the values indicated. For the other cases, R_1 was calculated for T_1=43 ohms, and for all cases R_0 was calculated when the terminal resistance T_0 was 0 ohms.

It may be noted that cases (1) and (6) are not physically realizable since either B or C is negative.

Also, it is noted that the value of R_0 (=102 ohms), in the case of the three-element physically realizable network, (=Case 4), lies between the values of R_1 (91 and 115 ohms) given by the two-element networks (=Case 2 and 5); and likewise the value of R_1 (=142 ohms), in the Case 4, lies between the values of R_1 (133 and 152 ohms) given by the two-element networks (=Case 2 and 5).

For the circuit of Fig. 2, the table below gives the calculated values of R and r for three values of T produced by three values of direct current I that flows in heater H_2 for three specified values of R_L+34. R_L designates the variable direct current resistance of the loop circuit connected to link 22 by plug 18; and 34 is the value, in ohms, assumed for the total direct current resistance of the elements 23, 24, H_1 and H_2 in series in the link 22, as indicated by the resistance values appearing in Fig. 1. The direct current resistance of the substation sets is assumed to be 60 ohms as indicated in Fig. 1; and I is calculated as

$$\frac{24}{154+R_L}$$

because, as indicated in the Fig. 1, the voltage of battery 45 is assumed to be 24 volts, the direct current resistance of the secondary winding of the amplifier output transformer is assumed to be 20 ohms, and that of the hybrid coil windings traversed by I is assumed to be 40 ohms.

R_L	R_L+34	$I=\frac{24}{154+R_L}$	T	R	$r=.76R$
0	34	0.156	19	44	33.4
300	334	.053	530	462	351
600	634	.0318	1250	835	634

It will be noted from the table that the three values of r closely approach the corresponding values of R_L+34.

Below is a similar table for a circuit similar to that of Fig. 1 but with network 31 omitted, the ratio of transformer 32 made 3:1, and the resistance of heaters H_1 and H_2 each made 1 ohm.

R_L	R_L+32	I	T	r
0	32	0.160	61	20
100	132	.096	287	96
200	232	.069	615	205
300	332	.053	1000	333
400	432	.044	1270	417
500	532	.037	1470	490

As indicated by the degree to which r approaches R_L+32 the network 31 may well be omitted as unnecessary in some cases.

Fig. 7 illustrates application of the invention to a system comprising a cord circuit repeater of 22-type including amplifiers 1 and 1′ and hybrid coils 2 and 2′, for connecting any chosen one of a group 6 of subscribers' loops or trunk circuits such as the two indicated at 7 and 8 with any chosen one of a group 6′ of subscribers' loop or trunk circuits such as the two indicated at 7′ and 8′. To make such a connection, a plug 18 at one end of the cord circuit is inserted in the cooperating jack of the chosen one of lines 6 and 8 and plug 18′ at the other end of the cord circuit is inserted in the cooperating jack of the chosen one of lines 6′. The lines 6 and also the lines 6′ may have various lengths or substantially different impedances facing the cord circuit.

The cord circuit includes a balancing network or circuit N attached to the network terminals 53 of the hybrid coil 2. The network N comprises a link circuit 81 terminated in a dummy telephone set or an impedance 80 simulating the impedance of a set such as 11 or 12. The link 81 as shown is like link 21 of Fig. 1, except that an optional blocking condenser 85 and a resistance 86, which are referred to hereinafter, are shown in the link 81.

The cord circuit includes a link 82 connecting the line terminals 52 of the hybrid coil 2 with the plug 18. The link 82 as shown is like link 22 of Fig. 1, except that the supervisory relay 23 and central office wiring resistance 24 are omitted and a heater element H_9 of an additional thermistor 90, similar to the thermistors 25 and 26, is shown in the link 82. The thermistor 90 comprises temperature-dependent resistance T_9 heated by H_9 and electrically insulated from H_9. The resistance T_9 may have a negative temperature coefficient of resistance, for example. It is connected across the input circuit of amplifier 1, either directly or through a shaping network 87 shown as of the same type as network 67, and controls the gain of that amplifier as indicated hereinafter. If desired, the network 87 may be a shaping network of the type of network 31, or may be of any of the types shown in Figs. 2 to 6, for example.

