

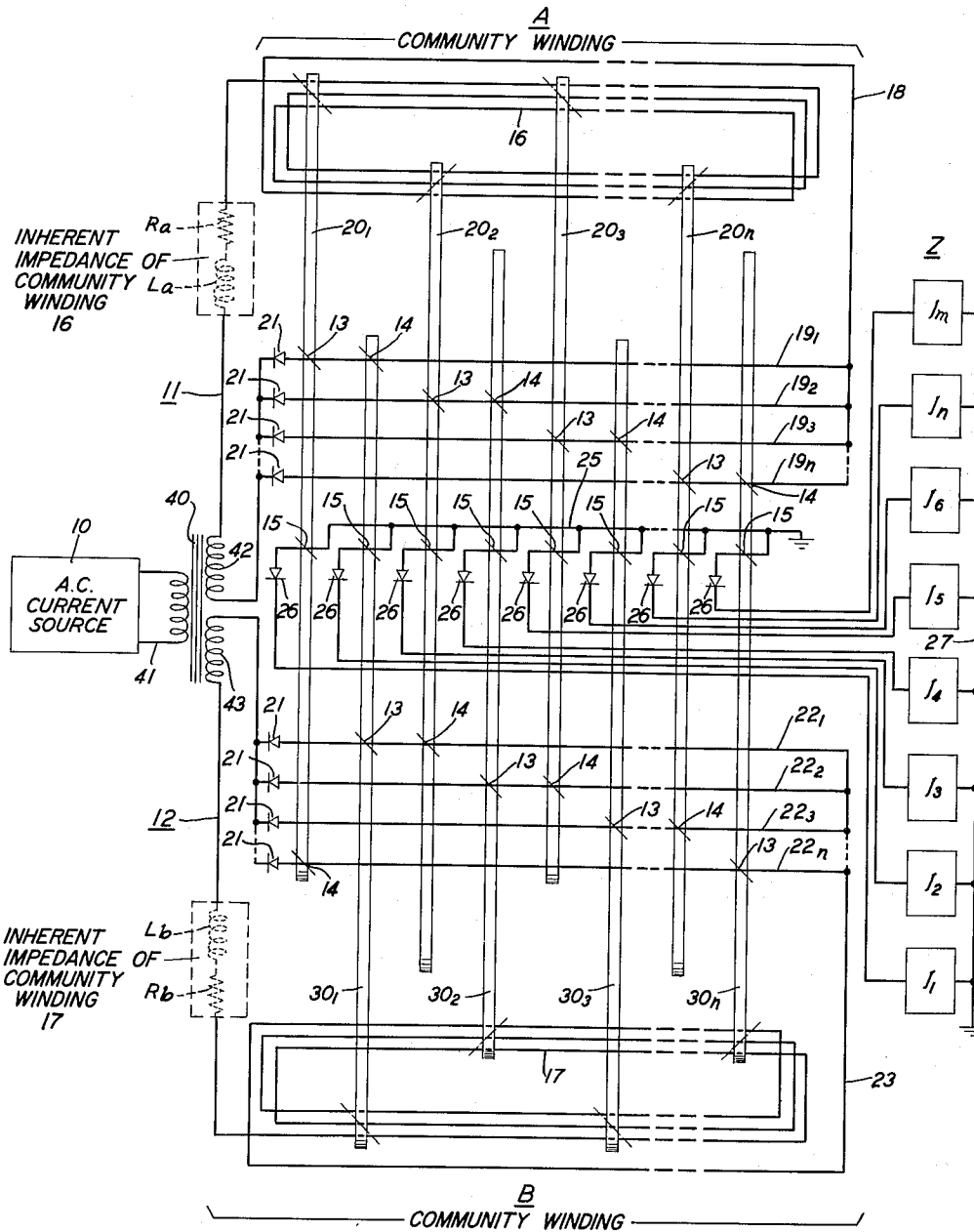
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MAGNETIC CORE COUNTING CIRCUITS

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MAGNETIC CORE COUNTING CIRCUITS

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This invention relates to sequential counting circuits and more particularly to such counting circuits employing magnetic cores.

Counting switches in which the basic switching elements comprise magnetic cores have found wide application, and have been found particularly well suited for use, for example, in digital computers and data processing systems generally, in which a stepping switch producing a sequential output is required.

