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(54) Miniaturized transformer.

(57) A miniaturized transformer comprising a winding assembly with a plurality of windings enclosed within a magnetic core is disclosed. The winding assembly is formed of a plurality of substrate boards stacked on top of each other. Each substrate board has a conductor on at least one side. The conductors are arranged in the shape of a spiral so as to serve as the turns of the transformer windings. Conductors on two or more boards may be electrically connected together so as to form a continuous transformer winding located on more than one winding board. The magnetic core has outer legs that are located adjacent to the sides of the winding assembly and a center leg that extends through a center leg hole in the assembly. The conductors are arranged to spiral around the center leg hole. The winding assembly board is provided with terminals in electrical contact with the ends of the transformer windings.

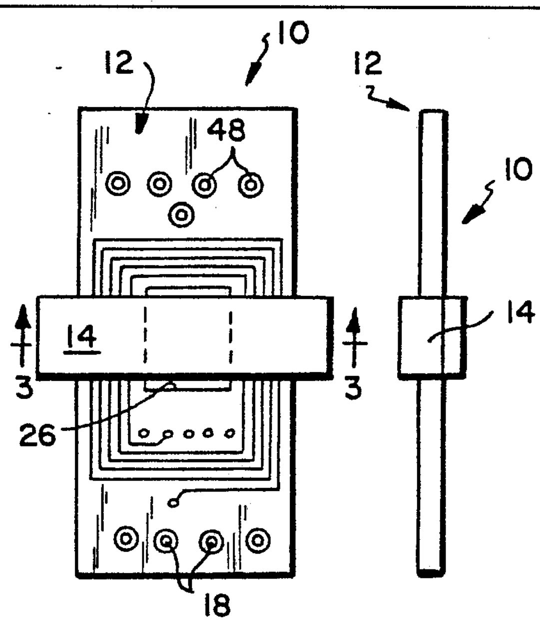

FIG. 1

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Description

MINIATURIZED TRANSFORMER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to transformers, and more particularly to miniaturized power transformers and inductors that are used with electrical circuits such as those mounted on closely packed printed circuit boards.

2. Background of the Invention

An electrical component which, to date, it has been difficult to significantly miniaturize is the power transformer. Miniaturized transformers have been provided for a number of purposes, but none have been suitable for providing the power needed to operate many electronic circuits. As a result for some purposes it is necessary to provide some electric circuits with standard wire-wound transformers that are relatively bulky. These transformers are difficult, if not impossible, to install in some locations where space is at premium, such as on a printed circuit board that is placed in close proximity to other circuit boards.

As stated, there have been some attempts at providing miniaturized transformers. In one embodiment of a miniaturized transformer, disclosed in U.S. Patent No. 4,547,961, each winding is in the form of a spiral embedded on an insulating matrix on a rigid substrate. The individual turns of each winding are spiraled around the substrate and the spirals are stacked or layered on top of each other. The window layers are separated from each other by an insulating dielectric. The substrates are assembled with a magnetic core that provides a magnetic path around the windings.

Miniaturized transformers such as these are of limited use. The turns, formed or fused conductive particles, have a vertical profile of approximately 1 mil, (0.001"). If the transformer is used for a power transfer application, the internal resistance of the windings will dissipate a significant fraction of the power to be transferred, with consequent inefficiency. Moreover, the heat generated in the windings may cause such a temperature rise that the insulating dielectrics will melt or burn out, causing the windings to short circuit. Thus, these transformers can only be used for low-power applications, e.g. 10 watts or less.

Furthermore, the windings layers are separated from each other by a relatively great distance, the thickness of the rigid substrate. Since inductive coupling is inversely proportional to the distance between the coils, this means that the power transfer efficiency of the transformer is reduced. This problem can be very significant for multiple secondary windings that are spaced more than a substrate away from the primary winding.

Moreover, each winding must be provided with a separate substrate. If the transformer is designed to have more than two or three windings its thickness will significantly increase and the unit can no longer be considered miniature.

