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(54) **Transformer and power supply using the transformer**

(57) A transformer comprises a primary winding and a secondary winding, wherein a shielding foil sheet is provided between the primary and secondary windings. The sheet comprises a material having a resistivity of more than copper. The shield is to reduce the CM-noise but with a reduction in the additional losses introduced by the shield.

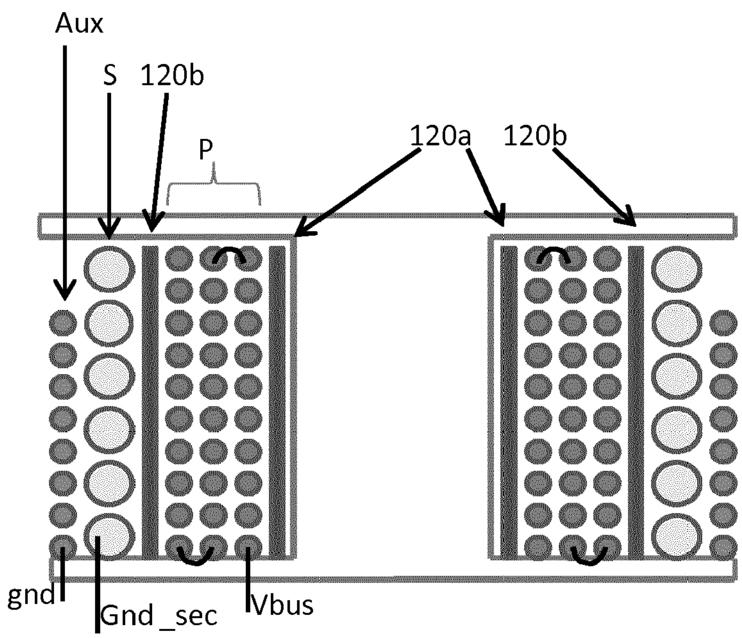

FIG. 12

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Description

[0001] This invention relates to transformers, and to power supply circuits using transformers.

[0002] A power supply is a part of system which supplies the other components of the system with energy.

[0003] In addition to the functional requirements, every system has to fulfil a number of environmental requirements including safety and EMC (electromagnetic compatibility), based on approval body directives. These directives provide a number of standards which describe what has to be done to fulfil specific requirements.

[0004] Normally, the EMC requirements are only valid for the total apparatus, but it is also customary to look at the power supply separately as a standalone apparatus. Within EMC, two areas can be distinguished: emission and immunity.

[0005] This invention relates particularly to EMC emission standards.

[0006] Every alternating source (current or voltage) will generate radiated noise via different kinds of medium (air or copper wire). This emission has to be limited to prevent other apparatus from being disturbed in their operation. The way the disturbance has to be measured and the maximum allowed level of disturbance can be found in the specific standards.

[0007] The noise which an apparatus and specifically a power supply emits can be split into common mode noise and differential mode noise. For both types, different measures have to be taken to restrict this emission. Therefore in a power supply a number of components can be found which do not contribute to the fundamental functionality but are only present to fulfil EMC regulations.

[0008] In the case of a power supply which also has a galvanic isolation the different components are shown in Figure 1.

[0009] Figure 1 shows that the mains input is coupled to an overvoltage protection varistor 10, a common mode filter 12 and a differential mode filter 14 before application to a switch mode power supply (SMPS). The SMPS the provides the power supply to the application 18, and includes a transformer providing galvanic isolation.

[0010] The various units are used to fulfil the EMC requirements of overvoltage protection, CM-filtering and differential-mode filtering.

[0011] This galvanic isolation provided by the SMPS is needed to prevent a conductive connection between the mains and the real application. To obtain a galvanic isolation, normally a transformer is used with a primary winding connected with the mains and a secondary winding connected with the application.

[0012] An alternating source is needed to transport energy from the primary side to the secondary side, but noise is also transported. Even though there is no conductive connection between the primary and secondary side, noise can be transported to the secondary side by the parasitic capacitance which is present between the primary and secondary side.

[0013] In dependence on the size of this capacitance and the capacitance to the environment, this noise can be significant. The basic formula for a capacitance is:

$$i_{cap} = C_1 \frac{dv_{c1}}{dt}$$

[0014] In this equation, i_{cap} is the capacitive current, C_1 is the size of the capacitance and V_{c1} is the voltage over the capacitance.

[0015] This formula shows that the amplitude of the capacitance current which is responsible for the noise is a product of the capacitance and rate of change of the capacitance voltage.

[0016] To restrict this noise, at least one of these terms has to be made small. Furthermore, the capacitance to the environment plays a role.

[0017] In the left part of Figure 2 an example plot is given of an EMC measurement of a flyback converter connected to the mains with galvanic isolation and the secondary side connected to the protected earth. The graph plots the EMC measurement in μV as a function of frequency.

