

March 21, 1961

W. A. REENSTRA

2,976,520

MATRIX SELECTING NETWORK

Filed Sept. 20, 1955

3 Sheets-Sheet 1

FIG. 1

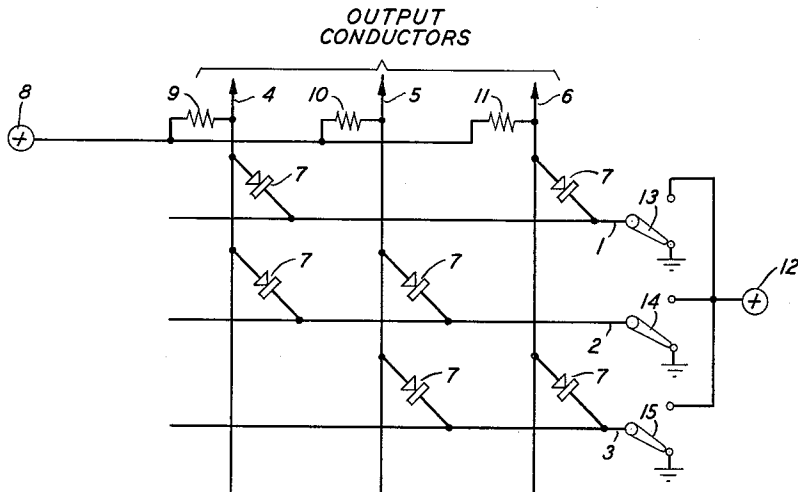
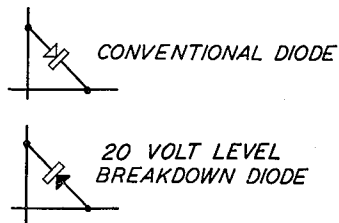
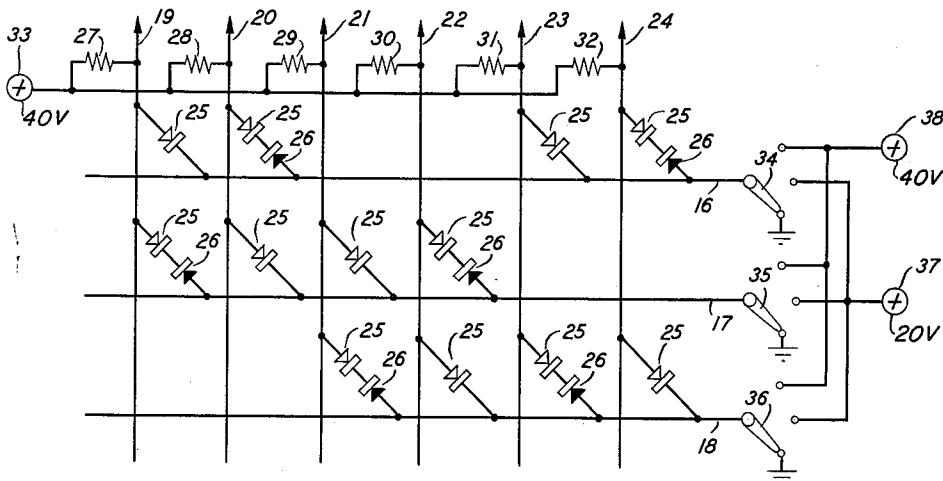


