Dec. 13, 1955 J. E. SUNDERLIN 2,727,159

SWITCHING APPARATUS

Filed June 14, 1954 2 Sheets-Sheet 1

Fig. 1.

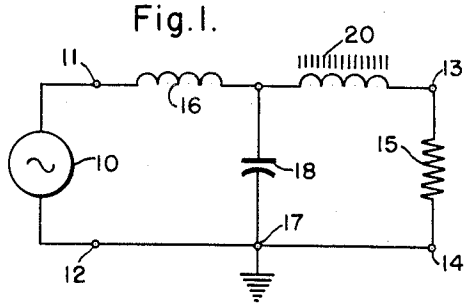


Fig. 2.

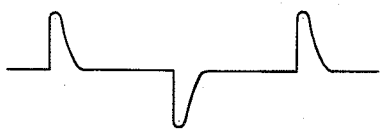


Fig. 3.

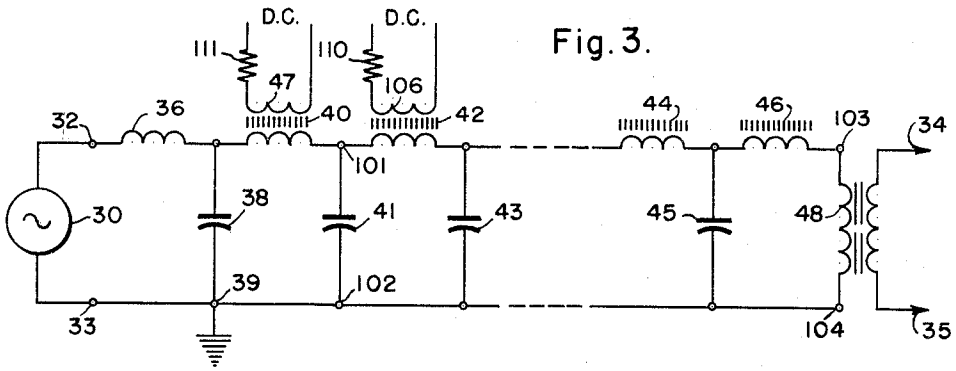


Fig. 4.

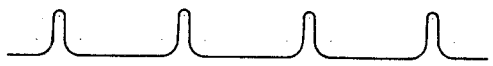
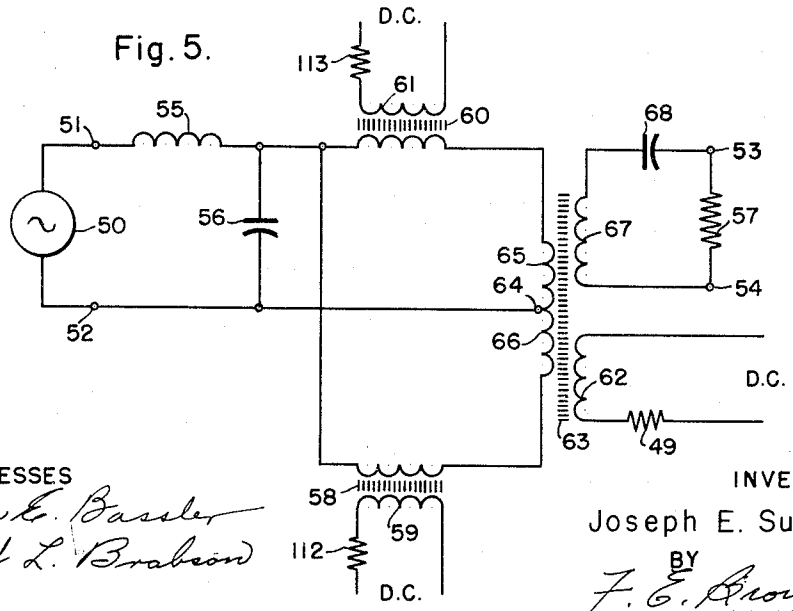


Fig. 5.



WITNESSES

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Fig. 6.



Fig. 7.

