Aug. 25, 1959 R. L. SNYDER, JR 2,901,731

SWITCH DEVICES

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FIG. 1.

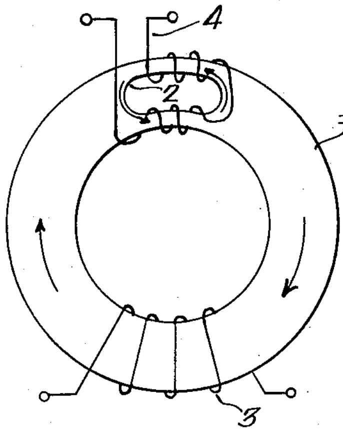



FIG. 2.

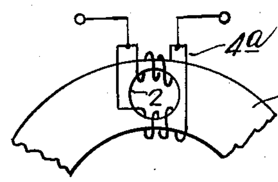



FIG. 3.

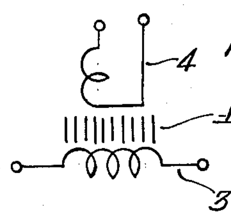



FIG. 4.

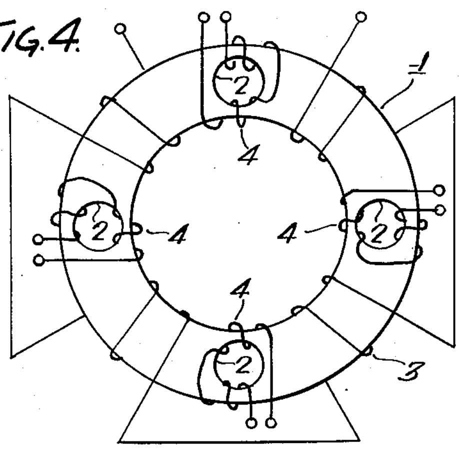



FIG. 5.

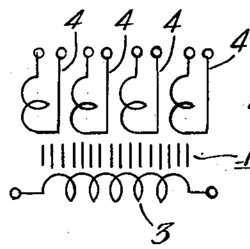
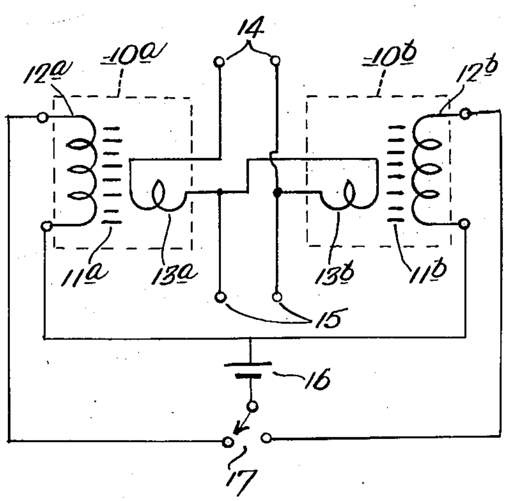



FIG. 6.

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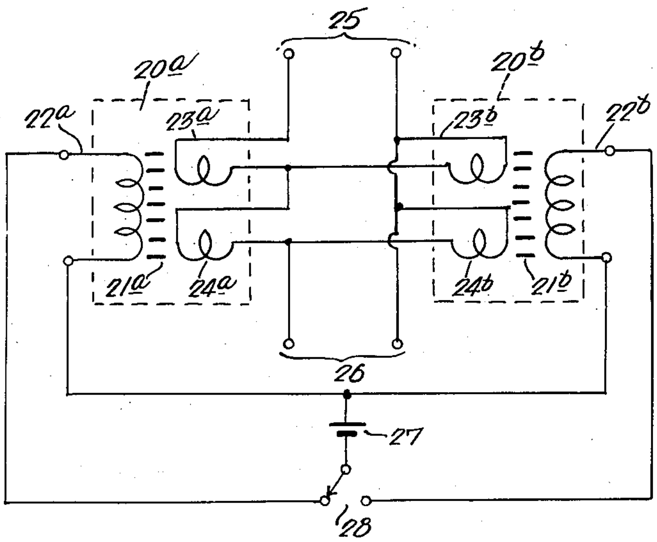


FIG. 7.

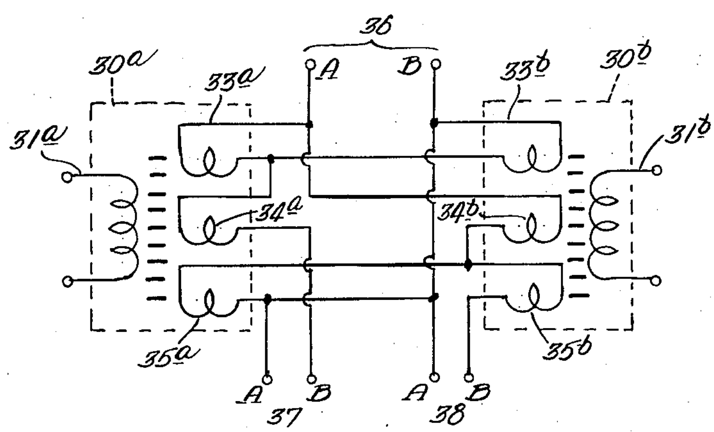


FIG. 8.