FIG. 2



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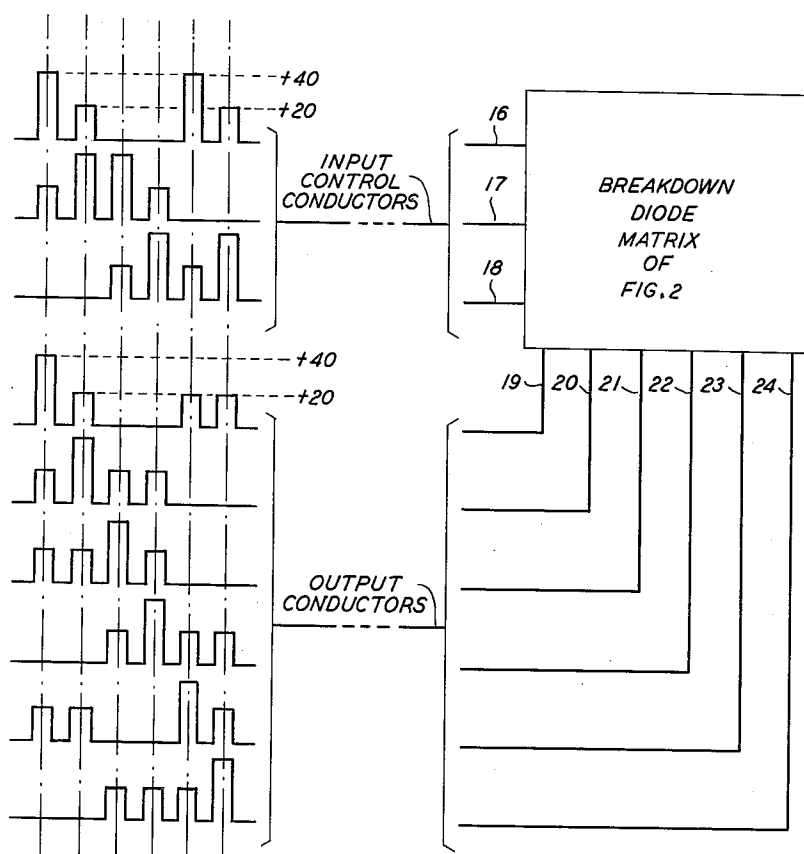
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FIG. 3



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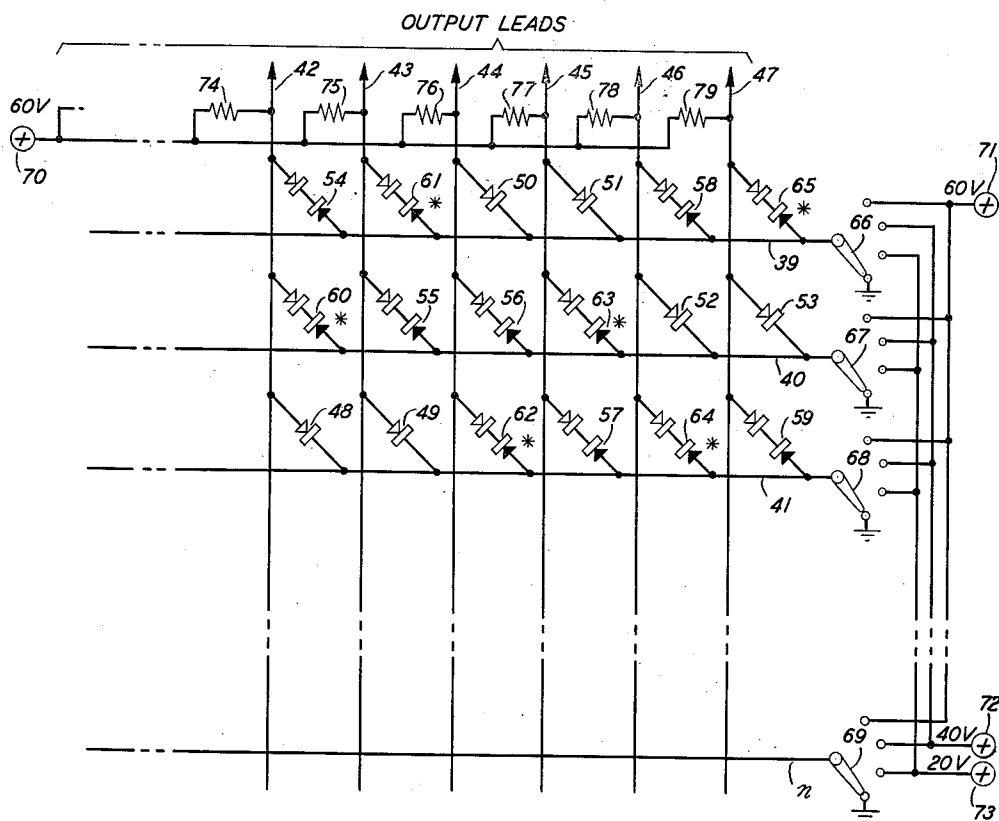
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FIG. 4



 40 VOLT LEVEL
BREAKDOWN DIODE

 20 VOLT LEVEL
BREAKDOWN DIODE



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2,976,520

MATRIX SELECTING NETWORK

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10 Claims. (Cl. 340—176)

This invention relates to high speed selection networks and more particularly to high speed selection networks of the type comprising an electrical matrix.

