

Nov. 24, 1959

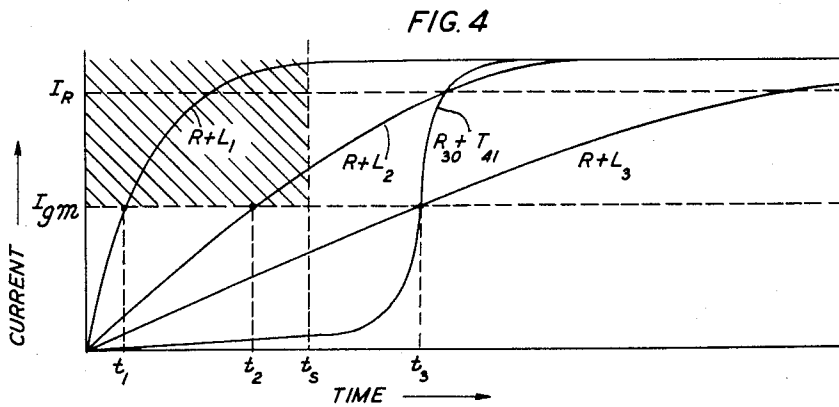
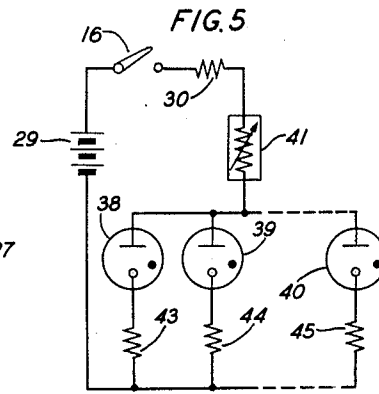
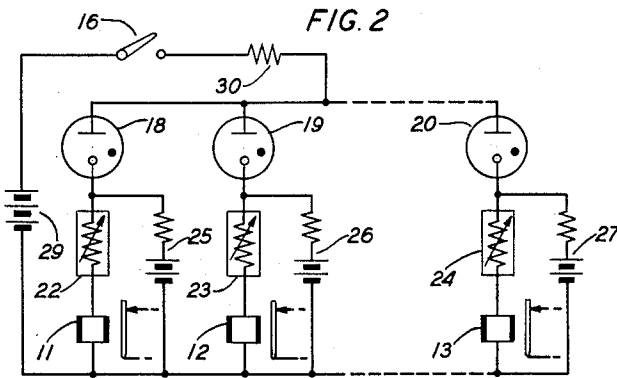
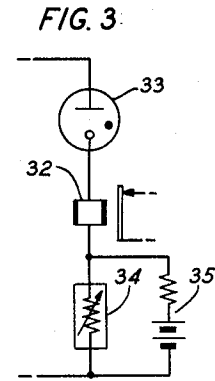
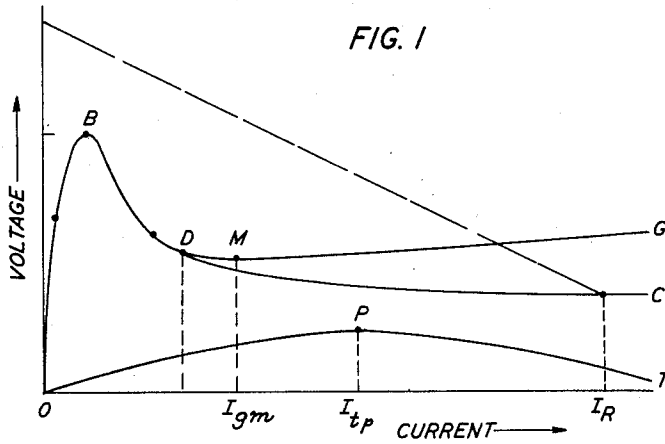
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2,914,747