Other miniaturized transformers, described in U.S. Patents 3,002,206 and 3,484,731, have been manufactured from strips of flexible insulation material with spiral patterns of conductors etched thereon. The spirals are arranged in pairs, with the spirals in each pair connected by a conductor. The strips are folded over and the adjacent pairs of spirals in a winding are electrically connected to each other by spot welding, or connection tabs, that are in close proximity to each other. Only a relatively small voltage, or potential difference, can be tolerated between vertically adjacent connectors of this type without incurring arcing between the connectors. Thus, these transformers cannot be used for transfer of more than moderate power.

A need therefore exists for a power transformer available for high-power applications and that occupies a minimal amount of space. The distance between the individual windings should be minimal so as to maximize inductive coupling. The transformer should have a thin profile, regardless of the number of windings, so it can be used at locations where space is at a premium. Furthermore, it would be desirable to manufacture the transformer with automated equipment. This would minimize the variance in operating characteristics of individual transformers. Also, the transformer should be relatively economical to manufacture.

SUMMARY OF THE INVENTION

This invention comprises a miniaturized transformer with windings located on a single, multi-layered printed circuit board. Each winding is composed of a number of turns of a conductor etched on a thin substrate board. Some windings have more turns than can be accomodated on a single board. These turns are electrically connected by buried vias that extend through the substrate boards. The individual winding boards are separated from each other by layers of insulating material. The substrate boards and insulating layers are pressed together to form a winding assembly.

The winding assembly is provided with a center leg hole around which the windings' turns are spiraled. A low-reluctance magnetic core has a center leg that extends through the center leg hole to provide a magnetic path which encloses the windings.

This transformer may be used for low or high power applications. The conductors that carry the current are designed to carry the required current and can be relatively thick and relatively wide. Therefore, the windings have only minimal internal resistance, so that only a small fraction of the applied energy is dissipated in them. Moreover, the individual winding layers are insulated from each other by the layer of insulation between adjacent substrate boards. Furthermore, the buried vias through which the winding layers are interconnected can be spaced apart from each other so as to minimize the possibility of arcing regardless of the potential difference between them. Thus, the transformer may be used in applications involving the transfer of up to 200 watts or more of power.

Another advantage of this transformer is that each substrate board and insulation layer is relatively thin. Providing the transformer with more than two or three windings, or providing the windings with a large number of turns that necessitates the stacking of a number of substrate boards, does not unduly increase the thickness of the overall winding assembly. Thus, for most applications, the transformer retains a thin profile and can be used in locations where space is at a premium.

There are other advantages to this type of transformer. The individual windings are spaced closely together, and the power density around the magnetic core is relatively high. Thus, the inductive coupling between the adjacent windings is correspondingly increased. This increases the power transfer efficiency of the transformer. Furthermore, since the adjacent windings and turns are located in close proximity to each other the leakage inductance and stray capacitance that can reduce the efficiency of the transformer can be closely controlled. Moreover, individual transformers can be manufactured almost entirely by automated processes. As a result, there is little variance in the operating characteristics of individual units. This feature is of special importance when the transformer is to by operated in situations where exact design characteristics must be met, such as for high frequency applications. Also, this invention can be manufactured with a single, continuous winding to form a miniaturized inductor. Furthermore, the transformer is relatively economical to manufacture.

BRIEF DESCRIPTION OF THE DRAWINGS

This invention is pointed out with particularity in the appended claims. The above and further advantages of this invention may be better understood by referring to the following description taken in conjunction with the accompanying drawings, in which:

Figure 1 is a plan view of a miniaturized transformer according to the preferred embodiment of this invention;

Figure 2 is a side elevation of the transformer shown in Figure 1;

Figure 3 is a cross-sectional view of the transformer taken along line 3-3 in Figure 1;

Figures 4 and 4a are exploded views of the layers of the winding assembly according to the preferred embodiment of this invention;

Figure 5 is a plan view of a miniaturized inductor according to this invention; and

Figures 6 and 6a are exploded views of the layers of the winding assembly according to the embodiment of this invention formed as an inductor.

DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

Figures 1-3 illustrate a transformer 10 comprising a multi-layered winding assembly 12 enclosed within a magnetic core 14. The winding assembly is provided with a number of plated-through bore terminals 18 so the transformer can be electrically connected to other components. The magnetic core comprises an E-shaped magnetic core 20, adjacent to one surface of the printed circuit board, mated to an I-shaped magnetic core 22 adjacent to the opposite surface. Center leg 24 of the E-core extends through central leg hole 26 in the printed circuit board. The E-core also includes a pair of outer legs 28 that are adjacent to opposite edges of the winding assembly 12.

From Fig. 4 it can be seen that the winding assembly 12 comprises a plurality of substrate boards 30a through 30f stacked on top of each other. The substrate boards 30 are separated from each other by insulator layers 32 approximately 6 mils thick (only one shown). The substrate boards and the insulation layers each have center holes 34, that combine to define the printed circuit board central leg hole 26. Each substrate board is approximately 6 mils thick with a conductor 38 approximately 4-14 mils thick etched on at least one side thereof (illustrated with a conductor on one side only). In one embodiment of the invention industry standard G-10 boards are used for the substrate boards 30, copper is used as the conductor 38, and Kapton or polyimide film serves as the insulation layer.

The conductors 38 are located on the substrate boards 30 in spiral patterns around the center hole 34. They serve as the windings 40, 42, 44 of the transformer. Thus, each spiral of the conductor functions as a turn of one of the windings. In this embodiment of the invention, winding 40 is the primary winding and windings 42 and 44 are secondary windings. There is insufficient space on the substrate boards to locate all the turns for an individual winding on a single substrate board, so the windings comprise layers of turns stacked on adjacent boards. Thus, winding 40 is located on boards 30a and 30b, winding 42 is located on boards 30c and 30d, and winding 44 is located on boards 30e and 30f.

The conductors 38 on each side of a substrate board 30 and on the separate boards, that comprise an individual continuous winding are electrically connected to each other by a buried via bores 48. For example, inner terminal point 50 of the conductor on substrate board 30e is located directly above inner terminal points 52 of the conductor on board 30f. The terminal points are connected to each other by conductive plating 46 on the cylindrical surfaces of the buried via bores 48, best seen by reference to Figure 1. The buries bia bores are plated holes that are formed in both the substrate boards 30 and in the insulation layers 32. The buried vias 48 are spaced apart, or isolated, from each other around the assembly 12 a sufficient distance so as to substantially minimize the possibility of arcing between adjacent vias if there is a relatively high potential difference between them.

As shown in Fig. 4a, the winding assembly 12 is also provided with a number of terminal conductors

54 to connect the windings 40, 42 and 44 to the appropriate terminal bores 18. In this embodiment of the invention the conductors 54 are located on a terminal board 56 that is on the opposite side of the bottommost substrate board 30f. The individual conductors 54 are connected to the appropriate windings by additional buried vias 48.

Each winding comprises a conductor with the appropriate characteristics for the current it is designed to carry. For example, winding 42 is designed to provide a low-voltage, high-current output. The conductor in the winding thus has a relatively broad cross section so that it has as minimal a current dissipating resistance as possible. Winding 44, on the other hand, is designed to provide a high-voltage low-current output and it requires a conductor with only a narrow cross-sectional area.

One advantage of this transformer is its size. As best seen in Figs. 2 and 3, the winding assembly 12 has a relatively thin profile. Each substrate board 30 with insulation layer 32 of the printed circuit board is approximately 20 mils thick. A winding assembly 12 can be provided with three or more windings, each of which occupies several winding boards, and still have a thin profile. This makes it convenient to install the transformer in a location where space is minimal, such as in electrical device assemblies where circuit boards are closely stacked together.

Another advantage of having a winding assembly 12 with a reduced profile is that the length of the magnetic path around the core magnets 20,22 is reduced. For a given power input the power density is greater than that of a conventional transformer. This increase in power density makes the transformer a more effective power transfer component.