In systems designed to transmit electrical information signals, it frequently is desirable to effect the selection of a unique combination of output conductors from a plurality of such conductors by the selective energization of a given combination of control conductors. In many of such systems, such as are utilized in the fields of computing, telemetering, communication, and the like, it further is desirable that such selection not only be brought about with a minimum of time and power consumption, but that a maximum of useful information be transmitted with a given number of conductors.

Networks known as matrices have been employed for these purposes, wherein a plurality of control conductors are connected, in various combinational arrangements, to a plurality of output conductors, there being a unique set of output conductors associated with each combination of control conductors. For the speeds of operation required in present day systems, the conductors advantageously are connected by unilateral impedance elements, such as rectifiers or diodes, the points of connection being known as crosspoints. Various forms of diode matrices have been disclosed in the prior art and some examples thereof are described in an article entitled "Rectifier Networks for Multiple Switching," by D. R. Brown and N. Rochester, at page 139, volume 37 of the Proceedings of the Institute of Radio Engineers (February 1949).

Generally, in such diode matrix networks, a selection of a desired one out of a plurality of output conductors is effected by applying potentials to a chosen combination of control conductors on a coded space division basis to cause only certain ones of the crosspoint diodes to conduct and thereby disable all of the output conductors but the one associated with the particular input code. Although matrices of this type have been found practical in a large variety of utilizations, they are somewhat limited in information handling capacity, that is, the number of possible output selections which can be made with a given number of control conductors. For the general m -out-of- n type of combinational diode matrix, it can be shown that the number of possible output codes is given by the equation:

$$x = \frac{n!}{m!(n-m)!} \quad (1)$$

where n equals the number of input information control conductors connected to the diode matrix and m equals the number of input information control conductors that must be energized in order to select a given output conductor.

It is an object of this invention to provide an improved electrical selecting matrix. More specifically, it is an object of this invention to provide an electrical selecting matrix which is capable of selecting a far

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greater number of output conductors for a given number of input conductors than is possible with known m -out-of- n matrices.

It is a further object of this invention to provide an electrical selecting matrix which operates on an amplitude division as well as a space division basis.

In one specific illustrative embodiment of this invention, a plurality of semiconductor diodes are interconnected between various ones of a plurality of control conductors and a plurality of output conductors to form an electrical matrix. Matrices generally are networks wherein the energization of various combinations of control conductors disables all but one of the output conductors to effect a selection of a single channel.

In this specific illustrative embodiment, selected ones of the semiconductor diodes have connected in series opposition thereto a further semiconductor diode of the so-called breakdown type. These breakdown diodes have the characteristic of relatively little or no conduction for all reverse voltages up to a given amplitude and of high conduction for all such applied voltages above the given amplitude. In effect, these breakdown diodes act as a bias battery in series with the semiconductor diodes so that there will be no conduction through the crosspoints defined by the plural diodes until voltages of sufficient amplitude are applied thereacross, as described in application Serial No. 365,080, filed June 30, 1953, of R. J. Kircher, now Patent 2,854,651, issued September 30, 1958. Thus, selection is based not only upon space division principles as in prior diode matrix circuits, but upon amplitude division principles as well, due to the bias effect of the breakdown diodes. For example, to select a desired output lead it is necessary not only to energize the proper combination of input leads but also to energize these leads at voltages of amplitudes sufficient to cause the breakdown diodes to conduct. Manifestly, the input signals may comprise a plurality of signals of different amplitudes applied to the various ones of the input conductors. The desired output conductor then will have a signal thereon of a given amplitude, but the undesired conductors may have signals of lesser amplitude thereon or no signal at all. In the utilization of the instant invention the effect of these smaller amplitude pulses can be eliminated by requiring the devices driven by the output conductors to have a definite excitation level below which they will not respond.

In another specific illustrative embodiment of this invention, multilevel breakdown diodes are used to provide a far greater number of output codes for a given number of input control conductors. This may be done by placing two or more breakdown diodes in series with each other or by utilizing breakdown diodes having different breakdown voltage levels.

