United States Patent

[11] 3,617,854

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[21] Appl. No. **029,813**
[22] Filed **Apr. 20, 1970**
[45] Patented **Nov. 2, 1971**

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[54] **PULSE TRANSFORMER**
3 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **321/15,** 336/229
[51] **Int. Cl.** **H02m 7/00**
[50] **Field of Search** 321/15; 323/49, 50, 85–88; 336/229

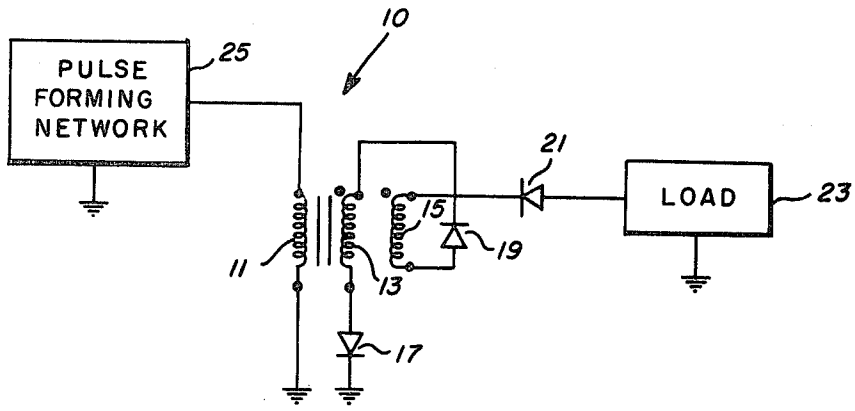
[56] **References Cited**

UNITED STATES PATENTS

3,149,296 9/1964 Cox ..... 336/229 X
3,381,204 4/1968 Cox 321/15

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ABSTRACT: An electromagnetic transformer of special design which, when operated with associated circuitry, exhibits, during at least one portion of each cycle of operation, a lower interwinding capacitance than known transformers of comparable design. The secondary winding, or windings, of the disclosed transformer consist of a plurality of single layer segments, successive ones of such segments being joined through a diode in such a manner that, when a signal of a given polarity is applied to the primary winding of the transformer, the diodes conduct to connect the segments in series and when a signal of opposite polarity is applied to the primary winding of the transformer the diodes are cut off to disconnect the segments one from the other. In the latter condition the interwinding capacitance of the transformer is a minimum.



