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(54) **A PLANAR TRANSFORMER AND A METHOD FOR REDUCING COMMON-MODE NOISE IN A PLANAR TRANSFORMER**

(57) The present invention relates to a planar transformer that comprises a primary winding (201) formed on at least one primary layer (102), a secondary winding (202) formed on at least one secondary layer (104), and a compensation winding (203) formed on a compensation layer (103) that is arranged between one primary layer (102) and one secondary layer (104). The planar transformer further comprises a first conductive area (204) formed on the compensation layer (103) and connected to the compensation winding (203), and a second conductive area (205) formed on the secondary layer (104) adjacent to the compensation layer (103) and located in parallel with the first conductive area (204). The present invention also relates to a method for reducing common-mode noise in a planar transformer.

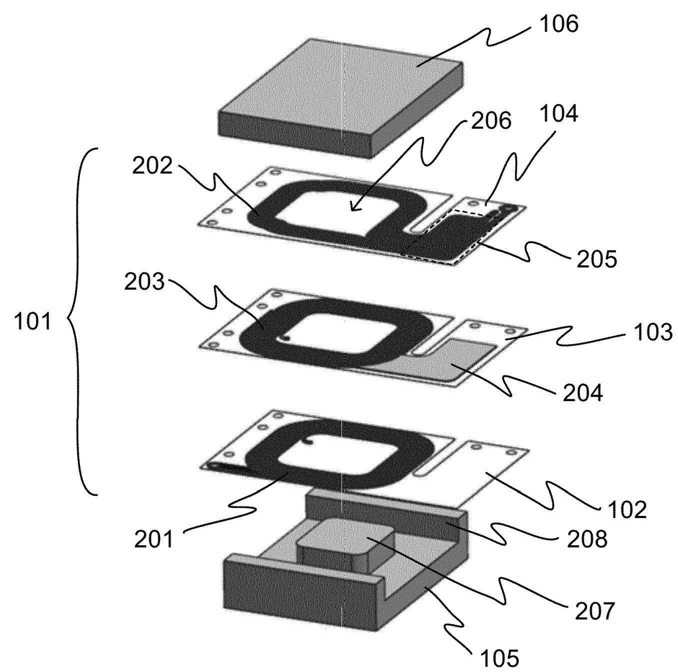

Fig. 2

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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to a planar transformer and a method for reducing common-mode noise in a planar transformer according to the preambles of the appended independent claims.

BACKGROUND OF THE INVENTION

[0002] Planar transformers are preferred in many small-sized and low-power applications, such as switched-mode power supplies (SMPS) due to their low-profile and good thermal characteristics. A known planar transformer comprises a primary winding and a secondary winding, which are formed on a primary layer and a secondary layer, respectively. The known planar transformer comprises a compensation winding formed on a compensation layer that is arranged between the primary layer and the secondary layer. The purpose of the compensation winding is to reduce common-mode noise in the planar transformer. The primary layer, the compensation layer and the secondary layer are stacked together, forming a planar structure. The known planar transformer comprises a transformer core that is arranged in connection with the planar structure.

[0003] A problem associated with this known planar transformer is that the common-mode noise reduction achieved with the compensation winding is not sufficient. This is because not enough winding turns can be arranged on a single compensation layer. The common-mode noise reduction effect could be improved by using one or more additional compensation layers between the primary layer and the secondary layer, but this would increase leakage inductance and manufacturing costs of the planar transformer.

OBJECTIVES OF THE INVENTION

[0004] It is the main objective of the present invention to reduce or even eliminate the prior art problems presented above.

[0005] It is an objective of the present invention to provide a planar transformer in which common-mode noise is minimised. It is also an objective of the present invention to provide a planar transformer that has a simple structure. It is a further objective of the present invention to provide a planar transformer that is easy and cheap to manufacture.

[0006] It is yet an objective of the present invention to provide a method enabling to reduce common-mode noise in a planar transformer.