It is a feature of this invention that a diode matrix utilize biasing elements at selected crosspoints for operation on an amplitude division as well as a space division basis. More specifically it is a feature of this invention that breakdown diodes be incorporated with the conventional diodes in an electrical selecting matrix whereby a larger number of outputs may be controlled by a smaller number of input leads or control wires.

It is another feature of this invention that breakdown diodes having similar breakdown voltage levels be connected in series opposition to conventional diodes at chosen crosspoints of an electrical selecting matrix.

It is a further feature of this invention that breakdown diodes having different breakdown voltage levels be connected in series opposition to conventional diodes at chosen crosspoints of an electrical selecting matrix.

A complete understanding of this invention and the

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features thereof may be gained from the following description and accompanying drawing in which:

Fig. 1 is a schematic diagram of a known type of electrical selecting matrix using conventional diodes;

Fig. 2 is a schematic representation of one embodiment of the present invention wherein single level breakdown diodes are employed with the conventional diodes at selected matrix crosspoints;

Fig. 3 is a block diagram representation depicting particularly the input and output codes of the diode matrix of Fig. 2; and

Fig. 4 is a schematic diagram of still another embodiment of the present invention which employs two breakdown diodes per output conductor and wherein the diodes have different breakdown voltage levels.

Turning now to the drawing, Fig. 1 shows a conventional diode matrix which comprises a plurality of input conductors 1, 2, and 3, respectively, in one coordinate, a plurality of output conductors 4, 5 and 6, respectively, in another coordinate, and a plurality of conventional diodes 7 interconnecting certain ones of the input and output conductors at selected crosspoints. Each of the output conductors 4, 5 and 6 is connected to a source of positive potential 8 by the resistances 9, 10 and 11, respectively. Each of the input conductors 1, 2 and 3 may be connected to a source of potential 12 or to ground by the selective operation of switches, 13, 14 and 15, respectively. Selection of any one of the output conductors in the conventional matrix of Fig. 1 may be effected by energizing the input conductors on a two-out-of-three code basis. For example, if the input conductors 1 and 2 each are energized by the connection through switches 13 and 14 to the potential source 12 and the input conductor 3 is connected to ground, only output conductor 4 will be selected, the selection being effected by having a potential existing on conductor 4. This is accomplished since all of the diodes 7 except those connected to output conductor 4 are placed in a conducting condition. The potentials from sources 8 and 12 being equal, the diodes connected to output conductor 4 have zero potential thereacross and therefore are nonconducting. Under these conditions there will be ground potential on output conductors 5 and 6 since the conduction of the diodes connected to switch 15 clamps these conductors to ground. Consequently there is positive potential on only output conductor 4. In a similar manner, output conductor 5 may be selected by energizing only the input conductors 2 and 3 and output conductor 6 may be selected by energizing only input conductors 1 and 3. Thus, a conventional matrix having three control conductors and utilizing a two-out-of-three code permits the selection of three individual output conductors.

Fig. 2 illustrates an embodiment of the present invention wherein twice as many output codes are available with the same number of input control conductors as were used in the matrix of Fig. 1. Fig. 2 depicts a circuit which comprises input conductors 16, 17 and 18, respectively, in one coordinate, output conductors 19, 20, 21, 22, 23 and 24, respectively, in another coordinate, and a plurality of diodes at selected crosspoints between the input and output conductors. At some of these crosspoints only a conventional diode 25 is interposed. At other ones of the crosspoints a conventional diode 25 in series opposition with a breakdown diode 26 is connected.

Diodes 26, which are herein referred to as breakdown diodes, have also been variously referred to as saturation diodes, threshold diodes, avalanche diodes, or Zener diodes and are described in an article "Transistors and Junction Diodes," by F. H. Chase, B. H. Hamilton, and D. H. Smith in the Bell System Technical Journal, volume 33, page 827 (July 1954), and in Patent 2,714,702 issued August 2, 1955, of W. Shockley. These diodes have the characteristic that upon the application of a voltage opposite to that which would ordinarily render the diode

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conducting no current will pass through the diode until this applied voltage passes a saturation or breakdown point. Beyond this point the diode becomes conductive and the current increases sharply due to the application of any additional reverse voltage. The explanation for this unusual increase in current appears to involve the sudden release of electrons or holes within the diode element which gives rise to the increase in the already prevalent reverse current. This process is cumulative and leads to large increases in currents for small further increases in voltage.

