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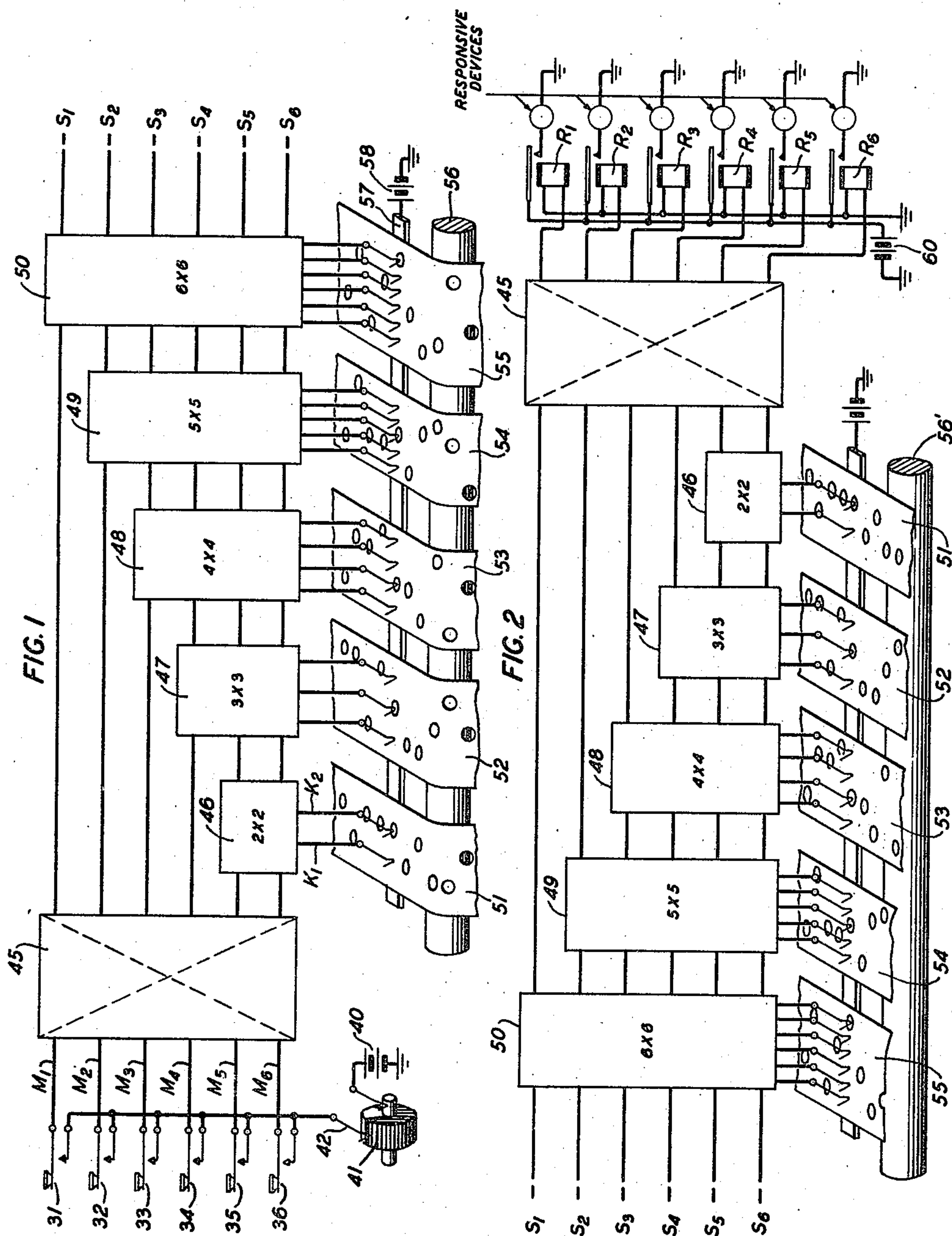
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2,424,998

