

[54] **HIGH FREQUENCY FERRORESONANT TRANSFORMER**

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[22] Filed: **Dec. 16, 1971**

[21] Appl. No.: **208,880**

[52] U.S. Cl. **321/16, 321/18, 321/25, 323/6, 323/48, 323/60, 336/212**

[51] Int. Cl. **G05f 3/08, G05f 1/32**

[58] Field of Search **323/6, 44 R, 48, 323/60, 61; 321/16, 18, 25; 336/212, 229**

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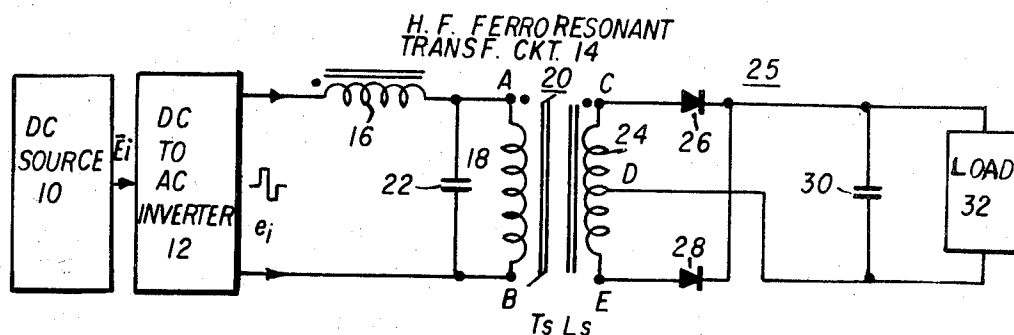
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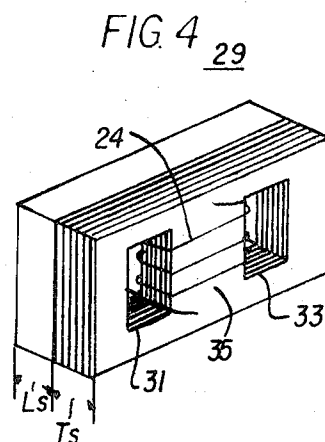
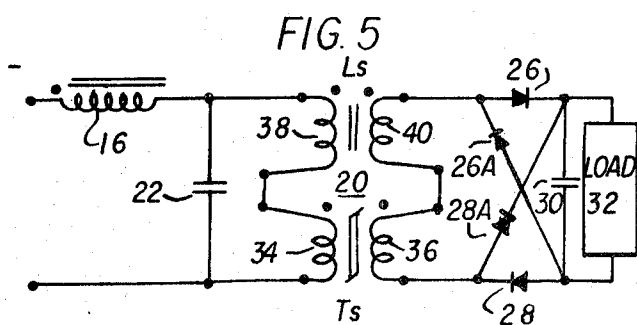
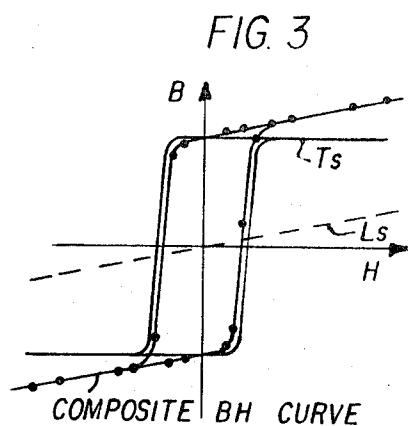
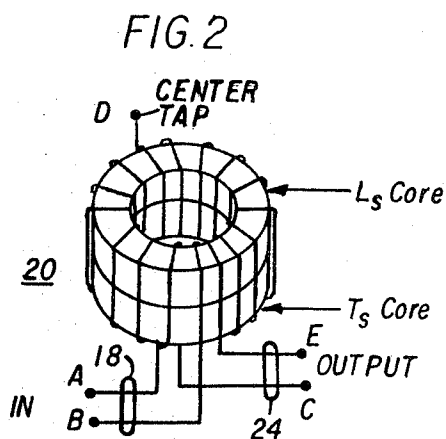
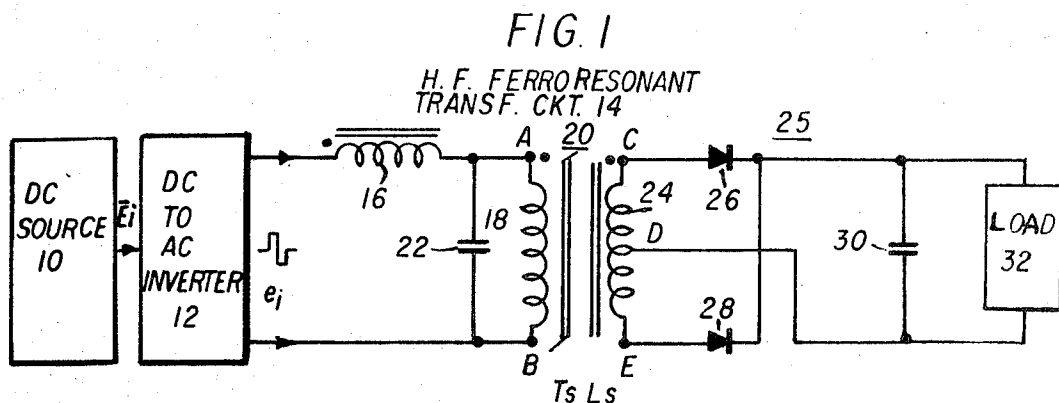
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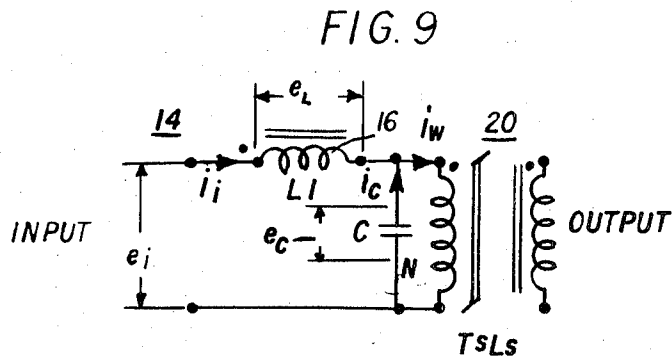
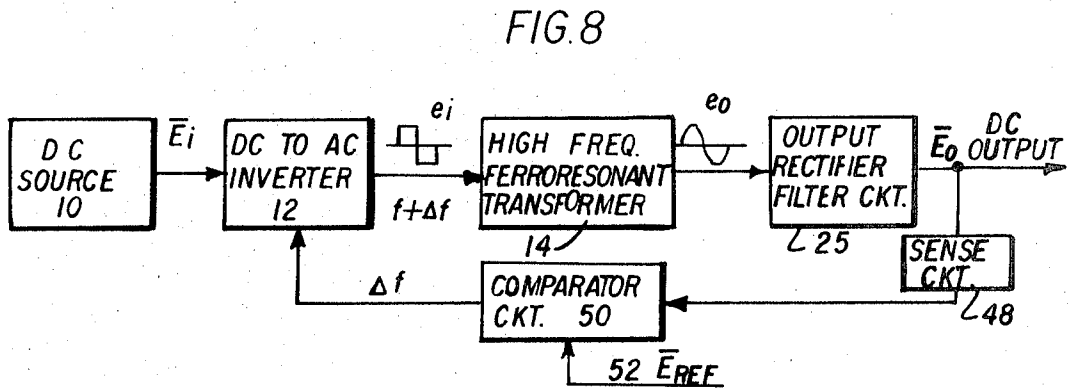
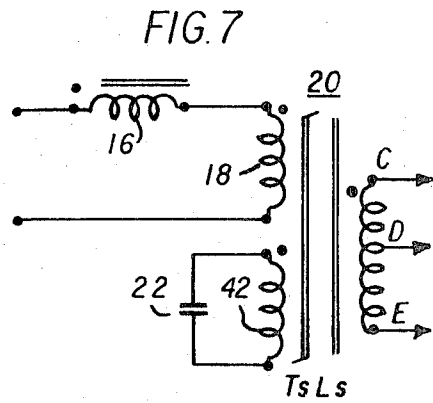
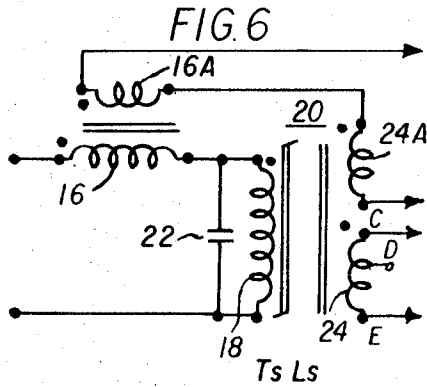
[57] **ABSTRACT**