The lower half of the cord circuit repeater as shown in Fig. 7 is a duplicate of the upper half. The reference characters designating the elements in the lower half are those designating the corresponding elements of the upper half primed. In Fig. 7 the dotted lines connecting thermistor T_{11} and coil 38 are for indicating that the connection may be as in Fig. 1. Similarly the connection between T_{11}' and 38′ may include the apparatus shown in Fig. 1 in the connection between T_{11} and 38. Direct current from battery 45 is supplied over the loop 6 to which plug 18 is connected, to the substation of that loop, either for talking and supervisory purposes if the substation is of the common battery type, or for supervisory purposes, only, if the substation is of the local battery type with common battery supervision. Similarly, direct current is supplied over the loop 6′ to which plug 18′ is connected, to the substation of that loop. The blocking condenser 85 is of negligible impedance at voice frequencies. It prevents direct current flow from battery 45 to network N. This results in a maximum variation of the resistance T, T_{11} and T_9 as a function of the loop length. Similarly, condenser 85′ prevents flow of direct current from battery 45′ to network N′.

Resistance 86 serves to counterbalance the resistance of heaters H_1, H_2 and H_9; and similarly resistance 86′ counterbalances the resistance of H_1', H_2' and H_9'.

The gain which it is possible to obtain from a 22-type repeater depends upon the closeness of the impedance balances between (a) the line in one direction and its balancing network, and (b) the line in the other direction and its balancing network. In the case of each of the two balancing networks of a 22-type repeater such as a cord circuit repeater, the impedance of the network ordinarily is given some value representing an average of the impedances of the lines it is to balance, since the lengths of the loops or trunks differ and consequently the impedance of the line to be balanced by the network varies. This variation may be considerable and consequently the ratios of the line impedances to the impedances of the two balancing networks may depart so far from unity that the gain of the repeater must be limited to a relatively low value (for example, 6 or 7 decibels) in order to prevent singing.

By proper use of thermistors, balancing networks can be so constructed that they are effectively duplicate copies of the actual lines that they must balance, regardless of the lengths of these lines. Hence, as the repeater is employed between lines of different lengths whose impedances vary, the impedances of the corresponding networks will vary in the same way, thereby maintaining a close balance between the impedance of the lines and that of their corresponding balancing networks. This makes it possible to obtain much greater gains from such a repeater than would be possible if the networks were fixed, i. e., not variable.

In the system of Fig. 7 this automatic balancing is done by means of thermistors **25**, **26**, **25'** and **26'**, which have their heater elements H_1, H_2, $H_{1'}$ and $H_{2'}$ inserted in series with the lines and a battery such as **45** and **45'**. As the length of the line varies, the current, or power dissipated in these heaters varies and the resistance values of their corresponding temperature-dependent resistance elements T_{11}, T, $T_{11'}$ and T' also vary, these resistance values (with the usual type of thermistor) becoming rapidly larger as the current through the heaters becomes less or as the length of the loop or trunk becomes greater.

When the cord circuit is connected between two lines, it is desired that before switches **51** and **51'** are closed to complete the repeater circuit, the link **81** automatically be given any adjustment required for building out the impedance of the connected set **80** to make the impedance z_2 presented to terminals **53** of hybrid coil **2** by network N equal the impedance Z_2 presented to terminals **52** of the hybrid coil **2** or balance the impedance Z_2 sufficiently closely, and the link **81'** automatically be given any adjustment required for building out the impedance of the connected set **80'** to make the impedance $z_{2'}$ presented to the terminals **53'** of hybrid coil **2'** by network N' equal the impedance $Z_{2'}$ presented to terminals **52'** of the hybrid coil **2'** or balance the impedance $Z_{2'}$ sufficiently closely, so the repeater will be prevented from having any undue singing tendency or any undue limitation on its permissible gain.

The automatic adjustment of the link **81** is effected by response of thermistor **26** and network **31** to give r the proper value, and response of thermistor **25**, switch **34** and the circuit therebetween (as described in connection with Fig. 1) to properly adjust the capacities **33** and **35** connected in circuit, so the π network formed by the resistance r and the capacities **33** and **35** will represent closely the actual loop or trunk to which plug **18** has been connected.

The longer the line **6** to which plug **18** is connected, the greater will be its resistance, the less will be the current in H_2 and the greater will be T, R and r. The responsiveness of T and **31** must, by proper design, be made such as always to establish and maintain within the limits of tolerance the balance between the resistance component of Z_2 and that of z_2.

The automatic adjustment of the link **81'** is similar to that of link **81**.