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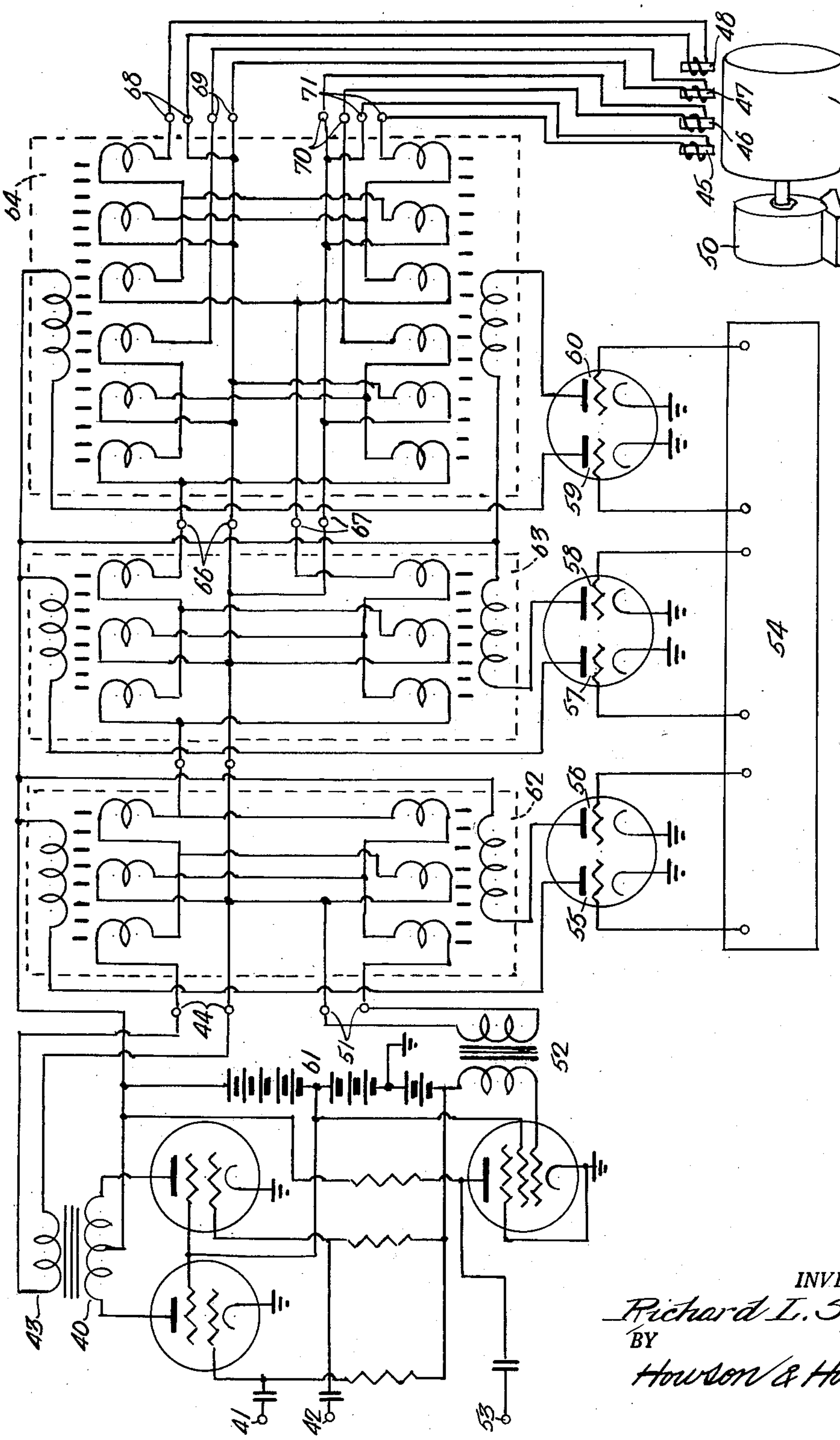


FIG. 9.

