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[54] **TRANSIENT VOLTAGE SUPPRESSOR**
11 Claims, 10 Drawing Figs.

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H03k 17/64

[50] Field of Search **328/67;**
307/268, 246, 318, 254

[56]

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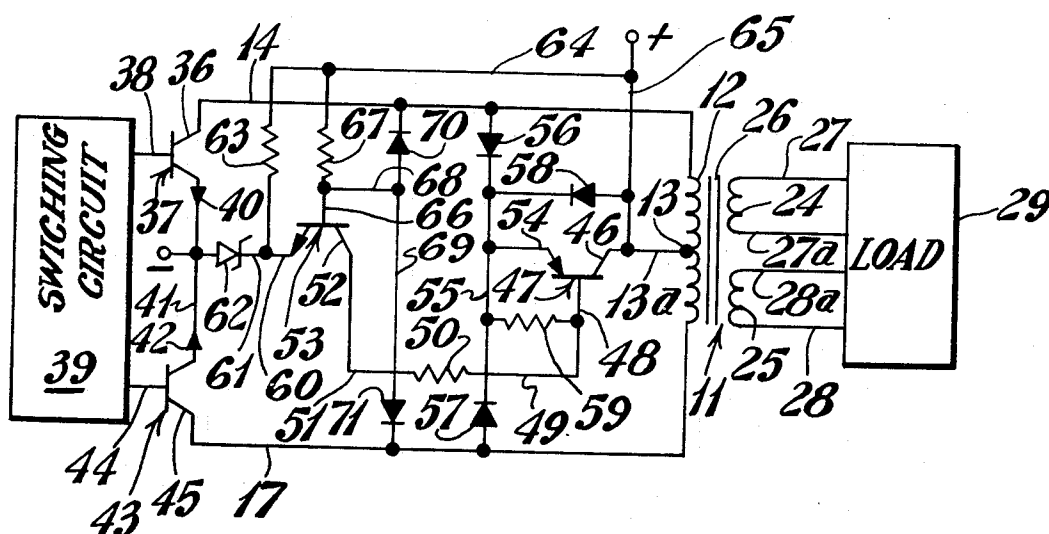
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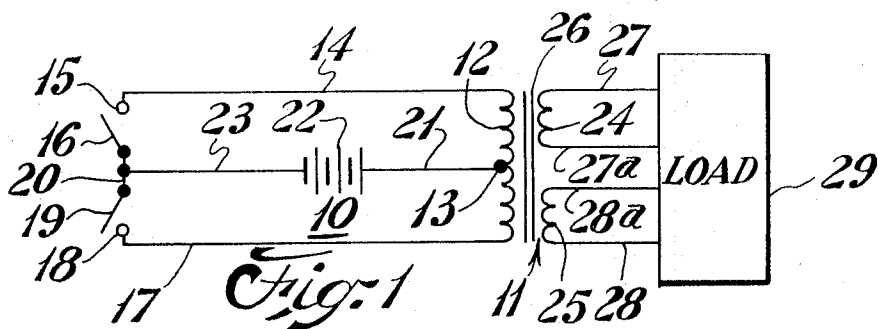
