Nov. 28, 1961 T. B. TOMLINSON 3,011,075

NON-LINEAR RESISTANCE DEVICES

Filed June 1, 1959 2 Sheets-Sheet 1

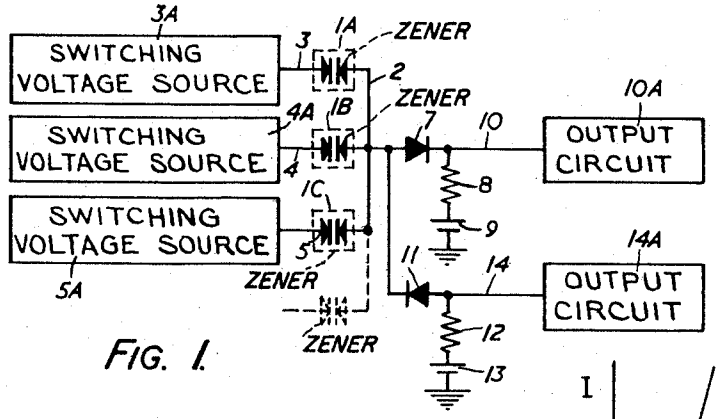


FIG. 1.

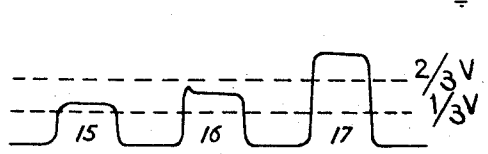


FIG. 2.

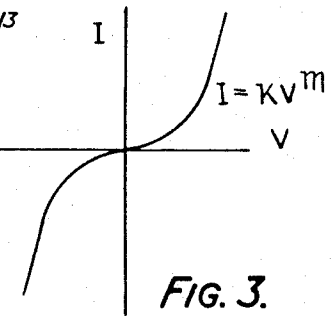


FIG. 3.

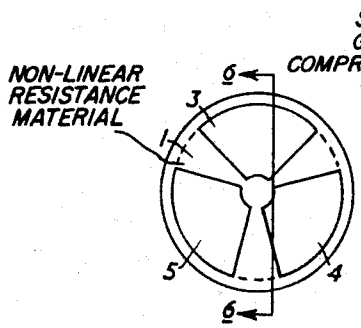


FIG. 4.

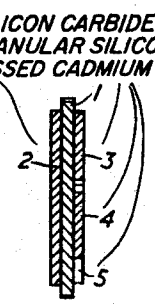


FIG. 5.

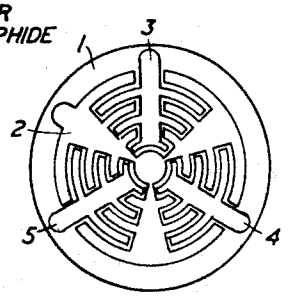


FIG. 6.

INVENTOR

BY

ATTORNEY

Nov. 28, 1961 T. B. TOMLINSON 3,011,075

NON-LINEAR RESISTANCE DEVICES

Filed June 1, 1959 2 Sheets-Sheet 2

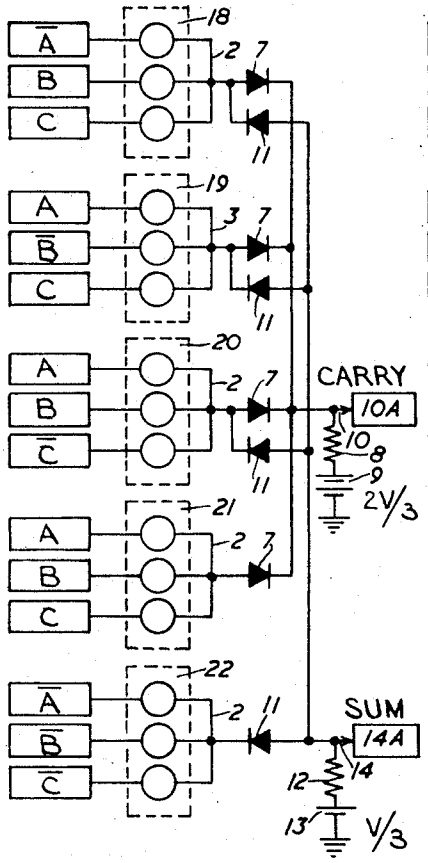


FIG. 7.