[0018] The emission is measured via a line impedance stabilisation network (LISN), and the converter has a passive load of 5V 1A. Plot 20 represents the peak measurements and plot 22 represents the average measurements. The lines 24 represent the peak and average limits imposed by standards. It is noted that the lines 24 appear in Figure 3, 4, 8 and 10, but an explanation of these lines is not repeated. The standards require measurement at certain frequencies.

[0019] The construction of the transformer is shown in the right part of Figure 2 as a cross section through the bobbin. The transformer has two auxiliary windings (Aux 1 and Aux 2), a primary (P) and a secondary winding (S).

[0020] The auxiliary windings used to generate voltages for internal use by the power supply, such as the supply for the the primary controller.

[0021] As can be seen, the noise level is above the limit lines 24 and therefore does not meet EMC requirements. In this case, the secondary side is connected to the environment, and therefore the capacitance to the environment is taken as infinite large.

[0022] To lower the emission, some measures have to be taken. One of the basic solutions is to place a capacitor between the secondary and primary ground to offer a return path for the noise.

[0023] Together with a common mode (CM) choke the CM noise can be drastically decreased. In Figure 3 an example is given, showing the CM choke 30 and capacitor 32. The effect of this on the EMC performance is shown in the right part of Figure 3. A disadvantage is that an additional leakage current from the mains is flowing through this added y-capacitor 32 in the case that the floating secondary side is touched e.g. by the hand of a user.

[0024] In a number of cases, this additional capacitance is prohibited or may only be extremely small such as in medical applications.

[0025] If an additional capacitance is not allowed then other solutions have to be found to restrict the noise. This noise can be restricted if the size of the capacitance is decreased or the rate of change the voltage is minimized.

[0026] Examples of minimizing the capacitance include restricting the contact area between the primary and secondary windings or increasing the distance between the primary and secondary windings. Examples of minimizing the contact area include not using a sandwich construction or minimizing the number of wires.

[0027] Examples of increasing the distance include using a resonant topology with separated chambers for the primary and secondary windings (although for a flyback converter this is not really an option).

[0028] Another option is to restrict the voltage rate of change. By using copper shields or by clever constructions of the windings this can be realized.

[0029] Figure 4 shows a modification to the transformer arrangement of Figure 2 in which a copper shield 40 is provided between the primary and secondary windings, and Figure 4 also shows the resulting change in EMC performance. As can be seen, the power supply fulfils the emission requirements to 30MHz.

[0030] An alternative way to minimise the rate of change of the voltage difference Is by choosing the best sequence of windings, or by placing additional layers between windings to shield the voltage or by cancelling currents.

[0031] Figure 5 shows a first example of transformer structure which is based on choosing the right sequence of windings to minimise the voltage difference. For example, with respect to the primary winding P, the turns close to the drain voltage will vary more in voltage than the turns close to the bus voltage. This is shown in Figure 5 by the waveforms. Thus, by placing the appropriate turns from the primary P and secondary S windings opposite each other the voltage difference can be minimized and therefore the noise current.

[0032] As shown in Figure 6, an alternative is to apply between the primary P and secondary S winding an additional winding 60 with the same polarity (voltage variation) as the secondary winding S but connected to the Vbus voltage on the primary side. The additional winding acts as shield. The capacitance on the primary side will be larger but the voltage difference between the primary and secondary sides will be almost zero. A disadvantage is the increase in thickness of the total winding package and the increase in losses.

[0033] An alternative shielding method is to use a one turn foil instead of an additional winding. The foil is less effective but is less thick. The voltage difference of the last layer which is:

$$Vbus/_{(number\ of\ layers)}$$

is replaced by:

$$V_{bus}/n_p$$

[0034] Figure 7 shows the additional winding 60 of Figure 6 replaced with a one turn shield 70, over the full winding width. Such a shield is made of copper foil.

[0035] Figure 8 shows the emission of a 5W adapter with a copper shield between the secondary and primary windings.

[0036] As can be seen in Figure 8, the disturbance measured by the receiver is much lower than without the shield. The disadvantage is that by using a shield, the magnetic field component perpendicular to this shield will induce a voltage and therefore a current in the shield. In addition to these capacitive losses, the shield will give rise to eddy current losses. These losses will be relatively high because of the low electrical resistivity (ρ=1.75*10-8) of copper.

[0037] In Figure 9, the difference in dissipation is shown between a flyback converter (5V, 1A) with a transformer with shield (plot 90) and a transformer without shield (plot 92). Figure 9 plots the efficiency against the output power. As can be seen, the losses increase as a result of the shield, as can be seen as a reduction in efficiency.

[0038] In summary, the first known methods to restrict CM-noise on the mains cable use a y-capacitor in combination with some external filter (CM-choke). If this method is not allowed because the leakage current from primary side to secondary side has to be minimized for e.g medical reasons or discomfort (e.g holding a mobile phone, connected to a charger) then other methods have to be found to restrict CM-noise. Second methods thus involve minimizing capacitance between the primary and secondary windings and/or minimizing the rate of change of the voltage difference.