Also, the insulation between the adjacent spirals and the spacing of the buried vias minimize the possibility of arcing between adjacent conductive elements. In addition, the conductors 38 may be provided with relatively wide cross-sectional areas so as to minimize their internal resistance. Thus, this transformer may be used for high power, 200 watts or more, transfer applications.

Furthermore, with the windings located in close proximity to each other, the inductive coupling characteristics of the transformer are enhanced. This is especially important if the transformer is used for high-frequency applications, (20 kHz or greater), where a significant amount of energy could be lost through leakage inductance. Also, in comparison to paired spirals connected by a length of conductive material, there is almost no loss of power transfer through leakage inductance of the buried vias connecting adjacent spirals.

Furthermore, the transformer of this invention can be manufactured almost entirely by use of automated assembly equipment. This insures that each transformer will be essentially identical with other transformers in its class. Parasitic parameters, such as leakage inductance and distributed capacitance, will not vary significantly from transformer to transformer. This is an important consideration when the transformer is to be used on a circuit where its operating characteristics must not vary beyond designated limits. Moreover, existing inexpensive printed circuit boards and E - I magnetic cores can be readily adapted to provide the parts necessary to form the transformer of this invention. Thus, this transformer is economical to produce.

Alternatively, an inductor 110 can be provided according to this invention. The inductor includes a winding assembly 112, as shown in Figs. 5 and 6 formed of at least one substrate board 130, (three 130a, b, and c, are shown). An insulator layer 132 is located between adjacent substrate boards. A single, continuous inductor winding 140 extends between two or more terminal bores 118 located on the assembly 112, and be connected between either the opposite sides of an individual substrate board or between the adjacent substrate boards by buried vias 148. The winding board 112 may be provided with a center leg hole 126 and enclosed within a magnetic core 114 as described according to the first embodiment of this invention. Also, as shown by Fig. 6a, the opposite sides of one of the substrate boards, here 130c, may serve as a terminal board 156 and carry one or more terminal conductors 154 that extend between inductor terminal bores 118 and the inductor winding 140. Additional buried vias 148 are used to connect the terminal conductor to the inductor winding.

In the embodiment of the invention described herein the transformer is a distinct component that is to be installed in electronic circuits such as on a mother board. Alternatively, the transformer, or the inductor, can be made as an integral part of the circuit in which it is to be used. This is done by providing a "mother" printed circuit board with a number of layered windings on separate substrate boards embedded therein. The mother board would also be provided with openings adjacent to the windings so a magnetic core can be installed around the windings, to form a complete transformer. Other circuit elements can then be positioned on the mother board to form a complete circuit. In this embodiment of the invention the only part of the transformer that will project above the surface of the mother board will be the outer portions of the magnetic core.

Alternative forms of this invention are also possible without departing from the scope of the claims. For example, the winding assembly 12 may be made using flexible circuit technology. In such an instance, the substrate boards 30 may be made from Kapton film. Thus, it is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described.

Claims

1. A transformer comprising:

A. a winding assembly with a plurality of windings, said assembly comprising a plurality of substrate boards, with a conductor on at least one side thereof, the conductor having a spiral pattern so as to form at least a portion of a transformer winding, each transformer winding having two ends;

B. a plurality of terminals on the printed assembly board, each terminal being electrically connected to a transformer winding, and at least one terminal electrically connected to one end of a transformer winding through at least a portion of the winding assembly; and

C. a magnetic core enclosing at least a portion of each of the transformer windings.

2. The transformer of claim 1 wherein the magnetic core includes two outer legs at the opposite ends of the magnetic core that are positioned adjacent opposite edges of the winding assembly and a center leg that extends through a center leg hole in the winding assembly.

3. The transformer of claim 2 wherein the individual conductors spiral around the center leg hole of the winding assembly.

4. The transformer of claim 1 wherein the substrate boards are separated from each other by an insulator layer positioned therebetween.