ELECTRICAL TRANSMISSION SYSTEM

Filed May 10, 1945

2 Sheets-Sheet 1



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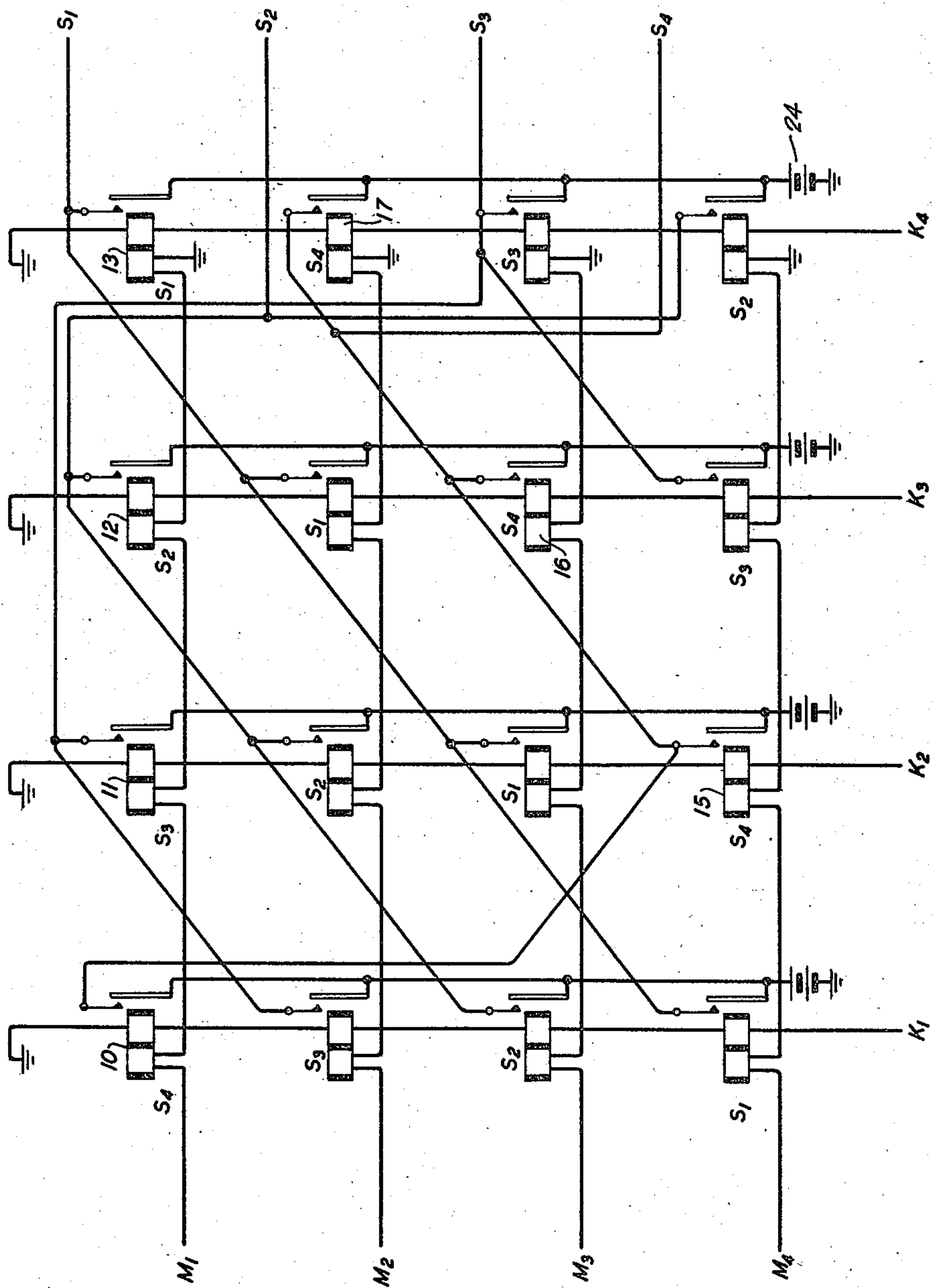
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2 Sheets-Sheet 2

FIG. 3



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ELECTRICAL TRANSMISSION SYSTEM

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1

The present invention relates to circuits or apparatus for closing control paths from any one of a number of input leads or terminals to any one of a number of output leads or terminals on a permutation basis. The circuits for performing this function are termed permuters.