[0039] According to the invention, there is provided a transformer and power supply as defined in the claims.

[0040] The invention provides a transformer comprising a primary winding and a secondary winding, wherein a shielding foil sheet is provided between the primary and secondary windings, comprising a material having a resistivity of more than $2 \times 10^{-8}\ \Omega m$ at 20 degrees Celsius.

[0041] The shielding foil has a higher resistance than copper. The increased resistance compared to copper results in reduced eddy current losses, while maintaining the electromagnetic shielding advantages. The material can have a resistivity of more than $4 \times 10^{-8}\ \Omega m$ at 20 degrees Celsius.

[0042] The higher the resistivity, the lower the shielding. Also the capacitance between the shield and the secondary winding plays a role. The shield has to be connected to a reference point (ground or bus voltage), so not all materials are suitable. Furthermore thin sheets have to made of the material and the material has to be flexible.

[0043] Taking these constraints into account, the material preferably comprises a copper-based alloy.

[0044] One example is brass such as CuZn30 brass, and another is bronze.

[0045] A first shielding foil sheet can be provided at the inside of the primary winding and a second shielding foil sheet of the same material can be provided at the outside of the primary winding.

[0046] In one arrangement, the primary winding is provided around a bobbin, and the secondary winding is provided around the outside of the primary winding, with the shielding foil sheet between them. This provides two shielding layers which sandwich the primary winding.

[0047] An auxiliary winding can be provided around the outside of the secondary winding.

[0048] The invention also provides a switch mode power supply comprising a transformer of the invention.

[0049] Examples of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a known power supply circuit;

Figure 2 shows an EMC measurement of a flyback converter as well as the construction of the transformer in the converter;

Figure 3 shows a power supply circuit using a common mode (CM) choke and capacitor, and also shows the effect of this on the EMC performance;

Figure 4 shows a modification to the transformer arrangement of Figure 2 in which a copper shield is provided between the primary and secondary windings, and also shows the resulting change in EMC performance;

Figure 5 shows a first example of transformer structure is based on choosing the right sequence of windings to minimise the voltage difference;

Figure 6 shows a transformer with an additional winding between the primary P and secondary S windings;

Figure 7 shows a transformer with the additional winding of Figure 6 replaced with a one turn shield;

Figure 8 shows the emission of a 5W adapter with a copper shield between the secondary and primary windings;

Figure 9 shows the difference in dissipation between a flyback converter with a transformer with shield and a transformer without shield;

Figure 10 shows the change to the EMC spectrum when the copper shield in a transformer is replaced by a bronze shield in accordance with one example of the invention;

Figure 11 shows an efficiency plot for the use of a copper shield, a bronze shield, and no shield; and

Figure 12 shows a transformer arrangement with two shields.

[0050] The invention provides a transformer comprising a primary winding and a secondary winding, wherein a shielding foil sheet is provided between the primary and secondary windings. The sheet comprises a material having a resistivity of more than copper.

[0051] The invention is based on obtaining the advantages of a foil shield but avoiding the disadvantage of a large increase of energy dissipation.

[0052] A foil material with a higher electrical resistivity can reduce the losses. Preferably the used foil material should have good solderability for simple electrical connection of the foil to ground.

[0053] Looking for available foil materials with both mentioned properties two materials are of particular interest:

1. CuZn30 (brass with 70% copper and 30% zinc)
2. CuSn6 (bronze)

[0054] The electrical resistivity for these two materials at room temperature are respectively $6.25*10^{-8}\Omega$m and $13.3*10^{-8}\Omega$m. For copper at 20 degrees, the resistivity is $1.75 \times 10^{-8}\ \Omega$m. Thus, the brass and bronze have resistivity 3.6 and 7.6 times higher than copper, so that the resistance for the same dimensions is higher by this factor.

[0055] Figure 10 shows the result of the spectrum when the copper shield in a transformer is replaced by a bronze shield. Compared to the spectrum in Figure 8 hardly any difference can be seen. However, the efficiency plot of Figure 11 shows an increase of approximately of 0.5% in efficiency. Plot 110 is for the use of a copper shield (corresponding to plot 90 in Figure 9), plot 112 is for the use of a bronze shield, and plot 114 is for no shield.

[0056] In this example, one shield is used but two shields can be used as shown in Figure 12.

[0057] Figure 12 shows shields 120a and 120b between which the primary winding P is sandwiched. This arrangement of the transformer gives even more efficiency gain.

[0058] The foils sheet or sheets of the invention are insulated from the other windings by having a coating or by using a layer of isolation tape.

[0059] The use of a higher resistivity shield (such as brass or bronze) in the transformer between the primary and the secondary windings enables the common-mode noise to be minimized and makes the use of a y-capacitor and CM-choke superfluous or at least lower in value. By using a shield from a conductive material with a higher resistivity than that of copper, the same reduction of CM-noise can be reached as with copper but the additional losses can be lower. Therefore the efficiency of a power converter based on the transformer can be increased.