A basic magnetic core counting switch of the character contemplated herein is made up of circuits such as that described by M. Karnaugh in Patent No. 2,719,961, October 4, 1955. A circuit of the character there described applies a highly advantageous current steering principle based on the control made possible by the switching of a magnetic core from one to the other condition of remanent magnetization. In a simplified circuit according to this principle an activating current applied to an activating winding inductively coupled to a core is caused to flow through an output winding also inductively coupled to the core if the magnetic condition of the core is switched by the applied activating current. If the core is not switched the activating current follows an alternate path to ground. By extending this principle to a circuit comprising a plurality of cores, the activating current may be steered to a selected one of a plurality of possible paths by presetting a particular one of the cores to one magnetic condition so that that core alone will be switched by the applied activating current.

When a plurality of possible paths are thus available to the applied activating current, each of the non-selected paths is rendered non-conducting by a unilateral conducting element such as a diode or varistor included therein. Thus, when the core associated with the selected current path begins to switch its magnetic condition upon the application of the activating current, a voltage is developed across the output winding of the switching core of a polarity to back-bias the diodes in the paths controlled by the non-selected, and therefore, non-switching cores. In a circuit such as that described it is apparent that load means may be connected to each output winding with the result that the loads may be selectively energized under the control of the associated switching cores.

A basic magnetic core counting switch may advantageously be realized by cooperatively associating two of the circuits as described to form a two-section switch. The cores of each section are arranged in alternate fashion and are alternately activated in a two-phase mode of operation. If the loads associated with each section are now constituted by input windings inductively coupled to the cores of the other section, each switching or resetting of a magnetic condition of a core of one section may be effective to set the magnetic condition of a core in the other section. Each core will thus have an activating winding and an output winding energized in one section and an input winding energized in the other section during its operative phase. In known two-phase magnetic core counting switches an activating current is alternately applied to the activating windings of the two sections and individual constant current sources for each section are required. A magnetic core counting switch of the character contemplated herein is also described by M. Karnaugh in the Proceedings of the IRE, vol. 43, May

1955, pages 570 to 583. By adding one more winding to each core of the switch and connecting each such additional winding to an external load, the loads may be sequentially driven by the currents induced in the additional windings as the cores are sequentially switched. A diode connected in series with each load may be employed to isolate the load during the time that the magnetic condition of the associated core is being set.

In present counting switches of the type described, although the use of magnetic cores has proven highly advantageous, a number of problems may still be encountered in their application. Considering a particular section of the switch during its operative phase, it will be noted that the activating windings inductively coupled to the cores are connected in series and, upon the application of an activating current pulse, only one core of the section will switch the condition of its remanent magnetization. This is in accordance with the previously described operation of the switch in which only one of a plurality of possible current paths is selected. The remaining cores of the section will, however, be shuttled by the applied activating current, that is, be driven farther into the condition of magnetic saturation already obtaining in the cores, with an attendant small flux change in each of the cores thus shuttled. Each small flux change will cause the activating winding of each shuttled core to present an inductance with a resultant impedance presented to the activating current being applied. In relatively short counters the effect of this inductance is negligible. However, in long counting switches such periodically encountered inductances together with incidental parasitic capacitances in effect render the counter a delay line. Then when this relatively high impedance circuit comprising the serially connected activating windings is terminated in the relatively low impedance of the input windings, the reflected impedance which thus results tends partially to cancel the applied activating current.

The fact that the counter effectively constitutes a delay line becomes particularly significant as the length of the counter is increased in which case a further problem is encountered. When the activating current is applied it is possible that the activating current pulse partially or completely switches the magnetic condition of an early core of the counter before the activating current pulse reaches activating windings of cores at the end of the counter due to the inductive delay introduced by the shuttled cores. It will be recalled in the previously described operation of the counting switch sections, that it is only during the time that a core is switching its magnetic condition that sufficient voltage is developed across its output winding to properly back-bias the diodes of non-selected current paths to render the latter paths non-conducting. Thus, if the controlling core has switched its magnetic condition before the activating current reaches the activating windings of later cores of the counter, the diodes associated with such later cores will not be properly back-biased and the activating current will divide and also flow in non-selected current paths. As a result, the activating current in the selected path will be less than the magnitude sufficient to set the succeeding core for the other phase of operation. The latter core will only partially switch its magnetic condition with a resultant failure of operation of the switch.