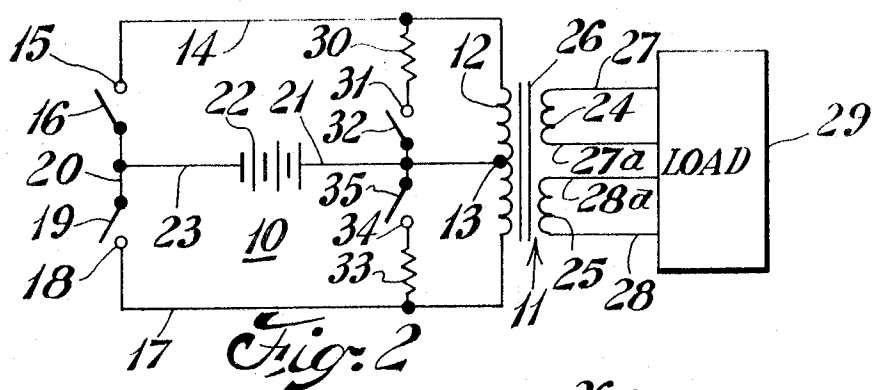
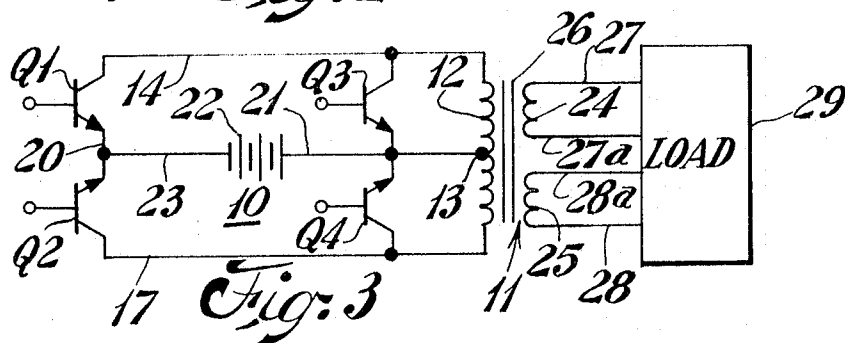
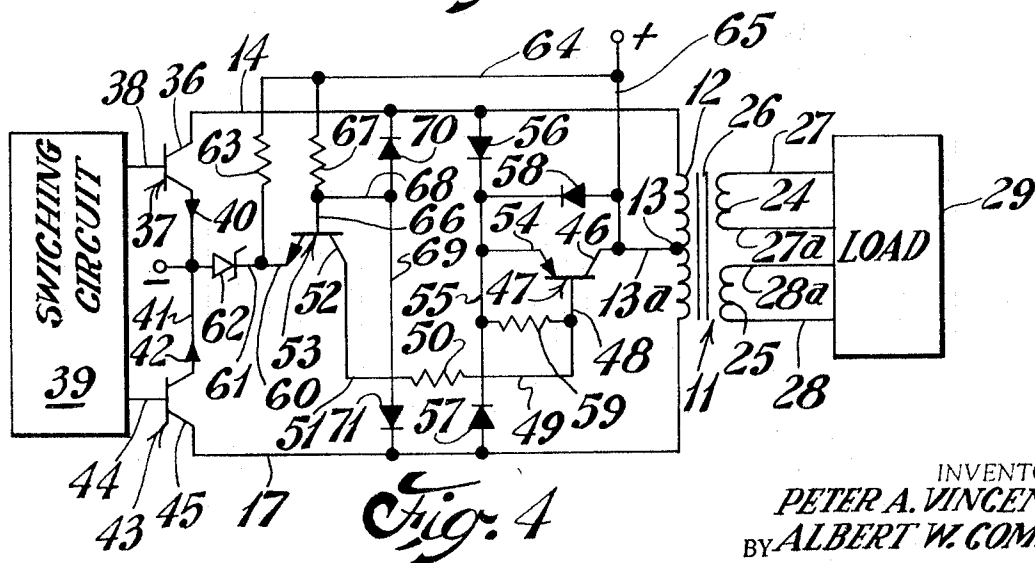
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ABSTRACT: A circuit for eliminating the effects of undesirable transient voltages generated by the removal of a primary source voltage from, or interruption of current flow through the windings of an inductive element.