With the system of Fig. 7, (as with that of Fig. 1), in cases in which the variation of length of the lines connected to the repeater, or the range of impedance variation of the lines, does not exceed certain limits, the adjustment of the resistance balance may be adequate for reducing singing tendency and permitting the desired amount of repeater gain, without necessity for provision of capacities **33** and **35** and capacities **33'** and **35'**; and then these capacities and their control circuits may be omitted. However, (as in the case of the capacities **33** and **35** of Fig. 1), the provision of the capacities **33** and **35** enables closer impedance balance between Z_2 and z_2 to be obtained, and similarly the provision of capacities **33'** and **35'** enables closer impedance balance between $Z_{2'}$ and $z_{2'}$ to be obtained.

If plug **18** be connected, for example, to a line that is so long or has such high capacity that, with switch **34** in its extreme right-hand position the degree of balance between Z_2 and z_2 is within the limits of tolerance, then the response of T_{11}, **34** and the circuit connecting them (as described in connection with Fig. 1) should be insufficient to disconnect any of the capacities **33** and **35**; whereas, if plug **18** be connected to a line so short as to require a given reduction of the capacities **33** and **35** in circuit in order to bring the degree of balance between Z_2 and z_2 within the limits of tolerance, then the response of T_{11}, **34** and their connecting circuit should be such as to effect such reduction. As indicated above, control of capacities **33'** and **35'** is similar to the control of the capacities **33** and **35**.

When the line **6** to which plug **18** is connected is comparatively short, the direct current from battery **45** through heater H_9 will be relatively large and the resistance of the heated element T_9 will be comparatively small. Since T_9 is connected across the input circuit of amplifier **1**, through network **87**, if desired, the output of this amplifier will be reduced and the amplifier gain will be smaller than were the line longer and the resistance of T_9 correspondingly higher. This is desirable because the longer the line the greater will be its attenuation and the greater will be the gain required from the amplifier in order to offset this greater attenuation and stabilize the transmission equivalent of the circuit and the levels at the terminals. If network **87** be omitted, then when the lines **6** to which plug **18** may be connected are long, the simple shunt bridging loss of T_1 may be not such as to give the required shape to the characteristic of the variation of amplifier gain as a function of the line length. In this case the required shaping can be obtained with a shaping network such as **87**, and if desired a transformer such as the transformer **32** shown in connection with shaping network **31**, (as the proper variation of r as a function of the resistance of T is obtained with network **31** and transformer **32**, and as the proper variation of the current through coil **38** as a function of the resistance of T_6 is obtained with the aid of network **67**, for example). As indicated above, the control of the gain of amplifier **1'** by thermistor **90'** is similar to the control of the gain of amplifier **1** by thermistor **90**.

In the systems of Figs. 1 and 7, the substations or telephone sets may be of any suitable type. If desired, **11**, **12**, **11'** and **12'** may be anti-sidetone telephone sets of any of the types disclosed in my copending application Serial No. 463,184, filed October 24, 1942, entitled Telephone system, having the balancing network in the set automatically adjusted in accordance with the length or impedance of the line to which the set is connected.

What is claimed is:

1. A wave translating system comprising a line impedance which may have different values, two circuits, electric wave amplifying means having an amplifier input circuit connected to one of said two circuits and an amplifier output circuit connected to the other, means providing a balancing circuit for said line impedance and a line circuit for two-way communication with said line impedance through said two first-mentioned circuits and said amplifying means, means comprising said balancing circuit for said line impedance for connecting said two first-mentioned circuits in energy transmitting relation to said line impedance and in conjugate relation to each other, and thermistor means responsive to change in the value of said line impedance for changing the impedance of said balancing circuit in substantially the same ratio to maintain conjugacy of said two first-mentioned circuits.

2. A wave translating system comprising a line impedance which may have different values, two circuits, wave amplifying means having an amplifier input circuit connected to one of said two circuits and an amplifier output circuit connected to the other, means providing a balancing circuit for said line impedance and a line circuit for two-way communication with said line impedance through said two first-mentioned circuits and said amplifying means, means comprising said balancing circuit for said line impedance for connecting said two first-mentioned circuits in energy transmitting relation to said line impedance and in conjugate relation to each other, impedances comprising a temperature-dependent resistance in said balancing circuit adjustable for producing changes of the impedance of said balancing circuit corresponding to changes occurring in said line impedance to maintain balance of said line impedance by said balancing circuit, and means comprising a heating element for said temperature-dependent resistance responsive to said changes in said line impedance for effecting said adjustment of said adjustable impedances.