[0060] Copper based alloys have been given as examples. Another example is an aluminium foil, although the electrical connection is then less straightforward. Tin is a further option.

[0061] In the examples above, a shield is provided between the primary and secondary windings. A shield can be provided between the different layers of turns within the primary and secondary windings.

[0062] The shield or shields are connected to the voltage which gives the best performance. This could be the primary ground, or the bus voltage or even an AC voltage if this gives the best result.

[0063] The invention can be used in all transformers used in switch mode power supplies supporting galvanic isolation. By using a shield of foil with higher resistance than copper, CM-noise can be effectively reduced with less increase of losses.

[0064] Various modifications will be apparent to those skilled in the art.

Claims

1. A transformer comprising a primary winding and a secondary winding, wherein a shielding foil sheet is provided between the primary and secondary windings, comprising a material having a resistivity of more than 2×10^{-8} Ωm at 20 degrees Celsius.

2. A transformer as claimed in claim 1, wherein the material has a resistivity of more than 4×10^{-8} Ωm at 20 degrees Celsius.

3. A transformer as claimed in any preceding claim, wherein the material comprises a copper-based alloy.

4. A transformer as claimed in claim 3, wherein the material comprises brass.

5. A transformer as claimed in claim 4, wherein the material comprises CuZn30 brass.

6. A transformer as claimed in claim 3, wherein the material comprises bronze.

7. A transformer as claimed in any preceding claim, comprising a first shielding foil sheet at the inside of the primary winding and a second shielding foil sheet of the same material at the outside of the primary winding.

8. A transformer as claimed in any preceding claim, wherein the primary winding is provided around a bobbin, and the secondary winding is provided around the outside of the primary winding, with the shielding foil sheet between them.

9. A transformer as claimed in claim 8, further comprising an auxiliary winding around the outside of the secondary winding.

10. A switch mode power supply comprising a transformer as claimed in any preceding claim.

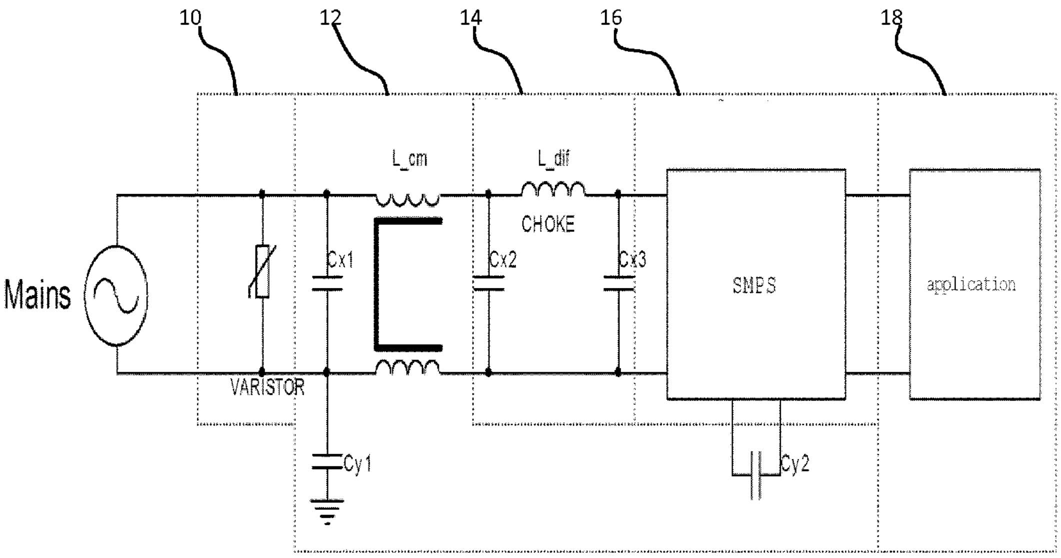
10
12
14
16
18
L_cm
L_dif
CHOKE
Mains
Cx1
Cx2
Cx3
SMPS
application
VARISTOR
Cy1
Cy2