A high frequency ferroresonant regulator circuit having a saturable core structure comprised of a first core of a square loop magnetic material and a second core; the first core having a first permeability region which provides low reluctance to the flux generated during the initial part of the period between resonant pulses of the ferroresonant circuit, and a second permeability region of different values upon saturation; the second core having a permeability which is less than the first permeability of the first core and which is greater than the second permeability of the first core, and which is of a value which does not saturate at the values of mmf provided by the ferroresonant circuit; which structure increases the width and decreases the amplitude of the resonant pulse provided by the ferroresonant transformer therein during the resonant period to provide increased circuit efficiency and more stable operation at all values of output load.

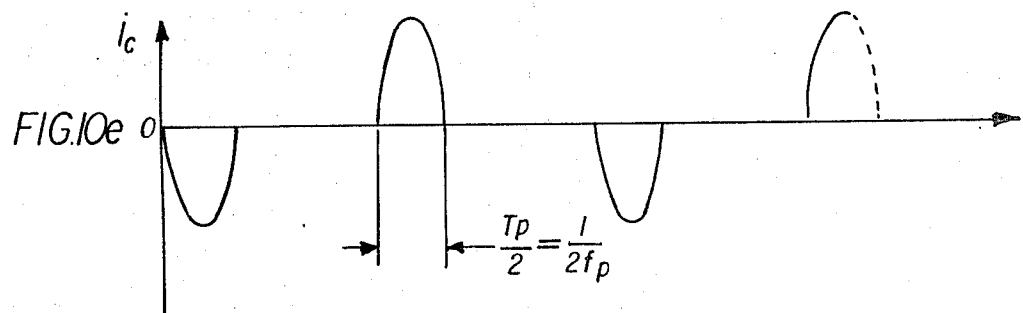
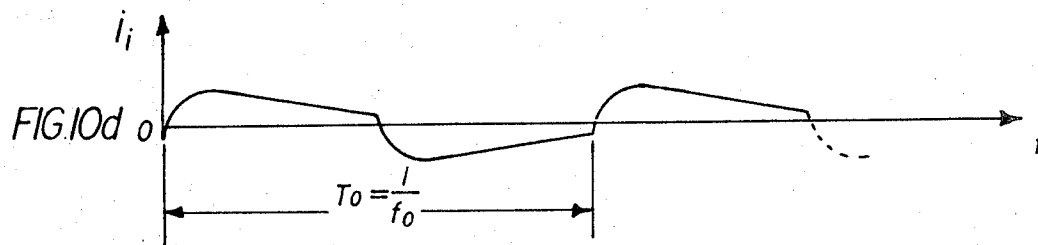
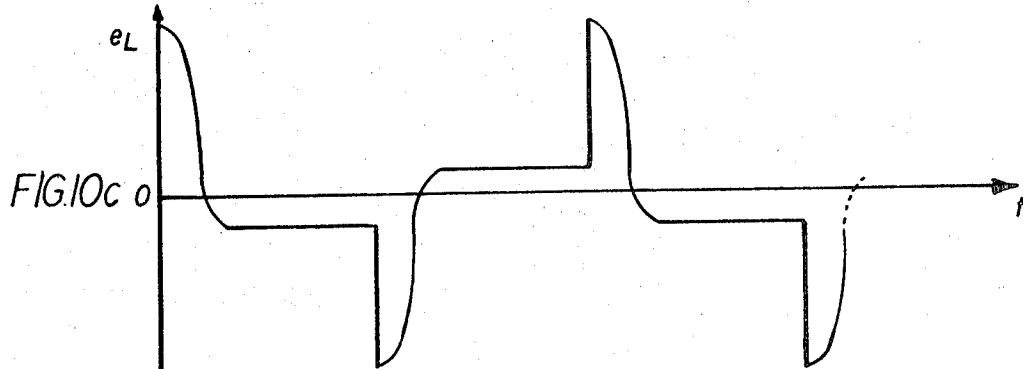
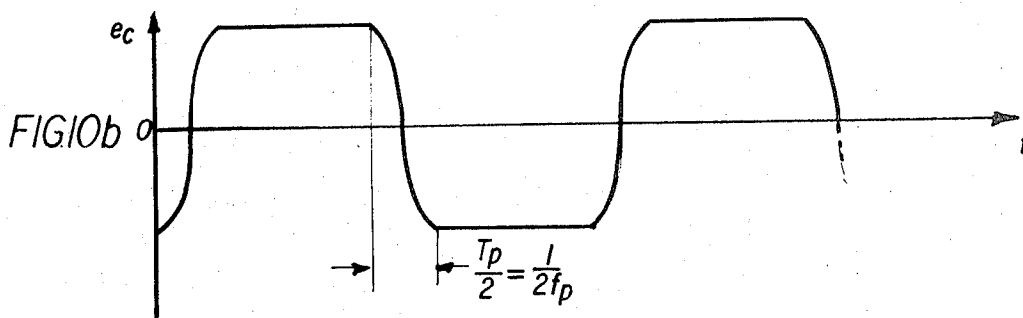
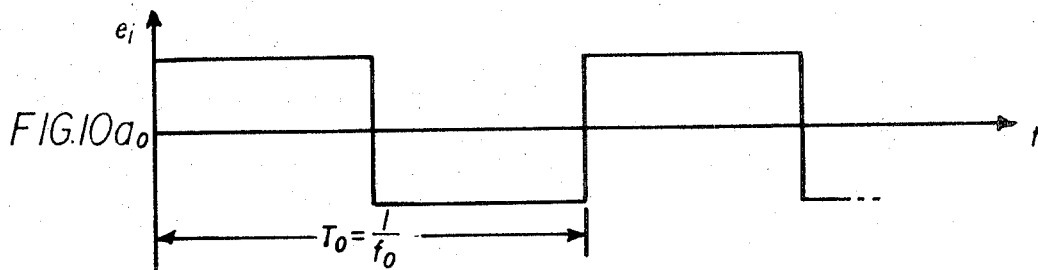
19 Claims, 18 Drawing Figures

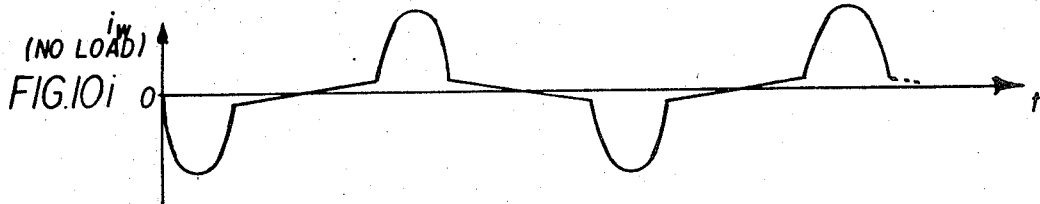
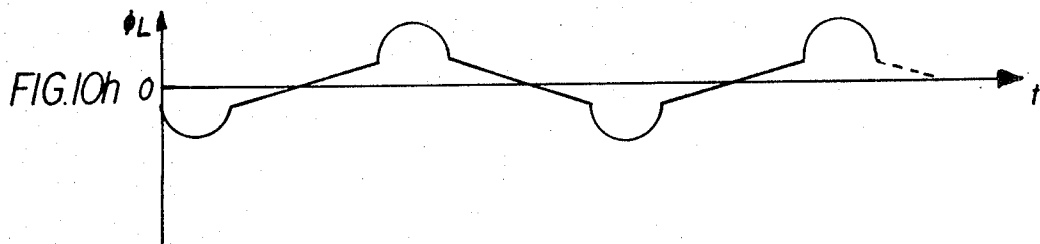
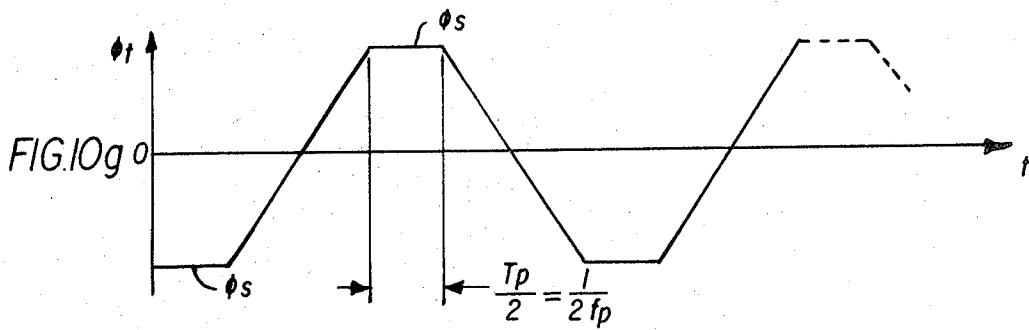
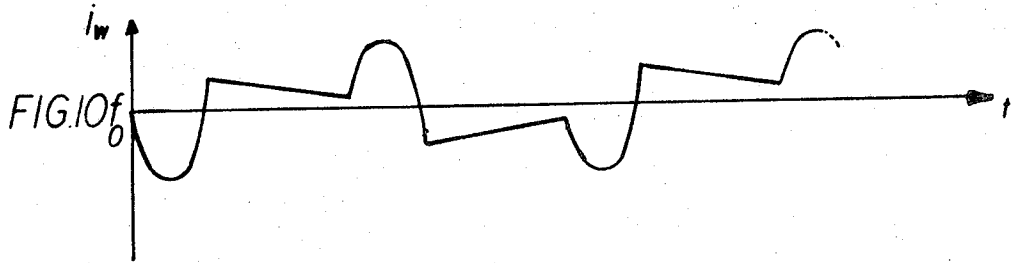