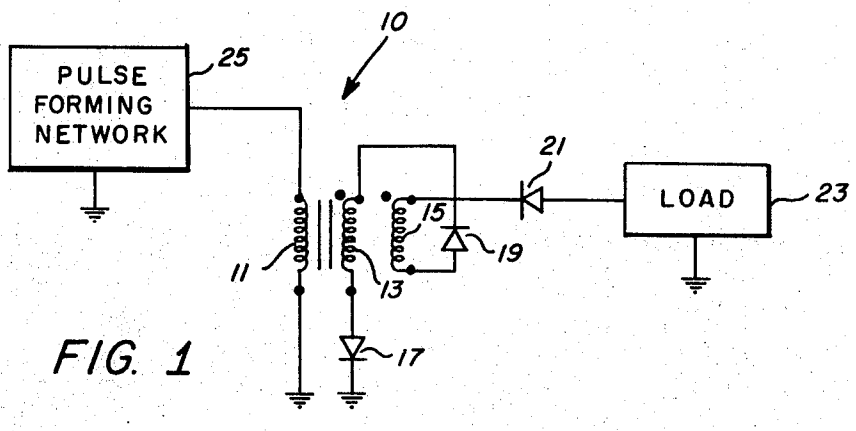


FIG. 1

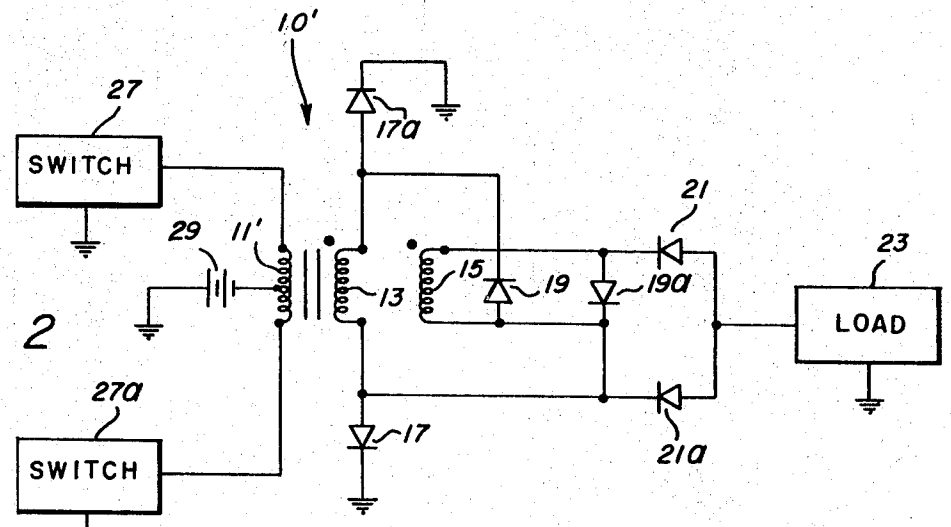


FIG. 2

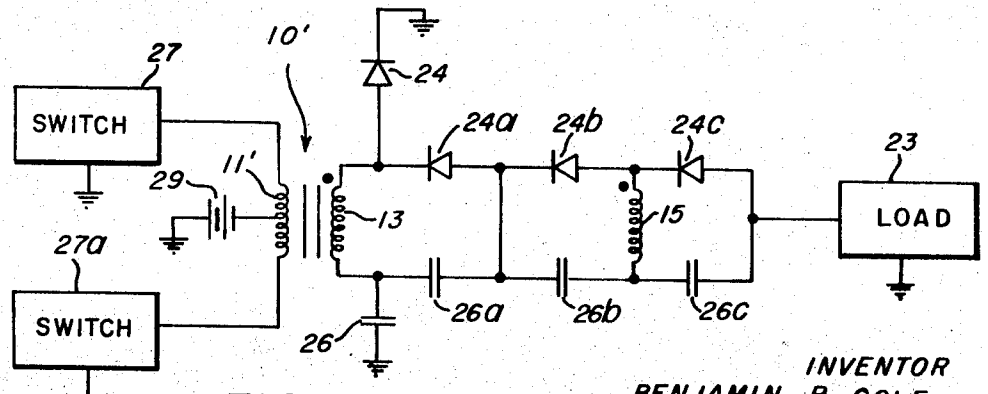


FIG. 3

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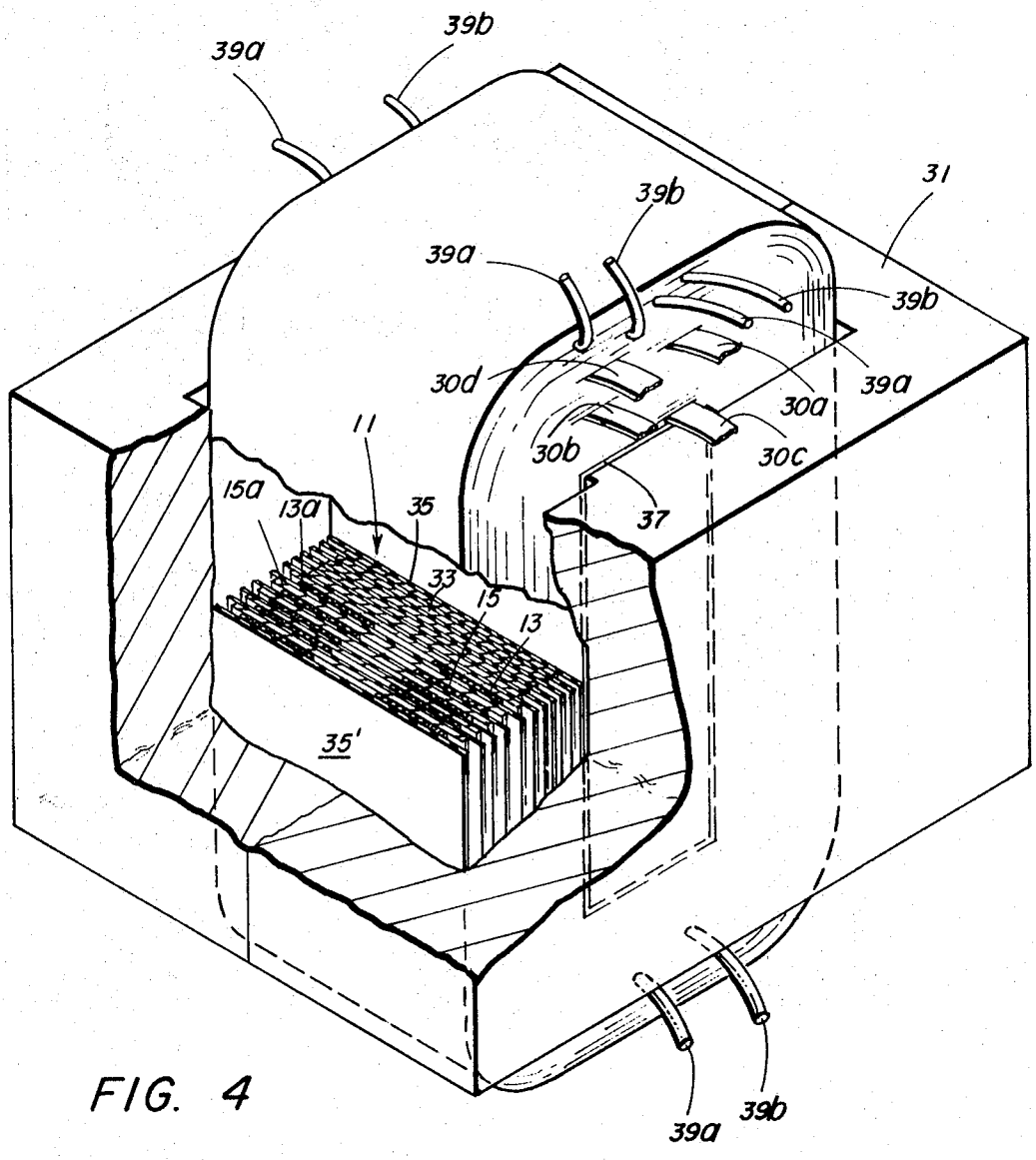


FIG. 4

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PULSE TRANSFORMER

The invention described was made in the course of or under a contract or subcontract thereunder, with the Department of Defense.

BACKGROUND OF THE INVENTION

It is known in the art that the effects of capacitance should be minimized in any properly designed electromagnetic transformer. It is particularly important that care be taken to minimize the effects of capacitance in a pulse transformer which is intended for use when the turns ratio is high (say, over 10:1) and when the pulse repetition frequency, or PRF, exceeds, say 30 kHz. It is, however, unfortunately true that the interwinding capacitance in the secondary winding, or windings, of known pulse transformers with high turns ratios cannot be reduced to permit operation of such devices at a PRF which significantly exceeds 30 kHz.

Therefore, it is an object of this invention to provide an improved pulse transformer in which the effect of interwinding capacitance is minimized during a portion of a cycle of operation.

Another object of this invention is to provide an improved pulse transformer which may be operated with a relatively high pulse repetition frequency.

SUMMARY OF THE INVENTION

These and other objects of the invention are generally provided by a pulse transformer in which the primary winding is formed around a ferromagnetic core and the secondary winding, which consists of a number of single layer segments serially joined by appropriately poled diodes, is wound over, or adjacent to, the primary winding.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this invention reference is now made to the drawings in which FIG. 1 is a schematic diagram of a transformer and associated circuitry according to this invention;

FIG. 2 is a schematic diagram of a second embodiment of a transformer according to this invention together with associated circuitry;

FIG. 3 is a schematic diagram of a third embodiment of a transformer according to this invention along with associated circuitry; and

FIG. 4 is an isometric view, partially cut away to show the disposition of the various windings, of a pulse transformer according to this invention.

Referring now to FIG. 1, it may be seen that a transformer **10** according to the invention includes a primary winding **11** and a secondary winding (not numbered) made up of at least two segments **13, 15**. The primary winding **11** and the segments **13, 15** are supported on a core (not numbered) in a manner to be illustrated in detail hereinafter in connection with FIG. 3, it being sufficient here to note that the segments **13, 15** are superimposed on the primary winding **11**. The polarity of each one of the segments **13, 15** is indicated by conventional polarity markings (not numbered) adjacent each one of such segments.