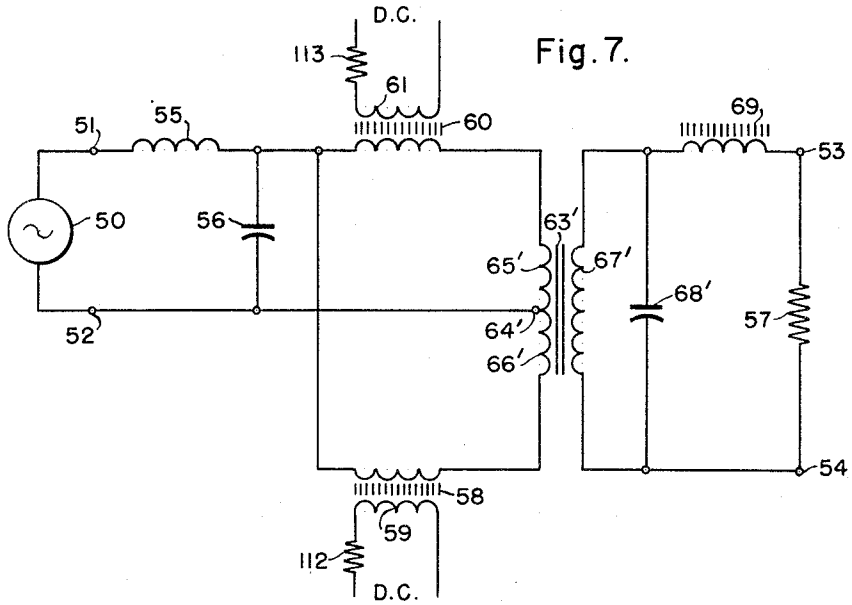
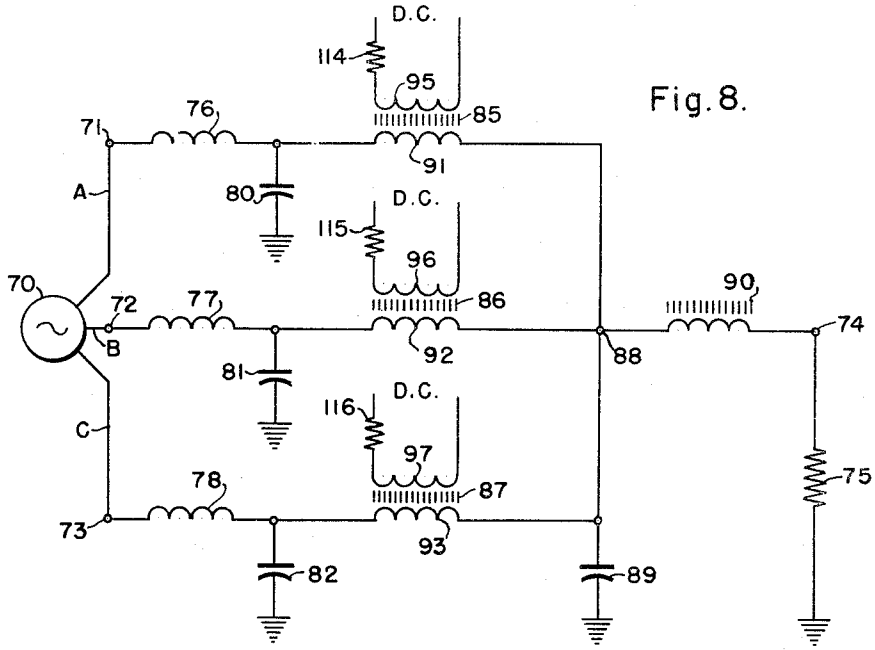


Fig. 8.



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2,727,159

SWITCHING APPARATUS

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7 Claims. (Cl. 307—106)

This invention relates to switching apparatus, and more particularly to magnetic switching apparatus for supplying recurring pulses to a load that appears resistive during the time of the output, such as a magnetron.

The pulses that are utilized for pulsing a magnetron are generally high power recurrent pulses of very short duration compared to the interval between pulses. A prior art device for producing recurrent pulses operates on the principle of the periodic storage of energy in an inductive system, the transfer of that energy to a storage capacitor and finally the discharge of that energy to the load circuit. The building up of energy in the inductive system is initiated by the periodic conduction of a control tube whose conduction is regulated by a pulsating voltage supplied to the grid of the control tube.

It is an object of my invention to provide an improved switching apparatus for supplying recurring pulses to a load.

It is another object of my invention to provide a magnetic switching apparatus in which no electron discharge devices are employed and hence the apparatus is quite rugged.

It is an additional object to provide a magnetic switching apparatus in which saturable reactors, having cores of a material which exhibits a rectangular hysteresis loop, are employed in a relatively simple circuit for pulse forming.

