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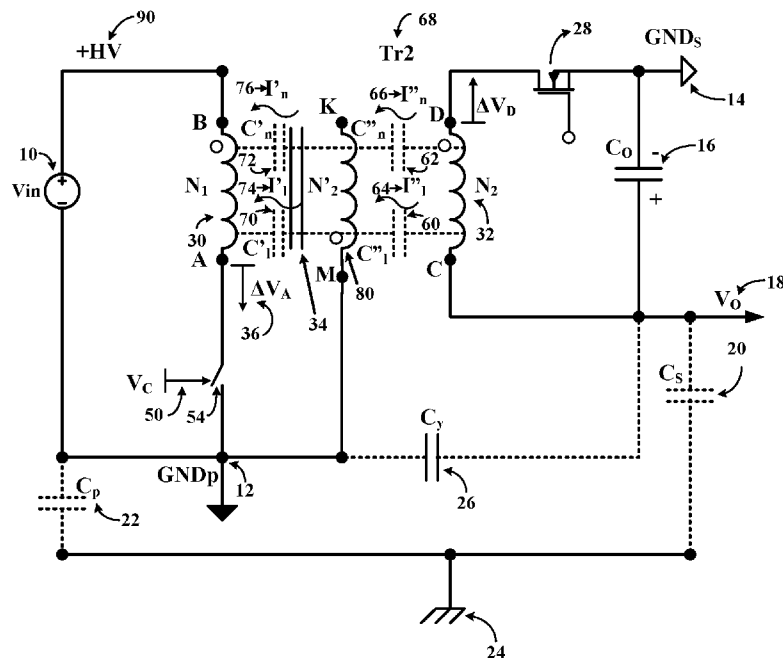


Fig. 5A

(57) Abstract: A system for reducing common-mode noise includes a switch mode power supply having primary and secondary sides, primary and secondary side grounds (12, 14), an input voltage source (10), a primary switch (54), a transformer (68), a core (158), and a power output. The primary and secondary sides each have a quiet termination (12, 18). The transformer (68) includes a primary winding (30), a secondary winding (32), and an active shield winding (80) between the primary and secondary windings (30, 32). The active shield winding (80) has two terminations (K, M), is wound in a same direction as the secondary winding (32), and occupies a same axial position on the core as the secondary winding. One of the terminations of the active shield winding (80) is connected to the quiet termination (12) of the primary side, so that the terminations of the secondary winding and the active shield winding that are



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POWER TRANSFORMER FOR MINIMUM NOISE INJECTION IN BETWEEN
PRIMARY AND SECONDARY WINDING “ROMPOWER ACTIVE SHIELD”

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 62/787,199, filed December 31, 2018, which is hereby incorporated by reference.

FIELD

[0002] This specification relates to power converters and in particular to the reduction of noise emissions or electromagnetic interference (EMI) in switch mode power supplies or other applications.

BACKGROUND

[0003] High Frequency noise, or Electro-Magnetic Interference (EMI), is generated by the switching elements in a power converter using an isolated power transformer, via the primary-secondary stray capacitances, either back to the line supplying the SMPS or into the load that it is powering. Such noise is also radiating and may affect any sensitive nearby components and circuits. There are strict conducted and radiated emission standards with which commercial devices have to comply.

[0004] Over the years, engineers developed many solutions to reduce interference generated by isolated switch mode power supplies which apply to common mode noise arising from capacitive coupling between windings and between magnetic core and windings associated with the transformer. Y capacitors are used between primary and secondary sides to

bypass the noise. However, Y capacitors increase the earth leakage current which places a limit on the value of the Y capacitors.

[0005] Electrostatic shields are also used to provide a solution to the passage of noise via capacitive displacement currents through the stray capacitance coupling in the transformer. A shield is usually made of an incomplete turn foil or a bobbin-width wire winding. The common mode noise couples across the shield stray capacitance and returns to the circuit connected to the shield usually the primary ground.

[0006] In U.S. Patent No. 5,990,776, Jitaru describes the problems associated with conventional shields, which include an increase of the parasitic capacitance across the primary winding and secondary winding. Jitaru proposes different techniques to minimize these drawbacks. Jitaru also offers some methodologies of shielding which can be applied in planar transformers. In planar transformers, the parasitic capacitances between windings are larger than those in conventional transformers due to the geometry of the windings. Jitaru also presents different methodologies for noise cancellation. Because the shield – or even multiple shields - between primary and secondary windings do not fully cancel the common mode current injected into the earth ground, cancellation methods of the residual noise have to be applied.

[0007] There are different methodologies used for the noise cancellation. Besides the methods suggested by Jitaru in the US Patent 5,990,776, there are other techniques such as the one presented in the US Patent No. 6,549,431. The solutions depicted there may increase the leakage inductance and add cost and complexity.

[0008] US Patent No. 5,724,236 presents a method of noise cancellation in which the classical shield is not connected to ground but to an auxiliary winding which injects a signal via the conventional shield into the secondary winding, a signal which is designed to be of opposite polarity of the residual noise.

[0009] U.S. Patent No. 8,023,294 presents different methods of noise cancellation in which there is an auxiliary winding to provide noise suppression in antiphase to the common mode noise which reaches the secondary winding and the coupling of this cancellation signal to the secondary winding is not done through the shield placed in between primary and secondary, as in U.S. Patent No. 5,724,236, but through other means such as an additional

shield placed in vicinity of the secondary winding or through the magnetic core or even through the conductive strap placed around the magnetic core.

[0010] U.S. Patent No. 5,107,411 presents a method of eliminating noise injection between primary and secondary without the use of a shield but rather by creating an ideal symmetry between the primary and secondary windings adjacent to each other and in which the primary and secondary winding adjacent to each other carry alternating voltages of the same polarity in the operating conditions. As a result, there is not displacement current through the parasitic capacitance between primary and secondary windings. This works well if the turns ratio in the transformer, which is the ratio between the members of turns in primary and secondary, is 1:1. In the case of different turn ratios, additional primary or secondary coils are required in the transformer. The solution from the above patent does not cover additional noise injection which can come through the magnetic core, layout and other coupling into the EMI filter.

SUMMARY

[0011] In an embodiment, a system for reducing common-mode noise includes a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a transformer, a core, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground. The transformer includes a primary winding on the primary side connected to the input voltage source via the primary switch, a secondary winding on the secondary side connected to the power output via a rectifier means, and an active shield winding placed between the primary and secondary windings, wherein the active shield winding has two terminations, is wound in a same direction as the secondary winding, and occupies a same axial position on the core as the secondary winding. The active shield winding and secondary winding each have a number of turns. One of the two terminations of the active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield winding that are adjacent each other carry alternating voltages of a same polarity and a same amplitude. In an embodiment, the number of turns of the active shield winding is the same as the number of turns of the secondary winding. In another embodiment, the number of turns of the active shield winding is different from the number of turns of the secondary winding, so as to induce a voltage into the secondary winding which has a polarity that is opposite a polarity of a residual common mode noise injected from the primary winding to the secondary winding.

[0012] In an embodiment, a system for reducing common-mode noise includes a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a transformer, a core, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground. The transformer includes a primary winding on the primary side connected to the input voltage source via the primary switch, a secondary winding on the secondary side connected to the power output via a rectifier means, and an active shield winding placed between the primary and secondary windings, wherein the active shield winding has two terminations, is wound in a same direction as the secondary winding, and

occupies a same axial position on the core as the secondary winding. The active shield winding and secondary winding each have a number of turns. One of the two terminations of the active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield winding that are adjacent each other carry alternating voltages of an opposite polarity and a same amplitude. In an embodiment, the number of turns of the active shield winding is the same as the number of turns of the secondary winding. In another embodiment, the number of turns of the active shield winding is different from the number of turns of the secondary winding, so as to induce a voltage into the secondary winding which has a polarity that is opposite a polarity of a residual common mode noise injected from the primary winding to the secondary winding.

[0013] In an embodiment, a system for reducing common-mode noise includes a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a transformer, a core, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground. The transformer includes primary winding on the primary side connected to the input voltage source via the primary switch, a secondary winding on the secondary side connected to the power output via a rectifier means, and at least two active shield windings. The active shield windings are adjacent to the secondary winding on both sides of the secondary winding, are wound in a same direction as the secondary winding, occupy a same axial position on the core as the secondary winding, and each have two terminations. The active shield windings and the secondary windings each have a number of turns. One of the two terminations of each active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield windings that are adjacent each other carry alternating voltages of a same polarity and a same amplitude. In an embodiment, the number of turns of the active shield windings is the same as the number of turns of the secondary winding. In another embodiment, the number of turns of the active shield windings is different from the number of turns of the secondary winding, so as to induce a voltage into the secondary winding which has a polarity that is opposite a polarity of residual common mode noise injected from the primary winding to the secondary winding. In yet another embodiment, the transformer is implemented in a multilayer PCB and, on both sides of the secondary winding, windings on layers of the PCB that are adjacent to the secondary winding mirror the secondary winding and carry alternating voltages

of a same polarity and same amplitude as the secondary winding. In still another embodiment, the windings on the layers of the PCB that are adjacent to the secondary winding are part of the primary winding.

[0014] In an embodiment, a system for reducing common-mode noise includes a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a transformer, a core, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground. The transformer includes primary winding on the primary side connected to the input voltage source via the primary switch, a secondary winding on the secondary side connected to the power output via a rectifier means, and at least two active shield windings. The active shield windings are adjacent to the secondary winding on both sides of the secondary winding, are wound in a same direction as the secondary winding, occupy a same axial position on the core as the secondary winding, and each have two terminations. The active shield windings and the secondary windings each have a number of turns. One of the two terminations of each active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield windings that are adjacent each other carry alternating voltages of an opposite polarity and a same amplitude. In an embodiment, the number of turns of the active shield windings is the same as the number of turns of the secondary winding. In another embodiment, the number of turns of the active shield windings is different from the number of turns of the secondary winding, so as to induce a voltage into the secondary winding which has a polarity that is opposite a polarity of residual common mode noise injected from the primary winding to the secondary winding.

[0015] In an embodiment, a system for reducing common-mode noise includes a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a multilayer PCB transformer having a planar magnetic core with multiple legs, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground. The transformer includes a primary winding on the primary side, which primary winding encircles the multiple legs of the planar magnetic core and is connected to the input voltage source via the primary

switch of the power supply, and a secondary winding on the secondary side, which secondary winding encircles the multiple legs of the planar magnetic core and is connected to the power output via a rectifier means. The system further includes at least two active shield windings, wherein the active shield windings are adjacent to the secondary winding on both sides of the secondary winding, mirror the adjacent secondary winding, are wound in a same direction as the secondary winding, have a same number of turns as the secondary winding, and each have two terminations. One of the two terminations of each active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield windings that are adjacent each other carry alternating voltages of a same polarity and a same amplitude. In an embodiment, the active shield windings is connected to the quiet termination of the primary side via an auxiliary winding around one of the legs of the planar magnetic core, and the auxiliary winding induces a voltage into the active shield windings which has a polarity that is opposite a polarity of a residual common mode noise injected from the primary winding to the second winding.