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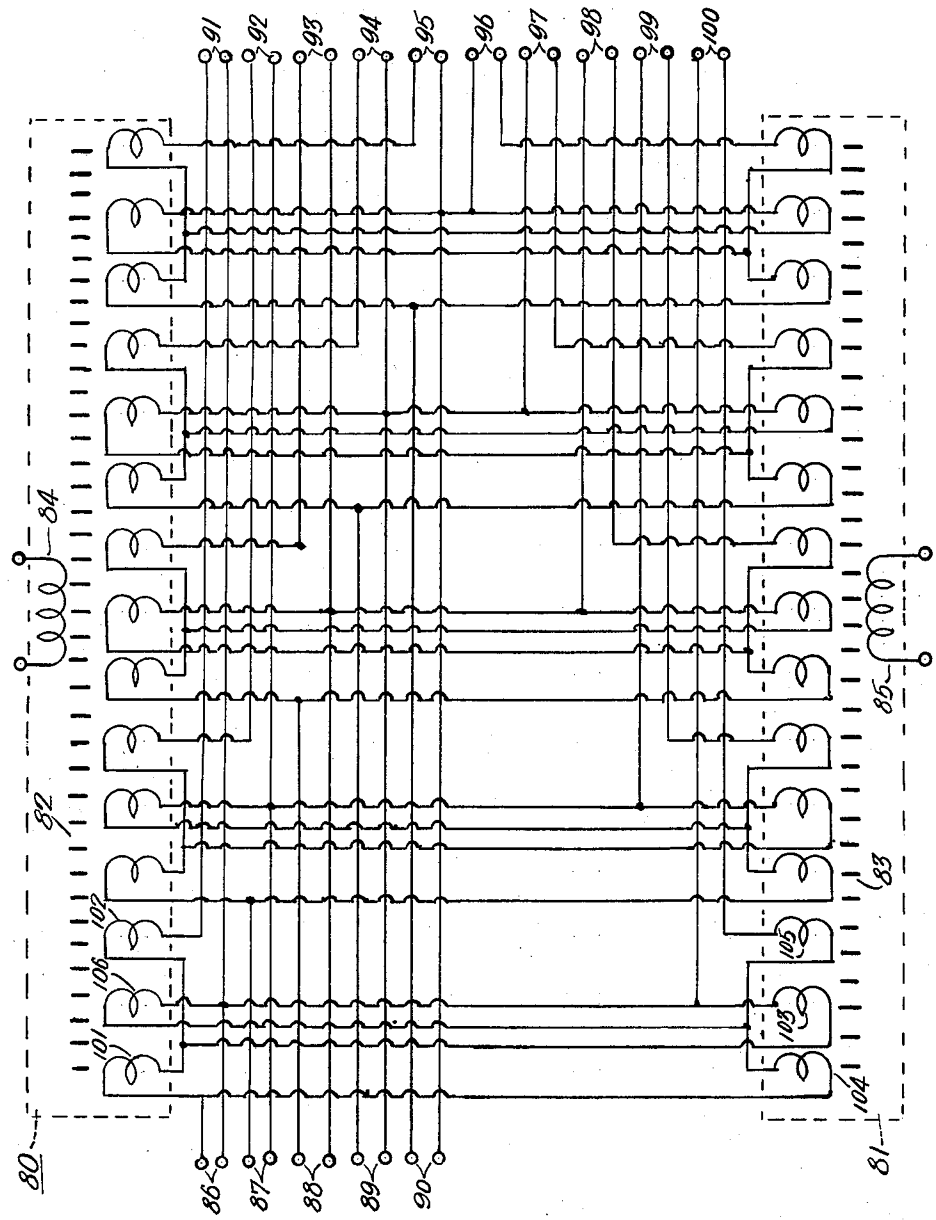


FIG. 10.

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FIG. 11.

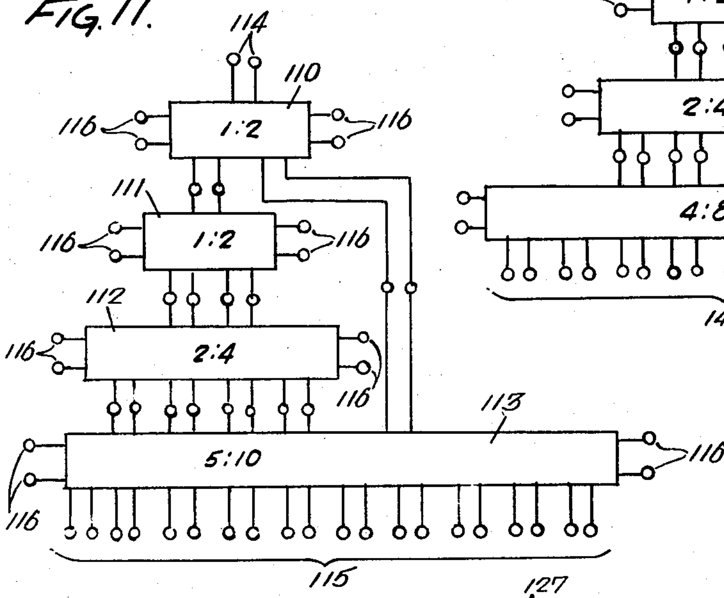



FIG. 13.