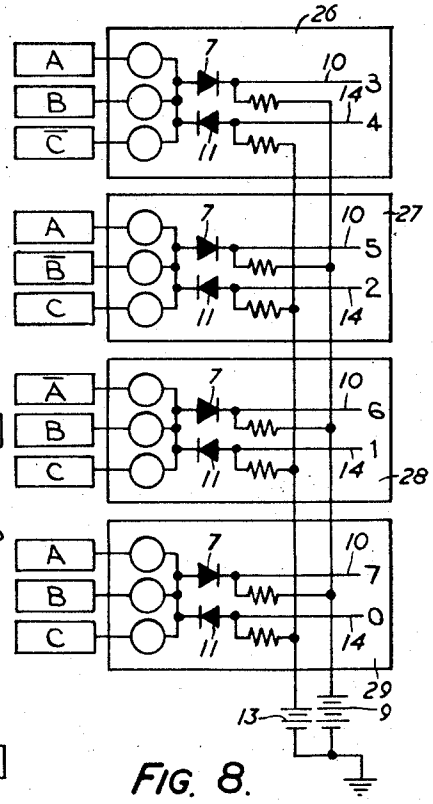


FIG. 8.

INVENTOR

BY

ATTORNEY

United States Patent Office 3,011,075 Patented Nov. 28, 1961

3,011,075

NON-LINEAR RESISTANCE DEVICES

Terence Bernard Tomlinson, Bracknell, England, assignor to Computer Developments Limited

Filed June 1, 1959, Ser. No. 817,351
Claims priority, application Great Britain Aug. 29, 1958
12 Claims. (Cl. 307—88.5)

The present invention relates to electric switching circuits which are suitable for use among other applications as gating circuits in, for example, electric computing and calculating apparatus. The invention also relates to switching networks including a plurality of such circuits.

The circuits according to the present invention make use of non-linear resistance elements of a kind which will be referred to in this specification as "constant voltage elements." These "constant voltage elements" are ones having a current/voltage characteristic such that with increase of current in either direction through the element the voltage across it effectively reaches a saturation value beyond which it does not increase as the current increases. If currents in opposite directions are regarded as being of opposite sign, such elements have positive and negative saturation voltages $+V_{s1}$ and $-V_{s2}$ respectively which will usually but not always be of equal magnitude. This together with the actual magnitudes of the saturation voltages will depend in any particular case on the construction and/or the material of the element concerned.

In particular "constant voltage elements" may be constructed of material such as silicon carbide or cadmium sulphide having a current/voltage characteristic of the form $I=kV^m$ where I is the current, V the voltage, k a constant and m an index greater than three. Other examples of "constant voltage elements" are a pair of Zener diodes connected back-to-back, or an element of semi-conducting material and including two opposed Zener junctions.

According to the present invention an electric switching circuit comprises a network of three or more constant voltage elements, each having one terminal connected to a separate input and the other terminal connected to a connection common to all the elements, a separate switching voltage source associated with each input and adapted to apply to it one or either of two predetermined voltages which have the same values for every source, and two voltage discriminator circuits coupled to said common connection, one arranged to deliver an output signal in response to the voltage condition on said common connection occurring when one of the two predetermined voltages is applied to all the inputs and the other arranged to deliver an output signal in response to the voltage condition on said common connection occurring when the other of the two predetermined voltages is applied to all the inputs.

In a simple case, the two predetermined voltages may be a voltage V and zero voltage, the voltage conditions on the common connection when the inputs are all at voltage V or zero voltage, then being respectively the voltage V and zero.