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HIGH FREQUENCY FERRORESONANT TRANSFORMER

BACKGROUND OF THE INVENTION

The use and application of ferroresonant regulator circuits in the provision of regulated DC power derived from a 60 cycle source has become widespread and is well known in the field. In addition to being extremely reliable in operation, ferroresonant regulator circuits provide excellent voltage regulation with static and dynamic input line voltages, and have good efficiency and input power factor.

In addition to these operational advantages, the geometry of a conventional ferroresonant regulator is basically relatively simple. In its more basic form, the regulator comprises an input ballast inductance L effectively connected in series with the input winding of a saturable core T_s across a 60 cycle supply source. A resonant capacitor C is connected across the saturable core input winding, and the output winding of the saturable core T_s is connected to an output load. In operation, each half cycle of the input alternating current effects saturation of the saturable core T_s after a fixed volt time integral. That is, the product of the voltage across the primary winding and time for saturation remains constant. When the core saturates, the resonant capacitor C discharges and recharges to the opposite polarity. The saturable core then comes out of saturation and begins to measure a new volt time integral for the next half cycle.

While the known ferroresonant regulator circuits have been most successful in the provision of regulated outputs for large power sources which operate at relatively low order frequencies, such as 50 and 60 cycles, the attempted use of the known ferroresonant techniques and structures to regulate current derived from a high frequency source, such as for example 10–20 kilohertz, has not been particularly successful. It has been found, for example, that if a ferroresonant regulator circuit using a ferrite saturable core is used in high frequency applications, the circuit is extremely sensitive to ambient temperature changes, and in many instances variations in the B-H saturation characteristics of the material in the amount of 20–30 percent may be experienced. Obviously a circuit arrangement having such order of variation would have limited commercial application.

It has also been observed that if a saturable core of a material conventionally used in high frequency applications is provided, the saturable core is driven to saturation in each half cycle of the input voltage, the resultant current pulse through the resonant capacitor is of extremely narrow width (in the order of 5–10 percent of one cycle of the input waveform), and excessively high peak current values are experienced. The high peak current values result in high core and winding losses and, in most cases, instability at light load inputs is experienced.

SUMMARY OF THE INVENTION

It is an object of the present invention therefore to provide a novel ferroresonant transformer circuit for regulating high frequency circuits which is stable at all load values, and particularly a ferroresonant regulator circuit of such type which is of compact size, low component count, and which provides regulated outputs of acceptable values.

It is a specific object of the invention to provide an inexpensive ferroresonant transformer structure for use in ferroresonant regulator circuits in which the width or duration of the output pulse provided by the ferroresonant transformer during the resonant period is increased, and the current amplitude reduced to provide increased circuit efficiency and more stable operation at all values of output loads.

The novel ferroresonant transformer circuit, which is so operative, basically comprises an input ballast inductor L , which may be, for example, of the pot or toroid core type, connected across an alternating current high frequency input source in series with the input winding of a saturable core structure $T_s L_s$, which has multi-flux paths. A resonant capacitor C is coupled to the saturable core structure input winding. The output winding of the saturable core structure $T_s L_s$ is in turn connected via associated circuitry to a load.

The saturable core structure $T_s L_s$ in one embodiment of the invention comprises a unitary structure including a first core element comprised of a tape-wound, square-loop magnetic alloy, and a second core element comprised of sintered powdered core material, such as ferrite, molypermalloy or the like. In such embodiment, the two cores are of a toroid configuration and are held in aligned contact relation with each other by suitable means, such as epoxy, glue, tape or the like, to provide a unitary core structure upon which the input and output windings of the saturable core structure $T_s L_s$ are wound. If desired, such unitary structure may be encased by conventional potting methods. The saturation inductance thereby includes a first component comprising the air inductance of the saturable core input winding and a second component which is provided by the powdered core in conjunction with the input winding. The sum of these two components makes up the saturation inductance of the $T_s L_s$ core structure.

The unitary saturable core structure as thus wound and constructed is operative to provide an increased flux change during the resonant period to thereby effect the desired increase in width of the output pulse. That is, the tape-wound core of square loop material has a first permeability region prior to saturation in each half cycle of the input voltage which is of a higher value than the permeability of the second core. The second core has a relatively uniform permeability which is substantially less than the permeability of the first core prior to saturation of the first core. During the period prior to saturation of the first core (the second core is of a material which will not saturate at the value of mmf provided in the ferroresonant transformer) the first core absorbs most of the flux, and continues to absorb most of the flux until such time as the first core is driven to saturation. At such time, the permeability of the first core decreases to a value which is substantially less than that of the relatively uniform permeability of the second core, and the major portion of the further flux generated is absorbed by the second core.