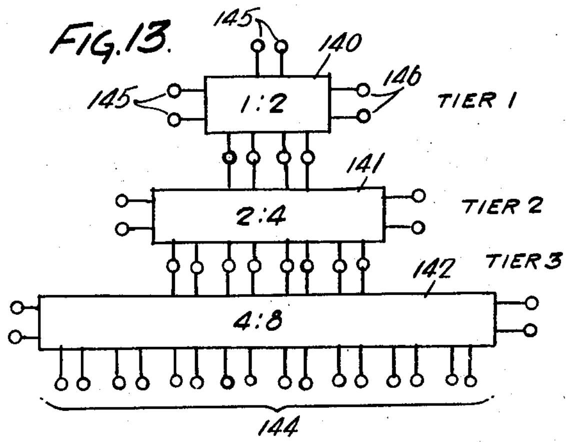
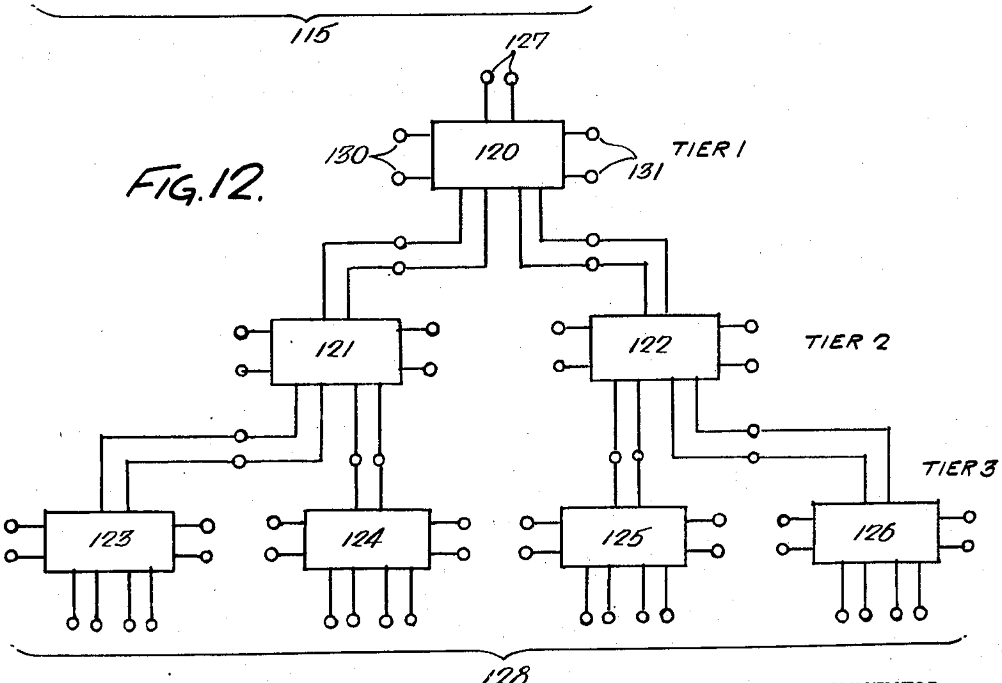



FIG. 12.

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SWITCH DEVICES

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Application May 12, 1954, Serial No. 429,351

3 Claims. (Cl. 340—174)

This invention relates to electrical switches and selectors for controlling the passage of electrical energy between two pairs of circuit terminals or between one pair of terminals and a selected pair of a plurality of other pairs of terminals. It relates particularly to switches and selectors utilizing reactance elements with saturable magnetic cores, the saturation of which can be controlled at will. The switches and selectors of the present invention comprise networks of such reactance elements, so controllable as to permit or prevent at will the transmission of electrical energy through a single switch and to permit such transmission through a selected path of a plurality of alternate paths between input and output terminals of a selector.

Transmission of electrical energy between pairs of terminals of a switching or selector device or non-transmission thereof, is conventionally controlled by mechanically moving metallic contacts, thereby to make or break metallic conductive connections. Such contacts are usually parts of electromagnetic relays. Since such devices employ mechanical motion and mechanical members with mass, they are not suitable for extremely rapid operation, such as required for example, in modern electronic computers. Moreover, they are subject to considerable wear and tear, making frequent replacement necessary when used in selector systems in which rapid and frequent switching must take place.

Selector systems have been devised using electronic tubes as switching devices. Such systems are not suitable, however, to handle a wide range of power levels of signals. Some modern computers, for example, require selector systems capable of reliable operation over a power range in the order of $10^8$ to one or greater.

Switches and selectors, hitherto devised using saturable-core reactance elements, do not provide sufficient discrimination, that is, the ratio of energy transmitted for the saturated and unsaturated conditions of the core, respectively, is not sufficiently great to fill the needs of modern equipment, such as some automatic computing machines.

An object of this invention, therefore, is to provide electrical switching and selecting devices adapted for extremely rapid operation and for extremely wide control of the degree of transmission or non-transmission of electrical energy.

A further object of this invention is to provide switching and selector systems capable of reliable and noisefree operation over a range of electrical energy transmitted of about $10^8$ to one, or greater.