Each voltage discriminator may simply comprise a diode having one pole connected to the common connection, means for applying a bias potential to the other pole of the diode and an output coupled to said other pole of the diode, the polarity of the diode and the magnitude and polarity of the bias potential being such that the diode conducts in operation only when the appropriate voltage condition occurs on the common connection. In a case where one of said predetermined voltages is zero, the diodes of the two discriminator circuits may have opposite poles connected to the common connection, the bias potentials then being of the same polarity, one greater than the largest possible intermediate voltage condition on the common connection and the other smaller than the smallest possible intermediate voltage condition on the common connection.

According to a feature of the present invention two or more of the elements are formed by a single piece of non-linear resistance material having a plurality of metallic electrodes suitably arranged on its surfaces. The piece of material may be in the form of a wafer having a single electrode on one major face electrically connected to said common connection and having two or more spaced electrodes on its other major face at positions opposite the electrode on the one face, each spaced electrode having a separate electrical connection to it. Alternatively the piece of material may be in the form of a wafer or block having one electrode on a surface thereof common to all the elements and connected to said common connection and two or more other electrodes, one for each element, on the same surface each similarly spaced from the one electrode.

Usually the elements of a circuit will be nominally identical, that is to say identical within the limits of manufacturing tolerances, although in some cases one or a small number may differ in a manner described hereinafter.

The present invention also provides electric switching networks comprising a plurality of switching circuits as set out above. Such networks may for example be or form part of the arithmetic units of electronic calculating and computing apparatus, or the function decoding networks, control circuits for sub-routines, or timing pulse generation networks of electronic computing apparatus. These networks may also find application as signal translating networks for example for translating binary coded signals to decimal signals.

An example of an electric switching circuit according to the present invention together with examples of its application will now be described with reference to the accompanying drawings in which:

FIGURE 1 shows a circuit diagram of the switching circuit;

FIGURE 2 shows waveforms illustrating the operation of the circuit of FIGURE 1;

FIGURE 3 shows the current voltage characteristic of a typical "constant voltage element";

FIGURE 4 shows a plan view of a non-linear resistance wafer arranged to form a plurality of constant voltage elements;

FIGURE 5 shows a section at the line 5—5 in FIGURE 4;

FIGURE 6 shows a plan view of an alternative form of non-linear resistance wafer;

FIGURE 7 shows the circuit diagram of an adder employing switching circuits as shown in FIGURE 1 and

FIGURE 8 shows the circuit diagram of a decoder (for a coded pulse signal system) employing switching circuits as shown in FIGURE 1.

Referring first to FIGURE 1, the circuit of a three input switching circuit is shown. This includes three constant voltage elements 1A, 1B and 1C having a common connection 2 connected to their terminals at one end and separate input leads 3, 4 and 5 respectively connected to their other terminals. Switching voltage sources 3A, 4A and 5A are connected to the leads 3, 4 and 5. Two voltage discriminator circuits, one comprising a diode 7, a resistor 8, a bias voltage source 9 and an output lead 10 and the other comprising a diode 11, a resistor 12, a bias voltage source 13 and an output lead 14, are connected to the common connection 2. Output circuits 10A and 14A which may for example be further gating circuits or amplifiers are connected to leads 10 and 14.

The constant voltage elements 1A, 1B and 1C may for example have a current/voltage characteristic of the form $I=kV^m$ where the value of the index m is greater than three. The form of such a characteristic is shown approximately in FIGURE 3.

If a switching voltage of V volts is applied to one of the inputs leads 3–5 from the corresponding one of the sources 3A–5A, the lead 3 for example, whilst the other two leads 4 and 5 are maintained at zero voltage, the common connection 2 will take up a voltage intermediate between V and zero, the particular value being determined by the characteristics of the elements 1A–1C. The current flowing in the element 1A will in this case divide equally between the elements 1B and 1C. If now the voltage V is applied to two leads simultaneously, leads 3 and 4 for example, whilst the other is maintained at zero voltage, the voltage on the common connection 2 will take up a slightly higher intermediate value, again determined by the characteristics of the elements 1A–1C. In this case the currents flowing through the elements 1A and 1B will be combined to flow through the element 1C. Finally, if all three sources 3A–5A apply a voltage V to the corresponding one of the leads 3–5, the common connection 2 will take up the voltage V. It will be understood that in the above explanation it has been assumed that the sources 3A–5A are low impedance sources.