One end of the segment **13** is connected, as shown, through a diode **17** to ground. The second end of the segment **13** is connected to one end of the segment **15** through a diode **19**. The second end of the segment **15** is connected through a diode **21** to a load **23**. The polarity of the diodes **17, 19, 21**, as illustrated, permits a negative voltage pulse to be impressed on the load **23**. If it is desired that a positive voltage pulse be applied to the load **23**, then the polarity of each one of the diodes **17, 19, 21** would be reversed.

A pulse-forming network **25** is connected in circuit with the primary winding **11** as shown. The pulse-forming network **25** may be any conventional pulse generator, as the well-known "hard-tube pulser" or "line-type pulser." The particular type of pulser used is not essential to this invention but rather is dependent upon the parameters required for any desired operation.

The transformer and just described circuitry of FIG. 1 operate in the following manner. When a negative going pulse is produced by the pulse forming network **25** and applied to the primary winding **11** of the transformer **10**, diodes **17, 19, 21** are biased so that each one of them is in its conductive state. In other words, segments **13, 15** are connected in series for the duration of the voltage pulse out of the pulse forming network **25** and the load **23** is connected to the second end of the segment **15**. When the polarity of the voltage pulse out of the pulse-forming network **25** is reversed, as at the end of a voltage pulse to be transformed, the bias on the diodes **17, 19, 21** is reversed, thus driving them to their nonconductive state. When this occurs, the segments **13, 15** are, in effect, disconnected one from the other and from ground and the load **23**. The effective capacitance between segments **13,15** then becomes very low, such capacitance being due primarily to stray diode and connecting lead capacitances. It follows, then, that the secondary capacitance, being the capacitance between the segment **13** and the primary winding **11**, is low, thereby permitting the pulse forming network **25** to "reset" the magnetization state of the core of the transformer **10** with less drive current required than otherwise. Actually, the disclosed embodiment will rapidly reset itself through a self-developed backswing voltage if the drive circuit is opened.

Referring now to FIG. 2 it may be seen that the transformer **10'** differs from the transformer **10** in that the former has a center tap primary winding **11'**. The segments **13, 15** in FIG. 2 are identical with segments **13, 15** in FIG. 1. Diodes **17, 19, 21** of FIG. 2 correspond with a diode **17, 19, 21** of FIG. 1. Diode **17*a***, **19*a***, **21*a***, each located and poled as shown, complete the circuitry in the secondary of the transformer **10'**. A switch **27** and a switch **27*a***, together with a source of voltage **29**, are connected to the primary winding **11'** as shown, complete the circuitry in the secondary of the transformer **10'**. A switch **27** and a switch **27*a***, together with a source of voltage **29**, are connected to the primary winding **11'** as shown. The operation of the circuit shown in FIG. 2 will now be described. Thus, switch **27** and switch **27*a*** operate during mutually exclusive time periods. When switch **27** is actuated, diodes **17, 19, 21** are biased into their conductive state to connect segments **13, 15** in series and apply a voltage to the load **23**. During this period of time diodes **17*a***, **19*a***, **21*a*** are nonconductive. When the switch **27** is opened at the conclusion of a voltage pulse diodes **17, 19, 21** open. The result is that the circuit of FIG. 2 is then in the same condition as the circuit of FIG. 1 at the end of the voltage pulse out of the pulse forming network **25**. When switch **27*a*** is actuated diodes **17, 19, 21** remain biased in their open condition. Diodes **17*a***, **19*a***, **21*a*** are, however, biased so as to connect segments **13, 15** in series and to apply a voltage pulse to the load **23**. It will be noted, however, that the polarity of the voltage applied to the load **23** is the same whether or not such voltage is applied through diode **21** or diode **21*a***.

It should be noted that, regardless of which one of the switches **27, 27*a*** is actuated, the capacitance of the segments **13, 15** reflected back into the primary is the same and is a minimum. This contrasts with any known multilayer transformer used to drive a full-wave bridge rectifier where the reflected capacitance changes, depending on the polarity of the signals to be rectified.