FIG. 1

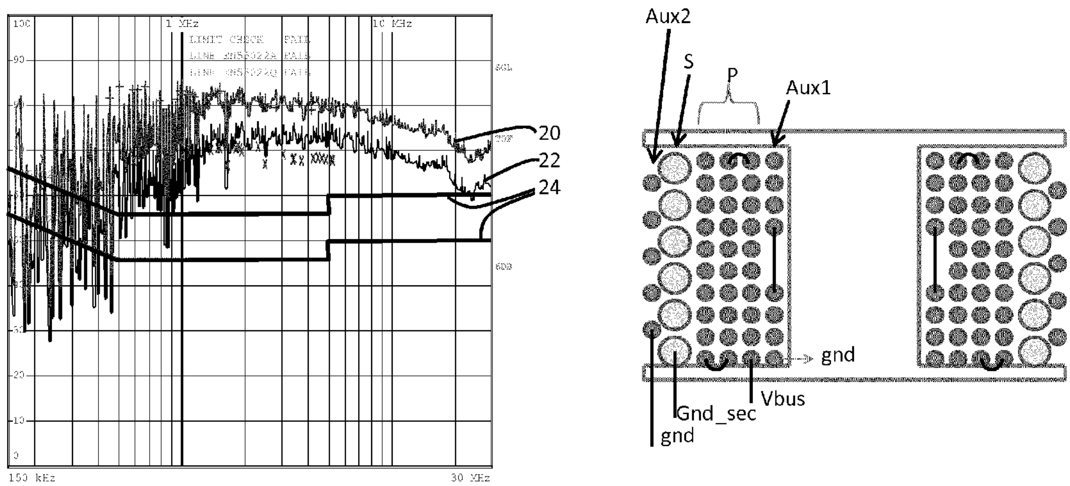

FIG. 2

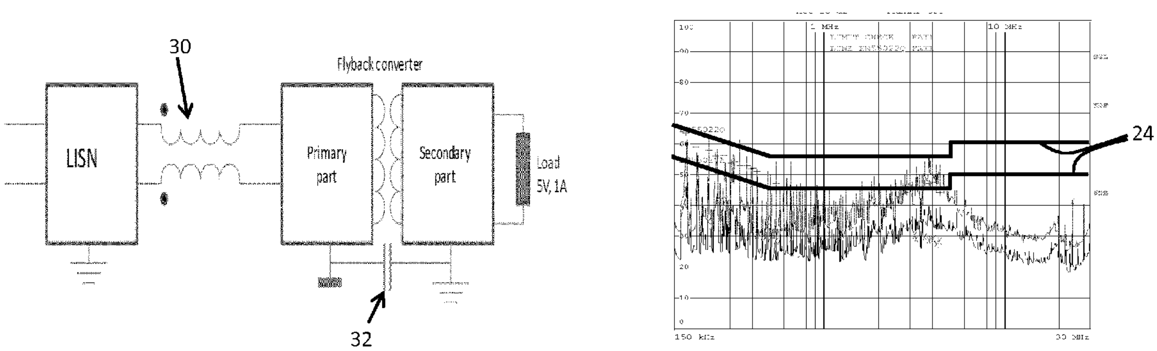
30
Flyback converter
LISN
Primary part
Secondary part
Load 5V, 1A
32
24
150 kHz
30 MHz
1 MHz
10 MHz