In present two-phase magnetic core counting switches it has been the practice to provide a separate activating current source for each section of the switch. Thus each activating circuit has its own current pulse source individually connected thereto. Obviously if the cores are to be properly switched and the outputs of the switch are to be properly sequenced the alternately applied activating

pulse magnitudes and time relationships become highly critical.

Accordingly, it is an object of this invention to eliminate the current delaying effect encountered in relatively long magnetic core counting switches due to the individual inductances presented by the activating windings inductively coupled to the cores not being switched by an applied activating current pulse.

It is another object of this invention to eliminate undesirable reflections in relatively long magnetic core counting switches due to inductances presented by the activating windings inductively coupled to the cores not being switched by an applied activating current, which reflections tend to a partial cancellation of the applied current pulse.

Still another object of this invention is the alternate application of activating current pulses in a two-phase counting switch by means of a single activating current source.

The foregoing objects of this invention are realized in one illustrative embodiment thereof comprising a two-section magnetic core counting switch similar to that described hereinbefore. Instead of utilizing separate activating windings for each core serially connected to form a pair of activating circuits, however, a pair of community windings is employed. The cores of each section are threaded simultaneously a number of times as may be necessary in view of core and circuit parameters. Each of the community windings is connected at one of its terminals to an associated plurality of circuit branches and each of the branches includes a winding of a core of one section, a winding of a core of the other section, and a diode. A single alternating current source is provided which applies an alternating current to the two-section counter. On each alternation the cores of one or the other of the sections have an effective switching current applied thereto by means of the associated community activating winding. This current is applied through a transformer having a primary winding connected to the current source and a pair of secondary windings. Each of the community windings is connected at the other of its terminals to one side of one of the secondary windings with the other side of the secondary winding being connected to the associated plurality of branch paths.

A complete circuit for the activating current is thus provided for each section through a secondary winding, a community activating winding, and one of the associated plurality of circuit branches. Initially one of the cores of one of the sections is set in a particular condition of remanent magnetization and the remaining cores of the switch then are subsequently switched to that particular condition in a sequence determined by the operative sequence of the core windings.

Accordingly, a feature of this invention is a means for simultaneously applying an activating current to the activating windings of a magnetic core counting switch, said means comprising a single community winding simultaneously threading all of the cores which are to be acted upon by the activating current.

Another feature of this invention is an improved means for alternately applying activating currents to the activating circuits of a magnetic core counting switch, said means comprising a single alternating current source and a transformer having a primary and two secondary windings, the activating circuits being connected to the secondary windings in a manner such that each receives an activating current during a respective alternation of the applied alternating current.

In an arrangement utilizing a community winding such as that employed in the present invention, instead of a number of small series inductances presented by the activating circuit, a community winding presents a single, relatively large inductance. Factors contributing to this total inductance include the particular magnetic core material itself and the air core inductance resulting from

the necessarily larger winding. Physically, the loop area of this community winding may be held to a minimum and this will serve to reduce the inductive contribution from this source to a relatively negligible factor when compared with that of the magnetic core material. A minimal loop area may be achieved by the selection of an advantageous geometrical configuration of the arrangement of the cores which in turn will be dictated by such factors as mechanical mounting considerations, and the like. For a description of the organization of the present invention, however, the latter considerations are not here pertinent.

In the present invention the single, aggregate inductance represented by a community winding, although conveniently maintained at a minimum value, presents a desirable circuit characteristics which is calculated to contribute to the overall efficiency of the switch.

Accordingly, another feature of this invention is a means whereby the aggregate inductances of the activating circuits are made to promote the core switching operation of the counter. When, during one alternation of the activating current, current is applied to a community activating winding, energy will be stored in the magnetic field generated by the current flowing in the inductance represented by that community winding. As the applied current alternation starts to decrease from a maximum value the energy thus stored will appear as a current source with the result that a continuing current flows in the associated secondary transformer winding. The latter current induces a corresponding current in the other secondary transformer winding in a direction such as to augment the activating current in the other secondary transformer winding applied by the other alternation of the activating current. This energy storage operation is repeated for each alternation of the applied activating current with a resulting smooth transfer of energy from one community activating winding inductance to the other.