While the invention is capable of general application it will be illustrated in connection with a secret transmission or control system, by way of specific example. In such a system it may be supposed that a number N of devices at the receiving end of the system are to be actuated individually by means of N controllers placed at the transmitting end of the system. Any type of transmission system may be visualized between the controllers and the devices, the simplest consisting, of course, of N separate conductors leading individually from the controllers to the respective devices. Any suitable type of multiplex transmission can be used in practice but the N conductors will be assumed as physically present at the transmitter and again at the receiver.

If a permuter be inserted in these N conductors at the transmitter and an identical permuter be inserted similarly at the receiver and properly connected in circuit, secrecy in transmission can be obtained over the intervening transmission system, of whatever type, provided the permuters are operated so as to avoid any recognizable rule or scheme of interconnection of control paths between the input and output leads of the permuter. Ideally a voltage impressed on any given input lead of the permuter should have an equal chance of energizing any output lead, regardless of the previous history of the interconnections used. Tapping any one or all of the N transmission lines or channels will under these conditions give no clue to the particular controllers that are being actuated. Correct control is exerted at the receiver, however, since the control paths there pass through the second permuter which is identical to the first in mode of operation.

It is the general object of the invention to provide for all possible permutations between a given group of input leads and a similar group of output leads without the use of excessive equipment.

A further and more specific object of the invention is a teledynamic system with a high degree of secrecy in the transmission of the control currents thereover.

The other objects and the various features of the invention will be more clearly apprehended

2

from the following detailed description of the illustrative embodiment shown in the attached drawings in which:

Fig. 1 shows in diagrammatic outline form a transmitting station for a teledynamic system according to the invention;

Fig. 2 is a similar showing of the receiver for such a system; and

Fig. 3 shows the wiring diagram in detail for a permuter of a type suitable for use, for example, in the system of Figs. 1 and 2.

Referring first to Fig. 3, a 4×4 permuter is shown comprising four input leads at the left labeled M_1, M_2, M_3 and M_4 and four output leads at the right labeled S_1, S_2, S_3 and S_4 . The input leads may, for example, be considered as message leads for impressing voltages having a certain message content and the output leads may be thought of as signal transmission leads for conveying the coded information further along in the system.

The lead M_1 passes in series through the left-hand windings of four double-wound relays shown at 10, 11, 12 and 13. A similar arrangement of wiring is provided for the leads M_2, M_3 and M_4 with respect to the second, third and fourth horizontal rows of relays. When a voltage is impressed upon any one input lead, such as M_1 , current flows through the four corresponding left-hand windings of the corresponding horizontal row of relays but this current of itself is insufficient to overcome the bias on the relay so that the relay armature is not attracted. The bias may be provided, for example, by means of a retractile spring (not shown) for the armature.

In order to operate the relays, circuits are provided for passing currents also through the right-hand windings from the four respective leads K_1, K_2, K_3 and K_4 . These voltages are key voltages which for purposes of the system shown in Figs. 1 and 2 are made to occur in a highly irregular order one at a time on the four K -leads. If a voltage appears simultaneously on one of the M -leads and one of the K -leads, one only of the sixteen relays in Fig. 3 will respond since this is the only relay which will have current flowing in both of its windings.