For the purposes of illustration, the breakdown diodes 26 each will be considered as having a reverse breakdown voltage of approximately 20 volts and will be effectively open circuited for all voltages below this value. Output conductors 19 through 24 are connected through resistances 27 through 32, respectively, to a source of positive potential 33, which in the instant illustrative example may have an amplitude of 40 volts. The input conductors 16, 17 and 18 each may be connected through the switches 34, 35 and 36, respectively, to either a source of positive potential 37, which advantageously may have an amplitude of 20 volts, a source of positive potential 38, which advantageously may have an amplitude of 40 volts, or to ground. Selection of a desired one of the six output conductors may be effected as described below.

If the positive potential of 40 volts is placed on input conductor 16 by closing switch 34, the positive potential of 20 volts is placed on input conductor 17 by closing switch 35, and ground potential is placed on input conductor 18 by closing switch 36, only the output conductor 19 is energized with a 40 volt potential and output conductors 20 through 24 are at a 20 volt or ground potential. When ground potential is placed on input conductor 18, output conductor 22 also is at ground potential since the conventional diode 25 at the crosspoint between conductors 18 and 22 is conducting due to the 40 volt drive initially applied thereacross. Substantially all of the potential drive is dissipated across resistor 30, thus placing conductor 22 at ground. Output conductor 24 is at ground potential for the same reason. Output conductor 21 is at 20 volts since the conduction of diode 25 connected at the crosspoint and between input conductor 17 and output conductor 21 clamps the latter at the potential of source 37. Output conductor 20 for similar reasons is clamped to a 20 volt potential. Output conductor 23 is at 20 volts since the 40 volt potential drive applied across conventional diode 25 in series with breakdown diode 26 at the crosspoint of conductors 18 and 23 is sufficient to break down the diode combination and cause current to be conducted therethrough. As there is a 20 volt drop across the breakdown diode, conductor 23 is clamped to 20 volts. The diodes connected at the crosspoints between output conductor 19 and input conductors 16 and 17, however, will not be in their conducting state since there is insufficient voltage thereacross to cause said diodes to break down. Since these paths will be open there will be a 40 volt potential on output conductor 19. The other output conductors can be selected in a similar manner by similar potential combinations on the input conductors on a two-out-of-three coded basis as shown by the following table:

Input Conductors	Output Conductors						
	19	20	21	22	23	24	Idle
16.....	+40	+20	+0	+0	+40	+20	0
17.....	+20	+40	+40	+20	0	0	0
18.....	0	0	+20	+40	+20	+40	0

Selected output conductor=40 volts.

Fig. 3 is a block diagram showing the input signal codes

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which are applied to the input conductors of the diode matrix of Fig. 2 and the output signal codes which appear on the output conductors thereof for each of the input signal codes. An examination of each of the output conductor voltage conditions clearly shows that for each input code one and only one of the output leads will have a potential of 40 volts thereupon. It also will be seen, however, that some of the other output conductors will have half size pulses having potentials of 20 volts thereon. It will be appreciated by those skilled in the art that a selection may be made on an amplitude basis by permitting the load circuits to be energized only by potentials greater than 20 volts, such as by requiring the device driven by the energized output conductor to have a definite threshold level higher than 20 volts, below which it will not respond.

In a circuit of the type shown in Fig. 2, that is, an electrical selecting matrix which uses one breakdown diode per output lead, the number of possible output codes is given by the equation:

$$x = \binom{m}{n} \frac{n!}{m!(n-m)!} \quad (2)$$

In a circuit which utilizes a two-out-of-three code, for example, m is equal to two. With this code the electrical matrix of Fig. 2 is capable of providing twice as many selections as is the prior art matrix of Fig. 1 with the same number of input or control conductors.

Where an even larger number of output codes is desired with a given number of input conductors, in accordance with an aspect of this invention, it is advantageous to use more than one breakdown diode per output lead. For example, an electrical matrix which utilizes two or more breakdown diodes per output lead, wherein the diodes have the same breakdown voltage, may produce a total number of output codes equal to:

$$x = \frac{n!}{p!(m-p)!(n-m)!} \quad (3)$$

where p equals the number of breakdown diodes required per output conductor. Many variations and modifications of the basic principles of the invention discussed above will be appreciated and recognized by those skilled in the art.