In a counting switch according to this invention and described generally hereinbefore, it will be noted that one activating circuit is ineffective to switch the cores of a section, due to the presence in the circuit of the unilateral conducting elements, while the other activating circuit is being effectively energized. The idle activating circuit is not, however, completely isolated during this operative phase. Since each switching core has a winding which is present in the idle activating circuit during a given operative phase, voltages will be induced in the idle activating circuit as a result of the switching of these cores. The sum of these voltages will be greater in magnitude than, and in a direction opposite to, the voltage developed across the secondary winding of the idle activating circuit while the other activating circuit is being energized. The difference voltage will then be sufficient to forward-bias the diode affected and cause a current to flow in its circuit branch with a resultant spurious switching of cores.

Still a further feature of this invention is therefore the means whereby the spurious switching of magnetic cores as a result of the desired switching of proper cores is prevented in a magnetic core counting switch employing a single source of activating current. According to this feature no additional elements are required to overcome the aforementioned difference voltage causing the spurious core switching. The inherent resistance of the activated windings is advantageously utilized to provide the resistance necessary for developing an overriding voltage in a direction opposite to that of the difference voltage. The inherent resistance of the activating circuits, ordinarily to be merely accepted, is thus also made to perform a useful function.

A complete understanding of this invention together with its objects and features will be gained from a consideration of the detailed description thereof which follows when taken in conjunction with the accompanying drawing, the single figure of which is a schematic repre-

sentation of an illustrative embodiment of an improved counting switch according to the principles of this invention. The switch is shown depicted in the well-known mirror symbol notation described in detail by M. Kar-
naugh in the article previously cited. The activating
windings associated with the cores of the switch are
also shown literally to clarify the physical relationship
between the elements.

An illustrative counting switch according to the principles of this invention is depicted in the drawing and comprises generally an alternating current source 10, a pair of switching sections A and B, and an external load section Z. Each of the sections A and B comprises a plurality of magnetic cores of the well-known ferrite or other type having a substantially rectangular hysteresis characteristic and capable of being driven to either of two conditions of remanent magnetization. The cores of each section are associated respectively by means of a pair of activating circuits 11 and 12. Switching section A comprises the cores $20_1, 20_2, 20_3 \dots$ and 20_n , and switching section B comprises the cores $30_1, 30_2, 30_3 \dots$ and 30_n . Each of the cores of these sections has inductively coupled thereto a selecting winding 13, an input winding 14, and an output winding 15. In addition, the cores of each section have respectively threaded therethrough a common activating winding. Thus the cores 20_1 through 20_n have simultaneously threaded through each the common activating winding 16 and the cores 30_1 through 30_n have simultaneously threaded through each the common activating winding 17.

A transformer 40 couples the alternating current source 10 to switching sections A and B by means of a primary winding 41 and a pair of secondary windings 42 and 43. In the illustrative switch being described a 1:1:1 ratio between the windings of transformer 40 was found advantageous. The selecting windings 13 and the input windings 14 are electrically connected in a manner such that a selecting winding 13 of a core of one section is connected to an input winding 14 of a core of the other section. In each section a plurality of circuit branches, each of which includes a winding 13, a winding 14 and a unilateral conducting element, such as the diode 21, provides selective paths for activating current in a manner to be described. Thus section A includes the branch 19₁, which includes the selecting winding 13 of the core 20_1 and the input winding 14 of the core 30_1 , the branch 19₂, which includes the selecting winding 13 of the core 20_2 and the input winding 14 of the core 30_2 , the branch 19₃, which includes the selecting winding 13 of the core 20_3 and the input winding 14 of the core 30_3 , and the branch 19_n, which includes the selecting winding 13 of the core 20_n and the input winding 14 of the core 30_n . Section B includes the branch 22₁, which includes the selecting winding 13 of the core 30_1 and the input winding 14 of the core 20_2 , the branch 22₂, which includes the selecting winding 13 of the core 30_2 and the input winding 14 of the core 20_3 , the branch 22₃, which includes the selecting winding 13 of the core 30_3 and the input winding 14 of the core 20_n , and the branch 22_n, which includes the selecting winding 13 of the core 30_n and the input winding 14 of the core 20_1 .