For pulsed switching voltages, the voltage conditions on the connection 2 corresponding to the three cases of one lead two leads and three leads energised by a pulse of peak voltage V are shown in FIGURE 2, the voltage pulses 15, 16 and 17 in order representing the three conditions. Where the characteristics of the elements 1A–1C have an index m equal to four, the three voltages can be shown by calculation ideally to the 0.46V, 0.54V and 1.0V respectively, these amplitudes being shown approximately in FIGURE 2.

Referring again to FIGURE 1, the bias source 9 of the upper discriminator circuit which source is shown diagrammatically as a battery but may of course take other more convenient forms, provides a voltage of approximately ⅔V (for the case $m=4$) and the diode 7 has its positive pole connected to the connection 2. Considering the three different input conditions, only that when all three leads 3–5 are at voltage V, will render the diode 7 conducting as the voltages on the connection 2 in the other two cases are less than the positive bias voltage applied to the negative pole of the diode 7. Thus only when all three sources 3A–5A apply a voltage V to the corresponding leads 3–5, will an output signal be passed to the output circuit 10A. Ideally the output would be an increase of voltage by ⅓V for as long as all three leads 3–5 are at the voltage V, but in practice this increase will be reduced by the finite value of the resistor 8 and of the input impedance of the output circuit 10A. It will be appreciated however that even though the magnitude of the output signal may be reduced in consequence, the output circuit 10A may have a low input impedance without affecting the operation of the gate circuit formed by the elements 1A–1C.

On the other hand, the bias source 13 provides a voltage of approximately ⅓V (again for the case $m=4$) and the diode 11 has its negative pole connected to the common connection 2. Thus only if the voltage on the connection 2 is less than ⅓V, i.e. when all three leads are at zero voltage, is the diode 11 rendered conducting and an output signal applied to the circuit 14A.

It will thus be seen that the circuit shown in FIGURE 1 provides an output signal on one output lead, the lead 10, 11 all three input leads 3–5 are at voltage V and an output signal on another output lead, the lead 14, if all three are at zero voltage.

The action of the two discriminator circuits is illustrated in FIGURE 2 by the dotted lines representing the voltages ⅓V and ⅔V.

In the above description, explanation has been confined to the case where the input voltages are confined to the two predetermined values V and zero. Whilst they must always be confined to two predetermined voltages, these may be selected in accordance with requirements and need not be confined to this particular case, subject of course to the necessary adjustments to the magnitudes of the bias voltages of the discriminators and/or the polarities of the diodes and the bias sources.

The switching circuits described above may be employed simply as gate circuits which provide alternative outputs when signals of one kind are applied to all the inputs and signals of a second kind are applied to all the inputs. If, however, a switching voltage, as opposed to a signal voltage, is applied to one input of, say, a four-element circuit, this voltage can be used to control the operation of the circuit in so far as it is acting as a gate circuit for the signal voltages applied to the other three. Thus, for example, taking the simple case where the predetermined voltages are V and zero, if the switching voltage is V, the circuit acts as a three AND-gate to the signals applied to the other three inputs since an output can only be obtained if all three are at voltage V. Similarly, if the switching voltage is changed to zero, the circuit becomes a three NOT-gate. If the switching voltage input is left disconnected, the element concerned takes no part in the operation of the circuit which thus operates in the normal way giving different outputs for all signals present or all absent.