Another object of the invention is to provide a switching system in which the inductance values of a plurality of controlled windings in transmission paths of electrical energy are controlled by the electrical current through a single associated control winding.

The various features of novelty which characterize my invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For

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a better understanding of the invention, its advantages, and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter, in which I have illustrated and described preferred embodiments of my invention.

Of the drawings:

Fig. 1 shows a basic saturable reactor structure;

Fig. 2 shows a similar structure with modified controlled winding;

Fig. 3 shows a schematic representation of Fig. 1;

Fig. 4 illustrates a reactor structure with a single control winding and several simultaneously controlled windings;

Fig. 5 shows a schematic representation of the reactor of Fig. 4;

Fig. 6 schematically illustrates a switch in accordance with the present invention;

Fig. 7 schematically illustrates a similar switch with with a higher degree of discrimination between on and off positions;

Fig. 8 schematically shows a novel selector system;

Fig. 9 schematically shows a novel binary selector system used in conjunction with a memory device for automatic computing machines;

Fig. 10 schematically shows a selector similar to Fig. 8 with a greater number of alternate transmission paths;

Fig. 11 schematically shows a novel selector system for use in a decimal-type system;

Fig. 12 schematically shows a novel selector system for binary operation; and

Fig. 13 schematically shows a modification of the system of Fig. 12.

Fig. 1 shows a reactor element having a magnetic core **1** of relatively easily saturable material, such as certain types of laminated iron or so-called ferrites. The core is of substantially uniform cross section, except at **2**, where it is provided with a window, leaving two magnetic paths of greatly reduced cross sections that can be saturated relatively readily. A control winding **3** is provided for saturating the narrow core sections at **2**, when an electrical current is passed through the winding. A controlled winding **4** is wound around the two core sections at **2** as shown, in such directions, that a change in magnetic flux generated by current passing through winding **4** causes voltages to develop across each coil of the winding in an additive fashion, and equal voltages of opposite phase are induced in winding **4** that cancel each other when changing magnetic flux is generated by winding **3**. Consequently, no net voltage is induced in winding **4** from winding **3**. Conversely, the same holds true.

It is well known, that under the above conditions, the inductive reactance of the controlled winding **4** decreases considerably when the core at **2** is saturated. In practice, I have found that inductance changes of the order of 100 to 1 are attainable from unsaturated to saturated condition of the core sections at **2**.

From Fig. 1, it is seen that, in the absence of current through control winding **3**, the two portions of the controlled winding **4** circulate their flux about the window at **2**, as indicated by the arrows. No flux is linked with control winding **3**.

When control winding **3** is fully excited and the core sections at **2** saturated, the flux in one section produced by the current through the controlled winding **4** opposes the flux produced by control winding **3**. The opposing flux, which must be overcome, can be appreciable, because for saturated conditions the current through the controlled winding becomes greatest as its impedance diminishes.

Fig. 2 shows a different type of controlled winding **4a** on a structure otherwise substantially identical to that of Fig. 1. In this arrangement the two sections of the controlled winding are connected "aiding parallel," so that their flux does not link with the control winding (not shown). When current is passed through the control winding to saturate the core structure, no appreciable voltage can be developed across one of the parallel sections of controlled winding *4a*, because this would require the flux to increase further in the saturated direction. Therefore, to produce minimum reactance of the controlled winding, current in the controlled winding does not require higher flux from the control winding for saturation of the core, as it does for the arrangement of Fig. 1. However, this type of controlled winding has the disadvantage of developing a short circuit when the control winding current is rapidly changed, thus preventing sufficiently rapid change in controlled winding inductance to make this arrangement satisfactory for very high speed operation.

My invention is not limited to the use of one or the other of these types of controlled windings, since either can be used, the choice depending upon the ultimate application of the switch or selector system in which such reactor elements are to be used.

Fig. 3 shows a schematic representation of reactor elements of Figs. 1 and 2. Core **1** is represented by short parallel lines indicating a saturable core. Control winding **3** and controlled winding **4** are drawn at right angles to each other, signifying that there is no flux linkage between the two windings.

Fig. 4 shows a basic reactor structure having a saturable core **1**, a sectionalized control winding **3**, a plurality of core openings indicated at **2**, and four separate controlled windings **4**. Fig. 5 is a schematic representation of such a structure.

I have found that a suitable reactor can be made, as shown in Fig. 4, using a cylindrical ferrite core, having a length of one inch, an outer diameter of 0.62 inch, and an inner diameter of 0.430 inch. The openings shown at **2** in Fig. 4 extend over the entire cylinder length and have a diameter of 0.05 inch. The number of openings depends upon the number of controlled windings to be controlled by a single control winding. In the example cited twelve holes are used. By way of example, the controlled windings may have from fourteen to twenty-eight turns, and the control winding one hundred and forty turns.