It is still another object to provide a magnetic switching apparatus in which the rate of pulses supplied to a load by the apparatus is twice the frequency of the input to the apparatus, without the use of rotating equipment to produce the frequency doubling.

It is a still further object of my invention to provide a magnetic switching apparatus in which the rate of pulses supplied to a load by the apparatus is triple the frequency of the three-phase input signal to the apparatus.

These and other objects of the invention are effected as will be apparent from the following description, taken in accordance with the accompanying drawings, which form a part of this application and in which like numerals are employed to designate like parts throughout the same:

Figure 1 is a schematic diagram of a magnetic switching apparatus in accordance with a first embodiment of my invention;

Fig. 2 graphically illustrates the output voltage wave of the embodiment of my invention shown in Fig. 1;

Fig. 3 is a schematic diagram of a magnetic switching apparatus in accordance with a second embodiment of my invention in which a multiplex pulse shaping network is employed;

Fig. 4 graphically illustrates the output voltage wave of the embodiment of my invention shown in Fig. 3;

Fig. 5 is a schematic diagram of a magnetic switching apparatus in accordance with a third embodiment of my invention, in which a saturating centertap transformer is utilized;

Fig. 6 graphically illustrates the output voltage wave of the embodiment of my invention shown in Fig. 5;

Fig. 7 is a schematic diagram of an equivalent circuit of the circuit illustrated in Figure 5, with a conventional centertap transformer being utilized in the equivalent circuit;

Fig. 8 is a schematic diagram of a magnetic switching apparatus in accordance with a fourth embodiment of my invention with the apparatus being adaptable for operation from a three-phase power supply to effect a pulse tripping of the frequency of the input power.

In Fig. 1, there is shown a schematic diagram of a circuit of a magnetic switching apparatus in accordance with one embodiment of the present invention in which an inductor **16** is serially connected with capacitor **18** and this series combination forms a charging circuit which is placed in parallel with an alternating signal source **10**, with source **10** being connected to the circuit through the connecting means **11** and **12**. This connecting means may be of any known prior art type. Inductor **16** has a fixed inductance and is utilized to isolate capacitor **18** from the source **10** when the capacitor is discharged. The various combinations of different values of inductance and capacitance will determine the shape of the charging voltage on the capacitor **18**, i. e., the input charging circuit may be resonant or non-resonant. A saturating reactor **20** is connected in a series arrangement with load **15** and this series arrangement is shunted by capacitor **18**. Load **15** is connected with the output of the magnetic switching circuit through connecting means **13** and **14**. Saturating reactor **20** is preferably wound on a core of a material which exhibits a rectangular hysteresis loop, more commonly known as a "square loop" material. Materials of this type when used in the form of cores for reactors or transformers exhibit a very large change in impedance, e. g., 1000 to 1, when driven from the unsaturated condition into saturation. The circuit may be grounded at junction **17**.

The combined impedance of the reactor **20** when it is unsaturated and load **15** should be much greater than the impedance of capacitor **18**. This is necessary in order that there is very little shunting of the capacitor **18** during the charging cycle. The impedance of the reactor **20** when it is unsaturated should be much greater than the impedance of the load **15**. This effectively causes all of the charging voltage on capacitor **18** to appear across the reactor **20**. The type of reactor **20** should be so chosen that when it becomes saturated its impedance should drop to a value that is much less than the impedance of the load **15**. The combination of the impedances of the load **15**, the capacitor **18**, and the reactor **20** when saturated, should be such that the discharge of capacitor **18** takes place in a short time compared with the time of the input cycle. This allows the charging circuit to operate in a stable manner.

In Fig. 3 there is shown a schematic diagram of a circuit of a magnetic switching apparatus in accordance with a second embodiment of the present invention by which pulses of one polarity are produced. Inductor **36** is serially connected with capacitor **38** and this series combination forms a charging circuit which is placed in parallel with an alternating signal source **30**, which source **30** being connected to the circuit through the connecting means **32** and **33**. A saturating reactor **40** is connected in series arrangement with capacitor **41** and this series arrangement is shunted by capacitor **38**. Reactor **40** is provided with an auxiliary winding **47** which may be connected to a source of direct voltage through impedance **111**. Impedance **111**, as well as all the impedances **112**–**116** used in the bias windings in the circuits in accordance with my invention, has a high A. C. impedance relative to the respective reactor across which it is connected.