5. The transformer of claim 1 wherein at least one substrate board includes conductors on both sides electrically connected together by an electrical connection extending through the substrate board so as to form a single continuous transformer winding.

6. The transformer of claim 1 wherein at least two conductors are electrically connected with each other by an electrical connection extending through the substrate boards so as to form a single continuous transformer winding.

7. The transformer of claim 6 wherein the conductors that are electrically connected with each other are located on adjacent substrate boards.

8. The transformer of claims 5, 6 or 7 wherein the conductors that are electrically connected with each other are connected by buried vias that extend at least partially through the winding assembly.

9. The transformer of claim 8 wherein the buried vias are spaced apart from each other so as to prevent arcing between adjacent buried vias.

10. The transformer of claim 1 wherein the terminals are electrically connected to the windings by terminal conductors located on a terminal board and the terminal conductors are each commected to one end of a transformer winding by a buried via that extends at least partially through the winding assembly.

11. An inductor comprising:

A. a winding assembly with a continuous inductor winding having two ends, said assembly comprising at least one substrate with a conductor on at least one side thereof, the conductor having a spiral pattern so as to form at least a portion of the inductor winding,

B. a plurality of terminals on the winding assembly, each terminal being electrically connected to the inductor winding through at least a portion of the winding assembly;

C. a magnetic core enclosing each of the transformer windings.

12. The induction of claim 11 wherein the magnetic core includes two outer legs at the opposite ends of the magnetic core that are positioned adjacent opposite edges of the winding assembly and a center leg that extends through a center leg hole in the winding assembly.

13. The inductor of claim 12 wherein the conductor spirals around the center leg hole of the winding assembly.

14. The inductor of claim 11 wherein the substrate boards are separated from each other by an insulator layer positioned therebetween.

15. The inductor of claim 11 wherein at least one substrate board includes conductors on both sides of the substrate boared electrically connected together by an electrical connection extending through the substrate board so as to form said continuous inductor winding.

16. The inductor of claim 11 wherein there are at least two substrate boards, each of said substrate boards carrying: a conductor, said conductors electrically connected to each other by an electrical connection extending through the substrate boards so as to form said continuous inductor winding.

17. The transformer of claims 15 or 16 wherein the conductors that are electrically connected with each other are connected by buried vias that extend at least partially through the printed circuit board.

18. The transformer of claim 17 wherein the buried vias are spaced apart from each other so as to prevent arcing between adjacent buried vias.