[0016] The above provides the reader with a summary of some embodiments described below. Simplifications and omissions are made, and the summary is not intended to limit, define, or focus the disclosure or claims in any way. Similarly, some parts of the detailed description and drawings are specifically summarized above, but nonetheless, the summary is not intended to limit, define, or focus the disclosure or claims in any way. Rather, this summary merely introduces the reader to some aspects of some embodiments in preparation for the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Referring to the drawings:

Figure 1A depicts a power train of a flyback converter with a “low side secondary rectifier”;

Figure 1B depicts equations associated with the circuit from Figure 1A;

Figure 2 depicts two waveforms from the circuit presented in Figure 1A;

Figure 3A depicts a power train of a flyback converter with a “high side secondary rectifier”;

Figure 3B depicts equations associated with the circuit from Figure 3A;

Figure 4A depicts a power train of a flyback converter with a “high side secondary rectifier” and the active shield;

Figure 4B depicts equations associated with the circuit from Figure 4A;

Figure 5A depicts a power train of a flyback converter with a “low side secondary rectifier” and an active shield;

Figure 5B depicts equations associated with the circuit from Figure 5A;

Figure 5C depicts a power train of the flyback converter a “low side secondary rectifier” and an active shield, wherein the displacement current in between the active shield winding and the secondary winding is zero by injecting between the active shield winding and the secondary winding displacement currents of the same amplitude and opposite polarities;

Figure 5D depicts equations associated with the circuit from Figure 5C;

Figure 6A depicts a power train of a flyback converter with a “high side secondary rectifier” and a dual active shield;

Figure 6B depicts a winding arrangement in a transformer bobbin;

Figure 7A presents a noise cancellation technique by adding fractional turns;

Figure 7B presents a noise cancellation technique by subtracting fractional turns;

Figure 8 presents an embodiment applied to a planar transformer;

Figure 9A presents an embodiment in which the displacement current between the active shield and the primary winding is minimized;

Figure 9B presents an embodiment in which the primary winding incorporated in two layers of a PCB is a total mirror of the secondary winding adjacent to the primary winding and there is no displacement current between primary and secondary winding;

Figure 9C presents an embodiment in which the primary winding also has the role of an active shield;

Figure 10A presents EMI test results for a 30W flyback converter using a transformer with no shield between the primary and secondary windings;

Figure 10B depicts a bobbin of the transformer used in the EMI test presented in Figure 10A just before the secondary winding is wound;

Figure 11A depicts EMI test results for a 30W flyback converter using a transformer with one conventional foil copper shield between the primary and secondary windings;

Figure 11B depicts a bobbin of the transformer used in the EMI test presented in Figure 11A just, after the copper foil shield is placed and before the secondary winding is wound;

Figure 12A depicts EMI test results for a 30W flyback converter using a transformer with the active shield;

Figure 12B depicts a bobbin of the transformer used in the EMI test presented in Figure 12A, just after the active shield is placed and before the secondary winding is wound;

Figure 13 depicts EMI test results for a 30W flyback converter using a transformer with an active shield, wherein the number of turns in the shield is three turns instead of four as the secondary winding;

Figure 14 depicts EMI test results for a 30W flyback converter using a transformer with

the active shield, wherein the number of turns in the shield is five turns instead of four turns as the secondary winding;

Figure 15A depicts a magnetic core structure using four identical posts;

Figure 15B presents a vertical cross-section of the magnetic structure of Figure 15A;

Figure 15C presents a power train and a transformer structure for a “low side secondary rectifier” and an active shield;

Figure 15D presents primary winding for the magnetic structure of Figure 15A;

Figure 15E presents the secondary winding and the active shield winding for the magnetic structure from Figure 15A;

Figure 16A presents an interleaved magnetic structure using two active shield winding and split primary winding configuration;

Figure 16B presents EMI test results of a flyback converter using a flyback transformer as in Figure 16A;

Figure 16C presents EMI test results of a flyback converter using a flyback transformer as in Figure 16A and with $N_{3'}$ is seven turns;

Figure 17A presents an interleaved magnetic structure using two interleaved shield winding wherein the second active shields connected; and

Figure 17B presents EMI test results of a flyback converter using a flyback transformer as in Figure 17A and with $N_{3'}$ is six turns and $N_{3''}$ is seven turns.

DETAILED DESCRIPTION

[0018] In Figure 1A is presented a flyback converter having an input voltage source, V_{in} , 10, a primary switch, 54, a control signal V_c , 50, which closes and opens the switch S, a transformer Tr1, 52, composed by a primary winding 30, a secondary winding 32, and a magnetic core 34. In the secondary there is a rectification means, 28, which can be a diode or a synchronized rectifier, and an output capacitor C_o , 16. For simplicity in this specification the rectification means has a cathode and an anode. In the event a synchronized rectifier is used the cathode of the rectifier means is the drain of the Mosfet and the anode of the rectification means is the source of the Mosfet. There is a primary side ground, 12 and a secondary side ground, 14. In between primary side and secondary side there is a Y capacitor C_y , 26 and a parasitic capacitor C_p , 22, between the primary ground 12 and the electrical earth 24. There is a parasitic capacitor C_s between the secondary ground, 14 and the electrical earth, 24. In some cases this capacitance is shorted out by a direct electrical connection between the secondary ground and earth ground.

[0019] In between primary winding, 30 and secondary winding 32, there are parasitic capacitances. The model is simplified, using just two parasitic capacitances at the terminations of the primary and secondary windings, C_1 , 42 and C_n , 46.

[0020] In Figure 2 are presented two key waveforms in the flyback topology, $V(S)$ which is the voltage across the primary switch S, and the control voltage V_c , 50. The voltage across the primary switch $V(S)$ does have several transitions. For simplicity, focus on the transition when the primary switch is closed. At that time the voltage across S, 54, start decreasing from a high voltage level which in discontinuous mode flyback is the input voltage V_{in} , after the natural ringing caused by the resonance in between the inductance of the primary winding and the parasitic capacitance reflected across the primary switch, amortizes. The time interval when both switchers, S, 54 and the output rectification means, 28 are not conducting, is referred in this specification as dead time. The primary winding has two terminations, A and B. The termination A is connected to the primary switch S and the other termination B is connected to V_{in} . The secondary winding has also two terminations.

[0021] One termination C is connected to the output voltage V_o , 18, and the other termination D is connected to the cathode of the rectifier means, 28.

[0022] When the primary switch S is closed the voltage in A, starts falling with a high voltage slope, and the voltage swing is ΔV_A . The other end of the parasitic capacitor C1, 42, is connected to C and the voltage in C does not change in report to the secondary ground GNDs, 14. A current I1, 38, will start flowing through the capacitor C1, from the secondary ground, 14 via Co, and further through S towards the primary ground, 12. This is referred as a common mode current, which is minimized in order to meet the EMI requirements. On the other end of the primary winding, in B, the voltage does not change versus input ground, 12,. On the other end of the parasitic capacitance Cn, 46, which is connected to D of the secondary winding the voltage will go up by a level ΔV_D . As a result of the voltage swing in D, a current will start flowing through Cn, 46 which is part of the common mode noise between primary ground and secondary ground. There are many parasitic capacities between primary winding and secondary winding and the amplitude of the currents through these parasitic capacitances will be function of the voltage swings at each terminal versus input ground and respectively output ground. For simplicity, the focus is only on the parasitic capacitances C1, 42 and Cn, 46.

[0023] In Figure 1B are presented the formulas describing the displacement current through the parasitic capacities C1, 42 and Cn, 46. In formula 4 and 5 of Figure 1B shows that the displacement current In, and I1 are proportionate with the Vin. A constant K is introduced which is proportionate with the value of the parasitic capacitance C1 and Cn and the slope of the voltage change.

[0024] The circuit configuration of the flyback converter presented in Figure 1A is referred in the field as a “low side secondary rectifier”, when the anode of the rectifier means is connected to the secondary ground, 14.

[0025] In this configuration the dot ,120, in the secondary winding is placed to the cathode of the rectifier means. The dots placed in the windings of the transformer represent the polarity of the windings. When a voltage is applied to a winding in a transformer with the positive polarity at the dot, the rest of the winding will have a positive polarity induced at the dot as well.

[0026] In conclusion, in the configuration from Figure 1, referred also as a “low side secondary rectifier” there is a displacement current through the parasitic capacitance between primary winding and secondary winding, displacement current described by the formula 4 and 5 from Figure 1B. This displacement current is proportionate with Vin and also with the turn

ratio.

[0027] In Figure 3A is presented a flyback converter in which the dot end of the secondary winding is placed to the secondary ground, 14. The transformer itself remains the same, only the rectifier means is connected with its anode to the termination C of the secondary winding and the termination D of the secondary winding is connected to the secondary ground 14. The circuit configuration of the flyback converter presented in Figure 3A is referred in the power conversion field as a “high side secondary rectifier”.

[0028] The flyback converter presented in Figure 3A works in the same way as the flyback converter presented in Figure 1A. There is no difference in operation but there are some clear differences in the displacement currents though the parasitic capacitances in between primary winding 30 and secondary winding 32.

[0029] In the termination A, at the time when the primary switch closes the voltage will decay by ΔV_A versus the primary ground 12. In the termination C of the secondary winding the voltage will decay by ΔV_C versus the secondary ground 14. A displacement current I_1 , 38 will be created through the parasitic capacitance C_1 , 42. The value of the displacement current I_1 is depicted by the equation 4 from Figure 3B, $I_1 = k \cdot V_{in} \cdot ((N-1)/N)$. In the case in which $N=1$, which means the number of turns in primary is equal to the number of turns in the secondary, the displacement current I_1 is zero.

[0030] In termination B of the primary winding the voltage does not change versus primary ground. In termination D of the secondary winding the voltage does not change either versus secondary ground. In conclusion the displacement current I_n , through C_n , 46 is zero.

[0031] In the configuration presented in Figure 3A, the displacement current through C_n is always zero and the displacement current through C_1 is smaller than the displacement current from the configuration in Figure 1. More than that in the event in which $N=1$ there is no displacement current because the terminations of the primary winding and secondary winding, swing with the same polarity. A quiet connection is a connection in which the voltage does not change when S closes or opens. Such a quiet connection is +HV, 90, GND_p, 12, GND_s, 14 and V_o , 18. The termination B and D in Figure 3A and termination B and C in Figure 1A are placed to a quiet connection.

[0032] In the circuit presented in Figure 3A the termination of the primary winding, A,

and the termination of the secondary winding, C do move in the same direction versus the primary and respectively secondary ground when the switch S is closed and opened.

[0033] In conclusion the flyback converter configuration depicted in Figure 3A is quieter in respect of noise injection from primary to secondary, via the parasitic capacitance between primary winding and secondary winding, than the configuration depicted in Figure 1A. When ultrafast rectifiers or Schottky diodes were used for the rectifier means, 28, the utilization of the “the high side secondary rectifier” it was a relatively easy implementation. In the recent application in which synchronized rectification is used, the “high side secondary rectifier” becomes more challenging because the Mosfet used for synchronized rectifier has to be driven at the high side. In the case of synchronized rectification utilization of the output rectifier the implementation depicted in Figure 1A is easy to implement because the gate of the mosfet which is used as synchronized rectifier is driven from the ground level.

[0034] Some of the embodiments herein make the use of a Mosfet as synchronized rectifier easy and the Mosfet will be driven from the ground level while still benefiting of zero displacement current as is achieved in Figure 3A when $N=1$.

[0035] By analyzing the displacement current through the parasitic capacitances in the transformer Tr1, 52 in configuration from Figure 1A and Figure 3A it shows clearly that at high side secondary rectifier has lower displacement current through the parasitic capacitance between primary and secondary winding. More than that for a transformer with a turns ration $N=1$ there is zero displacement current through the parasitic capacitances from primary to secondary winding of the transformer, which validates the main embodiment of the US Patent 5,107,411. The difference in EMI behavior between the high secondary rectifier and the low secondary rectifier is known by the experts in the field. This analysis was done in this patent in order to introduce an analysis methodology for underlining the key advantages of the main embodiments of this invention over the prior art.

[0036] The most traditional technique in preventing noise injection from the primary winding to the secondary winding of a transformer, technique used in switch mode power supply is the placement of an electrostatic shield formed by an incomplete turn of copper foil placed in between the primary winding and secondary winding. This electrostatic shield is usually connected to the input ground directly or via a ferrite bead or to the high voltage rail where the primary winding is connected in topologies such as flyback or single ended forward.

In between the primary windings and also between secondary winding and the electrostatic shield there are parasitic capacitances which generate displacement currents during the operation. This specification generally refers to one application of the isolated transformer which is a flyback converter though the methodology described in this specification can be applied to any transformer and any topology. Further, for simplicity, the specification initially presents a simple non interleaved transformer structure having a primary winding and a secondary winding and in some cases some additional auxiliary windings. The embodiments of this specification are applied to any transformer structure, such as interleaved or multiple interleaved in which the primary and secondary windings are placed alternatively on the bobbin.

[0037] In Figure 10A is presented the EMI test results of a 30W flyback converter having a non-interleaved transformer using a RM8 type magnetic core and having an EMI filter designed to filter the differential and common mode noise. In Figure 10B is presented the bobbin on which the primary winding is placed followed by an isolator and further the secondary winding will be placed. This experiment has 18 turns in primary and 4 turns in secondary. The test results are for $V_{in}=230V_{ac}$ @ 50hz for an output voltage of 12V @ 2.5A and the plot from Figure 10A is the QPEAK and the limits are based on the EN 55022 class B. It is visible than in some frequency ranges the violation of the limit is more than 15dB.

[0038] In Figure 11A is presented the EMI measurements results after one open turn copper shield is connected to primary ground is placed in between the primary and secondary, copper shield depicted in Figure 11B. After the copper shield is placed the EMI level did decrease by 10dB in some frequency ranges. The expectations were that the impact of the shield would have been more significant because the shield would prevent the displacement current through the parasitic capacitance between the primary and secondary winding. Analyzing the reasons why the traditional copper foil shield which is Prior Art is not as effective as expected it will lead us to the embodiments of this specification. The embodiments within the scope and spirit of this specification improve significantly the noise reduction of the shield.

[0039] There are several ways the noise generated by the voltage swing across the primary switch in a flyback converter and actually in any power converter, reaches the secondary. The voltage swing in the primary winding leads to displacements current into the secondary winding via the parasitic capacitances between primary and secondary winding. Another path of the noise injection from primary to secondary winding is via the core of the

transformer. The primary winding will inject noise into the magnetic core via the parasitic capacitance between the primary winding and the core and further via the magnetic core this noise is injected into the secondary winding. To address that is common practice that in the power transformer a shield is placed in between the magnetic core and the primary winding. In most of the Prior Art the shield is made of a foil of copper which form an open turn in the transformer. In other Prior Art, the shield is formed by a wire wound layer of copper wire with one of the terminal not connected and another terminal connected to a primary ground or to DC input voltage, +HV, 90.