Fig. 6 shows a circuit diagram of a switch according to my invention. It comprises two saturable reactor elements **10*a*** and **10*b***, each having saturable magnetic cores **11*a*** and **11*b***, control windings **12*a*** and **12*b***, and controlled windings **13*a*** and **13*b***. The controlled windings are connected between two pairs of terminals **14** and **15**. Winding **13*a*** is connected in series between two corresponding terminals of pairs **14** and **15**, whereas winding **13*b*** is connected in parallel relation to terminal pair **15**.

Control windings **12*a*** and **12*b*** are connected in an energizing circuit, shown by way of illustration of principle only, comprising a battery **16** and a switch **17**. Examples of practical circuit arrangements will be described later.

In operation, control windings **12*a*** and **12*b*** are selectively energized by switch **17** and battery **16**. In the switch position shown, winding **12*a*** is energized, saturating core **11*a*** to minimize the inductive reactance of controlled winding **13*a***. No current flows through control winding **12*b*** and the inductive reactance of controlled winding **13*b*** has its maxitmum value.

With minimum series impedance and maximum shunt impedance, transmission of electrical energy between terminal pairs **14** and **15** is least impeded.

When switch **17** is thrown to the right-hand position, control winding **12*a*** becomes deenergized and winding **12*b*** energized, so that the inductive reactance of controlled winding **13*a*** assumes its maximum value, and the reactance of **13*b*** a much lower value. With a high series impedance and low shunt impedance, minimum transmission between terminal pairs **14** and **15** is effected.

The difference between maximum and minimum transmission with this novel switch is considerably greater than with saturable magnetic devices hitherto known, since those use single controlled windings only, instead of a network thereof. Increased discrimination between maximum and minimum transmission can be obtained by other networks, as shown below. The source of energy can be connnected to either the terminal pairs **14** or **15** and a receiver to the opposite pair, or transmission of energy can be effected selectively in either direction, as will be shown later.

Fig. 7 shows a switch similar to that of Fig. 6, except that it utilizes a network capable of greater discrimination in that it employs two series and two shunt inductances. Again there are provided two saturable reactor elements **20*a*** and **20*b*** having cores **21*a*** and **21*b***, respectively, control windings **22*a*** and **22*b***, and controlled windings **23*a***, **24*a***, and **23*b*** and **24*b***. Control windings **22*a*** and **22*b*** are connected to a source of current **27** by way of a switch **28**.

For the switch position shown, winding **22*a*** is energized and controlled windings **23*a*** and **24*a*** are at their minimum inductance value because of saturation of core **20*a***. Controlled windings **23*b*** and **24*b*** have their maximum inductance value, since control winding **22*b*** is deenergized and core **21*b*** unsaturated. For this condition, minimum series inductance values and maximum shunt inductance values, maximum transmission of energy between terminal pairs **25** and **26** can take place.

When switch **28** is turned to the right-hand position, then maximum series and minimum shunt inductance values obtain and minimum transmission between terminal pairs **25** and **26** can take place.

Fig. 8 shows a selector for selectively connecting one pair of first terminals to one of two pairs of second terminals by greatly increasing the degree of transmission between these pairs of terminals, while simultaneously reducing to a minimum the transmission between the first terminals and the other pair of second terminals.

Accordingly, there are provided two saturable reactor elements **30*a*** and **30*b***, with control windings **31*a*** and **31*b***, saturable cores **32*a*** and **32*b***, and controlled windings **33*a***, **34*a***, **35*a*** and **33*b***, **34*b*** and **35*b***, as shown. The controlled windings are connected in networks between terminal pairs **36**, **37** and **38**, so that windings **33*a*** and **34*a*** are in series between terminals **36*a*** and **37*b***, and **33*b*** connected between the junction of **33*a*** and **34*a*** and terminals **36*b*** and **37*a***, the latter being conductively connected as shown. Controlled windings **34*b*** and **35*b*** are connected in series between terminals **36*a*** and **38*b***, whereas **35*a*** is connected between the junction of **34*b*** and **35*b*** and terminals **36*b*** and **38*a***, the latter being conductively connected.

In operation, assume control winding **31*a*** to be energized, core **30*a*** saturated, while control winding **31*b*** is deenergized and core **30*b*** unsaturated. In this condition, the inductance values of series windings **33*a*** and **34*a*** is very low, whereas that of shunt winding **33*b*** is very high, permitting maximum transmission of energy between terminal pairs **36** and **37**. Conversely, the inductance values of series windings **33*b*** and **34*b*** is very high, whereas that of shunt winding **35*a*** is very low, permitting minimum transmission of energy between terminal pairs **36** and **38**. Hence, terminal pair **36** is effectively connected to terminal pair **37** and effectively disconnected from terminal pair **38**.

In one embodiment of my invention, I found extremely effective discrimination to be obtained when varying windings **33*a*** and **34*b*** from 10 to 2000 micro-henries, **34*a*** and **35*b*** from 5 to 1000 micro-henries, and **35*a*** and **33*b*** from 20 to 4000 micro-henries, from saturated to unsaturated condition of the cores.