LOCKOUT CIRCUITS UTILIZING THERMISTOR-GAS TUBE COMBINATIONS

Filed Jan. 30, 1953

3 Sheets-Sheet 1



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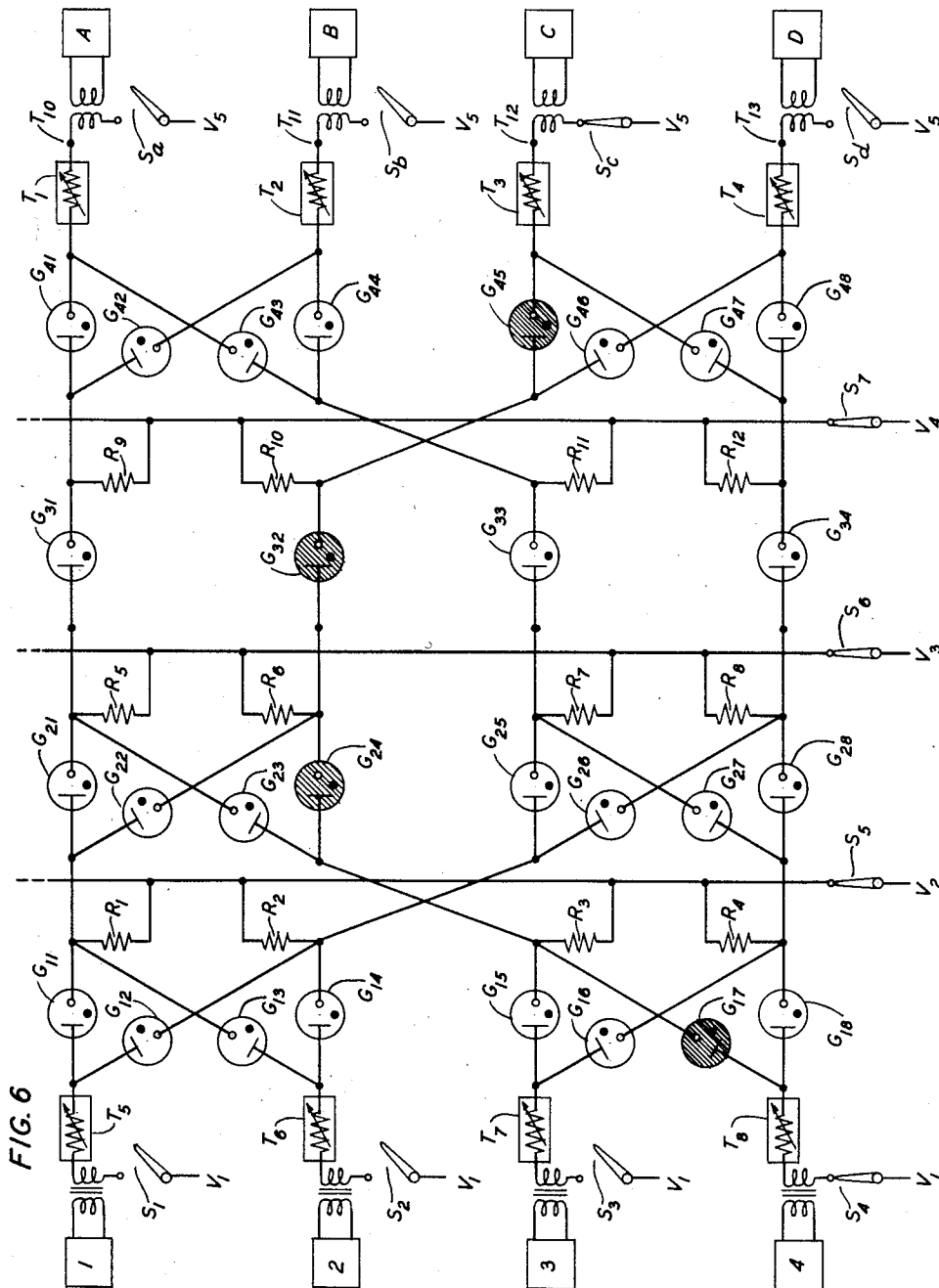
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3 Sheets-Sheet 2