[0040] Another source of noise injection is caused by the secondary winding voltage swing, which generates displacement currents via the parasitic capacitance towards the copper shield and further into the primary ground or +HV, 90 where the shield is connected. Though the voltage swing in the secondary winding is not as big in amplitude as the voltage swing in the primary winding in many applications, this source of noise can be still high preventing the EMI test results to be within 6dB under the EN 55022 class B limit, such is the case in this particular application mentioned in the specification. The embodiments presented in this specification will present solutions which will eliminate the noise injection from the secondary winding into the shield and further into the primary ground.

[0041] In Figure 4A is presented the flyback converter using a transformer Tr2, 68 with a primary winding 30 with two termination A and B, wherein A termination is connected to the primary switch ,54, and the B termination at the dot is connected to the Vin, 10, which is also labeled as +HV, 90 . There is also a secondary winding with two terminations, a termination D at the dot, connected to secondary ground 14 and another termination, C connected at the anode of the rectifier means. In addition to these two main windings there is an active shield winding, 80 which has the number of turns N_2' and wound in the same direction as the secondary winding. The active shield, 80, has two terminations, K and M. The K termination is placed to a quiet connection, +HV,90, and the M termination, of the active shield, 80, is not connected. The winding, 80, is referred in this specification as an active shield winding because acts as a shield and in the same time the active shield winding move with the same polarity and amplitude as the adjacent secondary winding preventing any displacement current to flow through the parasitic capacitances between secondary winding and the active shield winding. It can be built with exactly the same winding as the secondary winding or by using several stands of thinner wire in parallel to reduce its width and as a result reduce the

leakage inductance between primary and secondary.

[0042] In between the active shield 80, and the primary winding, 30, there are parasitic capacitances. For simplicity, the specification defines just $C1'$, 70, in between the primary winding located to the termination A, and the active shield winding, 80, located to the termination M, and $C'n$ in between the primary winding located to the termination B, and the active shield winding, 80, located to the termination K.

[0043] In between the active shield 80, and the secondary winding, 32, there are parasitic capacitances. For simplicity, the specification defines just $C1''$, 60, in between the secondary winding located to the termination C, and the active shield winding, 80, located to the termination M, and $C''n$ in between the secondary winding located to the termination D, and the active shield winding, 80, located to the termination K.

[0044] When the primary switch 54, is closed the voltage in A terminal of the primary winding will start decreasing rapidly versus the input ground, 12. The voltage in the terminal B of the primary winding does not change. The voltage in K of the active shield winding does not change being connected to a quiet connection, which is the +HV. The voltage in M does change by ΔVM going lower versus the primary ground 12. A current will be produced through the parasitic capacitance between primary winding 30, and active shield winding, 80, displacement current which is proportionate by the difference in between ΔVA and ΔVM . The displacement current through $C1'$, 70 is presented in formula 2 from Figure 4B. The displacement current through Cn' is zero because both ends of the parasitic capacitor Cn' do not swing being connected to a quiet connection, +HV,90. It is mentioned that $I1'$ displacement current and $I'n$ displacement current flow from the primary ground to the primary ground and is not part of the common mode noise. These displacement currents will impact the “effective capacitance “reflected across the primary switch S. In hard switching operation of the converter that will increase the switching losses, and in soft switching operation of the converter will require more energy to discharge the parasitic capacitance across the primary switch before the primary switch turns on. In the event $N'2$ is equal with $N1$, the $I'1 = 0$. In such a case, the effective capacitance reflected across the primary switch is reduced to the static parasitic capacitance across the main switch.

[0045] The static parasitic capacitance in the winding is the physical capacitance which is measured in a static mode when there is not AC voltage present across the windings. The

effective capacitance is defined by the displacement current caused by the movement of the winding towards each other when ac voltages are present across the windings.

[0046] When the primary switch closes the voltage in termination D of the secondary winding 32 does not change being connected to the secondary ground 14. The voltage in terminal C of the secondary winding does swing lower reported to the secondary ground by ΔVC . In equation 3 and 4 from Figure 4B is concluded that displacement currents between secondary winding, 32 and the active shield, 80, via, $C1''$, 60 and Cn'' , 62 are zero if $N'2 = N2$. That means that in the configuration depicted in Figure 4A if the number of turns in the active shield has the same number of turns as the secondary winding, $N2=N2'$, then the displacement current in between the active shield winding and the secondary winding is zero. In conclusion there is not displacement current between the secondary winding and the active shield winding. Because the active shield winding, 80 is connected to the input ground, there is not displacement current between secondary ground and the primary ground. The active shield winding has the role of an electrostatic shield and because the windings which form the active shield 80, move with the same polarity and the same amplitude as the secondary winding there is no common mode noise. For an ideal operation the secondary windings and the active shield winding shall be identical, which can be easily implemented in a multilayer PCB planar magnetic.

[0047] In wire wound transformers the active shield, 80, shall be implemented by using multiple strands in parallel of thin wire with the same number of turns as the secondary winding. The thin wire used in multiple strands in parallel will decrease the distance in between the primary and secondary winding and in this way will decrease the leakage inductance between primary winding and secondary winding. The multiple strands of wire used for the active shield will cover the entire winding area in the bobbin covering fully the secondary winding. The use of thin wire in the active shield will also decrease the eddy current losses in the shield. In Figure 12 B is presented such an implementation of the active shield winding. A method of reducing common-mode noise in a switch mode power supply; the switch mode power supply having a primary side and a secondary side, a primary side ground and a secondary side ground, the primary side and the secondary side having a quiet termination wherein the voltage does not change versus the input ground and versus secondary ground during the operation of the switch mode power supply, and further having an input voltage source, at least one primary switch, a transformer and a power output; the transformer having

at least a primary winding in the primary side, of the power supply and connected to the input voltage source via the primary switch, and at least one secondary winding of the transformer on the secondary side of the power supply, and the secondary winding connected to the power output via at least one rectifier means, at least one active shield winding placed in between the primary winding and the secondary winding having the same number of turns as the secondary winding and wound in the same direction as the secondary winding, the active shield windings having two terminations and occupy the same axial position on the core as the secondary winding; and one termination of the active shield is connected to the primary quiet termination so that in operation all correspondingly adjacent the terminations of the secondary winding and the active shield winding carry alternating voltages of the same polarity and same amplitude.

[0048] In the configuration depicted in Figure 4A zero displacement current between the parasitic capacitance between active shield and the secondary winding can be achieved. Because the active shield, 80, is connected to a quiet connection +HV, 90, further connected to the primary ground, zero common mode noise is flowing through the primary and the secondary ground. .

[0049] Figure 5A presents a flyback converter using the “low side output rectifier” configuration in which the secondary winding has the dot to the cathode of the rectifier means. The transformer Tr2, 68 from Figure 5A has the same windings as the transformer presented in Figure 4A. The difference is that the active shield winding, 80 is connected to the input ground, 12 at the terminal M. In the secondary the D terminal of the secondary winding 32 is connected to the cathode of the rectifier means and the C terminal of the secondary winding is connected to the V_{o+} , 18.

[0050] At the time when the primary switch S is closed the voltage in termination A of the primary winding start decreasing towards input ground, 12 by an amplitude ΔV_A . The voltage at the terminal M of the active shield winding, 80 does not move in reference to input ground. The current through the parasitic capacitance $C_{1'}$ is described by the equation 1 from Figure 5B.

[0051] The current through the parasitic capacitance $C_{n'}$ is described by the equation 2 of Figure 5B.

[0052] The voltage in termination C of the secondary winding does not change when S

is closed, and neither the voltage in termination M of the active shield winding. In the termination K of the active shield winding and the voltage in termination D of the secondary winding move with the same polarity and because $N' = N_2$ and the current through C_n is zero as described by the equation 4, for $N_2 = N_2$ from Figure 5B.

[0053] Regardless of the configuration of the flyback converter, such is the “low side secondary rectifier” as depicted in Figure 5A or the “high side secondary rectifier” configuration as depicted in Figure 4A, the transformer Tr2, 68 using the active shield winding there is not common mode noise from the primary to the secondary of the transformer for $N_2 = N_2$.

[0054] In Figure 5C is presented another structure with low side secondary rectifier but with the dot of the shield winding at the terminal M and the connection to the quiet spot is done at the terminal K and not in at the terminal M as is done in Figure 5A. The currents through the parasitic capacitances C''_1 and C''_n are depicted in formula 1 and 2 from Figure 5D. The displacement current I_n'' is induced from the secondary into the primary ground via C_n'' and the displacement current I_1'' is induced from the primary, via the active shield 80, into the secondary ground via C_1'' . In formula 3 from Figure 5D is depicted the common mode current which is the difference between I''_n and I''_1 . In the event that $N_2' = N_2$ the common mode noise is zero. Unlike the embodiment presented in Figure 5A in which the displacement current through the parasitic capacitances in between the active shield windings and the secondary windings is zero because the voltage on the active shield windings and the voltage on the secondary windings adjacent to each other move with the same polarity and the same amplitude, in the embodiment presented in Figure 5C there is displacement current through the parasitic capacitances between active shield winding and the secondary windings but the displacement current induced at each termination of the active shield winding and the secondary winding is of the same amplitude but of opposite polarity and they cancel and the common mode current from the primary ground to the secondary ground is zero.

[0055] This discloses a system and method of reducing common-mode noise in a switch mode power supply; the switch mode power supply having a primary side and a secondary side, a primary side ground and a secondary side ground, the primary side and the secondary side having a quiet termination in which the voltage does not change versus the input ground and versus secondary ground during the operation of the switch mode power supply, and further having an input voltage source, at least one primary switch, a transformer and a

power output; the transformer having at least a primary winding in the primary side of the power supply and connected to the input voltage source via the primary switch, and at least one secondary winding of the transformer on the secondary side of the power supply, and the secondary winding connected to the power output via at least one rectifier means, at least one active shield winding placed in between the primary winding and the secondary winding having the same number of turns as the secondary winding and wound in the same direction as the secondary winding, the active shield windings having two terminations and occupy the same axial position on the core as the secondary winding; and one termination of the active shield is connected to the primary quiet termination so that in operation all correspondingly adjacent the terminations of the secondary winding and the active shield winding carry alternating voltages of the opposite polarity and same amplitude.

[0056] The configurations from Figure 5A and 5C lead to the same results though the dot position in the active shield winding and the connection to the quiet connection are different. This configuration is another key embodiment of this invention.

[0057] This configuration is suitable in the event noise cancellation is necessary. Noise cancellation is a signal cancellation technique in which a signal is injected via the path between primary ground and secondary ground, signal injection which has the same amplitude but the opposite polarity of the common mode noise. This specification refers to the technique of signal cancellation as a noise cancellation. By tuning the number of turns in the active shield winding noise is injected in between primary to secondary ground via the parasitic capacitances between the active shield winding and the secondary winding, with a polarity controlled by the positive or negative sign of the flowing expression ($N_2 - N_2'$). The amplitude of the noise injection is done by the difference between N_2 value and N_2' value.

[0058] If the number of turns in the active shield winding is different than the number of turns in the secondary winding, then the displacement current through the parasitic capacitance in between the active shield winding and the secondary winding is not zero, which means that common mode noise will be injected, common mode noise of a given polarity and a given amplitude function of the difference of turns between the active shield winding and the secondary winding. This displacement current can be utilized for the purpose of noise cancellation.

[0059] The common mode noise in between primary and secondary of a converter is

transferred not only through the parasitic capacitance between the primary winding and secondary winding. As previously mentioned it can be transferred via the parasitic capacitance between the windings, primary and secondary winding and the magnetic core of the transformer. There are also other path of common mode noise transferred, via layout, and coupling between the converter components. In such cases having zero displacement current via the parasitic capacitance between secondary and primary winding or via the secondary and active shield winding does not eliminate the common mode noise entirely.

[0060] In such cases allowing a controlled displacement current of the right amplitude and polarity through the parasitic capacitance between active shield winding and secondary winding can reduce significantly to common mode noise. In Figure 16A is depicted a transformer, having interleaved primary and secondary winding and two active shield windings, $N3'$ and $N3''$. The primary winding is placed first on the bobbin, half of primary forms the first layer, $N1$, and the other half of primary forms the last layer, $N1'$. In between the primary windings formed by $N1$ and $N1'$ there are placed the active shields $N3'$ and $N3''$ and the secondary winding $N2$, is placed in between the two active shields, $N3'$ and $N3''$. The configuration from Figure 16A is using the embodiment of Figure 5A, in which the active shields windings have the same number of turns as secondary winding and the voltages on the windings terminations move with the same amplitude and with the same polarity. For the configuration in which $N1=N1'=11$ turns, $N3'=N3''=4$ turns and $N2=4$ turns, and using a very small Y cap of 68pF, the EMI measurements are depicted in Figure 16B. As is visible from Figure 16B the common mode noise exceeds the EN55022 Klasse B, QPEAK limits at several frequencies. Though the displacement current via the parasitic capacitance between the active shield windings and the secondary winding is zero, the common mode noise is not zero, due to noise penetration via the parasitic capacitance between windings and the magnetic core and other means as previously presented. In such cases the solution presented in this specification is to control the noise injection in the transformer via the parasitic capacitance between the active shield winding and the secondary winding by tuning the number of turns in the active shields.