[0007] In order to realise the above-mentioned objectives, the planar transformer and the method according to the invention are characterised by what is presented in the characterising parts of the appended independent claims. Advantageous embodiments of the invention are described in the dependent claims.

DESCRIPTION OF THE INVENTION

[0008] A planar transformer according to the invention comprises a primary winding formed on at least one primary layer, a secondary winding formed on at least one secondary layer, and a compensation winding formed on a compensation layer that is arranged between one primary layer and one secondary layer. The planar transformer according to the invention further comprises a first conductive area formed on the compensation layer and connected to the compensation winding, and a second conductive area formed on the secondary layer adjacent to the compensation layer and located in parallel with the first conductive area.

[0009] In the planar transformer according to the invention, the layers are superimposed, forming a planar structure. The planar structure can be, for example, a multilayer printed circuit board (PCB). Each of the windings is formed on one or more layers, and on each layer the winding comprises an essentially spiral pattern that is arranged to wind around an aperture provided in the layer. The windings are preferably arranged concentrically with respect to each other. The winding direction, the number of the winding turns, the spacing between the winding turns and the track width in each winding can be chosen according to the application.

[0010] The planar transformer according to the invention may comprise a transformer core that is arranged in connection with the planar structure consisting of the layers. A leg of the transformer core can be arranged through the apertures provided in the layers so that the windings surround the leg. The transformer core can be, for example, an EI-core, a centre leg of which is arranged through the apertures.

[0011] In the planar transformer according to the invention, each of the primary winding and the secondary winding can be formed on a single layer or a plurality of layers. The number of the primary and secondary layers can be, for example, one, two, three, four or five. Each of the primary winding and the secondary winding can be divided into sub-windings, which are arranged on different layers. The sub-windings of the primary or secondary winding are connected in series and their winding directions are the same. The number of winding turns in the primary winding can be, for example, 20-50. The number of winding turns in the secondary winding can be, for example, 1-6. In high frequency applications, the number of winding turns in each winding is typically small.

[0012] The compensation winding is formed on a single layer, i.e. the compensation layer, that is arranged between one primary layer and one secondary layer. The compensation winding is arranged on a primary side or a secondary side of the planar transformer. The compensation winding is connected to a primary circuit that contains the primary winding or to a secondary circuit that contains the secondary winding. The compensation winding is arranged in such a manner that it has a reversed polarity compared to the primary winding. The compensation winding reduces the common-mode noise in the planar transformer. When the planar transformer has only one primary layer and one secondary layer, the compensation layer is arranged between the primary layer and the secondary layer. When the planar transformer has a plurality of primary layers and a plurality of secondary layers, the compensation layer is arranged between one of the primary layers and one of the secondary layers. Each of the plurality of primary layers and the plurality of secondary layers may be stacked on top of each other to form a set of layers, whereby the compensation layer is arranged between these sets of layers. The number of winding turns in the compensation winding can be, for example, 5-25.

[0013] The first conductive area is connected to the compensation winding. Preferably, the first conductive area is connected to the outermost winding turn of the compensation winding. The second conductive area is formed on the secondary layer that is closest to the compensation layer. The first conductive area and the second conductive area are arranged in such a manner that they are opposite to each other. The second conductive area is connected to the secondary winding or it is formed by a portion of the secondary winding, preferably by a portion of the outermost winding turn of the secondary winding. The first conductive area and the second conductive area act as a capacitor that reduces the common-mode noise in the planar transformer. Together with the compensation winding, the first and second conductive areas ensure that the common-mode noise in the planar transformer is efficiently reduced.

[0014] The planar transformer according to the invention can be applied in various applications. A preferred application is a switched-mode power supply (SMPS). In the SMPS, a pulsed electrical current is supplied to the primary winding, which creates a cyclically changing magnetic field in and around the transformer core from which energy is discharged to the secondary winding. The compensation winding together with the capacitor formed by the first conductive area and the second conductive area effectively reduces the common-mode noise in the SMPS.