The pluralities of circuit branches and common activating windings are connected to the secondary windings 42 and 43 of transformer 40 as shown in the drawing to complete the activating circuits 11 and 12. Thus the circuit 11 of section A may be traced from one terminal of the secondary winding 42 to its other terminal as follows: common activating winding 16, the conductor 18, and the circuit branches 19₁ through 19_n. Similarly, the circuit 12 of section B may be traced from one terminal of the secondary winding 43 to its other terminal as follows: common activating winding 17, the conductor 23, and the circuit branches 22₁ through 22_n.

Each of the output windings 15 of the cores are connected at one side to a common ground conductor 25 and

at the other side to respective loads l_1 through l_n and l_m . Unilateral conducting elements such as the diodes 26 isolate each winding 15 from the associated loads during incidental magnetic condition changes in the cores and each of the loads l is connected to ground by means of a common conductor 27.

The common activating windings 16 and 17 have an inherent resistance and inductance represented by the resistances R_a and R_b and the inductances L_a and L_b , respectively. Although shown as inserted between the activating windings 16 and 17 and the secondary windings 42 and 43 respectively, the resistances R and inductances L are understood to represent the resistance and inductance distributed the length of each of the activating windings 16 and 17.

The novel features of this invention will become readily apparent from a consideration of the circuit phenomena during the operative phases of the illustrative switch shown in the drawing. For purposes of description it will be assumed that only the first core, 20_1 , of section A is initially in a set magnetic condition, that is, in an upward direction as viewed in the drawing. When the alternating current source 10 is energized a current will be applied to the primary winding 41 of the transformer 40 with the result that a current is induced in the secondary windings 42 and 43 in the conventional manner. Since the operation of the switch is repetitive for each cycle of applied alternating current, its operation with respect to only one cycle will here be described. It will further be assumed that the sense of the windings 41, 42, and 43, is such, with respect to each other, that the first alternation of the applied alternating current cycle is effective to activate section A of the switch.

The secondary winding 42 of the transformer, having a one-to-one turns ratio with respect to its primary winding 41, will have a current induced therein substantially of the magnitude and wave form of the first current alternation applied to the primary winding 41 from the source 10. As the magnitude of the activating current half-cycle rises in the activating circuit 11, it appears in increasing magnitude in the common activating winding 16 and an increasing magnetic field is generated in the cores 20_1 through 20_n inductively coupled to the winding 16. This field exerts a magnetomotive force driving all of the latter cores to magnetic saturation in one direction, this direction being the direction of the remanent magnetization of the cores 20_2 through 20_n . The latter cores will, as a result, be driven further into magnetic saturation in this direction, that is, the latter cores will be "shuttled," as this flux change is known in the art. The core 20_1 , however, is in a set magnetic condition, which condition is in a direction opposite to that of the applied magnetomotive force. As a result core 20_1 will be reset, that is, switched to its opposite condition of remanent magnetization. Thus, for each application of an activating current of the proper polarity to the common activating winding 16, it is obvious that one core of the section will be reset and the remaining cores will be shuttled.

While the core 20_1 is resetting, a voltage will be induced in its selecting winding 13. The polarity and magnitude of this induced voltage obviously depends respectively upon the sense and number of turns of the selecting winding 13. This induced difference of potential causes the activating current to take the path presented by the circuit branch 19₁, which branch also includes the input winding 14 inductively coupled to the core 30_1 , appearing in section B of the switch. The induced voltage back-biases the diodes 21 included in the remaining circuit branches 19₂ through 19_n of the activating circuit 11, thus effectively preventing current flow in those branches. The flow of the activating current through the branch 19₁ and the input winding 14 causes

the core 30₁ to be set, that is, to be switched to the opposite condition of remanent magnetization. Although in the illustrative circuit being described the core of the other section being set is shown as the next adjacent core, it is to be understood that any core of the other section could have been selected. Obviously, by a selective arrangement of input windings in the branch circuits, any sequence of core switching may be realized.

In accordance with one novel feature of this invention it is obvious that the activating current is available at the junction of the plurality of paths at the same instant that the back-biasing voltage is induced in the selecting windings. Thus no matter which core of the section is being reset only one diode 21 will be in a conducting state, thereby insuring the passage of virtually all of the activating current through the branch containing the conducting diode. All of the activating current is thus available to perform the desired core switching function.