[0061] In Figure 16C are presented the EMI measurement results for the configuration from Figure 16A for the configuration in which $N1=N1'=11$ turns, $N3'=7$ turns, $N3''=4$ turns and $N2=4$ turns. It is visible by comparing the measurement from Figure 16C and Figure 16B, that by using the controlled noise injection between active shield winding and the secondary

winding, there is an attenuation of 8dB and in this mode bring the EMI into compliance level.

[0062] Another embodiment combines the active shield from the embodiment presented in Figure 5A with the active shield embodiment presented in Figure 5C. Such implementation is depicted in Figure 17A.

[0063] In Figure 17A the active shield, N3' is in compliance with the configuration depicted in Figure 5A and the shield, N''3 is in compliance with the configuration depicted in Figure 5C. The EMI test results from the configuration from Figure 17A, wherein N1=N1'=11 turns, N3'=6 turns, N3''=7 turns and N2=4turns is presented in Figure 17B. In this configuration the attenuation is 14dB in comparison with the test results from configuration from Figure 16A with the test results from Figure 16B. The test results from the configuration from Figure 17A which are presented in Figure 17B, is passing the EN 55022, Klasse B QPEAK with 8dB of margin and using a Y capacitor of 68pF.

[0064] This discloses a system and method of reducing common-mode noise in a switch mode power supply; the switch mode power supply having a primary side and a secondary side, a primary side ground and a secondary side ground, the primary side and the secondary side having a quiet termination in which the voltage does not change versus the input ground and versus secondary ground during the operation of the switch mode power supply, and further having an input voltage source, at least one primary switch, a transformer and a power output; the transformer having at least a primary winding in the primary side and connected to the input voltage source via the primary switch of the power supply, and at least one secondary winding of the transformer on the secondary side of the power supply, in which the secondary winding connected to the power output via at least one rectifier means, at least two active shields winding adjacent to the secondary winding on both sides of the secondary winding having the same number of turns as the secondary winding and wound in the same direction as the secondary winding, and occupy the same axial position on the core as the secondary winding; and one termination of each active shield is connected to the primary quiet termination so that in operation all correspondingly adjacent the terminations of the secondary winding and the active shield windings carry alternating voltages of the same polarity and same amplitude.

[0065] As mentioned before the noise injection in the secondary winding does not always come from the primary winding via the parasitic capacitance between the primary

winding and the secondary winding. The embodiments using an active shield winding do prevent only this type of noise injection. In addition to that, noise can be injected into the secondary winding from the auxiliary windings when the auxiliary windings are placed near the secondary winding. In Figure 6A and Figure 6B is presented another embodiment in which an active shield winding is placed between the primary winding and the secondary winding and another active shield winding is placed on top of the secondary winding to prevent noise injection from the core or from the auxiliary windings. This embodiment is presented in Figure 6A and the construction technique is depicted in Figure 6B. In Figure 6B on the first layer is placed the primary winding. On the second layer is placed the active shield winding in this drawing implemented by multi-strands of thin wire, the active shield winding having the same number of turns as the secondary winding. On the third layer is placed the secondary winding, on the fourth layer is placed the active shield winding and on the top layer is placed the auxiliary winding or no other winding function of the application. The purpose of this configuration is to shield the secondary windings not only from the noise generated by the primary windings but also from noise generated from the auxiliary windings.

[0066] In additions to the noise injection methodologies based on tuning the numbers of turns in the active shield versus the number of turns in the secondary windings, another embodiment uses even fractional turns in the active shields to adjust the noise suppression signal.

[0067] In Figure 7A and 7B is presented another embodiment in which the number of turns in the active shield winding varies slightly versus the number of turns in the secondary winding by using a different number of turns or even fractional turns to adjust the noise suppression signals.

[0068] In Figure 7A and 7B the magnetic core, 34, has one central post, CP, and four outer legs, 11, 12, 13 and 14. That allows the use of fractional turns starting with quarter turn, $\frac{1}{4}$, and also half turn, $\frac{1}{2}$.

[0069] For example for 1 turn secondary in Figure 7A, the number of turns in the active shield is modified to be 1.25 turns and in Figure 7B is modified to be 0.75 turns.

[0070] Because there is not power delivered via the active shield winding the fractional turns can work without the risk of magnetic flux unbalance. In some cases even a larger increment can be used, such as full turns, rather than fractional turns. For example for a 4 turns

secondary, the number of turns in the active shield can be 3 or 5 turns function of the polarity of the additional noise injected. In Figure 13 shows the EMI if only 3 turns is used for the active shield and in Figure 14 if 5 turns are used in the active shield rather than 4 turns as is depicted in figure 12A. In Figure 12A when 4 turns are used for the active shield, the same numbers as the secondary winding, there is a larger amplitude noise around 1Mhz caused by the ringing across the main switch during the dead time of the flyback converter. That noise could have been injected through other means rather than the parasite capacitance between primary winding and secondary wining, such as through the magnetic core. By placing 5 turns in the active shield rather than 4 turns a signal of opposite polarity of the common mode noise was injected from the active shield to the secondary winding via the parasitic capacitance in between the active shield and secondary winding and that signal did cancel the 1 MHz noise as can be seen in Figure 14.

[0071] This discloses a system and method for which the number of turns for the active shields windings is adjusted in order to create a mismatch to the secondary winding and induce a voltage into the secondary winding designed to be of opposite polarity of the residual common mode noise injected from primary to secondary.

[0072] In noise cancellation technique in which the number of turns in the shield is tuned to be higher or smaller than the number of turns in the secondary winding the noise injection from the primary winding to the secondary winding can be also tuned by partially removing wire wound active shield allowing the noise from the primary to reach the secondary.

[0073] The embodiments herein can be also used in planar transformers. Figure 8 presents the power train of a flyback converter for which the transformer winding is embedded in a multilayer PCB. Primary windings are placed on four layers 892, 894, 802 and 804. The number of turns per layer may vary function of the application. The secondary windings are placed on the layer 898. The active shield windings are placed on the layer 896 and 800, and have to have the same number of turns as the secondary or can have a slight different number of turns including fractional turns as described by the embodiment from Figure 7A and 7B if noise cancellation technique is employed. The secondary winding placed on the layer 898 may be placed on several layers, usually an even number. In the event the secondary winding is placed on several layers, the number of turns and the dot (120) for the active shield on layer 896 and 800 shall be the same as the secondary layers adjacent to the shield to comply with the active shield solution from Figure 4A.

[0074] The displacement current between the active shield and the secondary windings adjacent to it shall be zero.

[0075] Further, in embodiments, the transformer is implemented in a multilayer PCB and the windings on the layers adjacent to the secondary windings, on both side of the secondary winding, are the mirror image of the secondary winding and they carry alternating voltages of the same polarity and same amplitude as the secondary winding.

[0076] In applications in which controlled noise injection is utilized the number of turns in the active shields may be different than the number of turns in the secondary.

[0077] In the event the embodiment depicted in Figure 5C is employed, the connection to the quiet termination and the dot position for the active shield shall be in compliance with the concept depicted in Figure 5C.

[0078] Figure 9A presents another embodiment in which the active shields, on layer 900 and 996 are adjacent to the secondary windings on layer 998, and the active shields are connected to the quiet end of the primary at +HV, 90. For example if the number of turns of the primary winding per layer 992 and 994 is just one, and the active shield windings placed on layer 996 and 900, is also one, the displacement current via the parasitic capacitance between layer 992 and layer 900 and respectively from layer 994 to 996, is low because the primary windings placed on layer 994 and 992 have a lower voltage swing being connected closer to +HV. In addition to that the displacement current between primary windings from layers 992 and 994 and the active shield winding placed on layer 996 and 900 is in between primary ground to primary ground and it does not influence the common mode noise. This displacement current will just influence the switching losses and impact the efficiency of the power converter.

[0079] In Figure 9B is presented another embodiment. The secondary windings are placed on at least two layers, in this case layer 906 and 908. In one particular implementation let's consider that the number of turns in secondary is two, one turn per layer 906 and one turn per layer 908 and these windings are in series, in total two turns. The number of turns per layer 992 of the primary winding is one as well and the number of turns of the primary winding placed on layer 994 is one turn as well. In cases in which the total number of turns in the primary is 12, there will be 5 turns placed on the layer 902 and 5 turns on the layer 904. For practical purposes more layers can be added for the primary winding with the goal of

decreasing the number of turns per layer for layer 902 and layer 904. The primary winding on the layer 992 and on the layer 994 in this implementation will have two roles. One role is to be part of the primary winding and the second role to be the active shield winding for the secondary windings placed on layer 906 and 908. This would be the same implementation as in Figure 4A with the difference that the active shield winding is also part of the primary winding. This makes the active shield winding part of the power train, wherein power is transferred through these winding and also these windings are used as active shields. The embodiment of Figure 9B eliminates the need for two additional layers wherein to place the active shield winding. In this example, one turn per layer in the layers 992, 994, 906 and 908 is used. This embodiment works for any number of turns per layer as long as the number of turns per layer in 906 and 994 and respectively per 908 and 992 is the same.

[0080] Moreover, the windings on the layers adjacent to the secondary windings, are part of the primary windings.

[0081] In Figures 8, 9A, 9B and 9C is depicted also the magnetic flux B, produced by the current through the primary winding, 101, The arrow line, 102, represents the current flowing through the primary winding. The dotted line per layer 906 and 908, labeled 110, represent the current flow in the secondary winding after the switch, 54, turns off. This applies only for the flyback topology. The embodiments apply also for any topology such as forward derived topologies.

[0082] In Figure 9C is presented another embodiment in which the secondary winding is placed layer 914, on one or several layers. In this case the primary winding adjacent to the secondary winding placed on layer 992 and layer 994 are in parallel unlike the structure depicted in Figure 9B in which the primary winding 992, and 994 which act as active shield are placed in series. The primary windings 992 and 994 and have the same number of turns as the secondary windings and are placed on the adjacent layers to the secondary windings 914. Like in Figure 9B the primary winding on layer 994 and layer 992 takes the role of the active shield. This is done by having the primary winding adjacent to the secondary winding to have the same number of turns as the secondary winding and the voltage swing is in such way that the displacement current through the parasitic capacitance between 994 and 914 and 992 and 914 is zero. In addition to that the primary winding which takes the role of the active shield are also connected to the quiet termination. The winding 992 is connected to HV+ and the winding 994 is connected to +HV as well. The embodiment described in Figures 9B and 9C is

suitable for multilayer planar transformer because additional layers are not needed just for the active shield windings. For example in Figure 9B 4 layers are allocated for the primary winding and two layers for the secondary winding, in total only 6 layers instead of eight layers if the embodiment described in Figure 8 and Figure 9A would be used.

[0083] The embodiments within the spirit and scope of this specification are applicable also in the more complex magnetic structures as the one presented in U.S. Application Publication No. US 2016/0307695 entitled “Magnetic Structures for Low Leakage Inductance and Very High Efficiency.”

[0084] In Figure 15A is presented a horizontal cross-section through a multi-leg magnetic structure presented in the “Magnetic Structures for Low Leakage Inductance and Very High Efficiency” patent application. The magnetic structure depicted in Figure 15A contains has four legs, 150,152,154 and 156 and two plates 158 and 160, as is depicted also in the vertical cross-section of this magnetic structure in Figure 15B. The primary winding is wound around the four legs as depicted in figure 15D. The magnetic field through each leg has an opposite polarity to the legs adjacent to it. This magnetic structure is suitable for flyback transformer and also for forward derived transformer. The leakage inductance between primary winding and secondary winding becomes very small which makes this transformer structure suitable for flyback applications. In addition to that the number of layers in such structures can be reduced and the volume of the magnetic core is smaller than for independent transformers which will reduce the core loss.