Advantageously the three elements 1A–1C may be formed by a construction involving a single wafer of non-linear resistance material. Thus as shown in FIGURES 4 and 5, a single thin wafer of non-linear material has three separate electrodes, referenced 3, 4 and 5 to correspond to the leads 3–5 which are soldered to them on one face and a single electrode on the other face, referenced 2 to correspond to the common connection 2 which is soldered to it. Application of a voltage to any one of the electrodes 3–5 causes current to flow through the thickness of the disc 1 to the electrode 2, the spacing of the electrodes 3–5 being sufficient to render conduction between them negligible.

A further wafer incorporating all three elements 1A–1C is shown in FIGURE 6 in which the corresponding parts have been given the same references as in FIGURES 4 and 5. In this case, all the electrodes 2 and 3–5 are on one face of the wafer 1 which may therefore be of any convenient thickness and supported by any convenient substratum or support. As will be seen, the three sectors forming the electrode 2 are each provided with circumferentially extending fingers which are interlaced with similar fingers on the electrodes 3–5 to increase the conduction between the electrodes.

As stated above, non-linear resistance material is used in the elements 1A–1C and this may have a characteristic of the form $I=kV^m$, m being 3 or more over the range of voltage to be applied in operation. Silicon carbide is a material in this class and the dimensions of the elements whether they are constructed individually or of a wafer forming several elements as shown in FIGURES 4–6, can be chosen so that the characteristic has an index greater than three for the voltage intended to be applied in operation. Compressed cadmium sulphide is another material which can be employed and appears suitable for low voltages. Other compressed materials can be chosen appropriate to the voltages at which it is required to operate.

Elements or multiple elements constructed in the manner of those described with reference to FIGURES 4–6, may conveniently be manufactured by depositing a thin film of the non-linear material on a metal substratum. For example, cadmium sulphide or granular silicon might be deposited on the substratum in suspension in an insulating binder such as ethyl cellulose. Silicon carbide discs might be prepared in ceramic form by the usual firing process. Electrodes may be formed on the surfaces of

the bodies by printing, spraying or evaporation or by any of the techniques used in the printed circuitry art. The electrodes may be formed on one or both sides of a wafer as required.

Often the materials concerned not only have a non-linear resistance characteristic but have been found, at least when subjected to pulsed switching voltages, to have a non-linear capacitance characteristic also. In such a case, the current components both in phase and leading an applied voltage increase with the voltage according to a power thereof which is greater than one. This is of considerable advantage in the preservation of pulse shape where it is required to use the elements in switching circuits for operation at pulse repetition frequencies of 1 mc./s. or higher and pulse rise times of the order of 50 millimicroseconds.

Other elements which may be employed are a pair of Zener diodes connected back-to-back or a single element of semi-conducting material incorporating two Zener junctions. Such elements have sharply defined saturation voltages at which the current rises very steeply to large values for a small increcease in voltage.

Whilst reference has been made above to a switching circuit involving three elements 1A–1C, and precise voltage levels are given only for the case m equal to four. It will be understood however that the number of elements may be increased at will, as indicated by the one extra element shown in dotted lines in FIGURE 1, and that m takes other values. In all cases, however, the intermediate voltage levels on the common connection, resulting from one up to $(n-1)$, (where n is the total number of elements and switching voltage sources) of the input leads being held at voltage V are spaced further from the voltages V and zero ideally occurring when all or more of the inputs are energised than would be the case with linear resistance elements. This greatly facilitates the operation of the voltage discriminator circuits. The latter, in the general case and assuming biased diode discriminators are employed, are set so that the diodes remain non-conducting except in the respective extreme cases.

Where there are n elements, the worst case to be discriminated against is that in which $(n-1)$ out of n inputs are at voltage V. This will give a voltage v on the common connection of:

$$v=\frac{V.(n-1)^{1/m}}{1+(n-1)^{1/m}}$$

It can thus be seen that with fourth power law material, even if n is as large as ten, v is only approximately 0.63V, so that the upper voltage discriminator could still operate with a bias of ⅔V although a slightly higher one would be preferable. With linear material, in the same case, $v=0.9V$ and discrimination would be difficult.