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FIG. 7

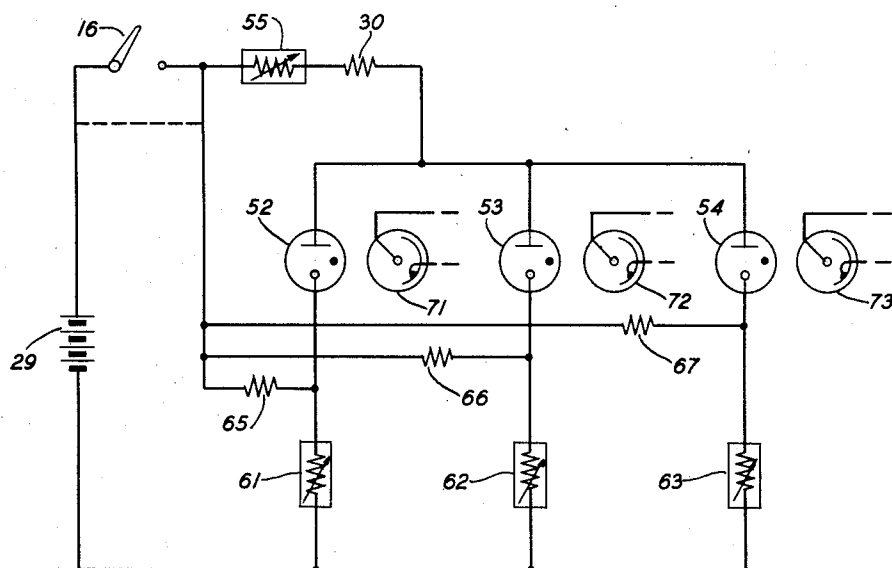


FIG. 8

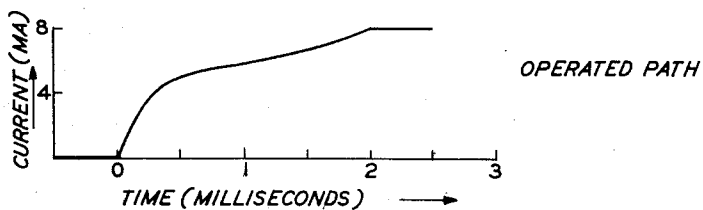
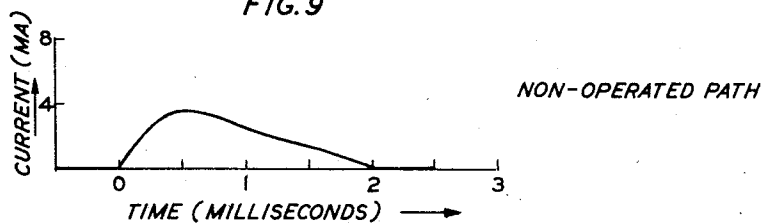


FIG. 9



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2,914,747

LOCKOUT CIRCUITS UTILIZING THERMISTOR-GAS TUBE COMBINATIONS

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Application January 30, 1953, Serial No. 334,329

16 Claims. (Cl. 340—155)

This invention relates to selecting systems and more specifically to improvements in selecting circuits of the type in which electrical components exhibiting negative resistance properties are employed to decrease the probability of more than one circuit being selected.

In selection systems in which it is desired to select at random one and only one of a plurality of parallel circuits interconnecting two electrical terminals, a gas tube is often placed in each of the parallel circuits. Because selection systems having a gas tube individual to each of the parallel circuits as the only selection element are not infallible, and occasionally reach a stable condition with two gas tubes conducting, various expedients have been employed to improve their characteristics. For example, it has previously been proposed to place inductances or resistances in the common energizing circuit of the parallel circuits to decrease the probability of the ionization of more than one of the gas tubes. Illustrative systems of this character are disclosed in G. Hecht Patent No. 2,609,454, issued September 2, 1952, and in M. E. Mohr Patent No. 2,564,125, issued August 14, 1951.

The selection systems of the prior art, however, have generally proved to be slow operating, unduly expensive, not failureproof, or to involve bulky components or complicated circuitry. In telephone switching system operation, where the selection circuits must operate reliably with other high speed switching apparatus, and where a great number of the selection circuits may be used, limitations such as those mentioned above become important.

One object of the present invention is to eliminate or to substantially reduce the frequency of failures in selection circuits.

Another object is to reduce the size, the cost, and the circuitual complexity of high quality selection circuits.

In accordance with one aspect of the invention, it has been found that negative resistance in each of several parallel selection circuits results in a temporary instability leading to increasing current in one circuit and decreasing current in the other circuits and the selection of a single one of the parallel circuits. The circuits of the present invention utilize one or more thermistors in selection systems having a gas tube in each of several parallel circuits. As an illustration of one specific embodiment of the invention, a biased thermistor is placed in series with each gas tube so that each of the parallel paths will have a negative resistance characteristic throughout the operating range.

Other objects, features and advantages of the invention will be developed in the course of the detailed description of certain particular embodiments which are illustrated in the drawings.

In the drawings,

Fig. 1 is a plot of voltage versus current for selection circuits in accordance with the invention;

Fig. 2 shows a selection system having biased thermistors individual to each of the parallel paths;

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Fig. 3 illustrates an alternative circuit branch which may be used in the selection system of Fig. 2;

Fig. 4 is a plot of current versus time for another selection system in accordance with the invention;

Fig. 5 depicts a selection system in which a single thermistor is placed in series with a number of parallel paths;

Fig. 6 illustrates diagrammatically the use of the selection circuit of Fig. 5 in a switching system;

Fig. 7 shows a lockout circuit in which a thermistor in series with all of the parallel paths is employed in combination with a biased thermistor individual to each path; and

Figs. 8 and 9 are plots of current versus time for the "on" tube and one of the "off" tubes, respectively, of the circuit of Fig. 2.