[0085] In Figure 15C is presented the simplified schematic of a flyback topology employing an active shield using the concept depicted in Figure 5A. In Figure 15E are presented four layers of the multilayer transformer using the magnetic core structure from Figure 15A. As presented in Figure 15E the secondary windings are implemented in two inner layers, Lsec1 and Lsec2. The shield layers are placed on two layers Lshield1 and Lshield adjacent to the layers in which the secondary windings are embedded. The secondary winding starts from Lsec1 layer, from X2 termination and ends on Lsec2 layer, to the termination X1 with the interconnection between layers X3. X1 termination is connected to the Vo, 18 and X2 termination is connected to the cathode of the synchronized rectifier 28. The active shield starts from YM connection on Lshield2 layer and ends on Lshield1 layer at YK with the interconnection between layers Y1. The shield winding on Lshield1 is the mirror imagine of the secondary winding on Lsec1 layer and the shield winding on Lshield 2 is the mirror imagine

of the secondary winding Lsec2. The voltage in the termination YK of the shield winding and the voltage in the termination X2 of the secondary winding move with the same polarity and the same amplitude. The termination YM of the shield winding and the termination X1 of the secondary winding are both connected to a quiet termination, GNDp, 12 and respectively Vo, 18, as in the configuration from Figure 5A. If noise injection is necessary, the termination YM of the active shield will not be connected directly to GNDp, 12. It will be connected to an auxiliary windings of one or more turns wound around one of the four legs and that auxiliary winding termination not connected to the active shield will be connected to the GNDp, 12. The winding direction of the auxiliary winding is chosen to inject a signal in the shield of a polarity designed to reduce the common mode noise. The number of turns for the auxiliary winding will be chosen to have the voltage amplitude that the noise injection via the shield into the secondary winding will reduce the common mode noise.

[0086] In an embodiment, a system and method of reducing common-mode noise in a switch mode power supply includes the switch mode power supply having a primary side and a secondary side, a primary side ground and a secondary side ground, the primary side and the secondary side having a quiet termination in which the voltage does not change versus the input ground and versus secondary ground during the operation of the switch mode power supply, and further having an input voltage source, at least one primary switch, a multilayer PCB transformer having a planar magnetic core with multiple legs, and a power output; the transformer having at least a primary winding in the primary side, the primary winding encircling the multiple legs of the planar magnetic core and connected to the input voltage source via the primary switch of the power supply, and at least one secondary winding of the transformer, the secondary winding encircling the multiple legs of the planar magnetic core, on the secondary side of the power supply, wherein the secondary winding connected to the power output via at least one rectifier means; at least two active shields winding adjacent to the secondary winding on both sides of the secondary winding the active shields winding are the mirror image of the secondary winding adjacent to them having the same number of turns as the secondary winding and wound in the same direction as the secondary winding, the active shield windings having two terminations, and one termination of each active shield is connected to the primary quiet termination so that in operation correspondingly adjacent terminations of the secondary winding and the active shield windings carry alternating voltages of the same polarity and same amplitude.

[0087] Further, in some embodiments, the connection of the active shield windings to the primary quiet termination is done via an auxiliary winding wound around one of the legs of the planar magnetic core, the auxiliary winding to induce a voltage into the active shield windings designed to be of opposite polarity of the residual common mode noise injected from primary to secondary.

[0088] A preferred embodiment is fully and clearly described above so as to enable one having skill in the art to understand, make, and use the same. Those skilled in the art will recognize that modifications may be made to the description above without departing from the spirit of the specification, and that some embodiments include only those elements and features described, or a subset thereof. To the extent that modifications do not depart from the spirit of the specification, they are intended to be included within the scope thereof.

CLAIMS

What is claimed is:

1. A system for reducing common-mode noise, the system comprising:

a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a transformer, a core, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground;

the transformer includes a primary winding on the primary side connected to the input voltage source via the primary switch, a secondary winding on the secondary side connected to the power output via a rectifier means, and an active shield winding placed between the primary and secondary windings, wherein the active shield winding has two terminations, is wound in a same direction as the secondary winding, and occupies a same axial position on the core as the secondary winding;

the active shield winding and secondary winding each have a number of turns; and

one of the two terminations of the active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield winding that are adjacent each other carry alternating voltages of a same polarity and a same amplitude.

2. The system of claim 1, wherein the number of turns of the active shield winding is the same as the number of turns of the secondary winding.

3. The system of claim 1, wherein the number of turns of the active shield winding is different from the number of turns of the secondary winding, so as to induce a voltage into the secondary winding which has a polarity that is opposite a polarity of a residual common mode noise injected from the primary winding to the secondary winding.

4. A system for reducing common-mode noise, the system comprising:

a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a transformer, a core, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground;

the transformer includes a primary winding on the primary side connected to the input voltage source via the primary switch, a secondary winding on the secondary side connected to the power output via a rectifier means, and an active shield winding placed between the primary and secondary windings, wherein the active shield winding has two terminations, is wound in a same direction as the secondary winding, and occupies a same axial position on the core as the secondary winding;

the active shield winding and secondary winding each have a number of turns; and

one of the two terminations of the active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield winding that are adjacent each other carry alternating voltages of an opposite polarity and a same amplitude.

5. The system of claim 4, wherein the number of turns of the active shield winding is the same as the number of turns of the secondary winding.

6. The system of claim 4, wherein the number of turns of the active shield winding is different from the number of turns of the secondary winding, so as to induce a voltage into the secondary winding which has a polarity that is opposite a polarity of a residual common mode noise injected from the primary winding to the secondary winding.

7. A system for reducing common-mode noise, the system comprising:

a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a transformer, a core, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground;

the transformer includes primary winding on the primary side connected to the input voltage source via the primary switch, a secondary winding on the secondary side connected to the power output via a rectifier means, and at least two active shield windings;

wherein the active shield windings are adjacent to the secondary winding on both sides of the secondary winding, are wound in a same direction as the secondary winding, occupy a same axial position on the core as the secondary winding, and each have two terminations;

wherein the active shield windings and the secondary windings each have a number of turns; and

one of the two terminations of each active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield windings that are adjacent each other carry alternating voltages of a same polarity and a same amplitude.

8. The system of claim 7, wherein the number of turns of the active shield windings is the same as the number of turns of the secondary winding.

9. The system of claim 7, wherein the number of turns of the active shield windings is different from the number of turns of the secondary winding, so as to induce a voltage into the secondary winding which has a polarity that is opposite a polarity of residual common mode noise injected from the primary winding to the secondary winding.

10. The system of claim 7, wherein the transformer is implemented in a multilayer PCB and, on both sides of the secondary winding, windings on layers of the PCB that are adjacent to the secondary winding mirror the secondary winding and carry alternating voltages of a same polarity and same amplitude as the secondary winding.

11. The system of claim 10, wherein the windings on the layers of the PCB that are adjacent to the secondary winding are part of the primary winding.

12. A system for reducing common-mode noise, the system comprising:

a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a transformer, a core, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground;

the transformer includes primary winding on the primary side connected to the input voltage source via the primary switch, a secondary winding on the secondary side connected to the power output via a rectifier means, and at least two active shield windings;

wherein the active shield windings are adjacent to the secondary winding on both sides of the secondary winding, are wound in a same direction as the secondary winding, occupy a same axial position on the core as the secondary winding, and each have two terminations;

wherein the active shield windings and the secondary windings each have a number of turns; and

one of the two terminations of each active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield windings that are adjacent each other carry alternating voltages of an opposite polarity and a same amplitude.

13. The system of claim 12, wherein the number of turns of the active shield windings is the same as the number of turns of the secondary winding.

14. The system of claim 12, wherein the number of turns of the active shield windings is different from the number of turns of the secondary winding, so as to induce a voltage into the secondary winding which has a polarity that is opposite a polarity of residual common mode noise injected from the primary winding to the secondary winding.

15. A system for reducing common-mode noise, the system comprising:

a switch mode power supply including primary and secondary sides, primary and secondary side grounds, an input voltage source, a primary switch, a multilayer PCB transformer having a planar magnetic core with multiple legs, and a power output, wherein the primary side and the secondary side each have a quiet termination wherein the voltage does not change with respect to the primary side ground and with respect to the secondary side ground;

the transformer includes a primary winding on the primary side, which primary winding encircles the multiple legs of the planar magnetic core and is connected to the input voltage source via the primary switch of the power supply, and a secondary winding on the secondary side, which secondary winding encircles the multiple legs of the planar magnetic core and is connected to the power output via a rectifier means;

at least two active shield windings, wherein the active shield windings are adjacent to the secondary winding on both sides of the secondary winding, mirror the adjacent secondary winding, are wound in a same direction as the secondary winding, have a same number of turns as the secondary winding, and each have two terminations; and

one of the two terminations of each active shield winding is connected to the quiet termination of the primary side, so that the terminations of the secondary winding and the active shield windings that are adjacent each other carry alternating voltages of a same polarity and a same amplitude.

16. The system of claim 15, wherein the active shield windings are connected to the quiet termination of the primary side via an auxiliary winding around one of the legs of the planar magnetic core, and the auxiliary winding induces a voltage into the active shield windings which has a polarity that is opposite a polarity of a residual common mode noise injected from the primary winding to the second winding.

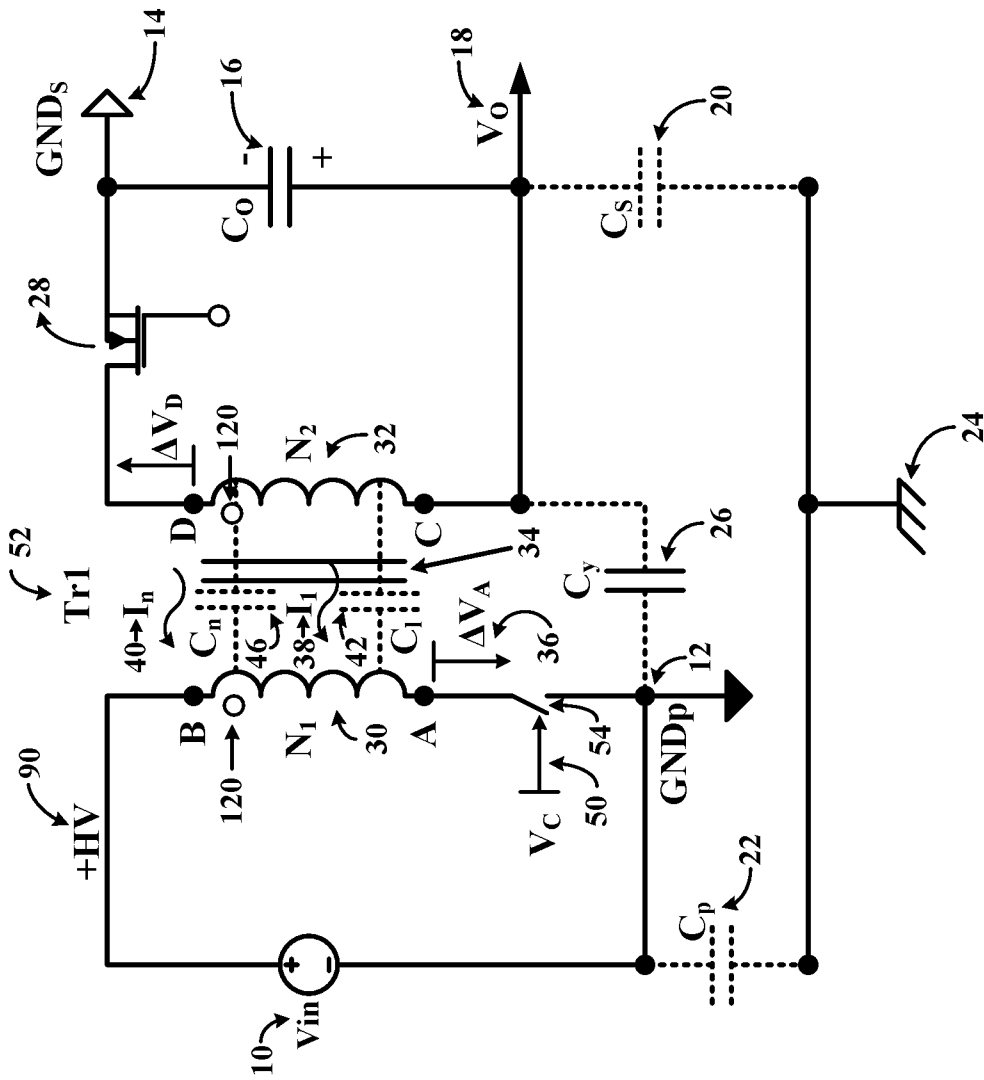


Fig. 1A

- 1) $N = \frac{N_1}{N_2}$
- 2) $\Delta V_A \cong V_{in}$
- 3) $\Delta V_D \cong \frac{V_{in}}{N}$
- 4) $I_n = K (\Delta V_D) \cong K * \frac{V_{in}}{N}$
- 5) $I_1 = K(\Delta V_A) \cong K * V_{in}$