[0015] An advantage of the planar transformer according to the invention is that common-mode noise in the planar transformer is efficiently reduced. Another advantage of the planar transformer according to the invention is that only one layer is needed to efficiently reduce the common-mode noise in the planar transformer. Yet another advantage of the planar transformer according to the invention is that the planar transformer has a simple structure. Yet another advantage of the planar transformer according to the invention is that the planar transformer is easy and cheap to manufacture.

[0016] According to an embodiment of the invention the second conductive area is formed by a portion of a winding turn of the secondary winding. Preferably, the second conductive area is formed by a portion of the outermost winding turn. The secondary layer that is adjacent, i.e. closest to the compensation layer may comprise only one winding turn, a portion of which forms the second conductive area. An advantage of forming the second conductive area by a portion of a winding turn is that it is easy to design and manufacture.

[0017] According to an embodiment of the invention the second conductive area is connected to the secondary winding. In this embodiment, the second conductive area is not part of the secondary winding. Preferably, the second conductive area is connected to the outermost winding turn of the secondary winding that is formed on the secondary layer adjacent, i.e. closest to the compensation layer. An advantage of providing the planar transformer with a second conductive area that is not part of the secondary winding is that it is easy to optimize for the common-mode noise reduction.

[0018] According to an embodiment of the invention the compensation winding is connected to a primary side of the planar transformer or a secondary side of the planar transformer with a reversed polarity compared to the primary winding.

[0019] According to an embodiment of the invention the surface area of the first conductive area and the second conductive area is at least 4 mm^2. The surface area of the first conductive area and the second conductive area is preferably 4-100 mm^2, and more preferably 4-50 mm^2.

[0020] According to an embodiment of the invention the number of the winding turns in the compensation winding is at most 25. The number of the winding turns of the compensation winding is preferably 5-25, and more preferably 5-15. When designing a planar transformer, the number of the winding turns in the compensation winding is preferably chosen together with the size of the surface area of the first and second conductive areas to achieve a minimum amount of common-mode noise in the planar transformer.

[0021] According to an embodiment of the invention the distance between the first conductive area and the second conductive area is at most 1 mm. The distance between the first conductive area and the second conductive area is preferably 300-600 μm. The smaller the distance between the first conductive area and the second conductive area, the more common-mode noise can be reduced.

[0022] According to an embodiment of the invention the primary winding is formed on a plurality of primary layers which are divided into a first set of primary layers and a second set of primary layers between which the at least one secondary layer is arranged. The compensation layer can be arranged either between the first set of primary layers and the at least one secondary layer or between the second set of primary layers and the at least one secondary layer.

[0023] According to an embodiment of the invention the secondary winding is formed on a plurality of secondary layers which are divided into a first set of secondary layers and a second set of secondary layers between which the at least one primary layer is arranged. The compensation layer can be arranged either between the first set of secondary layers and the at least one primary layer or between the second set of secondary layers and the at least one primary layer.

[0024] The present invention also relates to a method for reducing common-mode noise in a planar transformer that comprises a primary winding formed on at least one primary layer, a secondary winding formed on at least one secondary layer, and a compensation winding formed on a compensation layer that is arranged between one primary layer and one secondary layer. The method according to the invention comprises providing the compensation layer with a first conductive area that is connected to the compensation winding, and providing the secondary layer adjacent to the compensation layer with a second conductive area that is located in parallel with the first conductive area.

[0025] The compensation winding is arranged on a primary side or a secondary side of the planar transformer. The first conductive area and the second conductive area are arranged in such a manner that they are opposite to each other. The first conductive area and the second conductive area act as a capacitor that reduces the common-mode noise in the planar transformer. Together with the compensation winding, the first and second conductive areas ensure that the common-mode noise in the planar transformer is efficiently reduced.