Obviously, energy can be equally well transmitted selectively from **36** to either **37** or **38**, or from either **37** or **38** to **36**. Since these networks are bi-directional and this quality is made use of in accordance with my invention, I have avoided the use of the terms input and output terminals, since the same terminals are used in short succession in both capacities, as will be pointed out in connection with Fig. 9.

Fig. 9 shows the schematic circuit diagram of an embodiment of my novel selector system used in conjunction with an automatic computing machine. In such machines it is necessary to store intermediate solutions of a problem for later use by the machine. The information is often stored in the form of magnetic patterns in a relatively high coercive force ferro-magnetic surface of a rotating drum produced by positive and negative current pulses in windings on magnetic recording heads positioned close to the magnetizable surface of the drum. These pulses may have a duration in the order of between 0.2 and 10 microseconds, spaced in time by intervals in the order of between 3 and 30 microseconds.

This circuit includes a recording amplifier, generally indicated at **40**, adapted to receive from part of a computer (not shown) pulses to terminals **41** and **42**, indicative of one or zero as is conventional in binary computing machines. Such pulses produce current pulses of one direction or opposite direction in a transformer secondary winding **43**, applied to terminal pair **44** of my selector system. One of the functions of the selector is to connect selectively terminals **44** to one of four magnetic recording and reproducing heads **45**, **46**, **47** and **48** cooperating with a magnetic drum **49**, driven by a motor **50**, for recording pulses received at **41** and **42** on one of the four tracks on drum **49**.

Another function of the selector system is to disconnect the heads **45**, **46**, **47** and **48** from terminals **44** and connect a selected one to terminals **51**, connected to a reproducing amplifier generally indicated at **52**. The output of this amplifier at terminals **53**, is applied to a portion of the computer (not shown) requiring the stored information.

Selection of recording or reproducing of information and selection of the specific magnetic head is effected by the program section of the computer, generally indicated at **54**, transmitting properly timed pulses of proper polarity to the control grids of tubes **55**, **56**, **57**, **58**, **59** and **60**, whose anodes are connected to control windings and to a common battery **61**.

The selector system comprises three sections **62**, **63** and **64**, each with two saturable reactor elements. Sections **62** and **63** are the same as shown in Fig. 8 and described in connection therewith. When program section **54** places a positive voltage on the control grid of tube **56** and a negative voltage on the grid of tube **55**, terminals **44** and **65** are connected and terminals **51** disconnected from **65**. The system is in recording position.

The next step is to connect terminals **65** to one pair of terminals **68**, **69**, **70** or **71**, selectively. This is done in two steps in selector sections **63** and **64**. Section **63** connects terminals **65** to terminals **66** or **67**. Section **64** connects terminals **66** to **69** or **70** and terminals **67** to **68** or **71**. Assume a positive voltage on the grid of **57** and a negative voltage on the grid of **58**, then terminals **65** are connected to terminals **67**.

Section **64** comprises basically two sections **63**, except that they are combined into only two saturable reactor elements with only two control windings, instead of four elements. Assume a positive voltage on the grid of **59** and a negative voltage on the grid **60**, terminals **66** will be connected to **70** and terminals **67** will be connected to **71**. However, since there is no connection between **65** and **66**, the connection is now made from **65** via **67** to **71** and magnetic head **45** for recording information on drum **49**.

A positive voltage on the grid of **55** and negative voltage on the grid of **56** will cause the recorded signal to be reproduced and appear at terminals **53**.

Fig. 10 illustrates how a number of selectors of the type of Fig. 8 can be combined into a single selector unit with only two saturable reactor units. This selector comprises two saturable reactor elements **80** and **81**, each having a saturable core **82** and **83**, and a control winding **84** and **85**, respectively. This selector connects selectively each one of five first terminals **86**, **87**, **88**, **89** and **90** to one of two pairs of second terminals, there being a total of ten pairs, numbered **91** through **100**. If control winding **84** is energized while no current flows through **85**, all terminals **86**, **87**, **88**, **89** and **90** are connected to terminals **91**, **92**, **93**, **94** and **95**, respectively. Inspecting terminals **86**, **91** and **100**, and connecting controlled windings, it is seen that controlled windings **101**, **102** and **103** form the same series and shunt network between terminals **86** and **91** as shown in Fig. 8. Similarly, windings **104**, **105** and **106** form a network between terminals **86** and **100**. The same types of network are formed between other terminals. Obviously, similar selectors can be built for any number X of pairs of first terminals and 2X pairs of second terminals.

Fig. 11 shows how various selector units can be combined into a decimal selector system. This system comprises sections **110**, **111**, **112** and **113**, with one pair of first terminals **114** and ten pairs of second terminals **115**. Each section has two control windings, their terminals indicated by numeral **116**. Sections **110** and **111** are as shown in Fig. 8. Section **112** is the same as shown as section **64** of Fig. 9, while section **113** is shown in detail in Fig. 11.