Before proceeding to consider the particular selection circuits in detail, it will prove helpful to consider some of the factors involved in selection circuits for use in telephone circuitry. The ideal selection circuit would involve a plurality of parallel electric paths, one of which would be selected at random and would instantly become a low resistance path upon the application of a voltage across all the parallel paths. This selection process is sometimes termed "simultaneous lockout," as contrasted to the problem of successive selection of intercoupled circuits, which is termed "sequential lockout." In addition, when the circuits are used for signalling as well as selection, isolation of the circuits becomes important. The present invention, however, relates to an improvement in selection circuits involving "simultaneous lockout" and the factors of "sequential lockout" and circuit isolation will only be briefly mentioned.

Concerning these gas tube selection circuits, simultaneous lockout is said to obtain when one and only one of the individual paths remains conducting after a short transient interval following the application of voltage to the parallel paths. For successful operation, it has been found that the individual parallel circuits of these selection systems should have characteristic curves of voltage across the circuit versus current through the circuit such as those shown in Fig. 1. More particularly, a characteristic such as OBDC is preferred since it has continuous negative slope (or negative resistance characteristic) all the way from breakdown at point B to high operating currents. Failure proof selection may be realized with such preferred elements even though the common impedance element is a simple resistance. This follows from the fact that an unstable equilibrium arises when two or more such paths become conducting and the final stable steady state condition (which results after a finite transient interval) corresponds to high-current conduction in one, and only one, of the individual paths.

In addition to a continuous negative slope, as discussed above, the preferred characteristic should have a high positive slope in region O—B. This is desirable, from a selection point of view, in that the number of such individual impedance elements which may operate satisfactorily in parallel is directly related to the slope in region O—B.

Furthermore, when the circuits are used in selection systems in which the selected circuit is used for the transmission of signal information, the selection circuits must appear to be electrically "transparent" when operated, and electrically "opaque" when non-operated to isolate the signal channels.

It may be observed, therefore, that the plot OBDC, with its negative slope in the high current region and high positive slope in the pre-breakdown region satisfies transmission requirements as well as selection requirements.

Unfortunately, no single existing circuit component is

known which has the desired characteristic shown at OBDC. The cold cathode gas tube characteristic (shown at OBDMG in Fig. 1) is perhaps the closest approximation to this desired characteristic in the low current range, but lacks the desired negative resistance characteristic in the higher current ranges. The voltage minimum at point M in the plot OBDMG occurs at a current level designated I_{gm} in the plot of Fig. 1, where "gm" denotes "gas tube minimum."

Because of the positive slope region in the higher current ranges, lockout circuits using gas diodes occasionally fail when two of the gas tubes fire simultaneously. This follows from the fact that a stable equilibrium may be set up with two or more of the gas tubes conducting because of the positive slopes (or positive resistances) in the individual impedance characteristics.

In accordance with the present invention, it has been determined that thermistors may be used to overcome the foregoing deficiencies associated with the use of cold cathode discharge tubes. One specific circuit which accomplishes this purpose is shown in Fig. 2. In the selection system of Fig. 2, relays 11, 12 and 13 are located in three paralleled circuits. In addition to the relays, each circuit also includes a gas tube (18, 19 and 20) and a thermistor (22, 23 and 24) which perform selection functions which will be detailed hereinafter. A voltage source 29 having a greater output voltage than the breakdown voltage of the gas tube is connected across the paralleled selection circuits by a circuit including a switch 16 and a common impedance 30. In addition, each of the thermistors 22, 23 and 24 is provided with a biasing network 25, 26 and 27, respectively, to bias them to the proper negative resistance operating point.

In the operation of the circuit of Fig. 2, it is desired that, upon the closing of the switch 16, one relay is selected at random and only this one relay is operated. Various expedients, such as the use of heat to increase the electrode spacing, are used to prevent the repetitive energization of any one relay; the present invention, however, deals with the prevention of the energization of more than one of the parallel selection circuits.

The manner of creating a composite selection circuit having the preferred characteristic may be appreciated by reference to the plot OPT of Fig. 1 which represents the voltage-current characteristic of an unbiased high-speed thermistor. The thermistor plot has a positive slope at low current values, a negative slope at high current values, and a peak at a current value designated I_{tp} , where " t_p " denotes "thermistor peak." The position of the entire plot OPT may be shifted along the current axis by a suitable biasing current. For example, with a biasing current of I_{tp} from each of the networks 25, 26, 27 through each of the thermistors 22, 23, 24, each of the biased thermistors would present a negative resistance at any positive current level. Similarly by biasing the thermistor so that its peak P is slightly to the left of the point M on the gas tube characteristic, the composite plot of the gas tube and the biased thermistor series combination has the form of the preferred characteristic OBDC of Fig. 1 when the slope of the biased thermistor is more negative than the positive slope of the gas tube at each value of current. The biasing current required to shift the thermistor peak P to the left of the gas tube minimum M must be greater than the difference between I_{tp} and I_{gm} . With the thermistor biased to an operating point which places the thermistor peak in line with the point D on the gas tube characteristic, the sum of the slopes of the two characteristics, which corresponds to the composite resistance, is negative from the gas tube breakdown point up to high current values.