When the core 20₁ is being reset as described a voltage will also be induced in its load winding 15 with the result that a current will be caused to flow from ground in the circuit which includes the load I_1 . The load winding 15 is wound in a sense such that the induced voltage will be of a direction to render the diode 26 conducting. No current will flow to the other loads I_2 through I_n and I_m as a result of the switching of the core 20₁. This last holds true also for the voltage induced in the output winding 15 of the core 30₁ when the latter core is set.

It is evident from the relationship of the secondary windings 42 and 43 that when a voltage is induced across the winding 42 by one alternation of the applied alternating current a voltage will also be induced across the winding 43. This latter voltage will be of the same magnitude since the turns ratio of the windings is unity, however, the polarity will be opposite due to the sense of the windings. The voltage thus also induced across the secondary winding 43 ordinarily would be of a direction to back-bias the diodes 21 in the branches 22₁ through 22_n of the activating circuit 12 thus preventing any current from flowing in the latter circuit. This non-conductive state of the idle section is essential to prevent any switching of undesired cores while the switching of the desired cores is being accomplished. In this connection it is necessary to note that the cores presently being caused to switch their magnetic conditions, that is, the cores 20₁ and 30₁, each have windings inductively coupled thereto which could give rise to undesired interference during the switching operation.

The cores 20₁ and 30₁ have the windings 14 and 13 respectively coupled thereto and, in addition, the core 30₁ also has inductively coupled thereto the common activating winding 17. All of the last-mentioned windings appear in the activating circuit 12 which must be effectively idle during the operative phase being described. The sense of the windings 14 and 17 is such that a voltage will be induced across each, by the switching of the cores 20₁ and 30₁, respectively, of a direction opposite to that of the voltage induced at this time across the secondary winding 43 by the section A activating current alternation. Since the windings 14 and 17 and the secondary winding 43 are serially connected the voltages developed across each are additive with the algebraic sum of the voltages being of a magnitude and polarity sufficient to forward-bias the diode 21 connected in the branch 22_n. As a result a current will flow in the activating circuit 12 including the circuit branch 22_n. Since the latter branch includes the selecting winding 13 of the core 30_n the current in the branch 22_n would, as a result, cause an unwanted setting of the core 30_n with a resulting malfunctioning of the switch.

The spurious switching of the core 30_n accompanying the switching of the proper core 30₁ can readily be prevented by increasing the voltage developed across the secondary winding 43. Obviously, the latter voltage is dependent upon the voltage developed across the secondary

winding 42 during the application of an activating current alternation to the circuit 11. The desired voltage increase across the winding 43 may accordingly be accomplished by inserting a resistance of the proper value in the activating circuit 11.

In the present invention it was found that the distributed resistance of the activating winding 16, represented by the resistor R_a in the drawing, was substantially of a value advantageously to accomplish the required voltage increasing function. No separate resistor element is thus required and, in the present invention, the additional voltage developed by the distributed resistance R_a in the activating circuit 11 and, therefore, also in the activating circuit 12, is sufficient to overcome the voltages developed in the idle activating circuit 12 due to the switching of cores in section A.

When the desired switching function has been accomplished as described for section A of the switch the current applied to the activating circuit 11 begins to decrease as the current alternation falls to zero. At this time the magnetic field induced by the distributed inductance of the activating winding 16, represented in the drawing by the inductance L_a , collapses with the result that a continuing current is induced in the circuit 11 including the secondary winding 42. The voltage induced in the secondary winding 43 as a result of this continuing current flowing in the secondary winding 42 causes a current also to flow in the activating circuit 12. Because of the opposite sense of the secondary windings 42 and 43 the latter current will be in the same direction as the current also induced in the activating circuit 12 due to the other alternation of the alternating current cycle applied at this time. Energy thus stored in the inductance L_a by the magnetic field in this manner effectively constitutes a current source which provides a bridging current to effect a smooth transfer of energy between the activating circuits 11 and 12 as the applied alternating current alternates from one polarity to the other. In this way inductive effects present in the activating circuits 11 and 12 are made to do useful work.