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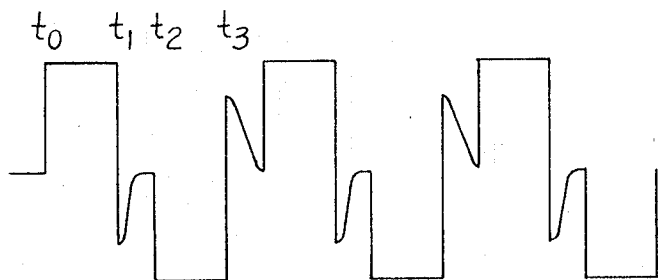


Fig. 5a

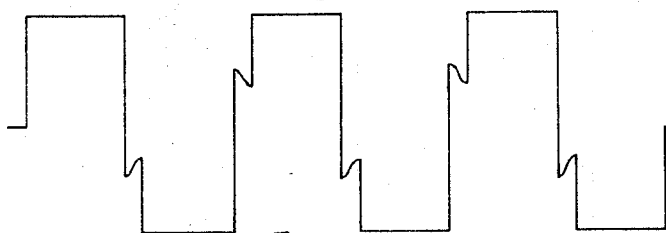


Fig. 5b

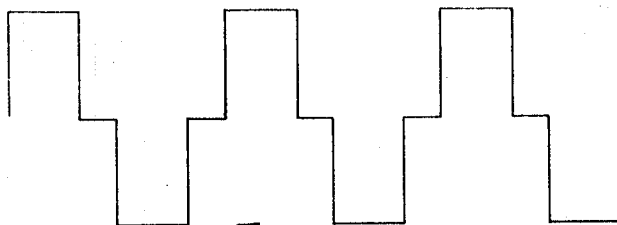


Fig. 6a

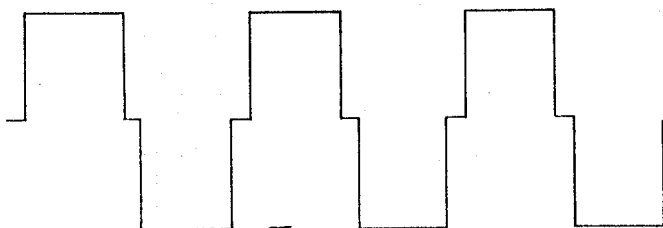


Fig. 6b

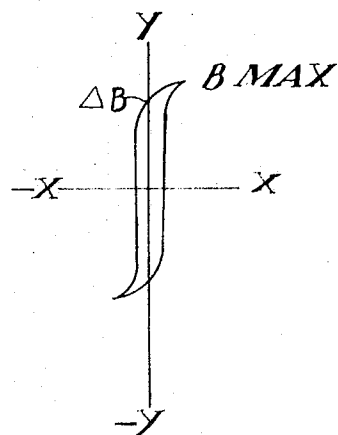


Fig. 7a

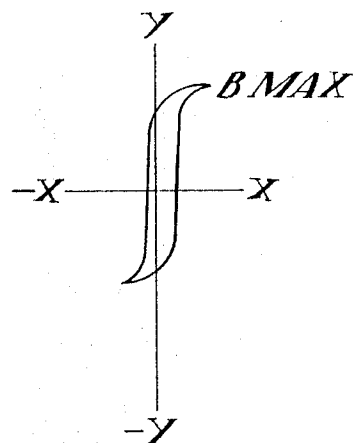


Fig. 7b

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TRANSIENT VOLTAGE SUPPRESSOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to the field of pulse-forming circuits and more particularly to pulse-forming circuits utilizing transformer coupling such as in static inverters.

2. Description of the Prior Art

The use of transformer coupling is desirable whenever electrical isolation or impedance matching may contribute to the performance of the circuit. Transformers, however, possess properties of inductance and respond to interruptions of current flow through their windings in accordance with Lenz's Law, $\mathcal{E} = L di/dt$, the essential properties of which, cause current to tend to continually flow unidirectionally through the windings.

Thus, the instantaneous interruption of current in an inductive element induces an electromotive force within the inductive element and is of such polarity as to oppose a change of current flow in the external circuit. The inductive element may now be considered as a voltage source. A prime problem that develops in such arrangements is that the voltage source, effectively, is looking into a high-impedance circuit with the resulting effect of an extremely high transient voltage being developed at the terminals of the inductive element.

The resulting transitory voltage may have deleterious effects on the reliability performance of the circuit in several ways:

1. Standoff voltage levels of circuit components may be exceeded, thereby causing punch-through or breakdown in the dielectric properties of the components.

2. Insulation between the wires and/or windings of the inductive element may deteriorate or breakdown.

3. False signals may couple to adjacent wires and/or circuits.

4. Spurious electromagnetic signals may radiate causing electromagnetic interference in susceptible equipment.

A second means by which an inductive element may generate a transient voltage is through the properties of Faraday's Law, $\mathcal{E} = d\Phi/dt$. When a step voltage is impressed in the primary winding of a transformer, the flux generated in the core increases linearly with the time duration of the step function. Upon removal of the step function voltage, the flux will decay to the remanence or residual flux level. This decay of flux generates a transitory voltage, $d\Phi/dt = \mathcal{E}$, in the windings of the transformer. This transient voltage may have the same deleterious effects on the reliability of the circuit as those heretofore described.