A pulse shaping network having input connectors **101** and **102** and output connectors **103** and **104** is provided in this circuit with the network consisting of a plurality of serially connected saturating reactors, such as reactors **42**, **44** and **46**, with the saturating reactors being shunted by a plurality of parallel capacitors, such as **41**, **43** and **45**. One or more of the reactors **42**, **44** and **46** may require a means for supplying a D. C. bias potential to the reactor such as winding **106** with impedance **110** on the reactor **42**. A pulse transformer **48**, serially connected with the last reactor **46**, is provided to inductively couple the output of the pulse shaping network with the connectors **34** and **35** for connecting a load to the circuit. The circuit may be grounded at junction **39**. In selecting the inductor **36**, capacitor **38** and saturating reactor **40**, relative values of the latter elements of the circuit should be similar to the ones suggested for the inductor **16**, capacitor **18** and saturating reactor **20** in the circuit shown in Fig. 1. Saturating reactors **40**, **42**, **44** and **46** should have cores made of a thin "square loop" core material to minimize eddy current effects. It should be understood that the number of serially connected reactors and parallel shunt capacitors utilized in the circuit is determined by the amount of pulse narrowing that is desired to be produced by the circuit.

In Fig. 5, there is shown a schematic diagram of a circuit of a magnetic switching apparatus in accordance with a third embodiment of the present invention in which a saturating transformer **63** is utilized with the transformer having a primary winding, which is divided into two portions **65** and **66** by centertap **64**, and a secondary winding **67**. A bias winding **62** including the impedance **49** may be provided for supplying a D. C. potential to saturating transformer **63** for biasing the transformer. An inductor **55** is serially connected with capacitor **56** to form a charging circuit and this charging circuit is connected in parallel with an alternating signal source **50** by means of connectors **51** and **52**. Two loop discharge paths are provided for capacitor **56**. One path includes a saturating reactor **60**, provided with an auxiliary winding **61**, including the impedance **113**, which winding may be connected to a source of direct current with the reactor **60** being connected in series with the first portion **65** of the primary winding of the transformer **63**. The second path for the discharge of the capacitor **56** includes a saturating reactor **58**, provided with an auxiliary winding **59**, including the impedance **112**, which winding may be connected to a source of direct current, with the reactor **58** being connected in series with the second portion **66** of the primary winding of the transformer **63**. Reactors **58** and **60** should be so biased by the flux from windings **59** and **61**, respectively, that reactor **58** will become saturated only during one half of the cycle of the input signal to the circuit and reactor **60** will become saturated only during the other half of the cycle of the input signal to the circuit. The secondary winding **67** of the transformer **63** is connected with capacitor **68** and load **57** in a series arrangement, with load **57** being connected to the capacitor **68** and winding **67** by means of connectors **53** and **54**. Reactors **58** and **60** and saturating centertap transformer **63** should contain cores of magnetic material having a rectangular hysteresis loop.

In Figure 7 is shown a circuit that is similar to the circuit shown in Figure 5. However, in the circuit shown in Figure 7, a conventional centertap transformer **63'** is used instead of a saturating centertap transformer. The secondary winding **67'** of the transformer **63'** is shunted by capacitor **68'** and is connected in a series arrangement with saturating reactor **69** and load **57**, with load **57** being connected to the reactor **69** and winding **67** by means of connectors **53** and **54**.

In Figure 8 is shown a schematic diagram of a magnetic switching apparatus in accordance with a fourth embodiment of my invention which is operable with a three-phase power supply. Three separate charging circuits are provided. Each charging circuit consists of an inductor and capacitor in series arrangement with one end of the capacitor grounded. In the embodiment shown, the three charging circuits comprise inductor **76** and capacitor **80**, inductor **77** and capacitor **81**, and inductor **78** and capacitor **82**, respectively. Each of the three charging circuits is connected to a three-phase power supply **70** by means of connectors **71**, **72** and **73**. Saturable reactors **85**, **86** and **87** are provided with respective main windings **91**, **92** and **93** on each of which windings are two end connector members. The respective auxiliary windings **95**, **96** and **97**, including the respective impedances **114**, **115** and **116**, are adaptable for connection to a direct-current source for biasing. One end connector member of each of the reactors is connected to the respective charging circuits at the junctions where the respective capacitors and inductors are connected in such a manner that the capacitors **80**, **81** and **82** may facilitate the saturating of reactors **85**, **86** and **87**, respectively. The other end connector member of the main windings of the reactors are connected together in a common junction **88**. Reactor **90** and connector **74** are connected in a series arrangement with this junction **88**. Connector **74** is provided as means for applying a load **75** to the circuit. Load **75** should be grounded as shown in the diagram. Also connected to common junction **88** and being in parallel arrangement with the above series arrangement is capacitive member **89**. Member **89** is also grounded as shown in the schematic diagram.