In addition, the tolerance to variation in the nominally identical characteristics of the elements is large. Thus an n gate having a voltage V applied to $(n-1)$ elements and zero voltage applied to the other, one of the elements to which a voltage V is applied being only 50% of standard, will be equivalent to applying a voltage V to n inputs of an $(n+1)$ gate having standard components. Such a gate will operate satisfactorily. If, however, one of the elements is 100% above standard, the maximum voltage v on the common connection in a case when no output is required will occur when a voltage V is applied to $(n-1)$ inputs, those being the inputs associated with all the elements except this one. The n gate then behaves similarly to a $(2n-1)$ gate containing standard value elements and with a voltage V applied to $2(n-1)$ elements. Hence a bias level set to discriminate for a $(2n-1)$ gate would still be operative with any one element −50% or +100% standard.

In general, the elements of a circuit will be as nearly identical as possible within the limits of manufacturing tolerances. In some cases, however, it may be found convenient to use one or more elements in which the "resistance" (this being used to denote the quantity $1/k$ of the characteristic equation $I=kV^m$) is an integral fraction of that of the remainder of the elements. Such an element acts as the equivalent of the integral number of elements each with the same voltages applied. Thus an element with half the resistance acts as the equivalent of two elements with the full resistance and so on.

Unlike many diode gates it is to be noted that in gating circuits according to the invention no power is dissipated in the constant voltage elements save when input voltages are applied, thus saving on power supplies and diminishing heating effects, a feature of considerable importance when gates are only occasionally in service as is often the case in complex gating systems.

Examples of application of the basic switching circuit shown in FIGURE 1 will now be described. A binary adder circuit employing the switching circuit of FIGURE 1 to form gating circuits, is shown in FIGURE 7. It will be understood that, in well-known manner, the circuit shown in FIGURE 7 may operate successively on the corresponding digits of two binary numbers fed to it in serial order, any carry digit resulting from the addition in one denomination being fed back to the appropriate input at the same time as the digits of the next higher denomination, for example through a delay device. Equally the digits of the binary numbers may be fed to a series of such circuits simultaneously, there being a single circuit for each denomination and any carry digit from one denomination being fed to the appropriate input of the circuit for the next higher denomination. In either case the operation of the circuit to add the corresponding digits A and B of the binary numbers together with the carry digit C from the next lower denomination is the same.

It is assumed that besides signals representing the binary digits A, B and C in the normal way (i.e. voltage V representing a binary one and zero voltage a binary zero), the inverse voltages $\overline{A}$, $\overline{B}$ and $\overline{C}$ are also available, as is the case in many computing and calculating apparatus, where a voltage V represents a binary zero as the digit concerned and zero voltage represents a binary one. Where the signal sources, for example, include flip-flops which change state according to whether the digit registered is one or zero, the inverse voltages may be derived from the opposite side of the flip-flop to the un-inverted digit signal.

The circuit shown in FIGURE 7 includes five three-element wafers **18–22** (three separate elements may be substituted in each case if desired) each constituted in the manner shown in FIGURE 4. The voltage discriminator circuits are partly common to the five wafers, a single resistor **8**, output lead **10** and bias source **9** (of voltage ⅔V) being provided for the diodes **7** connected to the common connections **2** of the wafers **18–21**. Similarly a single resistor **12**, output lead **14** and bias source **13** (of voltage ⅓V) is provided for the diodes **11** connected to the common connections **2** of the wafers **18–20** and **22**. The signals applied to the various input leads are indicated simply by the one of the symbols A, B, C, $\overline{A}$, $\overline{B}$ and $\overline{C}$ written in the block representing the switching signal source connected to each lead. The output circuits are also represented generally as blocks **10A** and **11A** and may take any suitable form.