As applied to Fig. 2, this means that each of the parallel paths has this preferred lockout characteristic. Thus, in accordance with the invention, if the two gas tubes 18 and 19 in two separate parallel paths should

fire initially, the instability of the negative resistance local loop comprising the gas tube 18, biased thermistor 22, relay 11, relay 12, biased thermistor 23 and gas tube 19, causes the extinction of one tube, leaving only the other tube conducting. This action is shown in Figs. 8 and 9, in which current versus time plots of the operated and non-operated parallel paths are shown. Load elements other than relays may be used, but they should be of low resistance so that the overall local loop resistance remains negative.

Thermistors are thermally sensitive resistances which have relatively high negative temperature coefficients of resistivity. Thermistor materials generally have negative thermal coefficients of resistivity greater than 1 percent per degree centigrade; coefficients of 3 to 4 percent are common and some thermistor materials such as boron have coefficients as high as 15 percent per degree centigrade. In regard to the biased thermistors 22, 23 and 24 of Fig. 2, although any one of a number of directly heated thermistors having negative resistance ranges could be used in this circuit, high-speed boron thermistors such as are described in J. J. Kleimack et al. Patent 2,389,915 issued November 27, 1945, have proved particularly satisfactory. As explained in the above-noted patent, the thermal capacity of the thermistor determines the maximum frequency at which a biased thermistor will exhibit negative resistance characteristics. The boron thermistor of the type noted above will, by way of example, exhibit negative resistance properties up to about 60 kilocycles, which is termed the negative resistance cut-off frequency of the thermistor. This frequency is a measure of the "speed" of thermistors, and a thermistor of the type described above is considered to be a relatively "high speed" thermistor.

Fig. 3 illustrates an alternative branch circuit which could be used in place of one of the branch circuits in the selection circuit of Fig. 2. In contrasting this circuit of Fig. 3 with that of the individual paths of Fig. 2, it may be noted that the thermistor biasing circuit may or may not include the relay winding depending on the current bias desired for the actuation of the particular type of relay which is employed. In the circuit of Fig. 3, relay 32 is directly in series with the gas tube 33 and the thermistor but is not included in the loop which is energized by the thermistor biasing circuit 35.

The thermistor selection circuit of Fig. 5 operates somewhat differently from the circuits of Figs. 2 and 3, and will be described in connection with the plots of Figs. 1 and 4. In the circuit of Fig. 5, the individual parallel paths have gas tubes 38, 39 and 40 individual to each path, and a time delay thermistor 41 in the common energizing circuit. By way of example, even the high speed boron thermistor mentioned hereinbefore resulted in substantially improved lockout performance, while a slower-operating thermistor made of nickel manganese oxide, such as is described in E. F. Dearborn et al. Patent No. 2,282,944 granted May 12, 1944, resulted in a circuit which did not fail once during extended test operation of this circuit which included many thousands of lockout trials. Low impedance load elements 43, 44 and 45 which correspond to the relays of Fig. 2 are individually in series with the gas tubes 38, 39 and 40. As in the case of the simultaneous lockout circuit of Fig. 2, it is desired that only one path remain conducting shortly after voltage from the source 29 is applied to the parallel circuits by the closure of the switch 16. In this circuit, reliance is placed on the negative resistance portion B—M of the gas tube characteristic OBDMG shown in Fig. 1 for successful operation. It has been found that there is a rather definite time, termed the severance time, required for two or more individual impedances having this type of voltage-current characteristic, which have become simultaneously conducting in their negative resistance states, to change over to a stable equilibrium in which only one of the devices is conducting.

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In the idealized plots of current buildup versus time which are presented in Fig. 4, these various factors are shown graphically. The severance time is indicated by the vertical dashed line labeled t_s . The current I_{gm} at which the gas tube characteristic has a minimum and above which the gas tube has a positive resistance, is shown as a horizontal dashed line in Fig. 4. The parallel horizontal dashed line labeled I_R is the current at which the individual load impedances or relays 43, 44 and 45 are energized or actuated. It may be readily seen that it is undesirable for the current buildup characteristic to enter the shaded area embracing that portion of the graph of Fig. 4 which is above the current I_{gm} and at time values below the severance time t_s . It is to be expected that circuits with buildup characteristics which enter this danger region will fail moderately frequently, as the gas tubes may be in their positive resistance condition (above I_{gm}) before severance, and a stable condition with both tubes conducting will occasionally result.