The present invention provides a means of eliminating the deleterious effects of the undesirable transient voltages generated by the removal of a primary source voltage from, or the interruption of a current flow through the windings of an inductive element, or interruption of current flow in the windings such as may be affected by a step function pulse of controllable duration.

SUMMARY OF THE INVENTION

The present invention provides a circuit in which a low-impedance path is provided across the primary winding of a transformer for clipping the transient voltages generated at the instant of switch off of voltage or interruption of current flow to the transformer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified schematic diagram illustrating the prior art.

FIG. 2 is a simplified schematic diagram illustrating the invention.

FIG. 3 is a similar to the circuit of FIG. 2 with transistors as the switching means.

FIG. 4 is a schematic diagram of a typical circuit embodying the invention.

FIGS. 5a, 5b are curves representing the prior art.

FIGS. 6a and 6b are curves representing the present invention.

FIGS. 7a and 7b are curves showing the inductive effect of iron cores.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1 of the drawing, a push-pull circuit is indicated generally by the numeral 10 and includes a transformer 11. The transformer 11 has a primary winding 12 having a center tap 13. One side of the winding 12 is connected by a conductor 14 to a stationary contact 15 of a switch member 16. The other side of the winding 12 is connected by conductor 17 to a stationary contact 18 of a switch member 19. The switch members 16 and 19 are connected together by conductor 20. The center tap 13 of the winding 12 is connected by conductor 21 to one side of a suitable source of current, indicated as a battery 22. The other side of the battery 22 is connected by conductor 23 to the conductor 20.

In addition to the primary winding 12, the transformer 11 has secondary windings 24 and 25 and an iron core 26. The windings 24 and 25 are connected by conductors 27, 27a, 28 and 28a respectively to a suitable load 29.

In the operation, when switch 16 is closed, the circuit in one-half of the push-pull arrangement is completed and primary source voltage is impressed across one-half of the primary winding 12 of the transformer 11. Magnetizing current then flows through the primary winding 12 of the transformer 11 generating an m.m.f. which drives the flux in the core. If after a time switch 16 is opened, with switch 19 remaining open, the primary source voltage will be instantaneously removed from the primary winding 12 and the magnetizing current will be abruptly interrupted causing a transient voltage to be developed at the terminals of the windings of the transformer 11. The second half of the cycle operates in the same manner with switch 19 closed and switch 16 open. The voltages as described are illustrated in FIG. 5a for narrow pulses and FIG. 5b for wide pulses. The cycle is repetitive as shown in FIGS. 5a and 5b. The switches 16 and 19 represent any switching components, mechanical, solid-state or other.

Referring now to FIG. 2 which is a modification of FIG. 1 and only the changes will be described in detail. A resistor 30 has one side connected to the conductor 14 and the other side connected to stationary contact 31 of a switch 32 which is connected to the conductor 21. A resistor 33 has one side connected to stationary contact 34 of a switch 35 which is connected to the conductor 17.

In the operation, the switches 32 and 35 are normally open. However, if either or both switches 32 and 35 are caused to close with the simultaneous opening of either switch 16 or 19, a complete path for current flow is provided through the switch 32, resistor 30 and the primary windings 12 of the transformer 11. The energy released in the circuit by the generation of a transient voltage when either switch 16 or 19 are opened will be directed to and dissipated in either or both resistors 30 and 33. This results in the clipping of the undesirable voltages present in FIGS. 5a and 5b. It is understood that the resistors 30 and 33 are of a relatively low ohmic value. The results of the clipping action is a relatively clean voltage pulse of controlled duration as shown in FIG. 6a for a narrow pulse and in FIG. 6b for a wide pulse.

FIG. 3 depicts the circuit arrangement of FIG. 2 but with the switches 16, 19, 32, and 35 replaced by transistors Q1, Q2, Q3 and Q4 respectively. Also the internal resistance of transistors Q3 and Q4 may be substituted for the resistors 30 and 33. The operation is similar to that of FIG. 2. Either or both Q3 and Q4 are caused to conduct simultaneous with the switching of either transistor Q1 or Q2 to a nonconducting state.