In accordance with the first embodiment of my invention shown in Fig. 1, an alternating signal from signal source **10** is supplied to the circuit through connectors **11** and **12**. Initially there is no voltage on capacitor **18** and reactor **20** is unsaturated. As the voltage of the capacitor rises, a change of flux occurs in the core of the reactor **20**. The reactor is designed so that when the voltage on the capacitor **18** has reached its peak, the core of the reactor will become saturated. The saturation of the core of reactor **20** causes a very great drop in the impedance of the reactor. Consequently, the capacitor **18** is now shunted by a low impedance path and discharges its energy into the load **15**. The shape of the output voltage wave to the load is illustrated in Fig. 2.

In accordance with the second embodiment of my invention shown in Fig. 3, an alternating signal from signal source **30** is supplied to the circuit through connectors **32** and **33**. Similar to the operation of the circuit illustrated in Fig. 1, the voltage across capacitor **38** tends to saturate the core of reactor **40**. However, the core of the reactor **40** is so biased that it will become saturated during only one half of the cycle of the input signal. Hence pulses of one polarity will be produced. A resonant circuit is formed when reactor **40** saturates. The resonant circuit consists of capacitors **38** and **41** and the reactor **40** which has become saturated. The voltage on capacitor **41** will appear as a pulse considerably reduced in width when compared with the voltage wave form on capacitor **38**. The wave form then passes through the rest of the pulse shaping network including serially connected reactors **42**, **44**, **46** and parallel capacitors **43** and **45**, and is inductively coupled by means of a pulse transformer to the connectors **34** and **35** to which a load may be applied. The output voltage wave of the circuit is illustrated in Fig. 4.

In accordance with the third embodiment of my invention shown in Fig. 5, an alternating signal from signal source **50** is supplied to the circuit through connectors **51** and **52**. A suitable D. C. bias potential may be supplied to the winding **62** of the saturating transformer **63**. Inductor **55** and capacitor **56** are provided as an alternating-current resonant charging circuit with the capacitor **56** being discharged every half cycle of the input signal. This results in positive and negative pulses. Reactors **58** and **60** are so biased by direct current being supplied to their

auxiliary windings **59** and **61**, respectively, that one reactor saturates when the voltage on capacitor **56** reaches its positive peak and the other reactor saturates on the reverse peak polarity. By feeding these pulses into the saturating centertap transformer **63** through winding **65** when reactor **60** is saturated and then through winding **66** during the other half of the cycle of the input signal when reactor **58** is saturated, the flux in the core of transformer **63** is caused to fluctuate in magnitude in one direction only and hence output pulses of one polarity will result and these pulses will occur at a rate which is twice the frequency of the input signal to the circuit.

It should be pointed out at this time why a saturating centertap transformer **63** is utilized in this circuit rather than a conventional centertap transformer. When capacitor **56** is discharged, it forms a resonant circuit with capacitor **68** and the saturated inductance of reactor **58** or reactor **60**, depending on which reactor is in the saturated state. The values of these circuit components, capacitors **56** and **68** and reactors **58** or **60**, are so chosen in order that some pulse sharpening occurs. During the time capacitor **56** is discharging into capacitor **68**, the transformer **63** operates as a conventional transformer. The transformer **63** should be so chosen that it will become saturated when the voltage on capacitor **68** reaches its maximum value. A new resonant circuit is now formed which comprises capacitor **68**, the transformer **63** which has become saturated and the load **57**. Consequently, more pulse sharpening occurs and in the circuit shown in Fig. 5 the narrowed pulses are dissipated into the load **57**. However, the pulses could be passed through an additional pulse sharpening network before supplying them to a load. In Fig. 6 is illustrated the output voltage wave supplied to the load **57** in the circuit shown in Fig. 5.