In accordance with the invention, applicant has provided the thermal storage delay device 41 having a buildup characteristic such as is shown at $R_{30}+T_{41}$ in Fig. 4. The heat capacity of this time delay thermistor is such that the current is held well below the critical current I_{gm} until well after the severance time t_s has elapsed, and then rises rapidly to the value I_R at which the relays are actuated. It is noted that it is this inherent time delay of the thermistor in combination with its variable resistance which provides the desirable current buildup characteristic.

The other plots $R+L_1$, $R+L_2$, and $R+L_3$ show wave shapes for circuits of this general type which have previously been proposed in which an inductance is used to delay the current buildup. A brief consideration of these three plots indicates the superiority of the thermistor delaying means. Using a low inductance ($R+L_1$) a high frequency of lockout failure would be expected since the current enters and remains in the danger region (above I_{gm}) for a large fraction of the severance time. If a larger inductance is used ($R+L_2$) so that the relay would be actuated in the same time that it would be with the thermistor, the current still exceeds I_{gm} substantially before the severance time elapses in contradistinction to the substantial safety margin shown by the time interval between the severance time t_s and the thermistor plot. When a still larger inductance is used ($R+L_3$) so that the buildup time to I_{gm} is the same as that of the thermistor, the speed of actuation of the relays is approximately halved. In addition to the foregoing, thermistors have other advantages in that they tend to be less expensive and less bulky than inductors.

With reference to Fig. 4, it is reiterated that the characteristics are idealized as they are based on linear impedance elements. Since the individual impedances would in fact be somewhat non-linear, the current buildup curves would tend to depart slightly from simple exponentials. In addition, the severance time t_s would tend to depend somewhat on the magnitude of current flowing, and would be somewhat greater for larger current flow. However, the general characteristics indicated do exist and contribute to the markedly improved performance of this selection system.

The circuit of Fig. 6 is essentially a condensation of the switching system disclosed in the application of E. Bruce and H. M. Straube, Serial No. 201,578, filed December 19, 1950, now Patent No. 2,684,405, and is inserted to illustrate the use of the time delay thermistor in a multiple circuit gas tube selection system. The system will be briefly described hereinafter; for a detailed explanation of its operation and the associated switching networks, reference is made to the patent application noted above.

In the system of Fig. 6 it is desired to interconnect any one of lines 1—4 with any one of lines A—D for voice frequency communication, when the appropriate switches S_1 to S_4 and S_a to S_d are closed. These connections must

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be made through four banks of gas diodes G_{11} to G_{18} , G_{21} to G_{28} , G_{31} to G_{34} , and G_{41} to G_{48} , and it may be noted that in any connection exactly four gas tubes will be included in the circuit. The voltage sources V_1 to V_5 together with the resistances R_1 to R_{12} provide the stepped voltages required for breakdown of individual gas tubes in the various banks of tubes as described in detail in the above-noted Bruce-Straube application. In operation, when switches S_4 and S_C for specific example are closed, a plurality of parallel paths between line 4 and line C through various gas diodes are available, and an electrical situation closely analogous to that shown in Fig. 5 is established. Relatively low speed thermistors T_1 to T_4 which are in series with each of the lines A to D, respectively, serve the same function of delaying current buildup for the circuit of Fig. 6 which is performed by thermistor 41 of Fig. 5. The gas tubes are held in their negative resistance condition until after the severance time has elapsed, and good lockout characteristics are assured. To compensate for the loss at voice frequencies caused by the insertion of the time delay thermistors T_1 to T_4 , the high speed thermistors T_5 to T_8 which have substantial negative resistance properties at voice frequencies, may be placed in series with lines 1—4 respectively. These high speed thermistors require no additional biasing equipment, as the direct current required for sustaining discharge in the gas tubes also passes through the thermistors. These high speed thermistors could, of course, also be placed at points T_{10} to T_{13} adjacent the time delay thermistors T_1 to T_4 instead of at T_5 to T_8 .