A still greater number of output codes may be obtained in an electrical matrix of the general type described above if breakdown diodes having different breakdown voltage levels are employed. Fig. 4 shows such a circuit which comprises a plurality of input conductors 39, 40, 41 . . . n in one coordinate, a plurality of output conductors 42, 43, 44, 45, 46, 47 . . . in another coordinate, and a number of diodes connected at the crosspoints thereof. Some of these diodes, such as diodes 48, 49, 50, 51, 52 and 53 are of the conventional type. Others, such as diodes 54, 55, 56, 57, 58 and 59 are of the breakdown type and have the same reverse voltage breakdown level, such as, for example, 20 volts. These diodes are connected in series opposition with conventional diodes at selected crosspoints. The remaining breakdown diodes, diodes 60, 61, 62, 63, 64 and 65 advantageously have a reverse breakdown voltage level of 40 volts and also are connected in series opposition with conventional diodes at certain of the crosspoints. The output conductors 42 through 47 are connected through the resistances 74, 75, 76, 77, 78 and 79 respectively, to a source of positive potential 70, which advantageously may be 60 volts. The input conductors 39, 40, 41 . . . n , may be connected selectively through their associated switching circuits 66, 67, 68 and 69 to positive potential sources 71, 72 and 73 which advantageously

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may be 60 volts, 40 volts and 20 volts, respectively, or to ground.

In the operation of the circuit of Fig. 4 the input signals comprise voltage pulses having discrete amplitude levels to cause the selective energization of the crosspoint diodes. Advantageously, these signals may be applied to the input control conductors in accordance with a general m -out-of- n coding scheme to provide the selection of a single output conductor for each unique input code.

If, for example, a three-out-of- n code is employed, output conductor 42 will be selected if the input code signals comprise a pulse of 40 volts applied to input conductor 39, a pulse of 20 volts applied to input conductor 40, a pulse of 60 volts applied to input conductor 41 and ground potential on all of the remaining input conductors down to n . None of these other input conductors are connected by crosspoints to conductor 42. Under these circumstances, output conductors 44 and 45 each will have a 40 volt potential thereon due to the conduction of conventional diodes 50 and 51 respectively, the conduction of these diodes clamping conductors 44 and 45 to the 40 volt level. Output conductors 46 and 47 each will have a 20 volt potential thereon due to the conduction of conventional diodes 52 and 53, these conductors similarly being clamped to the potential of source 73. Output conductor 43 has a 40 volt potential thereon due to the breakdown of diode 55 which has a 40 volt potential drive applied thereto. As diode 55 is a 20 volt level breakdown diode, the remaining 20 volts is dropped across resistor 75. Only output conductor 42 will have a 60 volt potential thereon, this potential being due to the non-conduction of any diodes connected thereto. So it is clear that one and only one output conductor may be selected by the application of the proper signal codes to the input conductors.

The three-out-of- n matrix just described makes possible a number of output combinations equal to:

$$x = 6 \frac{n!}{m!(n-m)!} \quad (4)$$

The various other output conductors can be selected in a manner similar to that described above for output conductor 42 as shown by the following table:

Input Conductors	Output Conductors						
	42	43	44	45	46	47	Idle
39.....	+40	+20	+60	+60	+40	+20	0
40.....	+20	+40	+40	+20	+60	+60	0
41.....	+60	+60	+20	+40	+20	+40	0
.....	0	0	0	0	0	0	0
.....	0	0	0	0	0	0	0

As previously stated, the load devices driven by this matrix will be required to have a definite threshold level below which it will not respond so as to eliminate all output voltages except those greater than 40 volts thereby giving rise to the energization of a single output conductor for each input code.

In general, the number of possible output codes produced with a matrix using multilevel breakdown diodes is given by:

$$X = \frac{1}{q!r!s! \dots} \times \frac{n!}{(m-p)!(n-m)!} \quad (5)$$

where p equals the number of breakdown diodes per output conductor, q equals the number of breakdown diodes having one breakdown voltage level, r equals the number of breakdown diodes having another breakdown voltage level, etc.