3. A wave translating system comprising lines of different resistance, two circuits, wave amplifying means having an amplifier input circuit connected to one of said two first-mentioned circuits and an amplifier output circuit connected to the other of said two first-mentioned circuits, means providing a balancing circuit and a line circuit for two-way communications with any selected one of said lines through said two first-mentioned circuits and said amplifying means, said balancing circuit being adapted to balance the impedance of the selected line, means comprising said balancing circuit for connecting said two first-mentioned circuits in energy transmitting relation to the selected line and in conjugate relation to each other, means for producing direct current dependent in magnitude on the magnitude of the resistance of the selected line, and means comprising a variable resistance in said balancing circuit responsive to said direct current for rendering the magnitude of said variable resistance a function of the magnitude of said direct current.

4. A wave translating system comprising lines of different resistance, two circuits, wave amplifying means having an amplifier input circuit connected to one of said two circuits and an amplifier output circuit connected to the other, means providing a balancing circuit and a line circuit for two-way communication with any selected one of said lines through said two first-mentioned circuits and said amplifying means, said balancing circuit being adapted to balance the impedance of the selected line, means comprising said balancing circuit for connecting said two first-mentioned circuits in energy transmitting relation to the selected line and in conjugate relation to each other, means in one of said two first-mentioned circuits for supplying direct current to the selected line, and means responsive to said current for controlling the resistance of said balancing circuit.

5. A wave translating system comprising lines of different resistance, two circuits, wave amplifying means having an amplifier input circuit connected to one of said two circuits and an amplifier output circuit connected to the other, means providing a balancing circuit and a line circuit for two-way communication with any selected one of said lines through said two first-mentioned circuits and said amplifying means, said balancing circuit being adapted to balance the impedance of the selected line, means comprising said balancing circuit for connecting said two first-mentioned circuits in energy transmitting relation to the selected line and in conjugate relation to each other, said balancing circuit comprising a four-terminal network having shunt capacity and series resistance, means for producing direct current in the selected line dependent in magnitude on its resistance, and means responsive to said current for varying said capacity and said resistance.

6. A telephone transmission system comprising a group of subscribers' circuits of different resistances, a group of subscribers' circuits of approximately a given resistance, a 21-type repeater having two pairs of terminals, a π-network comprising adjustable shunt capacities and a temperature-dependent resistance for connecting one of said pairs to any chosen one of said second group of circuits, means for adjusting said capacities, temperature-dependent resistance for controlling said adjusting means, a source of direct current for energizing said subscribers' circuits to condition them for operation, current responsive heating means for said temperature-dependent resistances, and a circuit comprising said heating means for connecting said other pair of terminals to any chosen one of said first group of circuits with said heating means in series with that chosen circuit and said source.

7. A wave translating system comprising a line impedance whose resistance component may have different magnitudes, two circuits, wave amplifying means having an amplifier input circuit connected to one of said two circuits and an amplifier output circuit connected to the other, means providing a balancing circuit for said line impedance and a line circuit for two-way communication with said line impedance through said two first-mentioned circuits and said amplifying means, means comprising said balancing circuit for said line impedance for connecting said two first-mentioned circuits in energy transmitting relation to said line impedance and in conjugate relation to each other, means for producing direct current dependent in magnitude on the magnitude of the resistance component of said line impedance, said balancing circuit comprising a four-terminal network terminated in a variable resistance, and means comprising said variable resistance responsive to variation of

said direct current for producing variation of said variable resistance, said network consisting of a plurality of resistances of such values and circuit configuration that the ratio of said variable resistance to the input resistance of said network has different preassigned values for given values of said variable resistance.

8. A wave translating system comprising a line impedance whose resistance component may have different magnitudes, two circuits, wave amplifying means having an amplifier input circuit connected to one of said two circuits and an amplifier output circuit connected to the other, means providing a balancing circuit for said line impedance and a line circuit for two-way communication with said line impedance through said two first-mentioned circuits and said amplifying means, means comprising said balancing circuit for said line impedance for connecting said two first-mentioned circuits in energy transmitting relation to said line impedance and in conjugate relation to each other, means for producing in said line impedance a current depending in magnitude on its resistance component, said balancing circuit comprising a four-terminal network terminated in a temperature-dependent resistance, and a heating element for said temperature-dependent resistance responsive to said current in said line impedance, said network consisting of a plurality of resistances of such values and circuit configuration that the ratio of said temperature-dependent resistance to the input resistance of said network has different preassigned values for given values of said temperature-dependent resistance.