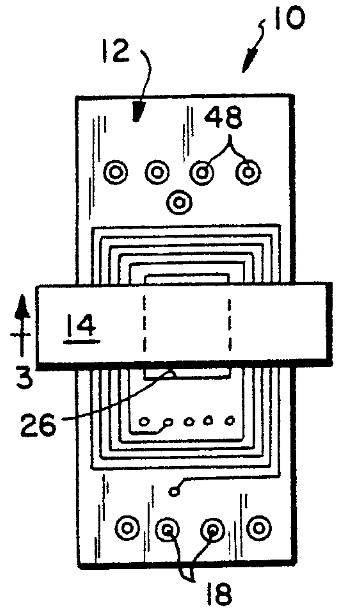

FIG.1

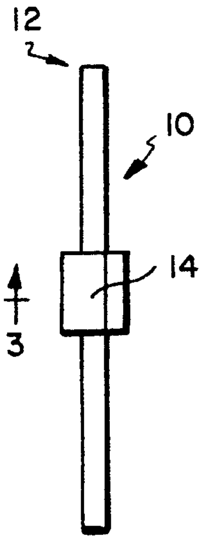

FIG.2

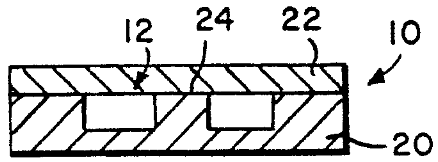

FIG.3

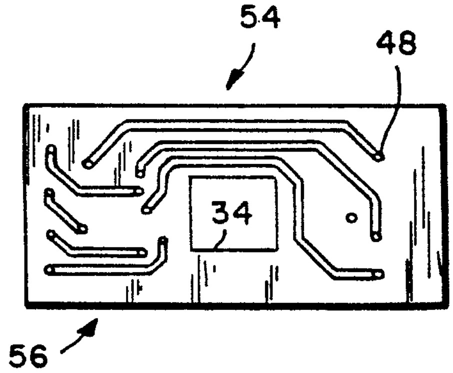

FIG. 4A

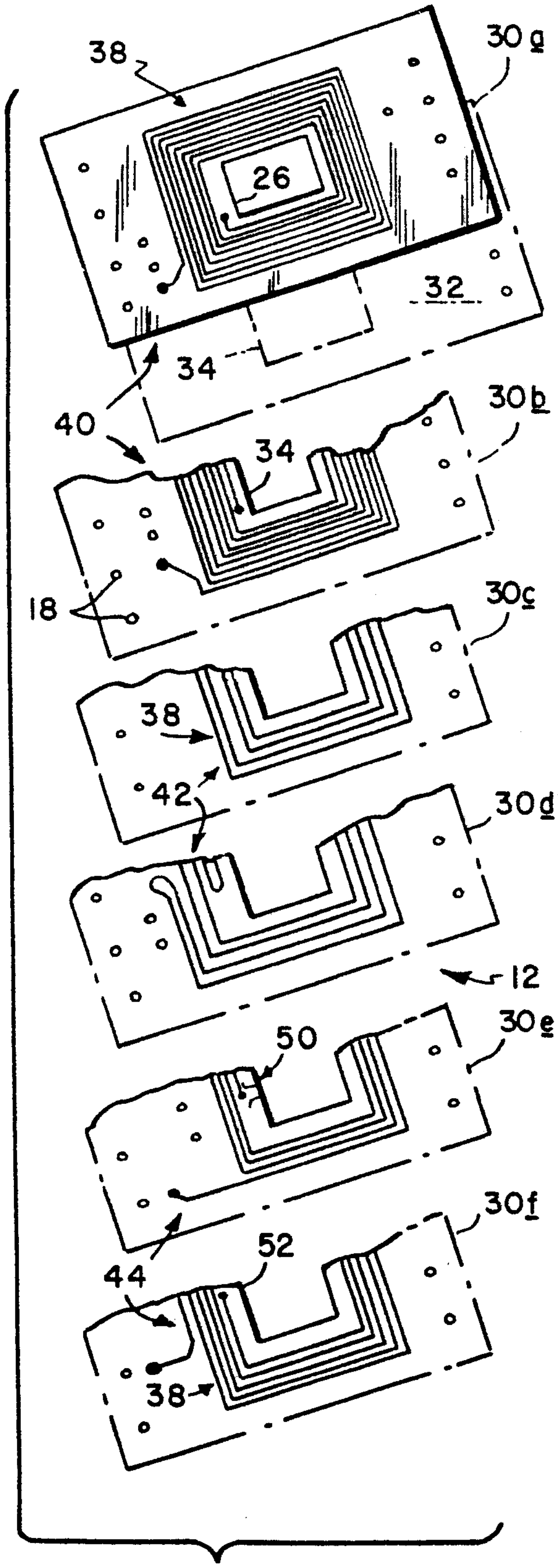

FIG.4

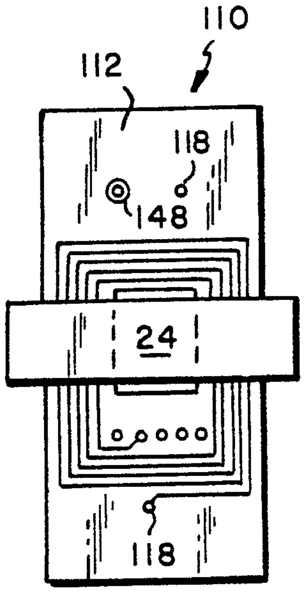

FIG. 5

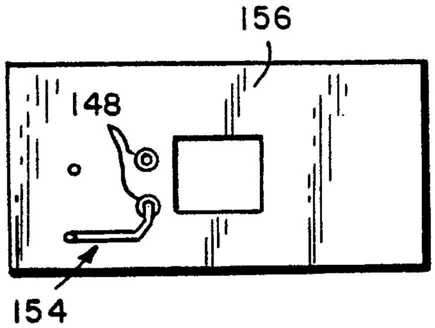

FIG. 6A

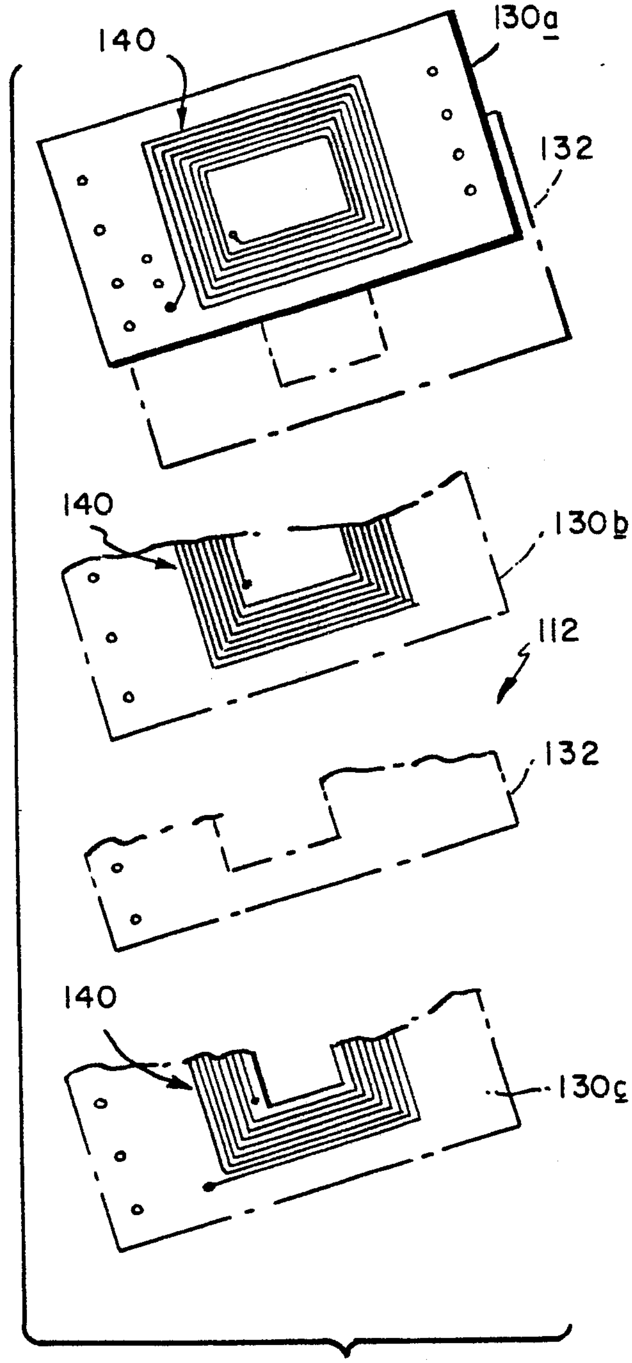

FIG. 6

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 87402451.6

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
D,A	US - A - 3 484 731 (RICH) * Abstract; fig. 6,8 * --	1-18	H 01 F 5/00
A	US - A - 4 367 450 (CARILLO) * Abstract; fig. 4,17-24 * --	1-18	
A	EP - A1 - 0 035 964 (WALCH) * Abstract; fig. 1-7 * --	1-18	
A	DE - A1 - 3 148 192 (BOSCH) * Abstract; fig. 1-5 * --	1-18	
D,A	US - A - 3 002 260 (SHORTT) * Totality * ----	1-18	

TECHNICAL FIELDS SEARCHED (Int. Cl.4)

H 01 F 5/00
H 01 F 27/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	12-02-1988	VAKIL

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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