FIG. 3

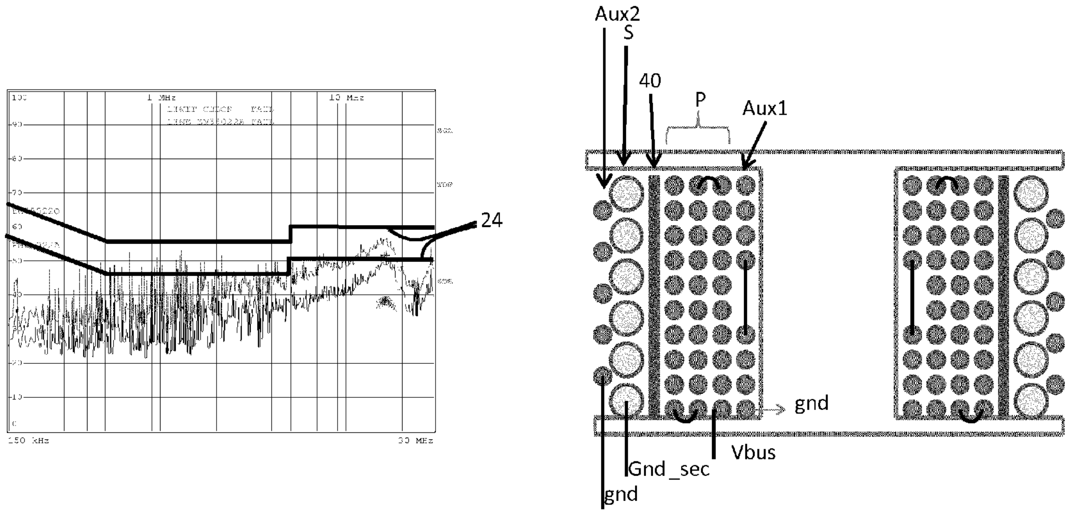

FIG. 4

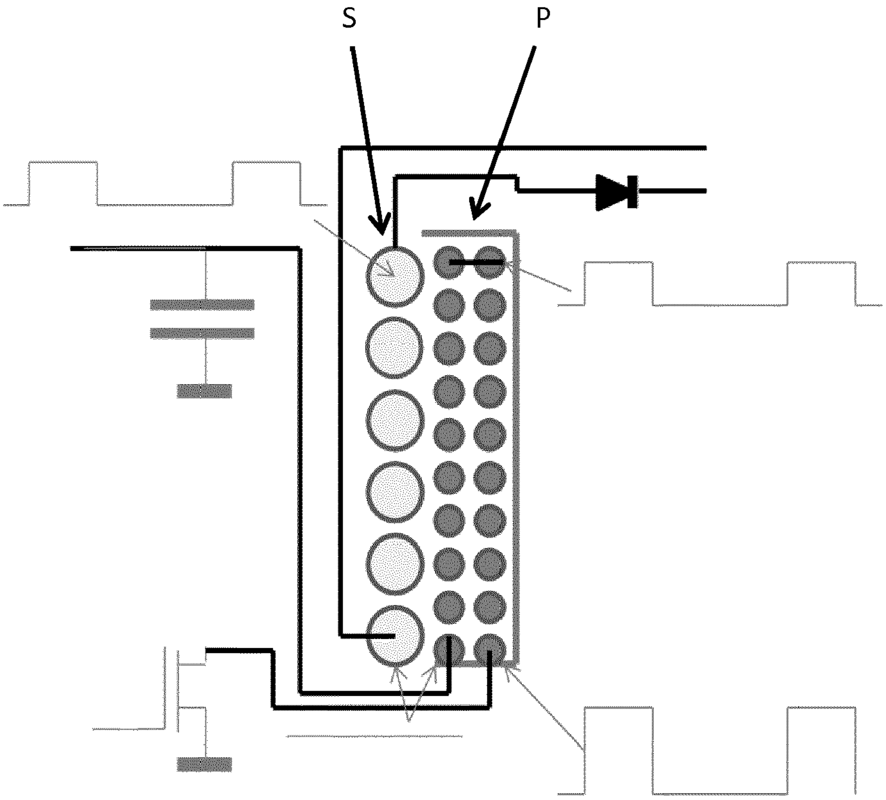

FIG. 5

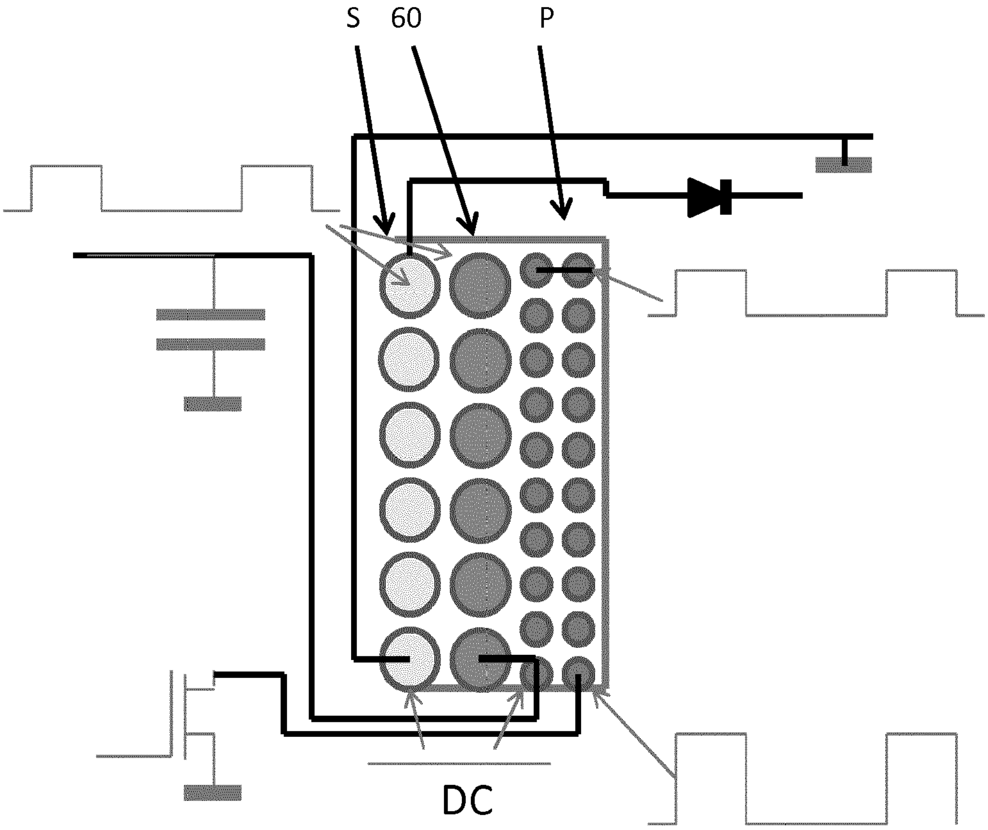

FIG. 6

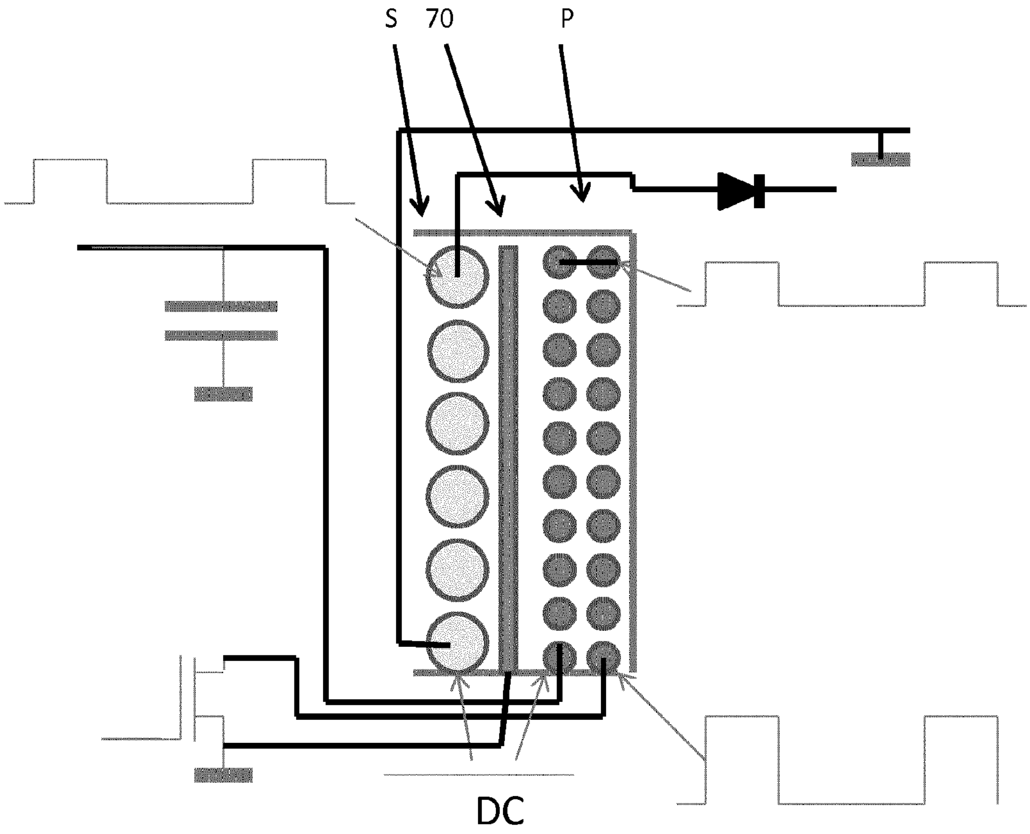

FIG. 7

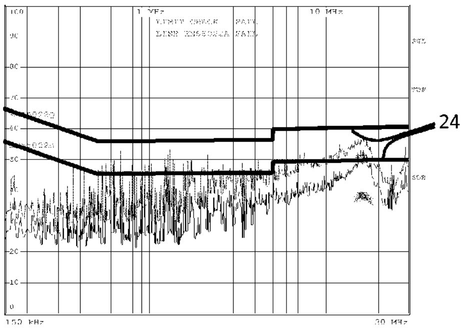