To illustrate the principles of sequential lockout and isolation which were mentioned briefly hereinbefore, reference is made to the shaded tubes of Fig. 6. With switches S_4 and S_C closed for selection purposes, and with switches S_5 to S_7 applying the appropriate stepped voltages to the banks of gas tubes, the particular path which was selected between lines 4 and C was through the shaded gas tubes G_{17} , G_{24} , G_{32} , G_{45} . The shading indicates that these gas tubes are fired and that they are operating at relatively low resistance points on their characteristic curves, such as between points M and G in the characteristic OBDMG of Fig. 1. Now, assuming that selection switches S_3 and S_b are closed, the connection between line 3 and line B must be made through either gas tube G_{15} or G_{16} . However, with gas tubes G_{17} , G_{24} , G_{32} , and G_{45} fired, the potential across tube G_{15} is reduced as compared with the potential across G_{16} and the connection between lines 3 and B is made by way of a non-interfering path including G_{16} . This action illustrates sequential lockout, as contrasted with the problem of "simultaneous lockout" with which the present application is chiefly concerned. To illustrate the isolation feature of gas tube selection circuits which are to be used for signal transmission, it may be noted that the unfired gas tubes G_{15} and G_{18} effectively isolate the transmission path 4—to—C from the transmission path 3—to—B. This quality of opaqueness in the unfired state, and transparency in the fired state as mentioned hereinbefore makes the gas tube a very useful selection element.

Returning to the subject of selection, or "simultaneous lockout," Fig. 7 illustrates a selection circuit utilizing both of the thermistor selection principles described hereinbefore. In particular, the usual voltage source 29 applies voltage to the paralleled gas tubes 52, 53 and 54, by way of a circuit including the time delay thermistor 55 and the resistance 30. In addition, the high speed thermistors 61, 62 and 63 are placed in series with the individual gas tubes 52, 53 and 54, and are biased during operation by current from the voltage source 29, which is supplied through the biasing network including resistors 65, 66 and 67. This biasing network, which bypasses the time delay thermistor 55 and the gas tubes may be connected directly to one side of the voltage source 29 as shown by a dashed line on the drawing. The connection of the biasing circuit to the voltage source through the

switch 16, however, has the advantage that there is no biasing current drain during the periods when the circuit is not in operation. Because of the relatively high-speed operation of the thermistors 61, 62 and 63, as compared to the total time delay of the thermistor 55 and the breakdown of the gas tubes, they develop current bias to bring them to the proper operating point, before the firing of the gas tubes 52, 53 and 54.

The complementary mode of operation of the two types of thermistor action is particularly useful when the desired operating current is unusually high or when the biased thermistors do not provide negative resistance to sufficiently high currents. Under these circumstances, with reference to Fig. 1, the voltage-current characteristic of the gas tube and biased thermistor combination would be similar to the plot OBDMG, but the minimum point M would be moved to a higher current value. This moves the horizontal line I_{gm} , representing this higher current, upward in the plot of Fig. 4 and permits more rapid actuation of the load devices with the same safety margin between the severance time t_s and the time t_3 at which the buildup current through the time delay thermistor 55, gas tube and biased thermistor reaches I_{gm} .

While the load element in the selection circuits of Figs. 2 and 3 is shown as a relay which energizes an external circuit, this function may be performed by the phototubes 71, 72 and 73 placed adjacent the gas tubes 52, 53 and 54, respectively. This use of the phototubes serves to reduce the local loop impedance and speed up the severance time. Relays or other low impedance load elements may, however, be placed in series with the gas tubes and thermistors in the individual parallel circuits as illustrated in Figs. 2, 3 and 5.

As mentioned hereinbefore, the plots of Figs. 8 and 9 illustrate severance action in lockout circuits such as are described above. Fig. 8 shows the current buildup in the "On" path, and Fig. 9 illustrates the initial firing of a gas tube in another path and the ensuing rapid reduction in current through this other path. These plots were taken from oscilloscope patterns observed in two parallel paths in a circuit of the Fig. 2 type, with biased boron thermistors in series with the gas diodes in each of the two paths.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A selection circuit for electrically interconnecting two terminals by one and only one of a plurality of possible connecting paths, comprising a pair of electrical terminals, a plurality of parallel paths between said pair of terminals, a series combination of a gas tube and a negative temperature coefficient impedance means in each of said paths, a biasing circuit coupled to each of said impedance means for biasing the same to a point at which said series combination exhibits a continuous negative resistance after gas tube breakdown, and means for applying a voltage to said pair of terminals, whereby, when the voltage is applied across said terminals, one and only one of said gas tubes will fire and remain conducting.

2. A selection circuit comprising a plurality of parallel paths, a gas tube in each of said paths, a low impedance load in each of said parallel paths, a voltage source a common impedance in series with said voltage source, means for applying said voltage to said parallel paths, and a negative temperature coefficient impedance means connected in series with each of said gas tubes for ensuring an overall negative resistance in each of said parallel paths, following gas tube breakdown, until such a time that only one of said paths remains conducting, whereby only one of said load impedances will be en-

ergized when said voltage is applied across said parallel paths.