9. A wave translating system comprising a line impedance whose resistance component may have different magnitudes, two circuits, wave amplifying means having an amplifier input circuit connected to one of said two circuits and an amplifier output circuit connected to the other, means providing a balancing circuit for said line impedance and a line circuit for two-way communication with said line impedance through said two first-mentioned circuits and said amplifying means, means comprising said balancing circuit for said line impedance for connecting said two first-mentioned circuits in energy transmitting relation to said line impedance and in conjugate relation to each other, means for producing in said line impedance a current depending in magnitude on its resistance component, said balancing circuit comprising an adjustable impedance, means for adjusting said adjustable impedance, a four-terminal network connected to said adjusting means and terminated in a temperature-dependent resistance for controlling said adjusting means, and means responsive to said current in said line impedance for controlling said temperature-dependent resistance, said network consisting of a plurality of resistances of such values and circuit configuration that the ratio of said temperature-dependent resistance to the resistance of said network facing said adjusting means has different preassigned values for given values of said temperature-dependent resistance.

10. A wave translating system comprising lines of different resistance, another line, a link circuit for establishing connections of said other line with any selected one of said first-mentioned lines, a two-way repeater in said link circuit having an amplifying path for amplifying waves transmitted from the selected line to said other line and an amplifying path for amplifying waves

transmitted from said other line to the selected line, a source of electromotive force in said link circuit for supplying direct current to the selected line, and means responsive to said direct current for increasing and decreasing the transmission efficiency of one of said paths upon increase and decrease, respectively, of the resistance of the selected line by change of the line selection.

11. In a telephone system, a plurality of subscriber lines of different resistances, a connecting circuit for establishing connections with said lines, a two-way repeater in said connecting circuit having an amplifying path for receiving and amplifying waves from said lines and an amplifying path for amplifying waves and transmitting the waves so amplified to said lines, a source of electromotive force in said connecting circuit for supplying direct current to the line with which connection is established, means comprising a resistance of high temperature coefficient in said first path, and a heating element therefor electrically insulated therefrom included in said connecting circuit and responsive to the direct current supplied to the line.

12. A wave translating system comprising a line, two circuits, means comprising a balancing circuit for said line for connecting said two circuits in energy transmitting relation to said line and in conjugate relation to each other, said balancing circuit comprising an adjustable impedance, means for adjusting said impedance, a circuit connected to said adjusting means and comprising a resistance of negative temperature coefficient for controlling said adjusting means, a heating element for said resistance electrically insulated therefrom, a second resistance of negative temperature coefficient, means for producing decreasing current in said heating element in response to decrease of said second resistance, and a heating element for said second resistance electrically insulated therefrom and responsive to current in said line for controlling said second resistance.

13. A system for transmitting current changes comprising an input circuit, an output circuit, means for producing variable input current in said input circuit and means for producing correspondingly variable output current in said output circuit, said last means comprising a resistance of high temperature coefficient connected in said output circuit, a heating element therefor electrically insulated therefrom, a second resistance of high temperature coefficient of the same sign as the first coefficient, a heating element for said second resistance connected in said input circuit, a source of constant voltage for supplying heating energy to said first heating element, and a circuit comprising said second resistance connecting said source to said first heating element to supply energy of said source thereto and responsive to magnitude change of one sign in current in said second heating element for producing magnitude change of opposite sign in current in said first heating element.

14. A control circuit comprising a resistance of high temperature coefficient, a heating element therefor electrically insulated therefrom, a second resistance of high temperature coefficient of the same sign as the first coefficient, a heating element for said second resistance electrically insulated therefrom, a source of electromotive force for supplying energy to heat said first heating element, and means comprising said second resistance connecting said source to supply heat-

ing energy to said first heating element and responsive to change of current of one sense in said second heating element for producing current change of opposite sense in said first heating element.

15. A system comprising a temperature-dependent resistance, a heating element therefor electrically insulated therefrom, a second temperature-dependent resistance having its temperature coefficient of resistance of the same sign as that of said first resistance, a heating element for said second resistance electrically insulated therefrom, a source of electromotive force for supplying energy to heat said first heating element, means comprising said second resistance and having variable transmission efficiency connecting said source to said first heating element to supply energy of said source thereto and responsive to change of current of one sign in said second heating element for so varying said transmission efficiency as to produce current change of opposite sign in said first heating element, and

means comprising a second source of electromotive force in circuit with said second heating element adapted to produce therein current change of magnitude sufficient to produce temperature change of said first resistance large compared to its maximum temperature change produced by ambient temperature.

16. In combination, a resistance of high temperature coefficient, a heating element therefor electrically insulated therefrom, a second resistance of high temperature coefficient of the same sign as the first coefficient, a heating element for said second resistance electrically insulated therefrom, a source of electromotive force of given frequency, and a circuit comprising in series said source, said first heating element and a network tuned to approximately said frequency, said network comprising a capacity and in parallel therewith said second resistance and an inductance in series.

KENNETH S. JOHNSON.