If a voltage appears simultaneously on lead M_1 and lead K_4 , the relay 13 will attract its armature and apply voltage from battery 24 to output lead S_1 . Whenever relay 13 is energized, therefore, output lead S_1 is actuated and the character S_1 is shown adjacent relay 13 to indicate this fact. It will be noted that each output or S lead is wired

3

to the front contacts of four different relays in accordance with a diagonal scheme. For example, the relays 10, 15, 16 and 17 have their contacts all connected to lead S₄. Lead S₄ can, therefore, be chosen by simultaneous currents on leads M₁ and K₁; M₂ and K₄; M₃ and K₃; or M₄ and K₂. The other relays are similarly grouped and connected four in a group to a different output conductor. The arrangement of Fig. 3, therefore, reduces to a table as follows:

M ₁	S ₄	S ₃	S ₂	S ₁
M ₂	S ₃	S ₂	S ₁	S ₄
M ₃	S ₂	S ₁	S ₄	S ₃
M ₄	S ₁	S ₄	S ₃	S ₂
	K ₁	K ₂	K ₃	K ₄

It will be noted from this table that any input lead can exert control over any output lead depending upon the K-conductor that is energized. This table also illustrates the fact that with only sixteen intersecting points arranged as in Fig. 3 only four of the possible twenty-four permutations can be obtained, these four being represented by the four vertical S columns.

Referring now to Fig. 1, six controllers in the form of switches or keys are shown at 31 to 36, there being no special significance to the number six. These keys are intended to be pressed one at a time or two or more of them may be pressed simultaneously. When any key is pressed and closes its operate contact, pulses of current are sent from battery 40 through rotary contact maker 41 and brush 42 over the corresponding input lead or M-lead, M₁ to M₆. The interrupter 41 rotates at a constant speed and may be arranged to close the circuit for any desirable fraction of a rotation, such as a quarter of a rotation, for example. The M-leads are wired to a cross-connecting panel 45 which permits the six input terminals to be cross-connected in any desired order to the six output terminals by means of patching plugs or otherwise. These cross-connections may be changed manually at stated times, such as once a day or once per mission of a directionally controlled device in accordance with a prearranged schedule or program.

In accordance with the present invention, assuming a six-conductor system, five permeters are used comprising a 2 x 2 permuter shown at 46 for any two, such as the lowermost two, message leads; a 3 x 3 permuter 47 for the two output leads from permuter 46 plus one of the other message leads; a 4 x 4 permuter 48 for the three output leads of permuter 47 plus another one of the message leads; a 5 x 5 permuter 49 similarly arranged; and, finally, a 6 x 6 permuter 50. These five permeters are capable of giving all possible permutations between the leads M₁ to M₆ and the output leads S₁ to S₆.

The K-voltages could be provided to these permeters in any desired manner, two such voltages being required for permuter 46, three voltages for permuter 47 and so on up to six voltages for permuter 50.

In a secrecy system it is desirable that the K-voltages be applied in a highly irregular and in as nearly a random order of occurrence as possible in order to make it difficult for one who does not know the key to reconstruct the message from the signals. In the arrangement of Fig. 1, the K-voltages are obtained from punched tapes which are prepared in advance and used in duplicate at the transmitting and receiving stations. These

4

punched tapes are shown at 51, 52, 53, 54 and 55 as passing over a continuously rotating roller 56 which may be geared to the circuit interrupter 41 so as to be driven from the same motor with a proper speed relation. The roller 56 moves the five tapes at uniform speed across bedplate 57 which is maintained at a positive voltage by means of battery 58. Sets of brushes are arranged above the bedplate 57 to make contact therewith whenever a hole appears in the tape beneath a given brush. At the instant shown in Fig. 1, voltage from the battery 58 is being applied through a perforation in tape 51 to the right-hand brush leading to the right-hand K-conductor K₂ of permuter 46. Also the middle brush of tape 52 is applying a voltage to the middle K-lead of permuter 47 and the second brush from the left in the case of tape 53 is applying voltage to a second K-lead of permuter 48 and so on. By arranging the holes in the tapes in an irregular manner, the application of the voltage pulses to the K-leads of the various permeters can be made in as highly irregular order as desired. The rate of movement of the tapes in relation to the drum 41 should be such that drum 41 closes the circuit for an interval and then opens the circuit while a brush is in contact with the bedplate 57 through a corresponding tape perforation. This insures that a voltage is always on a K-lead at the time when a pulse is applied to an M-lead and remains on the K-lead until the end of the corresponding pulse as measured by the interrupter 41.