At this time, upon the application of the current alternation of the opposite polarity during the other half-cycle of activating current, the operative phase of the switch in which the activating circuit 12 is energized is begun. Since in the immediately preceding operative phase the core 30₁ was set, this latter core is now reset with the result that the circuit branch 22₁ is effectively selected by the voltage developed across the selecting winding 13 and forward-biased diode 21 connected thereto. An input winding 14 is also included in this circuit branch and, responsive to the current in this input winding 14, the core 20₂ is set. With the resetting of the core 30₁ a current is applied to the load means I_2 as a result of the voltage induced in the output winding 15 of the core 30₁.

Since the sections of a counting switch according to this invention are symmetrical with respect to current and voltage polarities, it is to be understood that the description of the novel features thereof involving the distributed inductance and resistance L_a and R_a of section A, applies with equal force to the identical distributed inductance and resistance L_b and R_b of section B. For this reason a description of the advantageous results achieved by these circuit characteristics with respect to the operation of section B need not be repeated.

Upon the continued application of the alternating current from the source 10, the alternate succeeding cores of the switch will be set and reset by the respective applied current alternations with a resulting sequential application of energizing current to the succeeding loads I . Thus, responsive to subsequent successive cycles of applied activating current, cores 20₂ and 30₂, cores 20₃ and 30₃, and cores 20_n and 30_n will be respectively reset and set and the loads I_3 through I_m will have energizing current pulses sequentially applied thereto.

It is to be understood that the above-described arrange-

ment is illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An electrical circuit comprising a primary winding; a source of alternating current connected to said primary winding; a pair of mutually-intercoupled secondary windings each coupled to said primary winding; and a pair of switching sections each including one of said secondary windings, a plurality of magnetic cores each having a selecting winding and an input winding inductively coupled thereto, a community advance winding serially connected to said secondary winding of that section and inductively coupled in common to saturate all of said cores of that section in a first sense, and a plurality of branch circuits each being connected between said community advance winding and said secondary winding of that section and comprising unidirectional current means, one of said selecting windings on one of said cores of that section, and one of said input windings on one of said cores of the other section; and means for preventing spurious current flow in said branch circuits of the one of said sections in the non-advancing condition, said means including said mutually-intercoupled secondary windings, and a predetermined inherent resistance in each of said advance windings, said resistance being at least of a minimal value to produce a voltage across said secondary winding of the advancing one of said sections sufficient when coupled to the other of said secondary windings to maintain said unidirectional current means nonconducting.

2. An electrical circuit comprising a primary winding; a source of alternating current connected to said primary winding; and a pair of switching sections each comprising a secondary winding coupled to said primary winding and to the other of said secondary windings, a plurality of magnetic cores each having a selecting and an input winding coupled thereto, a plurality of diodes, a plurality of current paths each including the selecting winding of a core of that one of said sections, the input winding of a core of the other of said sections, and one of said diodes connecting one side of said path to one terminal of said secondary winding, community inductive means connected between the other side of each of said current paths and said secondary winding of that one of said sections for generating responsive to one alternation of an applied alternating current a single magnetic field in a sense magnetically to saturate all of said cores of

that one of said sections in a particular direction responsive to said field, and said community inductive means each having an inherent resistance of at least a value sufficient to generate a voltage at the one of said secondary windings connected thereto to maintain the diodes in said current paths connected to the other of said secondary windings non-conductive even in the presence of forward biasing voltages induced by switching of said cores of that one of said sections.

3. A two-section counting switch comprising a pair of sections each including a plurality of magnetic cores each having a selecting and an input winding inductively coupled thereto, an output winding coupled to each of said cores, inductive means comprising a community winding threading all of said cores of a section, a transformer secondary winding, and a plurality of electrical circuits each including said community winding, said secondary winding, the selecting winding of a particular core of that section, the input winding of a particular core of the other section, and a unilateral conducting element, said electrical circuits connecting said selecting and input windings to switch said particular core of said other section in response to switching said particular core of that section; a transformer primary coupled to said secondary windings of both of said sections; and an alternating-current source connected to said primary winding; each of said community windings having an inherent resistance of at least a predetermined minimal value for assuring that the voltage across the secondary winding of a section during flow of current from said source therethrough is sufficient, when coupled inductively to the other secondary winding, to maintain the unilateral conducting elements in said other section circuits non-conducting even in the presence of voltages induced in the other section electrical circuits due to switching of the cores.

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