[0026] An advantage of the method according to the invention is that common-mode noise in the planar transformer can be efficiently reduced. Another advantage of the method according to the invention is that only one layer is needed to efficiently reduce the common-mode noise in the planar transformer.

[0027] The exemplary embodiments of the invention presented in this text are not interpreted to pose limitations to the applicability of the appended claims. The verb "to comprise" is used in this text as an open limitation that does not exclude the existence of also unrecited features. The features recited in the dependent claims are mutually freely combinable unless otherwise explicitly stated.

[0028] The exemplary embodiments presented in this text and their advantages relate by applicable parts to the planar transformer as well as the method according to the invention, even though this is not always separately mentioned.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029]

Fig. 1 illustrates a planar transformer according to an embodiment of the invention,

fig. 2 illustrates an exploded view of the planar transformer according to fig. 1,

fig. 3 illustrates a first measured common-mode voltage,

fig. 4 illustrates a second measured common-mode voltage, and

fig. 5 illustrates a third measured common-mode voltage.

DETAILED DESCRIPTION OF THE DRAWINGS

[0030] Fig. 1 illustrates a planar transformer according to an embodiment of the invention. The planar transformer comprises a multilayer PCB 101, which consists of a primary layer 102, a compensation layer 103 and a secondary layer 104 on which windings are formed. A transformer core consisting of an E-core 105 and an I-core 106 is attached in connection with the multilayer PCB 101. The planar transformer of fig. 1 can be applied in a switched-mode power supply (SMPS).

[0031] Fig. 2 illustrates an exploded view of the planar transformer according to fig. 1. The multilayer PCB 101 comprises the primary layer 102, the compensation layer 103 and the secondary layer 104. A primary winding 201 is formed on the primary layer 102 and a secondary winding 202 is formed on the secondary layer 104. The compensation layer 103 is provided with a compensation winding 203 and a first conductive area 204 that is connected to the outermost winding turn of the compensation winding 203. The compensation winding 203 is connected to a primary side of the planar transformer with a reversed polarity compared to the primary winding 201.

[0032] A portion of the secondary winding 202 is located in parallel with the first conductive area 204. This portion forms a second conductive area 205 that together with the first conductive area 204 act as a capacitor. The first and second conductive areas 204 and 205 as well as the compensation winding 203 reduce the common-mode noise in the planar transformer.

[0033] The primary layer 102, the compensation layer 103 and the secondary layer 104 are provided with apertures 206. Each of the primary winding 201, the compensation winding 203 and the secondary winding 202 has a form of an essentially spiral winding pattern that is arranged to wind around the aperture 206. A centre leg 207 of the E-core 105 is intended to pass through the apertures 206. Side legs 208 of the E-core 105 are intended to be arranged around the multilayer PCB 101 so that the primary layer 102, the compensation layer 103 and the secondary layer 104 are between the side legs 208. The I-core 106 is used to magnetically couple the centre leg 207 to the side legs 208 of the E-core 105.

[0034] Fig. 3 illustrates a first measured common-mode voltage. The common-mode voltage illustrates in general a potential difference between the primary and secondary sides measured at the planar transformer.

The common-mode voltage of fig. 3 is measured at a planar transformer that corresponds to the planar transformer of fig. 1 but without the compensation layer 103. The common-mode voltage is illustrated during a time around three switching pulses where a primary switch that is coupled in series with the primary winding 201 is first closed and then opened. The primary switch is configured to repeatedly interrupt a current through the primary winding 201 according to the known principle utilised in switched-mode power supplies.

[0035] During the switching pulse (i.e. during the time when the switch of the primary current remains conductive) there can be seen a certain pulse-formed potential difference, which in fig. 3 appears during the time interval 301. At the switching moment at the end of the switching pulse, i.e. at the moment when the primary switch becomes non-conductive, the polarity of the voltage in the secondary winding 202 is reversed and the secondary side becomes conducting. During the time interval 302 the energy that was stored during the time interval 301 discharges to the secondary side. During the time interval 303 before the next switching pulse, when neither the primary nor secondary side is conducting, there is an oscillating waveform due to the primary switch node parasitic capacitance and the inductance of the planar transformer.