Of the two pairs of second terminals of **110**, one pair is connected to section **111**, and can be selectively connected to any one of four of the five pairs of first terminals of section **113**. The remaining pair of terminals is connected directly to one of the second terminals of section **110**. By properly energizing and deenergizing control windings of the various sections, terminals **114** can be connected to any one pair of terminals **115**.

Because of the attenuation of energy suffered by transmission through sections **111** and **112**, as contrasted to the absence of attenuation in the direction between sections **110** and **113**, section **110** is made unsymmetrical, that the attenuation of **111** and **112** are built into one of the networks. In this manner energy transmitted between **114** and any pair of terminals **115** suffers the same attenuation regardless of direct connection between sections **110** and **113** or transmission by way of sections **111** and **112**.

Fig. 12 shows a selector system comprising selector units **120** to **126**, each as shown in Fig. 8. These units are arranged in $N=3$ tiers, the system having a pair of first terminals **127** and $2^N=8$ pairs of second terminals **128**. Each unit has one pair of first terminals and two pairs of second terminals. Each tier has $2^{N-1}$ pairs of first $^N$ terminals and $2^N$ pairs of second terminals. Second terminals of one tier are connected to first terminals of the next higher order tier. Each unit has a pair of control windings, whose terminals are indicated for unit **120** as **130** and **131**. The networks of controlled windings in the units, can be exactly the same as in Fig. 8, or of any other suitable design employing more or fewer controlled windings, as will be obvious to those skilled in the art, without departing from the spirit of my invention.

This system has the advantage of using identical units, but has the disadvantage of requiring seven separate pieces of information, to energize seven and deenergize another seven associated control windings.

Fig. 13 shows another system for accomplishing the same purpose, using three selector units **140**, **141** and **142**, that is only one unit per tier. Unit **140** is of substantially the same design as shown in Fig. 8. Unit **141** is of the same design as section **64** of Fig. 9. Unit **142** is of the same design as shown in Fig. 10, except for omission of one pair of first terminals and associated two pairs of second terminals as well as associated controlled windings. For example, unit **142** is obtained from Fig. 10 by omitting terminals **86**, **91** and **100**, as well as windings **101** to **106**, inclusive.

The system has a pair of first terminals **143** that can be selectively connected to any one pair of second terminals **144** by selectively energizing and deenergizing the appropriate control windings of each unit. Each unit and each tier has two control windings, the terminals for unit **140** being indicated at **145** and **146**.

This system has the advantage of requiring only three pieces of information, to energize three and deenergize another three associated control windings. It has the disadvantage of requiring three different types of selector units.

While I have illustrated and described the best form of embodiment of my invention now known to me, it will be apparent to those skilled in the art that changes may be made in the form of the apparatus disclosed without departing from the spirit of my invention as set forth in the appended claims, and that in some cases certain features of my invention may be used to advantage without corresponding use of other features.

Having now described my invention, what I claim as new and desire to secure by Letters Patent, is:

1. An electrical switch comprising a pair of first terminals and a pair of second terminals, a first and second mechanically static electrical reactance element, said elements exhibiting non-linear controllable reactance characteristics, control means associated with each of said elements for varying the magnitudes of said reactances, an electrical circuit path, between said first and said second pairs of terminals including said first element in series relation to said circuit path and said second element in shunt relation to said circuit path, and circuit means including said control means for selectively effecting simultaneous increase of the reactance of one of said elements and decrease of the other of said elements, thereby to control the electrical impedance between said first and second pairs of terminals.

2. An electrical switch comprising a pair of first terminals and a pair of second terminals, a first plurality



and a second plurality of mechanically static electrical reactance elements, said elements exhibiting non-linear controllable reactance characteristics, first control means associated with said first elements for simultaneously and identically controlling the reactances of said first elements, second control means associated with said second elements for simultaneously and identically controlling the reactances of said second elements, an electrical network connecting said first and second pairs of terminals including said first elements in series relation to said pairs of terminals and said second elements in shunt relation to said pair of terminals, and circuit means including said control means for electively effecting simultaneous increase of the reactance of one plurality of elements and decrease of the reactance of the other plurality of elements, thereby to control the electrical impedance between said first and second pairs of terminals.

3. An electrical switch comprising a pair of first circuit points of reference and a pair of second circuit points of reference, a first and second mechanically static electrical aperiodic reactance element, said elements exhibiting non-linear controllable aperiodic reactance characteristics, control means associated with each of said elements for varying the magnitudes of said reactances, electrical circuit paths between said first and said second pairs of circuit points of reference including substantially solely said first element in series relation to said circuit points of reference and said second element in shunt relation to said circuit points of reference, and circuit means including said control means for selectively effecting simultaneous increase of the reactance of one of said elements and decrease of the reactance of the other of said elements, thereby to control the electrical impedance between said first pair and said second pair of circuit points of reference.

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