Referring now to FIG. 4 in which a typical circuit embodying the invention is illustrated. A transformer 11 has a primary winding 12 which has a center tap 13. One end of the winding 12 is connected by conductor 14 to collector 36 of transistor

37. The transistor 37 has a base 38 connected to one output of a switching circuit 39 and an emitter 40 connected by conductor 41 to emitter 42 of a transistor 43. The transistor 43 has a base 44 connected to another output of the switching circuit 39 and a collector 45 connected by conductor 17 to the other side of the winding 12.

The center tap 13 of the winding 11 is connected by conductor 13a to collector 46 of a transistor 47. The transistor 47 has a base 48 connected by conductor 49, resistor 50 and conductor 51 to collector 52 of a transistor 53. The transistor 47 also has an emitter 54 connected to a conductor 55 which is connected through diodes 56 and 57 between conductors 14 and 17. A diode 58 is connected between the emitter 54 and collector 46. The base 48 of the transistor 47 is also connected by resistor 59 to the conductor 55.

The transistor 53 has an emitter 60 connected by conductor 61 and Zener diode 62 to the conductor 41 which is also connected to the negative output of a suitable power source (not shown). The emitter 60 is also connected by resistor 63 and conductor 64 to the positive terminal of the power source which is also connected by conductor 65 to the tap 13 of the winding 11. The transistor 53 has a base 66 connected by conductor 68 to conductor 69 which is connected through diodes 70 and 71 between the conductors 14 and 17.

In addition to the primary winding 12, the transformer 11 has an iron core 26 and secondary windings 24 and 25. The winding 24 is connected by conductors 27 and 27a to a suitable load 29. In like manner, the winding 25 is connected by conductors 28 and 28a to the load 29.

The transistors 37 and 43 are overdriven amplifiers operating in the switching mode so that alternately they are either "full-on" driven into saturation, or "full-off," passing only their leakage current. The switching circuit may be any switching control that provides a means of alternately driving the transistors 37 and 43 "on" and "off," and provides means for controlling the conduction angles or, the durations of the "on" and "off" periods of the transistors. An example would be the forward stages of a static inverter.

When the transistor 37 is "on," the transistor 43 is "off" and the current path from the positive terminal of the power supply to the center tap 13 of the winding 12 of the transformer 11, through the winding 12 to the collector 36 of the transistor 37, and through the transistor 37 to the negative terminal of the power supply. This impresses the primary source voltage across one-half of the winding 12 of the transformer 11. During this time period, transistor 53 is biased to cut off by being derived of base drive current. Current flows from the positive terminal through resistor 67, blocking diode 70 and "switched-on" transistor 37 to the negative terminal. The Zener diode 62 is kept "alive" by bias current flow from the positive terminal through the resistor 63, and Zener diode 62 to the negative terminal and provides means for backwardly biasing the transistor 53 when either transistor 37 or 43 is conducting. When the transistor 53 is in cutoff, the transistor 47 is also in cutoff as the flow of base drive current is interrupted in its flow through resistor 50 and cutoff transistor 53.

When the transistor 37 is switched off and the transistor 43 has not yet been driven on, a "dwell time" exists in which the primary source voltage is not impressed on either half of the primary winding 12 of the transformer 11. During the dwell time, transient voltages are generated in the windings of the transformer 11 in accordance with Lenz's Law which tends to keep the current flowing unidirectionally in accordance with Faraday's Law for changing magnetic fields. During the dwell time, the transistor 53 is driven on by biasing current flowing from the positive terminal, through the resistor 67, base-emitter junction of the transistor 53 and through the Zener diode 62 to the negative terminal. The transistor 47 also is driven on during the dwell time by bias current flowing from the positive terminal, diode 58, base-emitter junction of the transistor 47, resistor 50, transistor 53, and through Zener diode 62 to the negative terminal. With transistor 47 "on" a low-impedance path is provided through diode 56 across one-

half of primary winding 12 enabling the energy in transformer 11 to be dissipated without generating high-transient voltages. Diode 57 provides the low-impedance path with transistor 47 for the dwell time after transistor 43 has stopped conducting. Thus, during the dwell time and in response to transistor 37 or 43 being switched to the off-state a relatively low-impedance path is presented across the primary winding 12 of the transformer 11. This provides means for clipping the transient voltages generated at the instant of switch off of the transistors 37 and 43.