[0036] Fig. 4 illustrates a second measured common-mode voltage. This common-mode voltage is measured at a planar transformer that corresponds to the planar transformer of fig. 1 but without the first conductive area 204. The common-mode voltage is illustrated during a time around three switching pulses where a primary switch that is coupled in series with the primary winding 201 is first closed and then opened.

[0037] The voltage graph of fig. 4 is comparable to that of fig. 3, with the difference that the voltage graph of fig. 4 was measured at the planar transformer that includes the compensation winding 203 arranged between the primary winding 201 and the secondary winding 202. The compensation winding 203 is connected to the primary side of the planar transformer with a reversed polarity compared to the primary winding 201. During the time interval 301 there is again the pulse-formed potential difference, and during the time interval 302 the voltage waveform associated with the energy discharge to the secondary side. During the time interval 303 before the next switching pulse, the common-mode voltage has the oscillating waveform. As is evident from figs. 3 and 4, the common-mode voltage at the planar transformer having the compensation winding 203 is much lower compared to the planar transformer without it.

[0038] Fig. 5 illustrates a third measured common-mode voltage. This common-mode voltage is measured at a planar transformer that corresponds to the planar transformer of fig. 1. The common-mode voltage is illustrated during a time around three switching pulses where a primary switch that is coupled in series with the primary winding 201 is first closed and then opened.

[0039] The voltage graph of fig. 5 is comparable to that of fig. 4, with the difference that the voltage graph of fig. 5 was measured at the planar transformer that also includes the first conductive area 204 that together with the second conductive area 205 act as a capacitor. The first conductive area 204 is connected to the compensation winding 203, which is connected to the primary side of the planar transformer with a reversed polarity compared to the primary winding 201. During the time interval 301 there is again the pulse-formed potential difference, which is now much less prominent than in fig. 4. Also compared to the voltage graph of fig. 4, the voltage variations during the time interval 303 are very small in fig. 5. As can be seen from fig. 5, the common-mode voltage at the planar transformer of fig. 1 is very low.

[0040] Only advantageous exemplary embodiments of the invention are described in the figures. It is clear to a person skilled in the art that the invention is not restricted only to the examples presented above, but the invention may vary within the limits of the claims presented hereafter. Some possible embodiments of the invention are described in the dependent claims, and they are not to be considered to restrict the scope of protection of the invention as such.

Claims

1. A planar transformer, comprising:

   - a primary winding formed on at least one primary layer,
   - a secondary winding formed on at least one secondary layer, and
   - a compensation winding formed on a compensation layer that is arranged between one primary layer and one secondary layer,

   characterised in that the planar transformer comprises:

   - a first conductive area formed on the compensation layer and connected to the compensation winding, and
   - a second conductive area formed on the secondary layer adjacent to the compensation layer and located in parallel with the first conductive area.

2. The planar transformer according to claim 1, **characterised in that** the second conductive area is formed by a portion of a winding turn of the secondary winding.

3. The planar transformer according to claim 1, **characterised in that** the second conductive area is connected to the secondary winding.

4. The planar transformer according to any of claims 1 to 3, **characterised in that** the compensation winding is connected to a primary side of the planar transformer or a secondary side of the planar transformer with a reversed polarity compared to the primary winding.

5. The planar transformer according to any of claims 1 to 4, **characterised in that** the surface area of the first conductive area and the second conductive area is at least 4 mm^2.

6. The planar transformer according to any of claims 1 to 5, **characterised in that** the number of the winding turns in the compensation winding is at most 25.