As a result of the ability of the unitary core structure to conduct the further flux, the width of the capacitor current pulse provided in the ferroresonant circuit is correspondingly increased. With an increase in the current pulse width, the high peak value currents are reduced and a more efficient and stable operating circuit is provided. In addition to achieving such improved mode of operation, the square loop, high-curie temperature magnetic material which has excellent tempera-

ture characteristics as used in the first core, results in a unitary core structure which minimizes output voltage shift.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of a novel ferroresonant regulator circuit including a first embodiment of a novel ferroresonant transformer structure;

FIG. 2 illustrates a physical configuration of a novel saturable core structure which is utilized in the ferroresonant regulator circuit of FIG. 1;

FIG. 3 illustrates the B-H curves for the T_s core and L_s cores of FIG. 2, and the composite B-H curve for the novel unitary core structure of FIG. 2;

FIG. 4 illustrates another embodiment of a novel saturable core structure for use in the ferroresonant regulator circuit;

FIG. 5 is yet another embodiment of a novel saturable core structure schematically shown in a ferroregulator circuit;

FIGS. 6 and 7 set forth further novel ferroresonant circuit arrangements;

FIG. 8 illustrates a ferroresonant regulator circuit of the type shown in FIG. 1 with a frequency feedback control;

FIG. 9 is a schematic drawing related to FIG. 1, with designations identifying the voltages and currents which occur therein; and

FIGS. 10a-10i comprise a set of curves which when taken with FIG. 9 illustrate the steady state voltages, currents and fluxes in the ferroresonant transformer circuit of the invention.

DETAILED DESCRIPTION

With reference to FIG. 1, there is shown thereat a novel ferroresonant regulator circuit including a DC source 10 which may comprise a battery, a regulated or unregulated direct current source, or the output of a commercial alternating current source as rectified and filtered. The output E_i of the DC source 10 is fed to a DC to AC inverter 12 which provides a high frequency output e_i (i.e. over 1 KHz). DC to AC inverters are well known in the field, and inverter 12, in one operative embodiment to be described, provided a 21-27 volt square wave output at a frequency of 8.922 KHz. The output of DC to AC inverter 12 is connected over input ballast inductor 16 to terminals A, B of the input winding 18 of the $T_s L_s$ saturable core 20. A resonant capacitor 22 is connected across the saturable core input winding 18.

An output winding 24 for the $T_s L_s$ saturable core transformer circuit 14 is connected via rectifier and filter circuit 25 to a load 32. That is, the starting and terminating terminals E, C of output winding 24 are connected via rectifiers 26, 28 respectively to one side of load 32 and the center tap D of output winding 24 is connected to the other side of load 32. Filter capacitor 30 is connected across the rectified output of winding 24.

The input ballast inductor 16 may be wound on a powdered core toroid, such as a ferrite or molypermalloy core or the like (or pot core, made of manganese-zinc material or the like). In the event that the unit is to be used for lower operating frequencies, as for example in the order of 1 KHz, silicon steel lamination cores may be used.

Capacitor 22 is coupled as shown to the input winding 18 on the saturable core structure 20 to operate therewith and with inductor 16 in a ferroresonant mode during each half cycle of the voltage input from inverter 12. Dipped mica capacitors, film capacitors, and metalized film capacitors may be used as the resonant capacitor 22.

One embodiment of a novel core structure $T_s L_s$ is shown in FIG. 2, and as there shown comprises a first toroid core T_s , which may be of a tape-wound core of a square loop, high curie-temperature magnetic material (such as nickel-iron alloy or the like) which is secured by suitable means, such as epoxy, etc., in aligned contacting relation as shown with a second toroid core element L_s , which may comprise a sintered powdered core made of ferrite, molypermalloy or the like having a filler material added in amounts to provide the desired permeability. In the arrangement of FIG. 2, the two toroid cores T_s and L_s are secured in aligned contacting relation as shown to form a unitary core structure about which the input winding 18 and output winding 24 are wound. In use, the terminal ends A, B of the input winding 18 are serially connected with ballast inductor 16 to the output of inverter circuit 12 (FIG. 1) with the capacitor 22 coupled as shown to winding 18, and the terminal ends E, C, and center tap D of winding 24 are connected over rectifier and filter circuit 25 to load 32.

In one successful embodiment of the circuit shown in FIG. 1, the inverter circuit 12 provided a square wave output having a voltage variable between 21-27 volts peak and at a frequency of 8.922 KHz over a potted core inductance 16 comprised of a 26mm by 16mm pot core of a manganese zinc material having an effective permeability in the order of 51, with a winding of 57 turns of 22 gauge insulated magnet wire wound thereon.

Capacitor 22 in such arrangement comprised a 0.47 microfarad, 100 volt DC mylar capacitor. $T_s L_s$ core 20 comprised a tape-wound core T_s of nickel-iron alloy, as available from Magnetics, Inc., Butler, Pa., No. 52061-1R, having a first permeability region prior to saturation in the order of 140 to 200,000, and a second permeability region after saturation which is near zero.

The L_s core was made of sintered powdered material, Magnetic Inc. No. 55932-A2, which is a nickel-iron alloy with filler added to provide a permeability in the order of 26. The cross-sectional area of the core L_s is selected to be of sufficient value to prevent saturation at the values of mmf generated during each cycle.

The core T_s in such embodiment had 1.0 inch OD; 0.75 inch ID; 0.25 inch thickness; and the core L_s had an 1.06 inch OD, 0.58 inch ID and 0.44 inch thickness.

The cores $T_s L_s$ were secured together, and an input winding 18 made up of 42 turns of 18 gauge insulated magnet wire equally distributed and wound tight on the unitary core structure $T_s L_s$ with the terminating ends A, B being brought out as indicated in FIG. 2 for connection in the ferroresonant transformer circuit 14 in the manner shown in FIG. 1. The output winding 24 which was also wound around the unitary core structure $T_s L_s$ comprised 20 turns of 18 gauge insulated magnetic wire equally distributed about and wound tight on the unitary core structure with the terminal ends E and C and center tap D being brought out as shown in FIG. 2 for connection to the ferroresonant circuit 14 as shown in FIG. 1.