FIG. 8

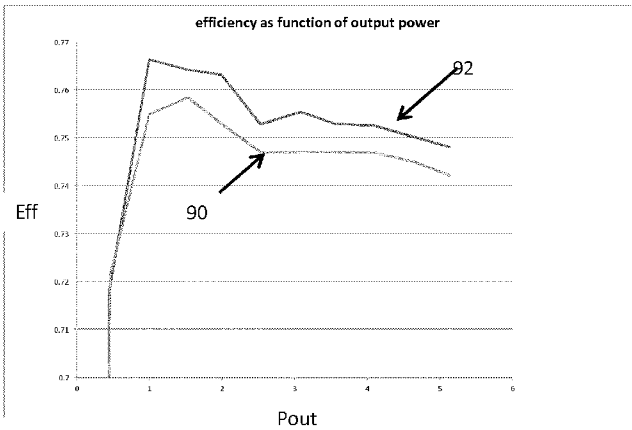

FIG. 9

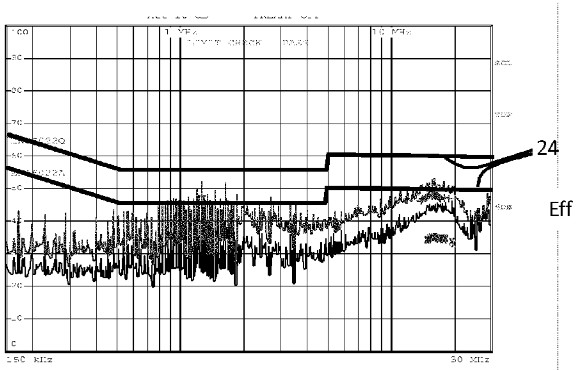
24

FIG. 10

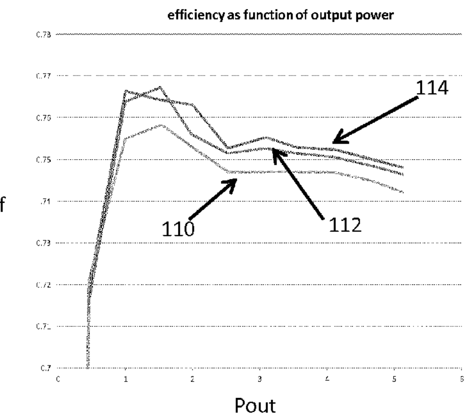
efficiency as function of output power
114
110
112
Eff
Pout