The following table shows a number of codes possible with a given number of information leads:

<i>n</i> Number of Control Leads	Min. Value of <i>p</i> for Max. Number of Outputs	$X_i = n!$ Max. Number of Outputs Available
3-----	1	6
4-----	2	24
5-----	3	120
6-----	4	720
7-----	5	5040
8-----	6	40320

It will be appreciated by those skilled in the art that the addition of breakdown diodes to the conventional diodes in an electrical selecting matrix, together with the use of input signals having discrete amplitude levels, provides a means of designing combinational diode matrix selecting circuits having up to "*n*!" outputs. The advantage of such a selective circuit lies in the reduced number of input conductors required to select any one of the many outputs. However, it is to be understood that the above-described arrangements merely are demonstrative 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 sphere and scope of the invention.

What is claimed is:

1. A network for enabling the selection of a unique output conductor by the coded energization of predetermined combinations of control conductors which comprises a plurality of output conductors, a plurality of control conductors, source means for supplying potentials of at least three different amplitudes, means for applying potentials from said source means to chosen combinations of said control conductors, and means connected between said control and output conductors for responding to said potentials for selectively energizing the output conductors associated with said chosen combinations of input conductors, said last-named means comprising a first plurality of crosspoints consisting only of conventional diode elements connected between certain ones of said control and output conductors and a second plurality of crosspoints consisting of conventional diode elements in series with breakdown diode means connected between others of said control and output conductors.

2. A selective signal network comprising a plurality of input conductors, a plurality of output conductors, means for selectively supplying a plurality of predetermined potentials to each of said input conductors, and means for selecting individual ones of said output conductors in response to the selective amplitude energization of various combinations of said input conductors, said means including a matrix connected between said input and output conductors and comprising a plurality of crosspoint means including first crosspoints consisting only of conventional diode elements and second crosspoints consisting of conventional diode elements in series with Zener diode elements, said Zener diode elements biasing said conventional diode elements in series therewith to be responsive only to applied potentials of predetermined amplitudes.

3. A selective signal network in accordance with claim 2 wherein said Zener diode elements bias said conventional diode elements in series therewith to conduct in response to applied potentials of an amplitude greater than a single predetermined value.

4. A selective signal network in accordance with claim

2 wherein said Zener diode elements associated with different ones of said conventional diode elements have breakdown levels of first and second predetermined values, and wherein said means for selectively supplying a plurality of predetermined potentials supplies potentials of values equal to, greater, and less than said first and said second predetermined values.

5. A selective signal transmission network comprising a plurality of input conductors, a plurality of output conductors, a plurality of potential sources having potentials of different amplitudes, switching means for applying potentials from said sources to chosen combinations of said input conductors, and means for responding to the potentials on said input conductors for selectively energizing a desired one of said plurality of output conductors, said means comprising an electrical matrix including a first plurality of crosspoints consisting only of conventional diodes connected between certain ones of said input and output conductors, and a second plurality of crosspoints consisting of conventional diodes in circuit with a plurality of amplitude sensitive voltage responsive means connected between others of said input and output conductors.

6. A selective signal transmission network in accordance with claim 5 wherein said amplitude sensitive voltage responsive means comprises breakdown diodes having predetermined reverse voltage breakdown levels.

7. A selective signal transmission network in accordance with claim 6 wherein the breakdown levels of individual ones of said breakdown diodes differ.

8. A network for enabling the selection of a unique output conductor by the coded energization of predetermined combinations of control conductors comprising a plurality of output conductors, a plurality of control conductors, source means for supplying potentials of different amplitudes, switching means for applying potentials from said source means to chosen combinations of said control conductors, and matrix means connected between said control and output conductors for responding to said potentials for selectively energizing the ones of said plurality of output conductors associated with predetermined combinations of said input conductors, said matrix means comprising a first plurality of crosspoints each consisting only of a conventional diode, and a second plurality of crosspoints each consisting of a conventional diode in series with a breakdown diode, said first and second crosspoints being individually connected between chosen ones of said control and output conductors.

9. A network as in claim 8 wherein all of said breakdown diodes have equal reverse voltage breakdown levels.

10. A network as in claim 8 wherein said breakdown diodes have different reverse voltage breakdown levels.

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