The rectifiers 26, 28 in circuit 25 comprised 3 amp DC, fast-recovery rectifiers available from Semtech, Calif., as 35F2; and the filter capacitor 30 was a 1,300 microfarad, 20 volt DC capacitor. The ferroresonant circuit of FIG. 1 provided regulated 5 volts DC voltage, and was designed to supply output current to a load at 1.5 amperes DC.

OPERATION

With the application of the square-wave output of the DC to AC inverter 12 over the input ballast inductor 16 to the input winding 18 of the $T_s L_s$ saturable core 20, the saturable core structure $T_s L_s$, capacitor 22, and the inductor 16 of ferroresonant transformer circuit 14 are operative in a ferroresonant action to provide a regulated output. Representative waveforms of the operation of the novel ferroresonant regulator circuit at the points identified in FIG. 9 are shown in FIGS. 10a-10i, which waveforms are representative of the circuit operation for a nominal input voltage and with the output load 32 at approximately full load.

With reference to FIG. 10a, the waveform there-shown represents the voltage waveform e_i of FIG. 9, output from the DC to AC inverter 12 of FIG. 1, each cycle of the waveform having a time period of $T_o = (1/f_o)$ (see FIG. 10a), wherein f_o is the input operation frequency to the ferroresonant transformer circuit 14. With reference to FIG. 10b, the voltage e_c which occurs across capacitor C (FIG. 9) follows the input waveform (FIG. 10a), the capacitor C being charged in the positive direction with the occurrence of the leading edge of the positive rectangular waveform which is output from inverter 12, and reaching a constant potential level which is maintained until the occurrence of the trailing edge of the rectangular waveform e_i output from inverter 12. At such time, the voltage e_c across the capacitor C decreases to zero, as shown, and increases in the opposite direction as charging of the capacitor C in the negative direction occurs. The time period for such changing condition of the voltage on capacitor C is expressed as $T_p = (1/f_p)$. As shown in FIG. 10, T_p is the total time period of the resonant pulse and f_p is the frequency of the resonant pulse.

The voltage e_L across inductance L during the corresponding half cycle as shown in FIG. 10c reflects the changing voltage on the capacitor C. That is, during the period capacitor C charges, the voltage across the inductance L decreases and reaches a constant negative value as the steady state, positive charge is reached on capacitor C. During the period $(T_p/2) = (1/2f_p)$ (see FIG. 10b), as the capacitor C begins to discharge, the voltage across inductance L (FIG. 10c) drops to a maximum negative value, and then changes (at the rate of change of the capacitor voltage e_c) towards zero, and further increases to a steady state positive voltage value. The voltage e_L across inductance L remains at such level until the capacitor C once more discharges and recharges in the positive direction.

The current waveforms i_i , i_c , i_w for the ferroresonant regulator circuit (see FIG. 9) are shown in FIGS. 10d-10f. With reference first to FIG. 10d, a representative current input i_i is shown for the assumed full-load condition, and as there illustrated, as the current i_i increases toward a maximum positive value, capacitor C charges in a positive direction as shown in FIG. 10b. After the capacitor C is fully charged, the current i_i decreases toward zero (i.e. the remaining period of the

positive pulse input from inverter 12). As capacitor C recharges in the opposite direction, the current i_i drops to a maximum negative value, and then slowly proceeds in the direction of zero during the remaining period of the negative half cycle of the input pulse.

The current i_c through capacitor C (FIG. 9) is illustrated by the waveform in FIG. 10e, and as there shown, current flow occurs during the periods of charge and discharge of capacitor C, which periods are identified by $(T_p/2) = (1/2f_p)$.

Current through input winding 18 of saturable core 20 is shown in FIG. 10f. It will be apparent that such waveform comprises the sum of the waveforms shown in FIGS. 10d and 10e (i.e., the sum of the current flow over the capacitor C and the inductance L).

With reference now to FIGS. 10g-10i, the manner in which the flux is developed in the unitary core structure $T_s L_s$ to effect the desired operation will become more apparent. With specific reference to FIG. 10g, it will be seen that until saturation of core T_s in each half cycle, nearly all flux (ϕ_T) generated flows in core T_s . After ϕ_T reaches the saturation level (ϕ_s) of the T_s core the permeability of the magnetic path provided by core T_s becomes less than the permeability of core L_s and the further flux generated by i_w during the remaining portion of the half cycle flows in core L_s (ϕ_L , FIG. 10h). Since the material and size of core L_s has been selected so that flux ϕ_L in the core L_s will never reach the saturation level, the width of the resonant pulse $(T_p/2)$ is basically determined by the permeability of the core L_s , the value of capacitor C and the number of turns in winding N (FIG. 9) on the core and the leakage inductance of the winding N.

With reference to FIG. 3, the resultant operation of the novel core is further set forth. As there shown, the solid lines represent the B-H curve for the T_s core. It is noted that the extreme end portions of such curves are essentially flat, which is characteristic of nickel-iron alloy material such as used for the tape wound core T_s (i.e., prior to saturation, as represented by the vertical portion of the BH curve, the permeability of core T_s is high—in the order of 140 to 200,000—and after saturation the permeability of core T_s as represented by the flat horizontal portions of the curve decreases to almost zero). The broken line L_s in FIG. 3 represents the BH curve of the second core L_s , and as there indicated the core L_s has a relatively linear permeability (in the order of 26). The dot-dash line in FIG. 3 represents the BH characteristic of the unitary core structure 20, and it will be seen from such showing that as the core T_s approaches saturation, the permeability across core T_s decreases to a value which is less than that of the core L_s , whereby the further flux generated in the half cycle is absorbed by the core L_s .