The sum output signal from the circuit appears on the output lead **14** and must occur whenever all three of the digits A, B and C is a one or when only one of them is a one. It will be seen that the three wafers **18–20** each have as their three inputs the three possible combinations of two digit signals and one inverse digit signal. In each case the diode **11** will conduct, giving an output signal, if all three inputs are zero voltage, this occurring in the three cases when the digit of which the

inverse signal is applied is a one and the other two are zero. The remaining diode **11** is connected to the wafer **22** which has all three inverse signals applied to it, so that the diode **11** will conduct giving an output signal if all three digits are one.

A carry output signal which is generated on the lead **10**, is required if two or three of the digits are one. The condition of two digits being one will cause the diode **7** associated with the appropriate one of the wafers **18–20** to conduct, giving an output signal on the lead **10**. In addition, the wafer **21** has the three digit signal voltages applied to its input leads, the associated diode **7** therefore conducting to give an output signal on the lead **10** if all three digits are one.

If in every case the inverse of the input signals shown in FIGURE 7 are applied to the input leads, a sum output signal will be produced as a positive signal on the lead **10** instead of a negative one on the lead **14**, the carry output appearing as a negative signal on the lead **14** instead of a positive one on lead **10**.

As a further example, FIGURE 8 shows a circuit for decoding three-element binary coded pulse signals, that is to say, signals in which values are represented by binary pulse groups in which pulses appear at some or all of three pulse positions, representing when they do so, the decimal values 1, 2 and 4. The circuit shown operates to produce the decimal equavalent of a pulse group as represented by a signal appearing on the appropriate one of eight output leads each associated with one of the decimal values 0–7.

As in the adding circuit of FIGURE 7, three-element gating circuits are employed, one for each of the four stages **26–29** of the decoding circuit. As in that case, the three elements may be formed by a single wafer or they may be separate according to requirements. The three pulse positions of a binary group are designated A, B and C and it is assumed that the pulses of a group appear simultaneously from different pulse input sources, a binary one being represented by voltage V and a zero by zero voltage. As in FIGURE 7, it is assumed that the inverse input voltages $\overline{A}$, $\overline{B}$ and $\overline{C}$ are also available from separate sources. In addition common bias sources **9** and **13** are provided for the two discriminators of such stage.

The three input leads of the stage **26** are coupled, as indicated, to the sources of signals A, B and $\overline{C}$. The diode **7** will conduct giving an output signal on the lead **10**, if the three inputs are voltage V, i.e. if $A=1$, $B=1$ and $C=0$. The equivalent decimal value will be $1+2=3$. The diode **11** of the same stage **26** will conduct giving an output signal on the lead **14** if all three input voltages are zero, i.e. if $A=0$, $B=0$ and $C=1$. The equivalent decimal value will be 4.

In each of the other stages **27–29** a different combination of inputs is applied A, $\overline{B}$ and C to the stage **27**, $\overline{A}$, B and C to the stage **28** and A, B and C to the stage **29**, output signals being produced on the output leads **10** or **14** representing the equivalent decimal values 5, 2, 6, 1, 7 and 0 in order as indicated in FIGURE 8. Output circuits of known form are connected to the leads **10** and **14**, for example relay circuits responding to a pulse on the associated lead to take up an actuated condition, to register the equivalent decimal value of each input pulse group as it is received.

It will be appreciated that a similar, though more complex circuit may be provided for binary pulse groups having four pulse positions and representing the decimal numbers 0–9. Four-element gate circuits would be required however.

In the applications described, the use of gating circuits according to the present invention allows an economy to be exercised in the amount of equipment that has to be provided for a given purpose, since each circuit can provide two outputs representing different input conditions.

Whilst only two applications of switching circuits according to the present invention have been described, it will be appreciated that many others are possible. For example circuits for effecting other arithmetical operations than addition, for example subtraction and multiplication, may employ these switching circuits, as also may translating networks for converting signals in one form to another and switching networks for selectively coupling one or a series of signal input terminals to one or a series of output terminals. In addition whilst both applications described above are in relation to computing or calculating apparatus, these switching circuits may equally find application for example in telecommunications equipment and particularly in electronic switching systems for telephone systems.