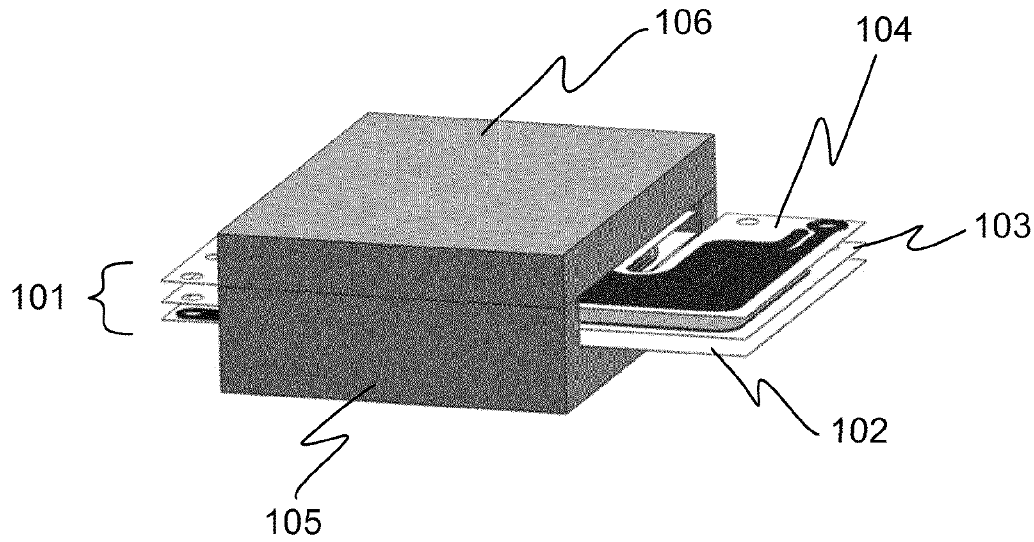
7. The planar transformer according to any of claims 1 to 6, **characterised in that** the distance between the first conductive area and the second conductive area is at most 1 mm.

8. The planar transformer according to any of claims 1 to 7, **characterised in that** the primary winding is formed on a plurality of primary layers which are divided into a first set of primary layers and a second set of primary layers between which the at least one secondary layer is arranged.

9. The planar transformer according to any of claims 1 to 7, **characterised in that** the secondary winding is formed on a plurality of secondary layers which are divided into a first set of secondary layers and a second set of secondary layers between which the at least one primary layer is arranged.

10. A method for reducing common-mode noise in a planar transformer that comprises a primary winding formed on at least one primary layer, a secondary winding formed on at least one secondary layer, and a compensation winding formed on a compensation layer that is arranged between one primary layer and one secondary layer, **characterised in that** the method comprises:

- providing the compensation layer with a first conductive area that is connected to the compensation winding, and
- providing the secondary layer adjacent to the compensation layer with a second conductive area that is located in parallel with the first conductive area.