FIG. 11

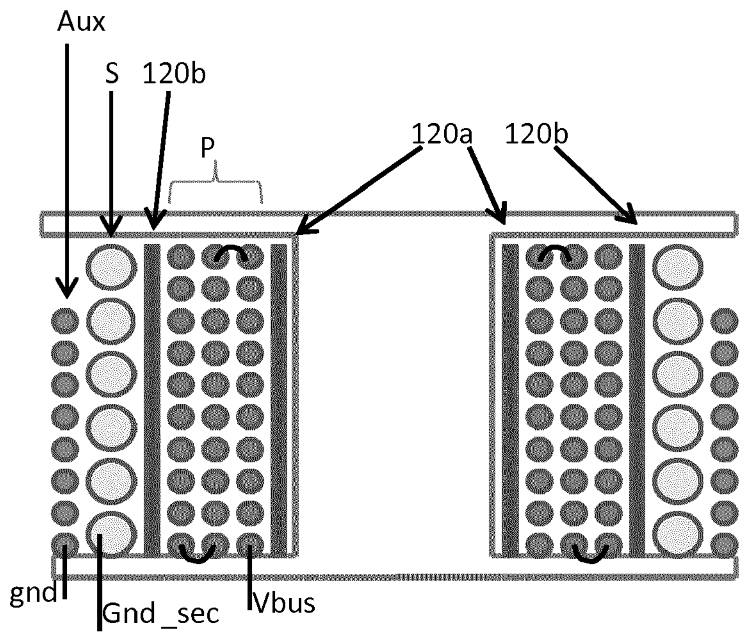

FIG. 12

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EUROPEAN SEARCH REPORT

Application Number
EP 13 16 5415

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 Y	EP 0 291 093 A2 (MATSUSHITA ELECTRIC IND CO LTD [JP]) 17 November 1988 (1988-11-17) * column 9, line 7 - line 13; figure 2 * * column 10, line 19 - line 37 * -----	1-3 4-6	INV. H01F27/28 H01F27/36
A	"Monel alloy 400 (Ni65/Cu33/Fe2)", , 1 January 2013 (2013-01-01), XP055067124, Retrieved from the Internet: URL:http://www.goodfellow.com/E/Monel-alloy-400.html [retrieved on 2013-06-18] * the whole document * -----	1	
X	EP 1 284 487 A2 (BOSE CORP [US]) 19 February 2003 (2003-02-19) * paragraphs [0004] - [0006], [0013]; figures 1-5 * -----	1,2,10	
Y A	US 4 308 512 A (CAPECCHIACCI GIORGIO ET AL) 29 December 1981 (1981-12-29) * column 6, line 42 - column 8, line 3; figure 1 * -----	4,6 1-3	TECHNICAL FIELDS SEARCHED (IPC) H01F
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~~The present search report has been drawn up for all claims~~

1

Place of search	Date of completion of the search	Examiner
Munich	18 June 2013	Rouzier, Brice

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

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EUROPEAN SEARCH REPORT

Application Number
EP 13 16 5415

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	Arnaud Devred: "Service technique de cryogénie et de magnétisme", , 1 January 1998 (1998-01-01), XP055067118, Retrieved from the Internet: URL:http://lss.fnal.gov/archive/other/dapnia-stcm-98-02.pdf [retrieved on 2013-06-18] * page 10, paragraph 5.5 * -----	1-3,6	
A	US 3 376 531 A (FISCHER HEINZ G ET AL) 2 April 1968 (1968-04-02) * column 1, line 60 - line 72 * -----	1	
A	EP 0 585 650 A1 (ANT NACHRICHTENTECH [DE] BOSCH GMBH ROBERT [DE]) 9 March 1994 (1994-03-09) * column 3, line 8 - line 11; figure 1 * -----	1	
			TECHNICAL FIELDS SEARCHED (IPC)

~~The present search report has been drawn up for all claims~~

1

Place of search	Date of completion of the search	Examiner
Munich	18 June 2013	Rouzier, Brice

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

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Application Number
EP 13 16 5415

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1-6, 10

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 13 16 5415

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-6, 10

   Use of a particular foil sheet material.

   ---

2. claims: 1, 7-9

   A particular arrangement of shielding means provided inside and outside the primary windings.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 13 16 5415

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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18-06-2013

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