As a result of the conduction of the further flux by core L_s (FIG. 10h) the unitary core structure 20 provides a capacitor pulse i_c (FIG. 10e) of increased width and reduced amplitude (i.e., the pulse width which would be obtained by the use of core T_s alone would be in the order of one-fourth to one-third the width achieved with the novel unitary core structure). With the increase in the pulse width, lower peak resonant discharge currents occur and the capacitor root-mean-square current value is minimized to effect reduced winding conductor losses. This also results in a reduction of core losses and the possibility of instability and

generally yields a smaller size ferroresonant transformer.

In addition, the novel hybrid core arrangement of the disclosure has the temperature characteristics of square loop magnetic core materials which substantially minimizes variation of the regulating characteristics in variable ambient temperature environments.

With reference to FIG. 4, a further embodiment of a unitary core structure which may be used for the $T_s L_s$ saturable core in the described ferroresonant regulator circuit is set forth thereat. As there shown, a plurality of E-shaped laminations are interleaved with I laminations in known manner to provide a first laminated core section T_s of a rectangular configuration which has a first and a second window 31, 33. The E, I laminations may be made from nickel-iron alloy material having a permeability region prior to saturation in the order of 140 - 200,000 and a thickness in the order of 4 mils, for operation at 1 KHz, for example, it being apparent that for higher frequencies a thinner material may be used. The unitary core structure 29 further includes a second rectangular-shaped core section L_s made of a sintered ferrite having an effective permeability in the order of 26 and which dimensionally conforms to the first section T_s . The second section L_s is fastened by suitable means to the first section T_s with the window and outer edges of section L_s in aligned relation with the corresponding edges of the section T_s . The core windings 18 and 24 are wound through the windows 31, 33 and around the center leg 35 which is located therebetween (FIG. 4—only winding 24 being shown for purposes of clarity). The unitary core structure 29 as connected in a ferroresonant regulator circuit, such as shown in FIG. 1, will operate in the manner of the unitary core structure shown in FIG. 2. Moreover, adjustment of the permeability of the structure 29 may be effected by grinding an air gap laterally between the two windows 31, 33 of the L_s core to thereby permit corresponding adjustment of the effective permeability of core L_s and thereby the width of the pulse output therefrom to correspondingly different values in an economical manner.

In a further embodiment the section L_s may comprise E and I laminations of nickel-iron alloy stacked in a butt jointed configuration with suitable insulation placed between the adjacent portions of the E and I laminations to provide the desired effective permeability.

Whereas the embodiments of FIGS. 1 and 2 illustrate arrangements in which the $T_s L_s$ cores are mounted in contacting location, in certain applications it may be desirable to separate the T_s and L_s cores and their associated windings. With reference to FIG. 5, there is shown thereat a circuit arrangement in which a T_s core (which may be similar to the T_s core of FIG. 2), is wound with an input winding 34 and an output winding 36. The second core L_s , which may be a toroid core similar to the L_s core of FIG. 2 (or a pot core), is wound with a separate input winding 38 and an output winding 40. The input windings 34, 38 of the T_s and L_s cores are connected in series with one another (with the polarity indicated by the dots adjacent thereto) and further are serially connected with the ballast inductor 16 to the output circuit of inverter 12. Resonant capacitor 22 is serially connected across windings 34, 38.

In like manner, the output winding 36 of the core T_s and the output winding 40 of core L_s are connected in

series with the indicated polarities and over bridge rectifiers 26, 26A, 28, 28A, to the load circuit 32. The filter capacitor 30 is connected across the load circuit 32.

FIG. 6 illustrates an arrangement wherein separate core windings 16A and 24A on the input ballast inductor and $T_s L_s$ core 20 are serially connected to provide an isolated AC voltage proportional to and with the wave shape shown in FIG. 10a. The load winding 24 is wound on saturable reactor core 20 as shown in FIG. 1 and is connected to the load 32 in like manner. The circuit of FIG. 5 can be similarly modified.

With reference to FIG. 7, there is shown thereat a further circuit arrangement in which a separate winding 42 is wound on the $T_s L_s$ unitary core structure 20 of the type shown in FIG. 1 and capacitor 22 is connected across the separate winding 42 for the purpose of isolating the capacitor 22 from the series circuit which includes the input winding 18 of the hybrid core $T_s L_s$.

It will be apparent from the foregoing examples that most circuit modifications and connections which are possible with known low frequency power ferroresonant transformer circuits may also be used with the novel high frequency ferroresonant transformer circuits disclosed herein.

FIG. 8 illustrates in block diagram a further regulating arrangement in which the high frequency ferroresonant transformer may be used. Specific selection of the various regulating circuits possible will, of course, depend on the application and input-output requirements. In the arrangement shown in FIG. 8, a DC source 10 is connected in the manner of FIG. 1 to the input of a DC to AC inverter 12 which in turn provides a pulse output at a high frequency rate (in the order of 10-20 KHz) to the high frequency ferroresonant transformer 14. The output of the transformer 14 is fed over the output rectifier filter 25 to a load (not shown). In addition, a feedback sensing circuit 48 is connected to the output of rectifier filter circuit 25 and a sensed voltage is fed by a circuit 48 to a comparator circuit 50 which compares such voltage output with a reference voltage input over path 52. A control signal representing the difference in values of the compared signals is fed back to adjust the output frequency of the inverter 12 in a direction to eliminate the difference in voltage output by means of the high frequency resonant transformer 14. Thus any variation of the voltage from the predetermined regulating value will result in an adjustment of the frequency input to high frequency ferroresonant transformer 14 to thereby adjust the voltage output of the transformer 14 in the direction of the desired voltage.

It is also apparent that the output of the circuit of FIG. 1 may be connected over a conventional series regulator for use in providing a highly regulated DC output in known manner.

The novel circuit can also be used for AC regulation by omitting the rectifier stage.