Referring now to FIG. 3 it may be seen that the concept of using a single layer secondary with diode coupling to reduce the effect of capacitance may be used to produce a voltage multiplier. In FIG. 3, the primary winding **11'** of transformer **10'** and the circuitry associated with such primary winding are the same as shown in FIG. 2 and the segments **13, 15** and load **23** are also the same. The segments **13, 15** are connected as shown to each other, the load **23** and ground. That is, diode **24** is connected between one end of the segment **13** and ground and a capacitor **26** is connected between the second end of the segment **13** and ground. Diodes **24*a***, **24*b***, **24*c*** and capacitors **26*a***, **26*b*** and **26*c*** are connected as shown to complete the required circuit between the transformer **10'** and the load **23**. Capacitors **26, 26*a*, 26*b*, 26*c*** preferably have identical ratings.

The operation of the just-described circuit is as follows, assuming that switch 27 and switch 27*a* are actuated during mutually exclusive periods of time. When switch 27*a* is closed, current flows in the lower half of the primary winding 11′ in such a direction as to induce a voltage in the segment 13 which causes diode 24 to conduct and diode 24*a* to be blocked. As a result, capacitor 26 is charged. The actual voltage across capacitor 26 is, of course, essentially dependent upon the parameters of the transformer 10′ and the rate of change of magnetic flux therein; that is, the turns ratio of the transformer 10′ and the characteristics of the signal applied to the primary winding 11′ when switch 27*a* is closed determine the voltage to which capacitor 26 is charged. It is noted here that, as was the case with the embodiments of FIG. 1 and FIG. 2, the adverse effect of intrasegment capacitance reflected back into the primary circuit of transformer 11′ is minimal and may be disregarded.

The difference between this circuit and a conventional voltage multiplier circuit is that, since the segments connected by diodes are of single layer, the capacitance reflected to the primary is due to the primary to secondary interwinding capacitance. Each additional secondary segment does not add interwinding capacitance. Hence, higher frequency operation can be obtained because of less stored energy in the winding capacitance.

The closing of switch 27*a* also causes a voltage to be induced in segment 15 which causes diode 24*b* to conduct and diode 24*c* to be blocked. As a result, capacitor 26*b* is also charged for the same reasons as put forth above for capacitor 26. When switch 27*a* is opened, the charge on capacitor 26 and capacitor 26*b* then remain essentially unchanged.

When switch 27 is closed, current flows through the upper half of the primary winding 11′, inducing a voltage in segment 13 and segment 15 to cause, respectively, diodes 24*a*, 24*c* to conduct and diodes 24, 24*b* to be blocked. Consequently, a voltage is then developed across capacitor 26*a* and capacitor 26*c*. The result is that capacitors 26, 26*a*, 26*b*, 26*c* are each then charged. The voltage across the load 23 is then, as referred to ground potential, the sum of the voltage across the capacitors 26, 26*a*, 26*b*, 26*c*.

Referring now to FIG. 4 it may be seen that an exemplary transformer consists of a tapped primary winding 11′ (here shown as having two taps 30*a*, 30*b*, along with end connectors 30*c*, 30*d*, a core 31 and a secondary winding (not numbered) which here is made up of four single wound layers (not numbered) each one of such layers consisting of two segments 13, 13*a*, 15, 15*a*.

In passing, it should be noted that one of the two taps, say tap 30*a*, may be a conventional center tap, making the transformer useful in applications such as are shown in FIG. 2 and FIG. 3. The remaining tap, here tap 30*b*, permits connection of a conventional diode clamp in the primary circuit to limit the backswing voltage to a value determined by the tap point and the supply voltage. In applications involving semiconductor pulse forming networks such a clamp is desirable to limit peak inverse voltages and to provide a return path for the magnetizing current back to the source.

The primary winding 11′ preferably is made up of 16 turns of copper foil 33 with an insulating sheet 35, as kraft paper, interleaved between turns. It is noted, however, that a conventional bifilar winding may be used. The primary winding 11′ is mounted as shown on a form 37 which fits over a leg (not numbered) of the core 31. The core 31 may be fabricated in any conventional manner from any known ferromagnetic material used for pulse transformer cores. For example, the material known as Ferramic "0–5" (a trademark of Indiana General Co., Keasbey, N.J.) may be used. This material exhibits a relatively high initial permeability and saturation flux density along with relatively low-power losses at frequencies up to 400 kHz. The segments 13, 13*a*, 15, 15*a* of the secondary windings here overlay the primary winding 11′, each segment consisting of 55 turns of insulated copper wire, with an insulating sheet 35′ of kraft paper between each successive pair of segments. An end connector 39*a*, 39*b* from each end of each segment 13, 13*a*, 15, 15*a* permits each segment to be connected with elements, as the diodes 17, 19, 21 of FIG. 1, external of the transformer 10′.