The voltages appearing on the output leads S₁ to S₆ are transmitted by individual line wire conductors or by multiplex transmission, for example on a carrier basis, over a line or radio channel or in any other manner to the station in Fig. 2, the incoming leads at the latter station being similarly labeled at the left. In Fig. 2, five permeters are used which are duplicates of those at the transmitter and are similarly designated by reference numerals. Also a similar cross-connecting frame or panel 45 is used. It will be noted that in Fig. 2 these six items appear in a reverse order from left to right with respect to the corresponding items in Fig. 1. Five duplicate tapes 51 to 55 are provided at the receiver and are driven by roller 56 in exact synchronism with the five tapes at the transmitter. This insures that K-voltages are supplied to the permeters at the receiving point at the same instants as at the transmitter and to analogous K-leads.

In order properly to decipher the signals it is necessary to connect the armatures of the receiving permuter relays in proper groups to the outgoing conductors. Arranging the S-leads as the incoming leads and the M-leads as outgoing, the manner of wiring the relay output circuits is indicated by the following table where like numbers

S ₁	4	3	2	1	M ₁
S ₂	3	2	1	4	M ₂
S ₃	2	1	4	3	M ₃
S ₄	1	4	3	2	M ₄
	K ₁	K ₂	K ₃	K ₄	

appearing in the table indicate which relay outputs are to be connected in parallel to the correspondingly numbered M-lead. Thus, if the incoming voltage is on lead S₃ and the key is K₂, the upper or M₁ output lead is chosen. Referring to Fig. 3 or to the previous table, when M₁ and K₂ were used in coding, lead S₃ was actuated. Thus

5

M₁ is recovered by decoding S₃ with the same key element K₂.

Analogous to the above tables, the tables for a 3 x 3 and for a 6 x 6 permuter would be as follows:

M ₁	3	2	1	S ₁
M ₂	2	1	3	S ₂
M ₃	1	3	2	S ₃
	K ₁	K ₂	K ₃	

M ₁	6	5	4	3	2	1	S ₁
M ₂	5	4	3	2	1	6	S ₂
M ₃	4	3	2	1	6	5	S ₃
M ₄	3	2	1	6	5	4	S ₄
M ₅	2	1	6	5	4	3	S ₅
M ₆	1	6	5	4	3	2	S ₆
	K ₁	K ₂	K ₃	K ₄	K ₅	K ₆	

It is not necessary that the arrangement be a symmetric one and by way of illustration the following asymmetric diagram is given for a 5 x 5 permuter. It will be noted that the interval

M ₁	2	5	3	4	1	S ₁	5	4	3	2	1
M ₂	5	3	4	1	2	S ₂	1	5	4	3	2
M ₃	3	4	1	2	5	S ₃	3	2	1	5	4
M ₄	4	1	2	5	3	S ₄	4	3	2	1	5
M ₅	1	2	5	3	4	S ₅	2	1	5	4	3
	K ₁	K ₂	K ₃	K ₄	K ₅		K ₁	K ₂	K ₃	K ₄	K ₅

connections are different in the transmitting and receiving permuters when the diagram is asymmetric.