I claim:

1. In a ferroresonant regulator circuit for high frequency application, input means over which input signals of a given operating range of voltages and frequencies are received, inductance means, saturable core means including a first magnetic core of a square-loop material having a first permeability region prior to saturation and a second substantially lower permeability region during saturation, and a second magnetic core

having a permeability which is less than the value of the first permeability region of said first core and greater than the value of said second permeability region of said first core, whereby with saturation of the first core responsive to said input signals in said given operating range said second core will absorb the further mmf, input and output winding means wound on said saturable core means, the core areas, the number of turns of said winding means, and the material of said first and second magnetic cores being of a value to effect saturation of the first magnetic core and to prevent saturation of the second core as a result of the flux generated in response to said input signals, means connecting said input winding means in series with said inductance means to said input means, resonant capacitor means, means coupling said resonant capacitor means to said input winding means, and means coupling said output winding means to an associated load.

2. A ferroresonant regulator circuit as set forth in claim 1 in which the permeability of said first magnetic core is of a value to absorb substantially all of the flux until saturation, and the permeability of said second magnetic core is of a value to absorb substantially all of the further flux generated after said first magnetic core has saturated.

3. A ferroresonant regulator circuit as set forth in claim 1 in which said first magnetic core comprises a tape-wound core of a nickel-iron alloy.

4. A ferroresonant regulator circuit as set forth in claim 1 in which said second magnetic core comprises a sintered powdered core of soft ferrite material.

5. A ferroresonant regulator circuit set forth in claim 1 in which said first and second magnetic cores are toroid cores secured to one another with the center aperture thereof in aligned relation to provide a unitary core structure and in which said input and output windings are wound on said unitary core structure.

6. A ferroresonant regulator circuit as set forth in claim 1 in which said means for coupling said resonant capacitor to said input winding means comprises a further winding wound on said saturable core means.

7. A ferroresonant regulator circuit as set forth in claim 1 in which said first magnetic core comprises a laminated section of a square loop material and said second magnetic core comprises a pressed granular section of a ferrite material.

8. A ferroresonant regulator circuit as set forth in claim 7 in which said first and second magnetic cores have an upper leg, a lower leg, two outer legs and a center leg, and in which said input and output windings are wound on said center leg.

9. A ferroresonant regulator circuit as set forth in claim 1 in which said output winding comprises a center-tapped winding, and said means for coupling said output winding means to an associated load includes rectifier means for connecting the ends of said output winding to one side of said load, and means for connecting said center tap to the other side of said load.

10. In a high frequency ferroresonant regulator circuit for high frequency application, input means over which input signals of a given operating range of voltages and frequencies are received, inductance means, saturable core means including a magnetic core of a square-loop material having a first permeability region prior to saturation and a second lower permeability during saturation, a first and a second winding wound on said first core and a second magnetic core having a

relatively uniform permeability which is less than the value of the first permeability region of said first core and greater than the value of said second permeability region of said first core, whereby with saturation of the first core responsive to the input signals in said given operating range said second core will absorb the further mmf, a third and fourth winding wound on said second core, means connecting said first and third windings on said first and second cores to said input means in series with said inductance means, the areas, the number of turns of said winding means, and the material of said first and second magnetic cores being of a value to effect saturation of the first magnetic core and to prevent saturation of the second core as a result of the flux generated in response to said input signals, resonant capacitor means, means coupling said resonant capacitor means to said first and third windings, and means coupling said second and fourth windings to an associated load.

11. A regulator circuit as set forth in claim 10 in which said means coupling said second and fourth windings to an associated load comprises a rectifier full wave bridge circuit.

12. In a high frequency ferroresonant regulator circuit, input means over which input signals of a given operating range of voltages and frequencies are received, inductance means having a first and second winding, saturable core means including a first magnetic core of a square-loop material having a first permeability region prior to saturation and a second magnetic core having a relatively uniform permeability which is less than the value of the first permeability region of said first core and greater than the value of said second permeability region of said first core, whereby with saturation of the first core responsive to the input signals in said given operating range said second core will absorb the further mmf, an input winding wound on said saturable core means, first and second output means wound on said saturable core means, the areas, the number of turns of said winding means, and the material of said first and second magnetic cores being of a value to effect saturation of the first magnetic core and to prevent saturation of the second core as a result of the flux generated in response to said input signals, means connecting the first winding of said inductance means and said input winding of said saturable core means to said input means, resonant capacitor means, means coupling said resonant capacitor to said input winding means on said saturable core means, and means coupling said first output winding means on said saturable core means to an associated load, and means connecting the second winding of said inductance means and the second output means of said saturable core means to provide an isolated output voltage proportional to the input voltage.

13. A unitary saturable core for a ferroresonant transformer circuit comprising a first magnetic core section of a square-loop high currie temperature magnetic material having a first permeability region prior to saturation and a second substantially lower permeability region during saturation, and a second section of a magnetic material secured to said first section having a permeability which is of a substantially lower value than the values of the first permeability region of said first core and greater than the values of the second permeability region of said first core.

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14. A saturable core as set forth in claim 13 in which said first magnetic core section comprises a toroid-shaped, tape-wound core of nickel-iron alloy.

15. A saturable core as set forth in claim 13 in which said second magnetic core section comprises a toroid-shaped powdered core of a soft ferrite material.

16. A saturable core as set forth in claim 13 in which said first and second magnetic core sections are toroidal in form, and which includes input and output windings wound thereon.

17. A saturable core as set forth in claim 13 in which said first magnetic core section comprises a plurality of laminations of square loop material, and said second magnetic core section comprises a section of pressed granular material in contacting relation therewith.

18. A saturable core as set forth in claim 17 in which

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said first and second magnetic core sections have an upper and lower leg, two outer legs and a center leg, and which have input and output windings wound on said center leg.

19. A saturable core as set forth in claim 18 in which said first and said second magnetic core sections comprise a plurality of E, I laminations of square loop material joined to provide a rectangular shaped unitary structure with a center leg and two windows, and in which the E, I laminations of the second magnetic core section are assembled with predetermined air gaps between the adjacent portions of the E, I laminations, the distance of the air gap being adjusted to provide the desired permeability of the second core.

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