It will be observed that the two segments 13, 13*a* or 15, 15*a* in each layer may be serially connected by joining the end connectors from the inner end of the segments of each layer. If this is done the transformer shown in FIG. 4 would be comparable to the transformer shown in FIG. 2 and FIG. 3. It is preferred, however, that a diode, not shown in FIG. 4, be inserted between the end connectors of each pair of segments in each layer when the illustrated transformer is used. Naturally a diode also would be inserted, as indicated hereinabove, between the end connectors of successive layers if the advantages of this invention are to be fully attained. In passing, it will be noted that, if it is required further to reduce the effects of capacitance or to reduce the maximum voltage across any segment during operation, the number of segments in each layer could be increased as required.

It will be obvious to those skilled in the art that modifications may be made to the disclosed embodiment of this invention without departing from the concept thereof. For example, it will be apparent that the disclosed transformer and associated circuitry may be mounted in a case which is filled with a cooling fluid to reduce the temperature rise of the assembly during operation. It will also be evident that the number of turns and the construction of the primary windings may be varied within wide limits as required.

Another variation of the invention, particularly adapted to use with the circuit shown in FIG. 2, is to form the secondary windings of the transformers in the same way as the primary winding shown in FIG. 4. That is, the secondary windings may be a number of layers of foil, similar to the primary winding shown in FIG. 4. The primary winding and secondary windings then would be wound around the core in layers with proper insulation between turns in the manner in which capacitors are sometimes fabricated. In such an embodiment the number of turns would be equal for all windings. Such assembly exhibits a maximum capacitance between turns and a minimum series capacitance from one end of each winding to the other. The between turns capacitance is used as a filter capacitance and the series capacitance reflects a minimum capacitance back to the primary winding. The net result is that the turns of a capacitor have been used as a transformer winding turns. The ratio of the transformer is in part determined by the number of layers sandwiched together.

It is felt, therefore, that the invention should not be restricted to its disclosed embodiments, but rather should be limited only the spirit and scope of the following claims.

What is claimed is:

1. A pulse-forming circuit comprising:
   a. a source of pulses;
   b. an electromagnetic transformer, fed by such source, wherein each one of such pulses to be transformed is electromagnetically coupled between a primary winding and a secondary winding of such transformer, the secondary winding being characterized by a plurality of single layers overlying the primary winding, each one of such layers having two end portions;
   c. a like plurality, plus one, of diodes;
   d. means for connecting a single one of the plurality of diodes between adjacent end portions of successive ones of the plurality of single layers to join such layers in circuit serially, with each one of the so-connected diodes being similarly poled; and
   e. means for connecting a single one of the two remaining ones of the plurality of diodes to a separate one of the remaining end portions, with each one of such diodes being similarly poled with respect to the other diodes in such plurality thereof.

2. The pulse-transforming circuit recited in claim 1 wherein each one of the plurality of single layers includes "n" segments and such circuit includes the additional elements of "n-

1" diodes, each one of such "n-1" diodes being coupled between adjacent end portions of successive ones of the "n" segments to join such segments in circuit serially, with each one of the so-connected "n-1" diodes being similarly poled with respect to each other and to the diodes between each one of the plurality of single layers.

3. In a circuit for multiplying the voltage of an electric signal whose polarity changes and for rectifying such signal before application thereof to a load, the combination comprising:

a. an electromagnetic transformer wherein the electric signal to be multiplied is electromagnetically coupled between a primary winding and a secondary winding of such transformer, the secondary winding being characterized by a plurality of single layer segments overlying the primary winding;

b. a plurality of diodes, there being twice the number of diodes in such plurality thereof as there are segments in the secondary winding, such diodes being similarly poled and serially connected between the input terminal of the load and ground to form a first plurality of junctions;

c. a plurality of capacitors, the number of capacitors in such plurality thereof being equal to the number of diodes in the plurality thereof, such capacitors being serially connected between the input terminal of the load and ground to form a second plurality of junctions;

d. means for connecting a separate one of the segments across alternate ones of the first and the second plurality of junctions; and

e. means for short circuiting the remaining alternate ones of the first and the second plurality of junctions.

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