106
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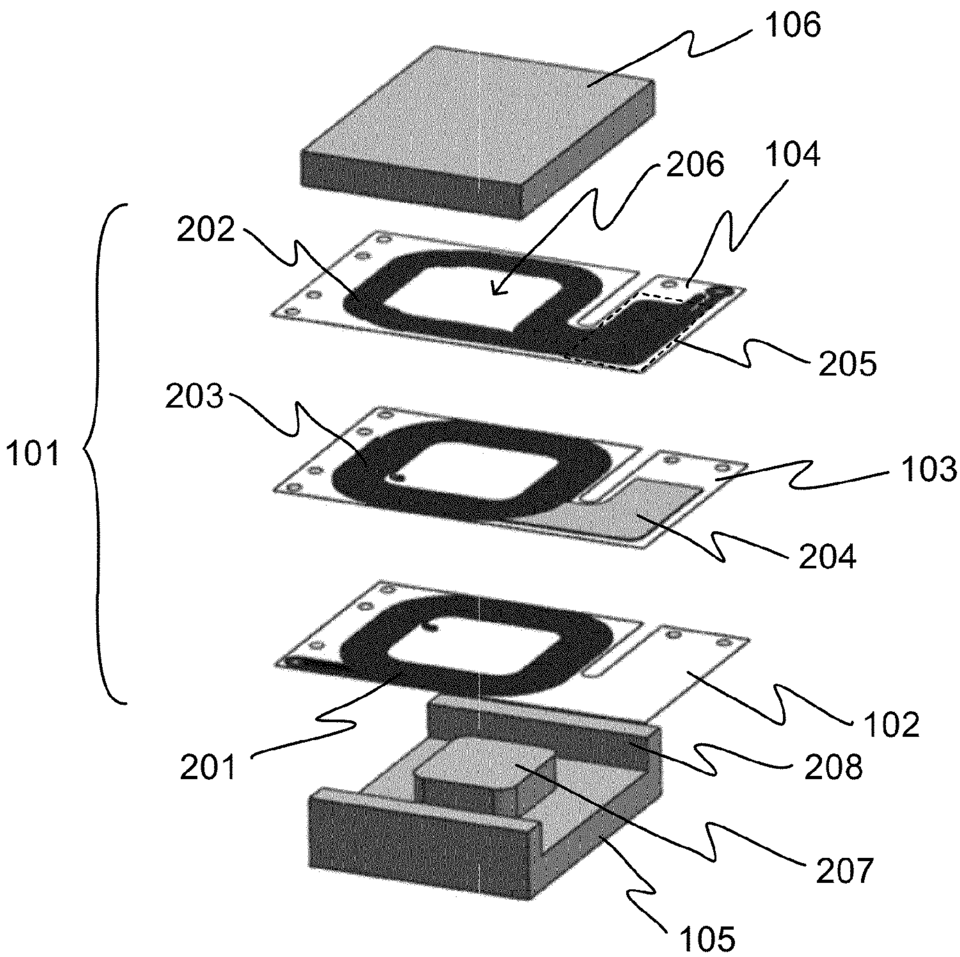
101
102
105

Fig. 1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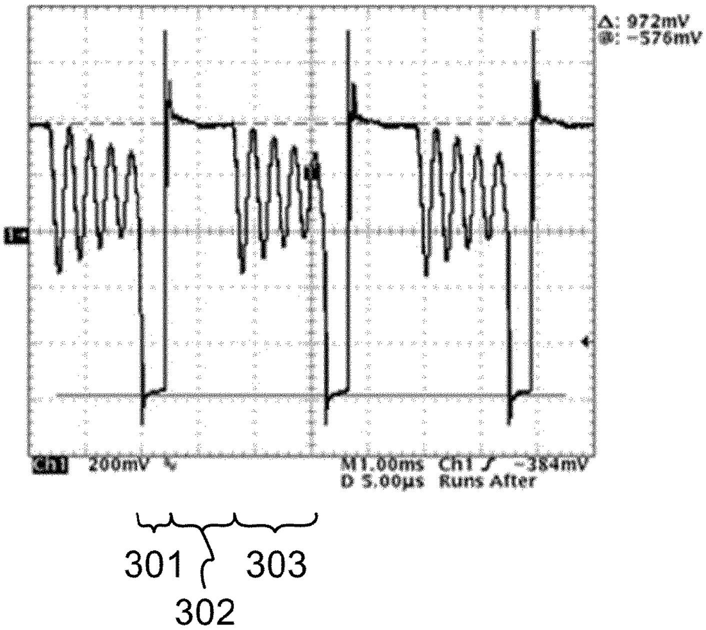
105

Fig. 2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@: -576mV
Ch1 200mV
M1.00ms Ch1 -384mV
D 5.00μs Runs After
301
302
303