By referring to Fig. 7, it can be seen that an additional component, saturating reactor **69**, must be added to the circuit in accordance with the third embodiment of my invention when a conventional centertap transformer **63'** is used instead of a saturating centertap transformer, if it is desired to obtain the same amount of pulse sharpening as was obtained from the circuit illustrated in Fig. 5. In other words, Fig. 7 is an equivalent circuit of Fig 5 when a conventional centertap transformer **63'** is used instead of the saturating centertap transformer **63**. The circuit shown in Fig. 7 operates in the same manner as the circuit shown in Fig. 5 up until the time when capacitor **68'** is receiving the charging voltage. The saturable reactor **69** should be so chosen that it will become saturated when the voltage on capacitor **68'** reaches its maximum value. A new resonant circuit is formed which comprises capacitor **68'**, the reactor **69** which has become saturated and the load **57**. Consequently, pulse sharpening occurs as is the case in the circuit illustrated in Fig. 5.

It can be seen from the above description that by utilizing a saturating centertap transformer in this particular embodiment of my invention, additional pulse sharpening can be obtained which could otherwise be brought about only by use of an additional component, namely, a saturable reactor. The elimination of the necessity of utilizing the additional saturable reactor for obtaining the desired pulse sharpening will result in a savings in space and weight which is quite a factor when the circuit in accordance with this embodiment of my invention is utilized in equipment for the military.

In accordance with the fourth embodiment of my invention as shown in Fig. 5, a three-phase alternating signal comprising phases A, B and C is supplied to the circuit through connectors **71**, **72** and **73**. Let us first consider phase A. With a proper bias on winding **95** of reactor **91** so that the reactor can become saturated during only one-half of a cycle of phase A, capacitor **80** will charge up to some peak value. At this point reactor **91** becomes saturated and capacitor **80** discharges into capacitive member **89**. When the charge on capacitive member **89** reaches its peak value, reactor **90** becomes saturated and member **89** discharges into the load **75**. Each time a discharge takes place, some pulse sharpening occurs. Phase B and phase C cause similar charging and discharging of capacitors **80** and **81** respectively, with the aid of reactors **86** and **87** in a manner as described above for phase A. Capacitive member **89** receives pulses at a rate which is three times the input frequency and supplies them to load **75**. Hence pulse tripling is achieved. It is within the scope of this embodiment of the invention to remove capacitive member **89** and reactor **90** from the circuit and connect the load **75** through connector **74** directly to junction **88**. However, the pulses would lack the desirable pulse sharpening which is effected by the charging and discharging of capacitive member **89**.

While I have shown the use of my invention in several embodiments, it will be obvious to those skilled in the art that it is not so limited but is susceptible to various changes and modifications without departing from the spirit thereof. For example, in all of the suggested embodiments of my invention, additional pulse sharpening components, including additional capacitors and reactors with cores of a material having a rectangular hysteresis loop, could be added to the circuits of the disclosed embodiments without departing from the scope of my invention. Further, the load may be of any type which appears resistive during the time of output.

I claim as my invention:

1. A magnetic switching circuit for applying recurring pulses to a load, said circuit comprising first means for applying a signal to said circuit, second means for connecting a load to said circuit, an inductor, a capacitor and a saturable reactor, said saturable reactor being serially connected with said second means, said inductor and said capacitor being connected in a series circuit, with said series circuit being connected in parallel arrangement with said first means, said serially connected saturable reactor and second means being shunted by said capacitor in such an arrangement that the voltage across the capacitor saturates the saturable reactor, said saturable reactor after being saturated thereby forming a low impedance path for the discharge of the capacitor into said load.

2. A switching circuit for applying recurring pulses to a load, said circuit comprising first means for applying a signal to said circuit, an inductor and a capacitor serially connected, said serially connected inductor and capacitor being connected in a parallel arrangement with said first means, a saturable reactor provided with a biasing winding, a pulse shaping network, said saturable reactor being serially connected with said pulse shaping network, said serially connected saturable reactor and pulse shaping network being connected in a parallel arrangement with said first capacitor, and second means for connecting a load to said circuit, said second means being inductively coupled to said pulse shaping network.