Fig. 1B

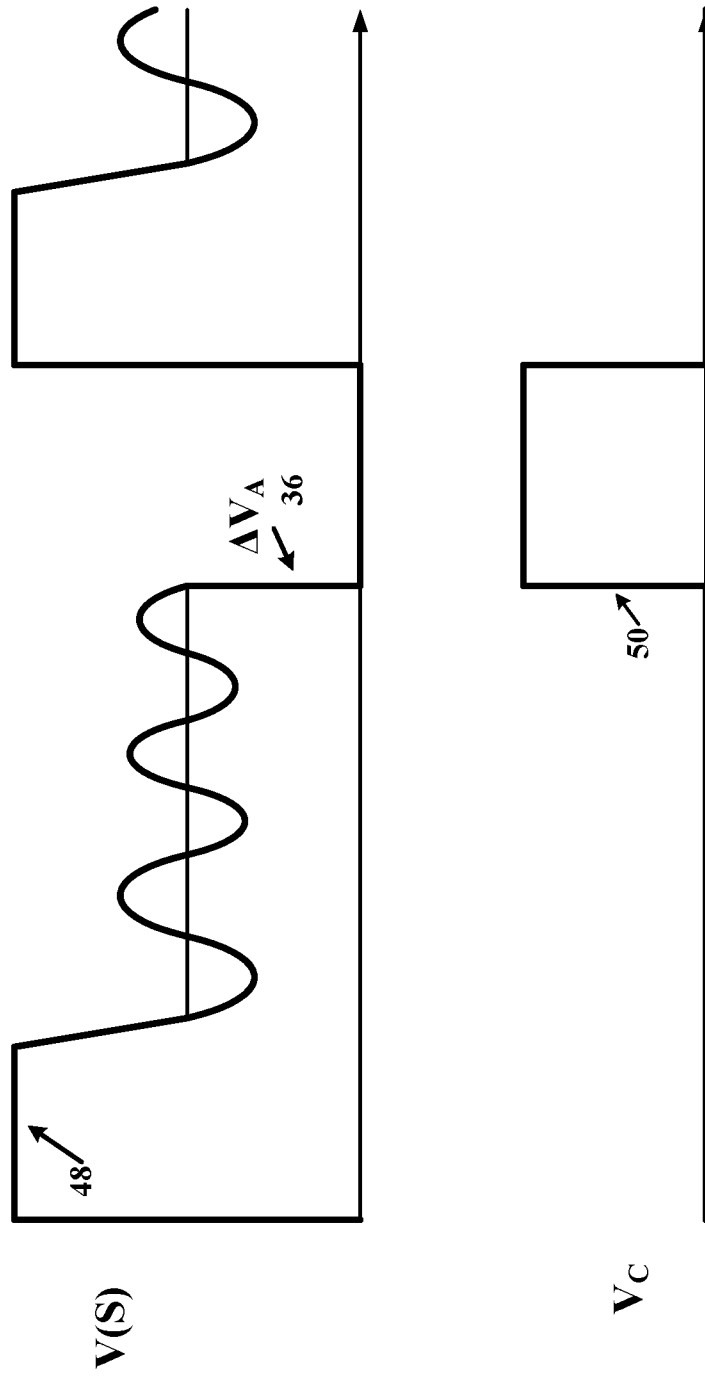


Fig. 2

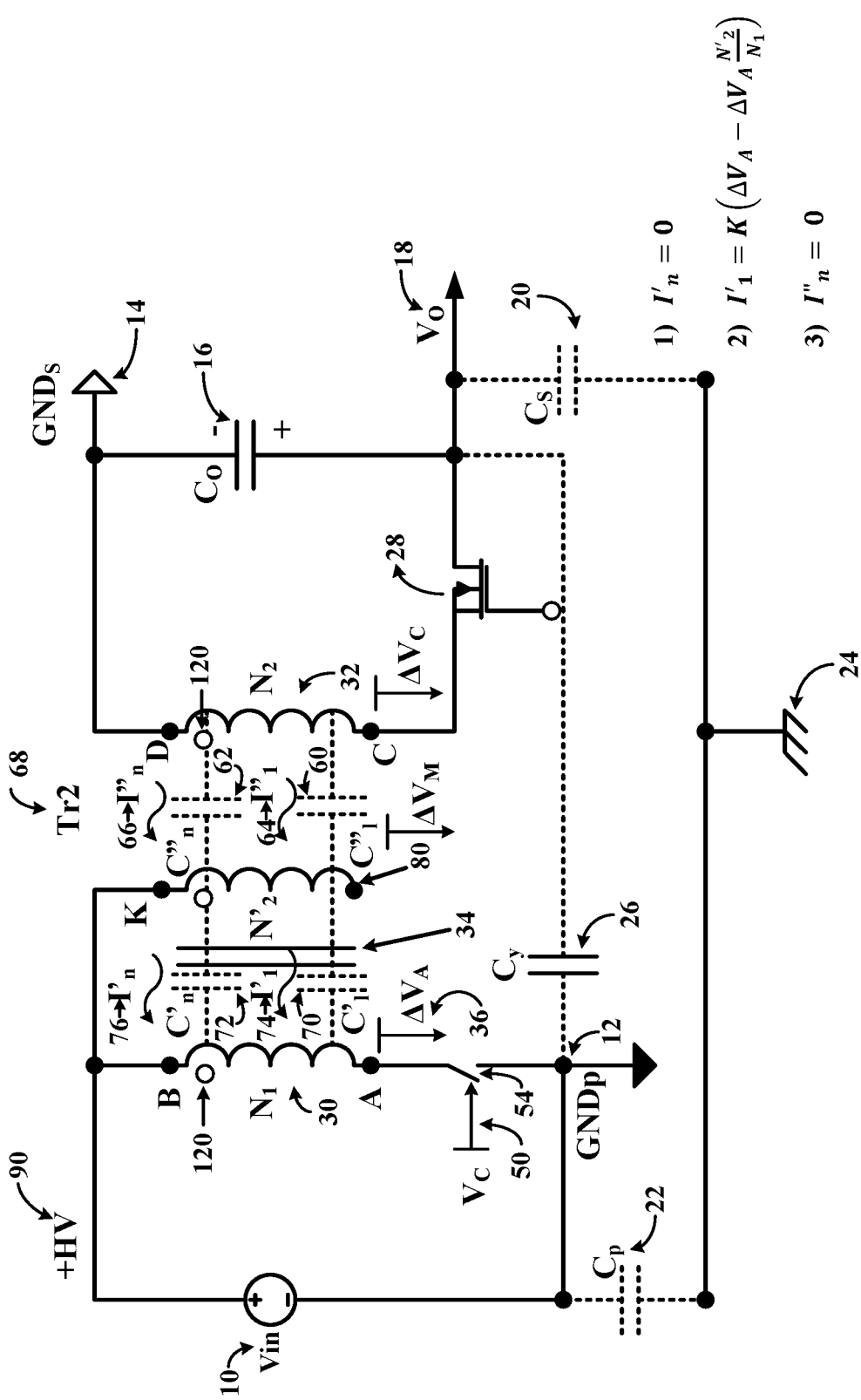


Fig. 4A

- 1) $I'_n = 0$
- 2) $I'_1 = K \left(\Delta V_A - \Delta V_A \frac{N'_2}{N_1} \right)$
- 3) $I''_n = 0$
- 4) $I''_1 = K \left(\Delta V_A \frac{N'_2}{N_1} - \frac{\Delta V_A N'_2}{N_1} \right)$