The output leads on the output side of the cross-connecting frame 45 are shown as wired to six different relays R₁ to R₆, the opposite terminal of each winding being grounded so that whenever one of the six output leads receives a pulse from the batteries in the permuters the corresponding relay attracts its armature and closes an operating circuit from battery 60 over the armature and front contact of the corresponding relay to whatever work circuit may be desired. By way of example, the upper two relays R₁ and R₂ may control a right and left rudder; the second pair of relays R₃ and R₄ may control an up and down elevator while the next pair of relays R₅ and R₆ may control a starting and stopping circuit or other actuating or control circuits. In this type of embodiment the six relays may be made, therefore, to control a dirigible body, such as an airplane, torpedo or the like. In such a system the relays R₅ and R₆ may instead, by way of further example, control the release or firing of a charge or perform a similar operation.

In the operation of the system, according to Figs. 1 and 2, key 31 when pressed will cause the transmission of impulses to the winding of the relay R₁ and cause that relay to attract its armature. The arrangement may be such that the relay R₁ holds its armature attracted as long as the key 31 is closed. This may be done by use of a holding circuit including a condenser and resistance in the circuit of the relay or otherwise in accordance with known practice. Similarly, whenever key 32 is depressed relay R₂ is actuated and so on, each key individually controlling its corresponding relay.

Any one listening in on the system between the sending and receiving stations would, however, be unable to perceive which types of control are being sent over the system since the pulses are being continuously permuted over the six

6

S-conductors in an unintelligible manner. For this reason also it will be impossible for an unauthorized person to directly control the receiver because he could not know at any instant what pulses must be sent over any of the channels S₁ to S₆ in order to effect a given type of response at the receiver. It is necessary in order to decode the signals to have possession of a receiving station according to Fig. 2 and also a set of key tapes identical with those in use at the transmitter. It is also necessary to know the character of cross-connections made in panel 45 at the transmitter.

It will be understood that the choice of six conductors instead of some other number has been merely by way of example and that the principles disclosed are equally applicable to systems of either greater or less number of conductors or signal elements or values.

What is claimed is:

1. In combination in an electrical circuit, a group of N separate input conductors and a group of N separate output conductors, where N is an integral number greater than 3, and means to establish simultaneous individual circuit connections between said input and output conductors respectively and to permute said circuit connections among themselves comprising a succession of N-1 permuters each embracing a different fractional number of said circuit connections from two to N such circuit connections respectively.

2. In combination in an electrical circuit, a group of N separate input conductors and a group of N separate output conductors, where N is an integral number greater than 3, and means to extend individual control paths simultaneously from said input to said output conductors, respectively, and to permute said control paths among themselves comprising a succession of N-1 permuter circuits, one of which embraces two only of said control paths, and others increasing in size and embracing successively one more of said control paths up to the largest one which embraces all N control paths.

3. In combination in an electrical circuit, a group of N separate input conductors and a group of N separate output conductors, where N is an integral number greater than 3, and means to extend individual control paths from said input conductors to said output conductors and to permute said control paths among themselves comprising N-1 permuter circuits for successively permuting groups of said control circuits varying in size by one additional control circuit from two to N control circuits.

4. An electrical circuit according to claim 3, each permuter having individual input leads and individual output leads, and means to extend a control path from any input lead to any output lead.

5. An electrical circuit according to claim 3, each permuter having individual input leads and individual output leads, and means to extend a control path from any input lead to any output lead, comprising a group of key leads forming intersecting points with said input leads, means at said intersecting points for exerting controls over said output leads, and means to apply key voltages to said individual key leads to control actuation of said control exerting means.

6. In a signaling system, more than three separate signal input circuits, a corresponding number of output circuits, means to exert controls upon individual output leads from individual signal input leads, including means to exert control

upon two intermediate leads from two of said signal input circuits in accordance with one key, means to exert control upon three other intermediate leads from said two intermediate leads and a third one of said signal input circuits in accordance with another key, and means to exert control upon said output leads from the last group of intermediate leads and the last of said signal input leads in accordance with another key.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,139,676	Friedman	Dec. 13, 1938