I claim:

1. An electric switching circuit comprising a network of at least three constant voltage elements each having a first and second terminal, the network having a separate input for each element connected to the first terminal thereof and a common connection connected to all the second terminals, said elements each comprising solid resistive material having a non-linear resistance characteristic in which the ratio of voltage to current varies as a power law greater than 3 and having metallic electrodes in intimate non-rectifying contact therewith so as to allow of bi-directional conductivity, a separate switching voltage source associated with each network input and adapted to apply to it either of two predetermined voltages which have the same values for every source, and two discriminators each connected to said common connection to provide an output signal when the majority of said voltage sources apply one of said predetermined voltages, and the other output signal when the majority of said voltage sources apply the other of said predetermined voltages.

2. An electric switching circuit comprising a network of at least three constant voltage elements each having a first and second terminal, the network having a separate input for each element connected to the first terminal thereof and a common connection connected to all the second terminals, said elements each comprising a pair of Zener diodes connected in series and back to back so as to allow a bi-directional conductivity, a separate switching voltage source asociated with each network input and adapted to apply to it either of two predetermined voltages which have the same values for every source, and two discriminators each connected to said common connection to provide an output signal when the majority of said voltage sources apply one of said predetermined voltages, and the other output signal when the majority of said voltage sources apply the other of said predetermined voltages.

3. An electric switching circuit according to claim 1 in which each voltage discriminator comprises a diode having one pole connected to the common connection, means for applying a bias potential to the other pole of the diode and an output coupled to said other pole of the diode, the polarity of the diode and the magnitude and polarity of the bias potential being such that the diode conducts in operation only when the appropriate voltage condition occurs on the common connection.

4. An electric switching circuit according to claim 3 in which one of said predetermined voltages is zero and the diodes of the two discriminator circuits have opposite poles connected to the common connection and the bias potentials are of the same polarity, one greater than the largest possible intermediate voltage condition on the common connection and the other smaller than the smallest possible intermediate voltage condition on the common connection.

5. An electric switching circuit according to claim 1 in which at least two of the elements are formed by a single piece of non-linear resistance material having a plurality of metallic electrodes on its surfaces.

6. An electric switching circuit according to claim 5

in which the piece of material is in the form of a wafer having a single electrode on one major face electrically conected to said common connection and having at least two spaced electrodes on its other major face at positions opposite to the electrode on the one face, each spaced electrode having a separate electrical connection to it.

7. An electric switching circuit according to claim 5 in which the piece of material is in the form of a wafer having one electrode on a surface thereof common to all the elements and connected to said common connection and at least two other electrodes, one for each element, on the same surface each similarly spaced from the one electrode.

8. An electric switching circuit according to claim 7 in which the one electrode has at least two equal sector shaped portions radiating from a central portion and each of said other electrodes is positioned in the gap between two of the sector shaped portions.

9. An electric switching circuit according to claim 7 in which the one electrode has at least two equal sector shaped portions radiating from equal angular spacings and each of said other electrodes is positioned in the gap between two of the sector shaped portions.

10. An electric switching circuit according to claim 8 in which the electrodes all have projecting tongues, those on said one electrode being interlaced with those on the other electrodes.

11. An electric switching circuit according to claim 1 in which all the elements are nominally identical.

12. An electric switching circuit according to claim 1 in which the constant voltage elements comprise a non-linear resistance material selected from the following materials silicon carbide, granular silicon and compressed cadmium sulphide.

References Cited in the file of this patent

UNITED STATES PATENTS

2,330,594	Kipphan	Sept. 28, 1943
2,758,264	Matthews	Aug. 7, 1956
2,770,762	White	Nov. 13, 1956
2,823,855	Nelson	Feb. 18, 1958
2,873,389	Cagle	Feb. 10, 1959

OTHER REFERENCES

Germanium Crystal Diodes, Electronics, February 1946, pages 118–123.