For $N'_2 = N_2$
 $\rightarrow I''_1 = 0$

Fig. 4B

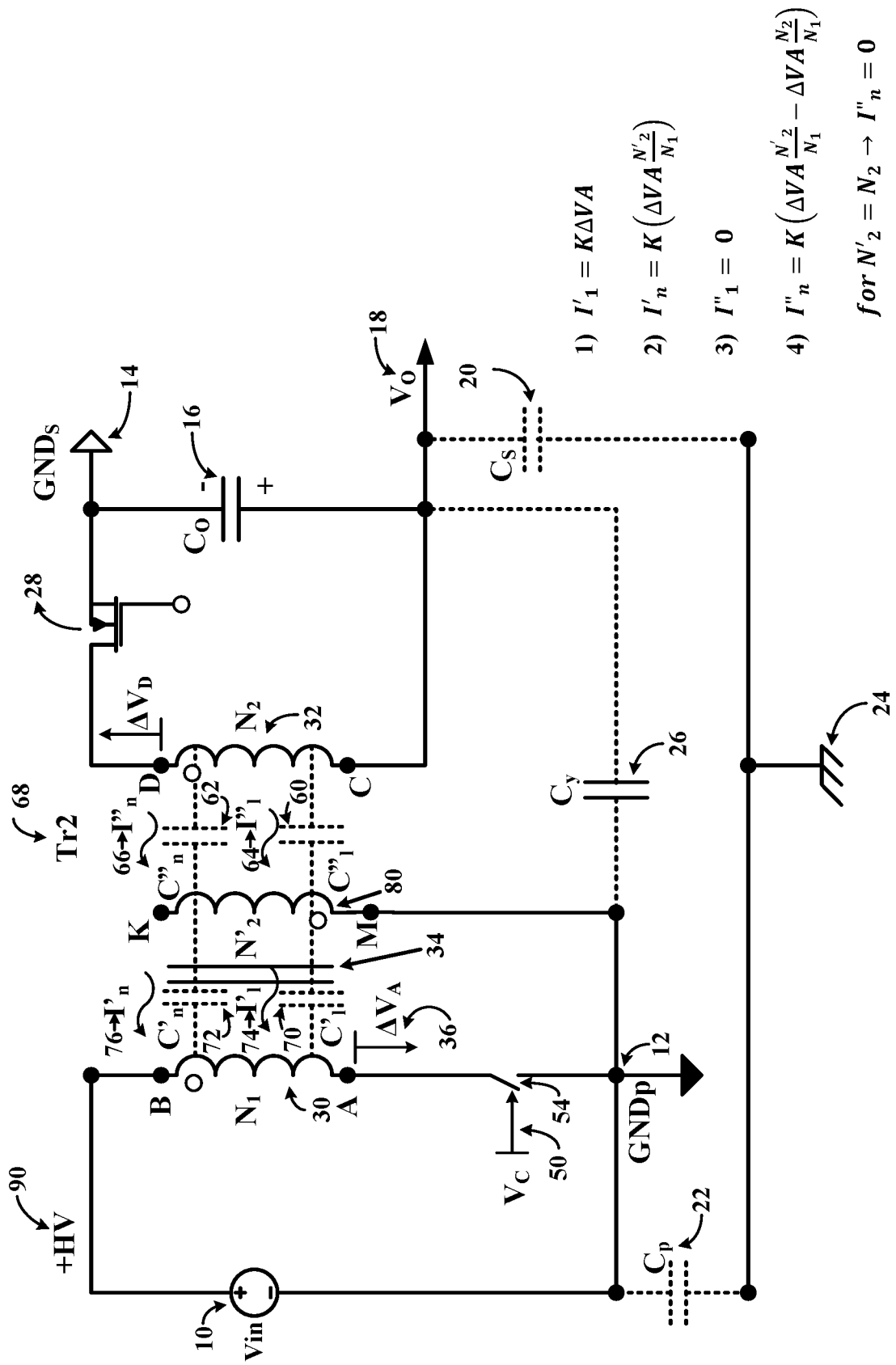


Fig. 5A

Fig. 5B

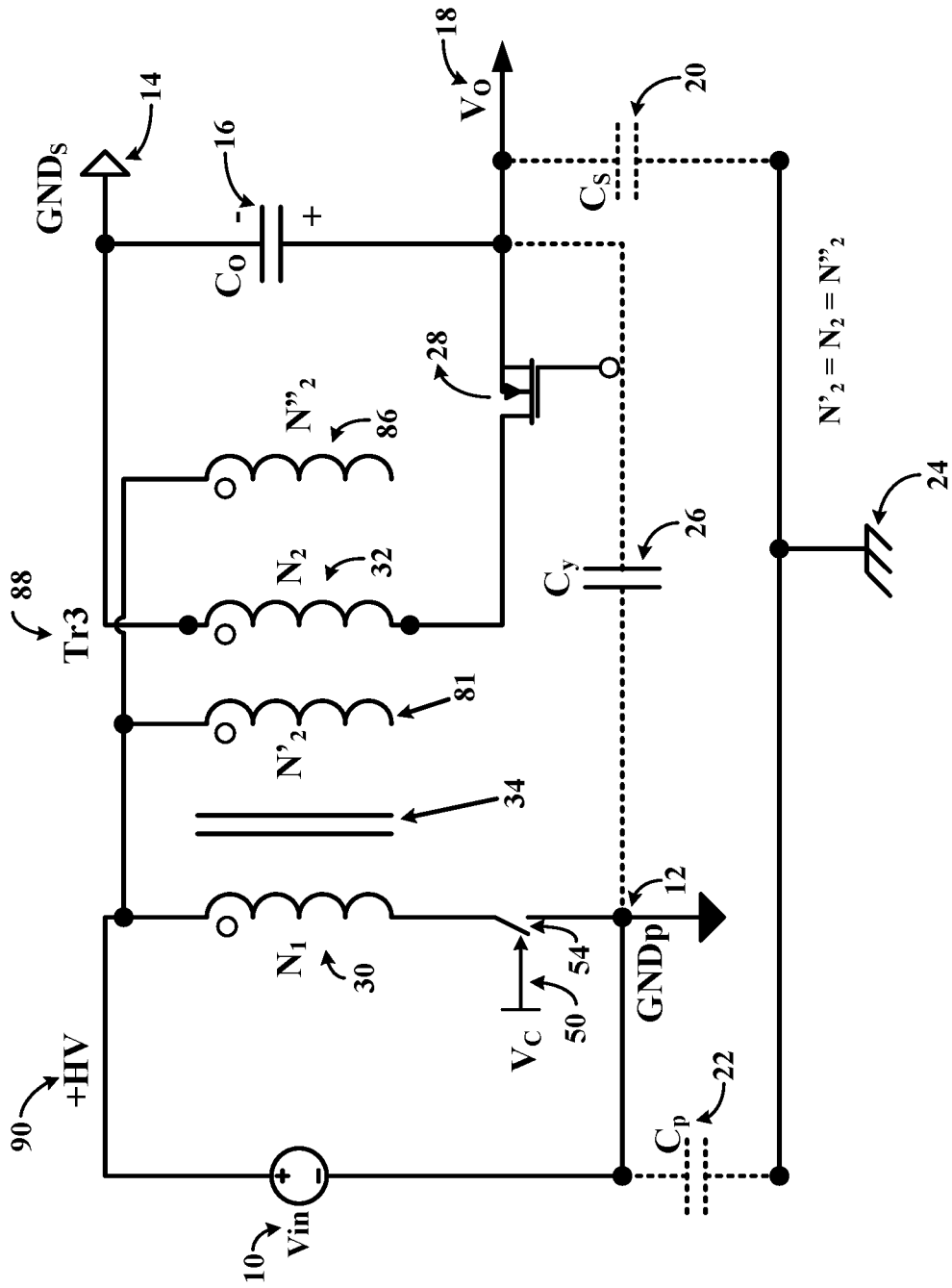


Fig. 6A

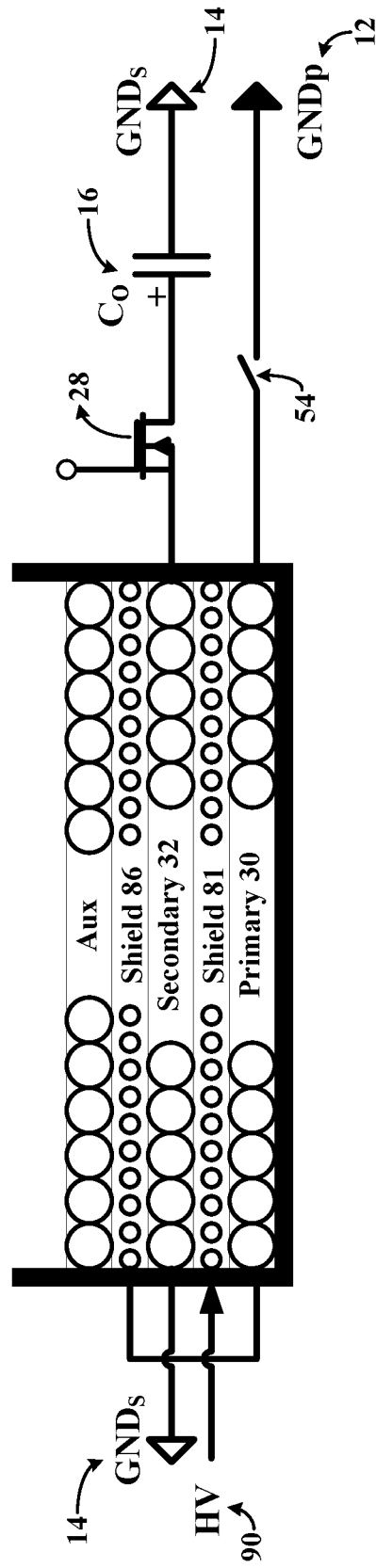


Fig. 6B

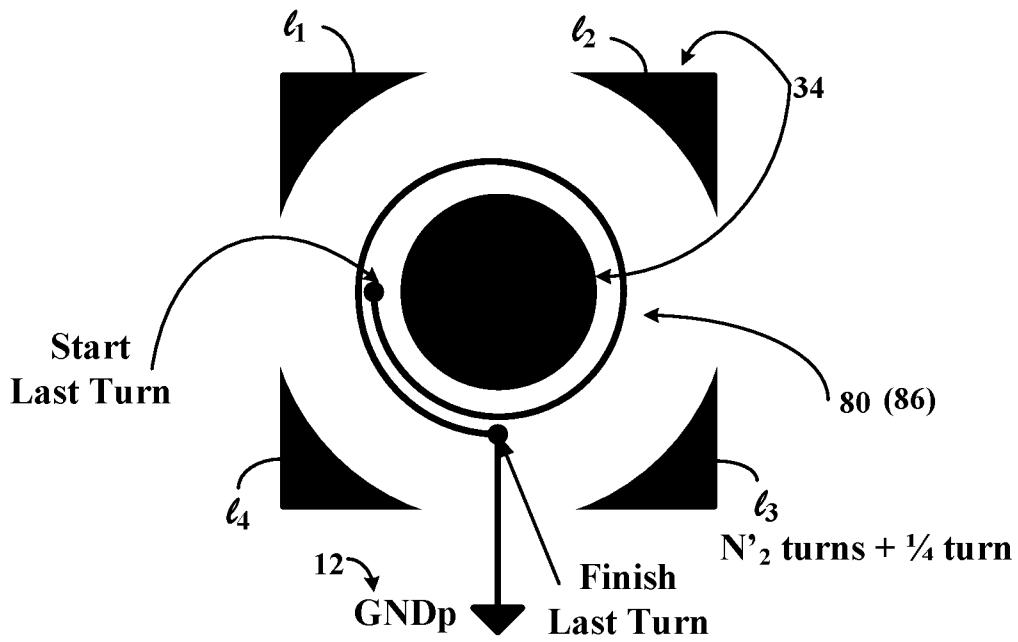


Fig. 7A

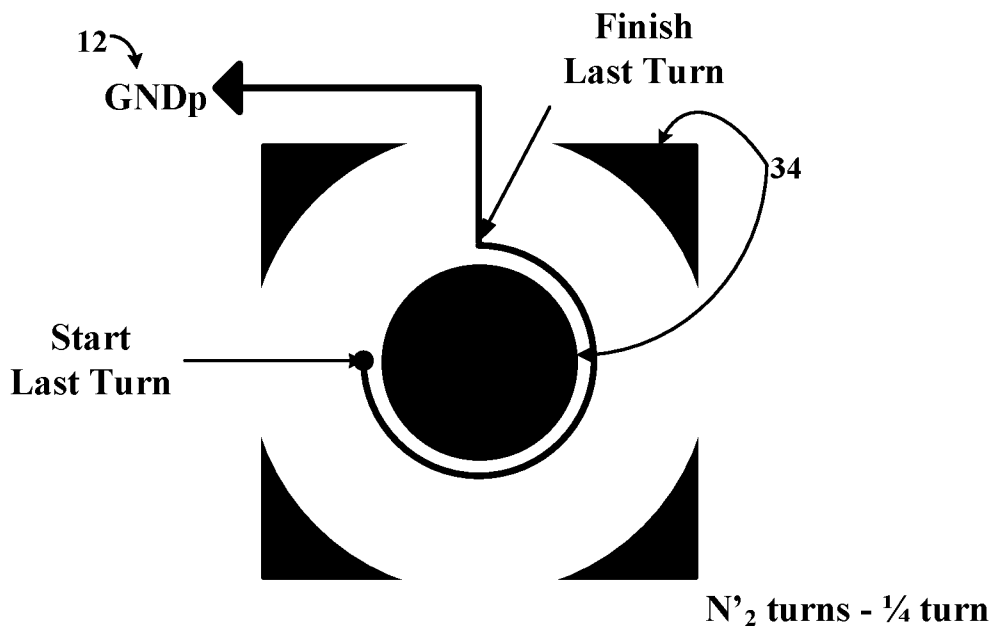


Fig. 7B

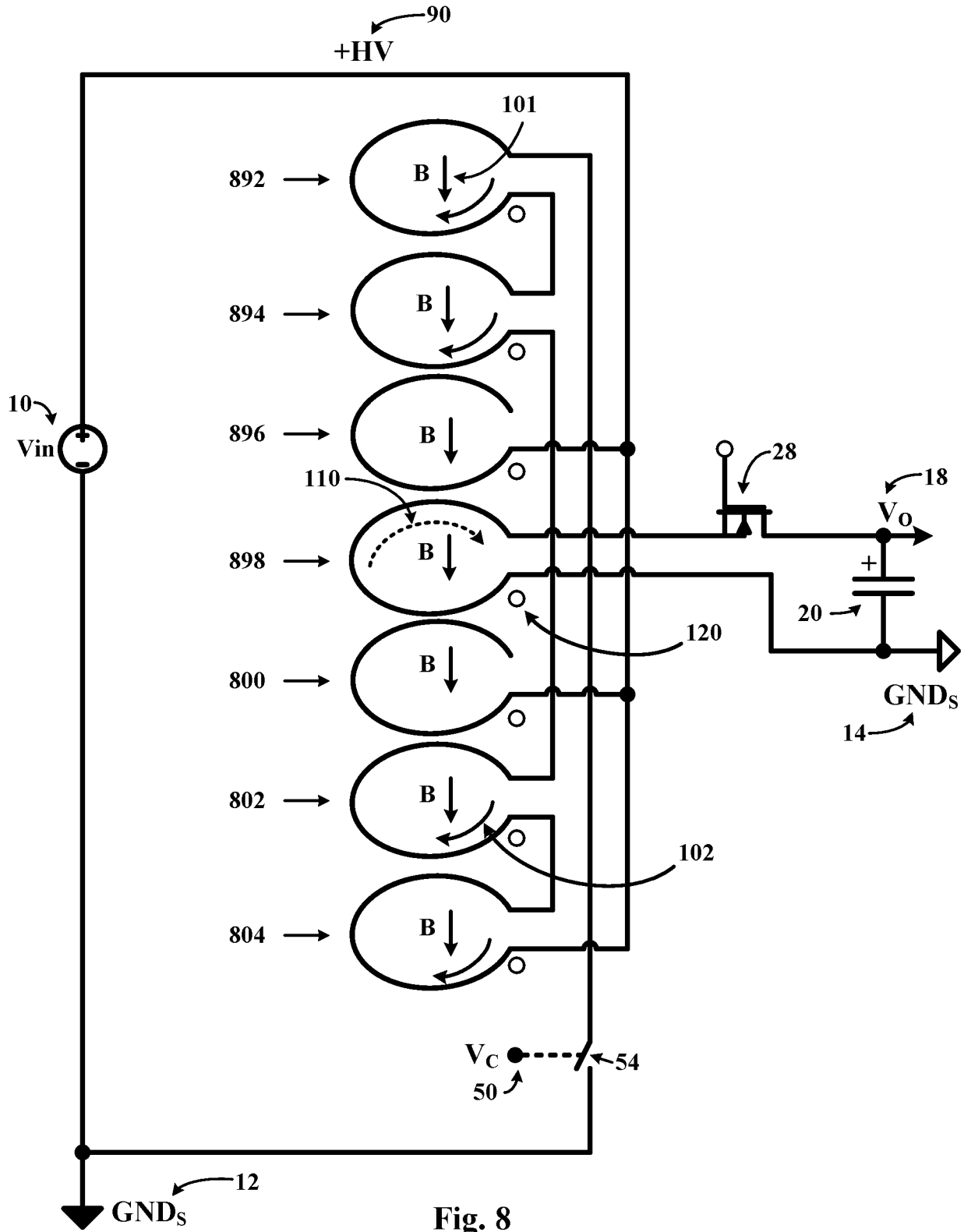