3. An electrical selection circuit comprising a pair of electrical conductors, a plurality of parallel paths between said two conductors, a gas tube individual to each of said parallel paths, and a thermistor having a negative temperature coefficient of resistivity, said thermistor being directly connected between one of said conductors and each of said gas tubes and serving to ensure an overall negative resistance in each of said paths from gas tube breakdown until such a time that only one of said paths remains conducting.

4. A selection circuit comprising a plurality of parallel electrical paths, a gas discharge device individual to each of said parallel paths, a negative resistance element in series with at least one of said gas discharge devices, and means for applying a voltage across said parallel paths, said negative resistance element and series connected discharge device exhibiting an overall negative resistance from gas tube breakdown until such a time that only one of said paths remains conducting.

5. A selection circuit as defined in claim 4 wherein said negative resistance element is a biased thermistor.

6. In combination, a series of parallel electrical paths, a gas tube in each of said parallel paths, means for applying a voltage to said parallel paths, and a thermal time delay means connected between said gas tubes and said voltage applying means, said time delay means having a negative temperature coefficient of resistance and serving to maintain the current in said parallel paths below a selected minimum value for a predetermined period of time.

7. A selection circuit comprising a first group of lines and a second group of lines, a plurality of parallel paths interconnecting said two groups of lines and including at least two parallel paths connecting one line in said first group with a line in said second group, a plurality of gas tubes in each of said paths, and thermal time delay means coupled to each of said paths, said time delay means having a negative temperature coefficient of resistance and serving to maintain the current in said parallel paths below a selected minimum value for a predetermined period of time.

8. A selection circuit comprising a plurality of parallel electrical paths, a gas tube individual to each of said parallel paths, a negative temperature coefficient thermistor and a low impedance load in series with each of said gas tubes, and a biasing circuit for said thermistor having a closed circuit loop which excludes said low impedance load, said thermistors being biased to a point at which each series path exhibits a continuous negative resistance following gas tube breakdown.

9. A selection circuit comprising a plurality of parallel electrical paths, a gas tube individual to each of said parallel paths, a negative temperature coefficient thermistor and a low impedance load in series with each of said gas tubes, and a biasing circuit for each thermistor having a closed circuit loop which includes said low impedance load, said thermistors being biased to a point at which each series path exhibits a continuous negative resistance following gas tube breakdown.

10. A selection circuit comprising a plurality of parallel electrical paths, a gas tube individual to each of said parallel paths, a thermistor in series with each of said gas tubes, and biasing means supplying each said thermistor with a current which is greater than $I_{tp} - I_{gm}$, where I_{tp} is the current at which the thermistor has its voltage peak, and I_{gm} is the current at which the gas tube has its voltage minimum.

11. A selection circuit as defined in claim 10 in which a single voltage supply provides the breakdown voltage for said gas tubes and the current bias for said thermistors.

12. In a selection circuit, a plurality of parallel electrical paths, a gas tube individual to each of said paths,

a time delay thermistor connected in series with said parallel paths, and a biased thermistor individual to each of said paths connected in series with each of said gas tubes, said thermistors having a negative temperature coefficient of resistance and serving to ensure an overall negative resistance in each of said parallel paths from gas tube breakdown until such a time that only one of said paths remains conducting.

13. In combination, a plurality of parallel circuitual paths, a gas tube in series with each of said paths having a voltage versus current characteristic which rises steeply to the breakdown point of the tube continues through a negative resistance region between breakdown and a minimum voltages point and then has a region of low positive resistance, and negative temperature coefficient impedance means in series with each of said gas tubes for offsetting said low positive resistance region of said gas tube and for making the overall resistance of each of said parallel paths negative following gas tube breakdown.

14. In a selection circuit, a plurality of parallel electrical paths, a gas tube individual to each of said paths, a time delay thermistor connected in series with said parallel paths and a biased thermistor individual to each of said paths connected in series with each of said gas tubes, each biased thermistor having a higher negative resistance cut off frequency than said time delay thermistor.

15. A selection circuit comprising a plurality of parallel paths, each of said parallel paths including a gas

tube, a high voltage source, means for applying said voltage source to said parallel paths, and thermistor means connected in series with each of said gas tubes for ensuring an overall negative resistance in each of said parallel paths until such a time that only one of said paths remains conducting.

16. In combination, a gas tube having a voltage versus current characteristic which rises steeply to a breakdown point of the tube, continues through a negative resistance region between breakdown and a minimum voltage point, and then has a region of low positive resistance, a thermistor in series with said gas tube, said thermistor having a voltage versus current characteristic comprising a region of negative resistance, and means for biasing said thermistor to a point at which its negative resistance offsets said low positive resistance region of said gas tube so that the series combination exhibits a continuous negative resistance after gas tube breakdown.

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