When transistor 47 is "off," the resistor 59 provides a low-impedance path which is in shunt with the base-emitter junction of the transistor 47, providing means for circuit leakage currents to flow without biasing on the transistor 47.

In like manner, when the transistor 43 is switched on, the second half of the cycle occurs. The transistors 53 and 47 are off until the transistor 43 is switched off, at which time they are once again switched on to present a low-impedance path to the primary winding 12 of the transformer 11.

The use of iron alloy cores in inductive elements introduces further complications which results in the generation of undesirable transient voltages. Iron alloy cores, such as silicon steel, nickel-iron alloys and more important those cores producing square hysteresis loop characteristics are highly sensitive to the magnetization effects produced by an m.m.f. The nature of the iron core element is to exhibit a balanced flux hysteresis loop which is symmetrically displayed around the intercepts of the X-, Y-axes for each full cycle of excitation when the driving magnetomotive force is symmetrically applied over each full cycle to the core, see FIG. 7A. During these conditions ΔB , the difference between maximum flux density and residual flux density, may be very small and the resulting transient voltage produced when the excitation force is removed, and the flux density changes from B_{max} to its residual level, may also be small. However, under actual operating condition, because of slight variations in commercially available circuit elements, such as transistors, diodes, resistors, etc., and in core materials themselves, the driving magnetomotive force may not be symmetrical about the Y-axis which results in the generation of an asymmetrical flux hysteresis loop, see FIG. 7B. The results of this asymmetry is equivalent to the presence of a direct current component in the m.m.f., and causes the core to tend to saturate on one-half of the cycle as illustrated in FIG. 7B. This asymmetry, therefore, has the effect of increasing ΔB and thereby generating relatively large undesirable transient voltages. The low-impedance path as heretofore described provides means for the direct current component to circulate, thereby resetting the flux hysteresis loop symmetrically about the X-, Y-axes and reducing the energy level of the transient voltages normally produced.

Although only a few embodiments of the invention have been illustrated and described, various changes in the form and relative arrangement of the parts, which will now appear to those skilled in the art, may be made without departing from the scope of the invention.

What we claim is:

1. Circuit means for suppressing transient voltages comprising in combination, switching means, a transformer having primary and secondary windings, circuit means connecting said switching means to a power source and to said primary winding of said transformer for energizing said transformer when said switching means is in the on-state, and means responsive to said switching means being switched to the off-state to provide a low-impedance path across said primary winding for clipping transient voltages generated at switch off of current flow to said transformer.

2. The combination as set forth in claim 1 in which said switching means form a push-pull circuit.

3. The combination as set forth in claim 1 in which said switching means are transistors.

4. The combination as set forth in claim 1 in which said transformer has an iron core.

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5. The combination as set forth in claim 1 in which said means for providing a low-impedance path across said primary winding includes a transistor biased in a nonconducting state when current is flowing to said transformer and biased in a conducting state upon the interruption of current flow to said transformer.

6. The combination as set forth in claim 5 having a second transistor biased to a nonconducting state by a Zener diode and arranged to bias the first-mentioned transistor in a nonconducting state when current is flowing to said transformer.

7. The combination as set forth in claim 1 in which said last-mentioned means includes a transistor and a diode to provide a low-impedance path.

8. The combination as set forth in claim 7 and including means for preventing leakage current from biasing said last-named transistor to a conducting state.

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9. The combination as described in claim 1 in which the switching means includes a pair of transistors connected in a push-pull circuit across two halves of the primary winding of the transformer to alternately energize the two halves of the primary winding.

10. The combination as described in claim 9 in which the means to provide a low-impedance path across the primary winding includes a pair of diodes connected in series with the primary winding and a transistor connected to a junction between the diodes and to a center tap of the primary winding to provide a low-impedance path across each half of the primary winding of the transformer.

11. The combination as described in claim 10 including means for rendering the last-mentioned transistor conducting when the switching means is nonconducting.

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