3. A switching circuit for applying recurring pulses to a load and adapted to be connected between a signal supply and a load, said circuit comprising an inductor and a first capacitor, said inductor being in a series circuit arrangement with said first capacitor, said series circuit arrangement being adapted for connection in parallel with said signal supply, a saturable reactor member provided with a biasing winding, a pulse shaping network including a plurality of branches, with each of said branches including a serially connected saturating reactor and capacitor member, said saturable reactor member being provided in a series circuit arrangement with the capacitor member of one of said branches, said latter series circuit arrangement being shunted by said first capacitor, and an inductive coupling member, said inductive coupling member providing a coupling between the saturating reactor of one of said branches and said load.

4. A magnetic switching circuit for applying recurring pulses to a load at twice the frequency of the alternating input signal to the circuit, said switching circuit

including a serially connected inductor and capacitor, and first means for connecting said input signal to said circuit, with said serially connected inductor and capacitor being connected in parallel with said first means, a first and a second loop conductive path, with each of said paths being shunted by said capacitor, first and second saturable reactors respectively provided with biasing windings, a saturable transformer having a primary winding and a secondary winding, said primary winding having a center tap and a first portion and a second portion, said first loop conductive path including said first saturable reactor serially connected with said first portion of the primary winding of said saturating transformer, said first saturable reactor being biased such that it will become saturated during only one half of each cycle of the alternating input signal, said second loop conductive path including said second saturable reactor serially connected with the second portion of said primary winding, said second saturable reactor being biased such that it will become saturated during the other half of each cycle of the alternating input signal, a second capacitor, and second means for connecting a load to said circuit, said second capacitor being connected in a series circuit arrangement with said secondary winding of said saturating transformer, with said series circuit arrangement being connected in a parallel circuit arrangement with said second means.

5. A magnetic switching circuit for applying recurring pulses of one polarity to a load at a rate which is twice that of the frequency of the alternating input signal to be supplied to the circuit, said switching circuit including a saturating transformer having a center tap, said transformer having a primary winding including first and second portions and a secondary winding, a first conductive loop and a second conductive loop, said loops being connected in a parallel circuit, each of said loops being shunted by first means for supplying an alternating charging voltage to said loops, said first loop consisting of a first saturable reactor and said first portion of the primary winding, said first saturable reactor having second means for biasing said first reactor, said second loop consisting of a second saturable reactor and said second portion of the primary winding, said second saturable reactor having third means for biasing said second reactor with said first and second saturable reactors being so biased that they will alternately become saturated by said alternating charging voltage, said charging voltage thereby effecting the passage of a peaked fluctuating unidirectional flux in the core of said saturating transformer, fourth means for connecting a load to said circuit, a capacitor, said fourth means and said capacitor and said secondary winding being serially connected, with said capacitor being operative to saturate said saturating transformer to thereby sharpen the pulses supplied to said load.

6. A magnetic switching circuit for applying pulses to a load at a rate which is three times that of the frequency of a three phase alternating input signal to be supplied to the circuit, said switching circuit including means for applying a three-phase supply signal to said circuit, first, second, third and fourth charging circuits, first, second, third and fourth saturable reactors, with said first charging circuit being connected in a first series circuit arrangement with said means and said first saturable reactor, said second charging circuit being connected in a second series circuit arrangement with said means and said second saturable reactor, said third charging circuit being connected in a third series circuit arrangement with said means and said third saturable reactor, said first, second and third series circuit arrangements being connected at a common point, said fourth charging circuit being connected to said common point, and said fourth charging circuit being connected in a fourth series circuit arrangement with said fourth saturable reactor and said load.

7. A magnetic switching circuit for applying pulses to a load at a rate which is three times that of the frequency of the alternating input signal to be supplied to the switching circuit, said switching circuit including first, second, and third connectors adaptable for receiving said input signal, first, second and third pulse forming circuits, each of said pulse forming circuits including an inductor member and a saturable reactor connected in series circuit arrangement to provide a point of connection therebetween, a grounded capacitive member connected to said point of connection, said respective first, second and third pulse forming circuits being serially connected with respectively the first, second, and third connectors, a fourth pulse forming circuit comprising a series circuit arrangement of a capacitive member and a saturable reactor member, connector members adapted for connecting said load to the switching circuit, said first, second and third pulse forming circuits being respectively connected to said fourth pulse forming circuit at a common point in such an arrangement that the pulses produced by the first, second, and third pulse forming circuits produce a charging voltage on the capacitive member of said fourth pulse forming circuit, said charging voltage thereby effecting the saturation of the saturable reactor of said fourth pulse forming circuit.

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