Fig. 3

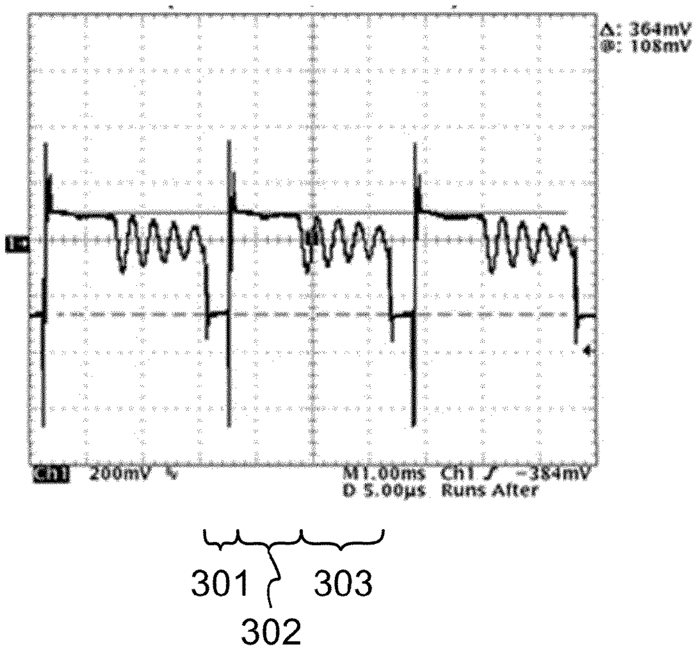
Δ: 364mV
@: 108mV
Ch1 200mV
M1.00ms Ch1 -384mV
D 5.00μs Runs After
301
302
303

Fig. 4

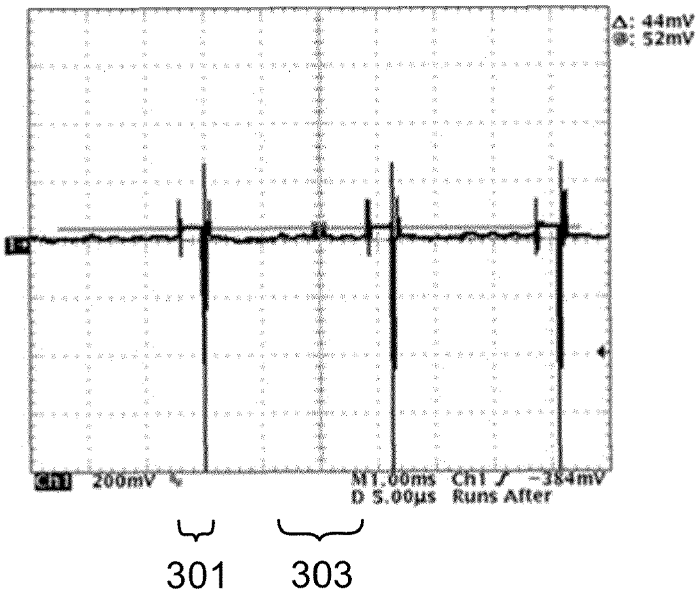
Δ: 44mV
@: 52mV
Ch1 200mV
M1.00ms Ch1 -384mV
D 5.00µs Runs After
301
303

Fig. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 18 17 5355

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	CN 107 993 814 A (SALCOMP TECH SHENZHEN CO LTD) 4 May 2018 (2018-05-04) * abstract * * figures 1-9 * -----	1 2-10	INV. H01F27/28 H01F27/33 H01F27/38 H01F27/40
A	JP 2014 053765 A (PANASONIC CORP) 20 March 2014 (2014-03-20) * abstract * -----	1-10	
A	JP 2006 156680 A (TDK CORP) 15 June 2006 (2006-06-15) * abstract * -----	1-10	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01F

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	26 October 2018	Winkelman, André

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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26-10-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		JP 2014053765 A	20-03-2014
JP 2006156680 A	15-06-2006	NONE	

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82