Fig. 8

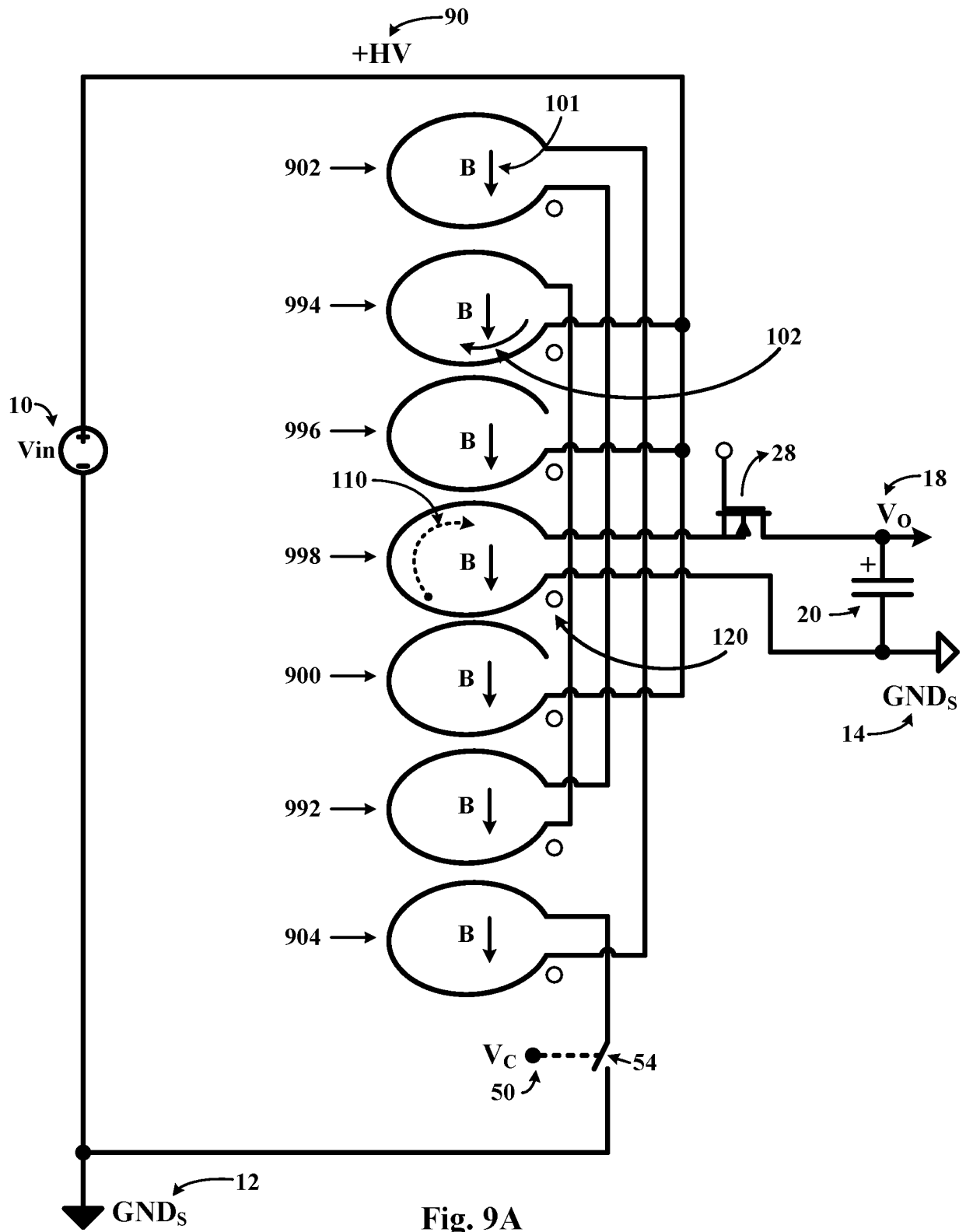


Fig. 9A

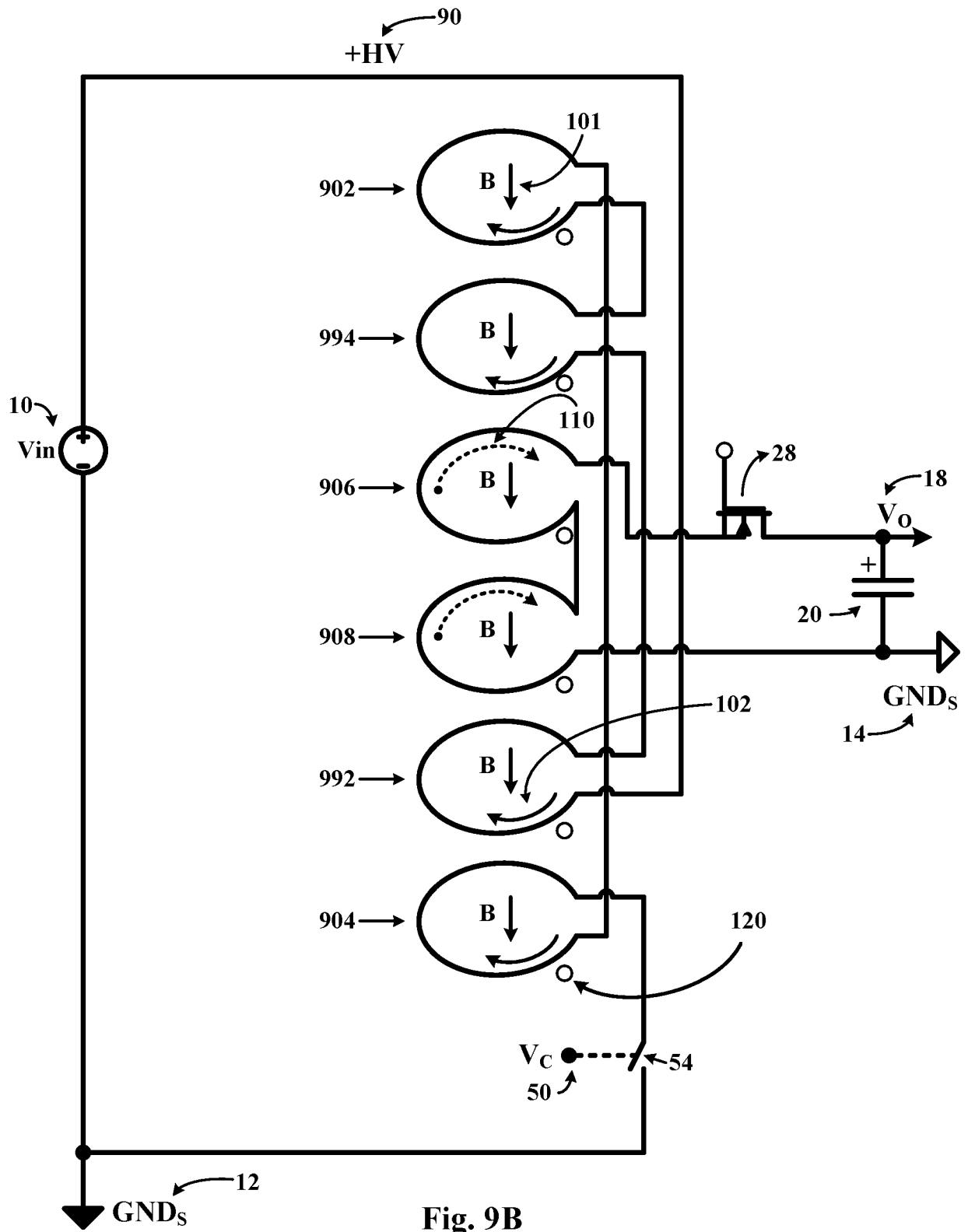


Fig. 9B

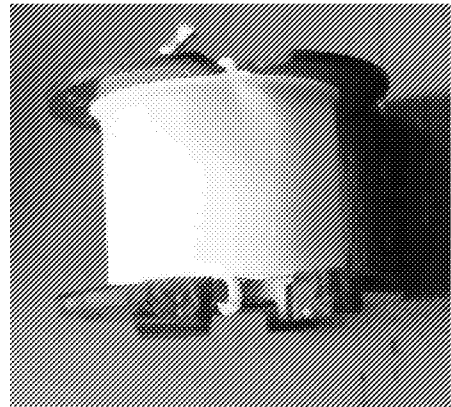
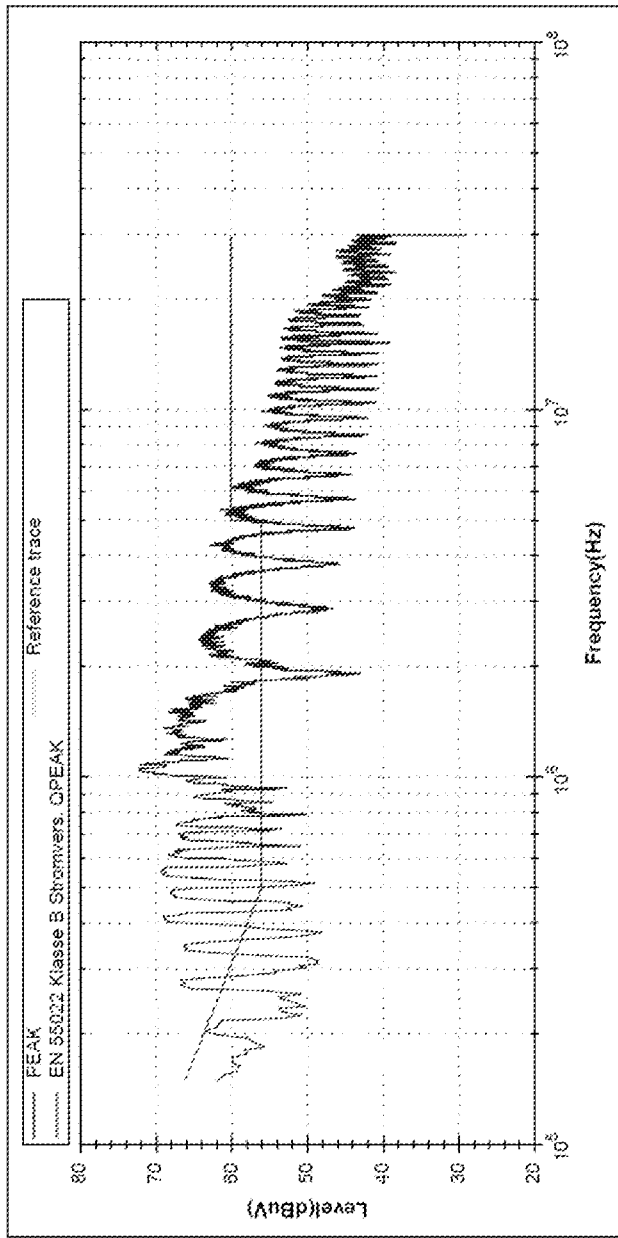


Fig. 10A

Fig. 10B

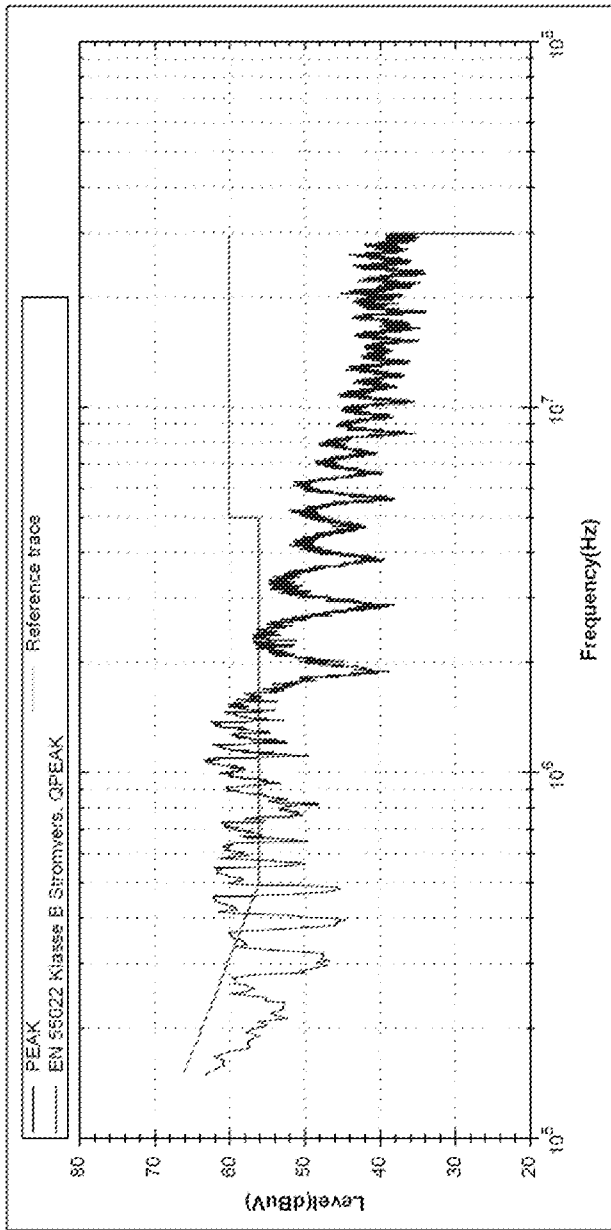


Fig. 11A

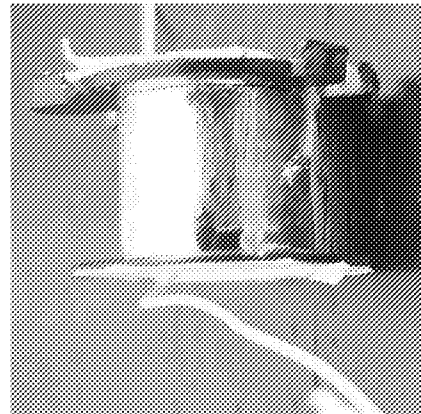


Fig. 11B

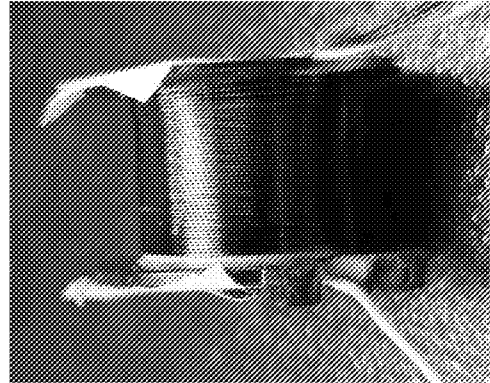
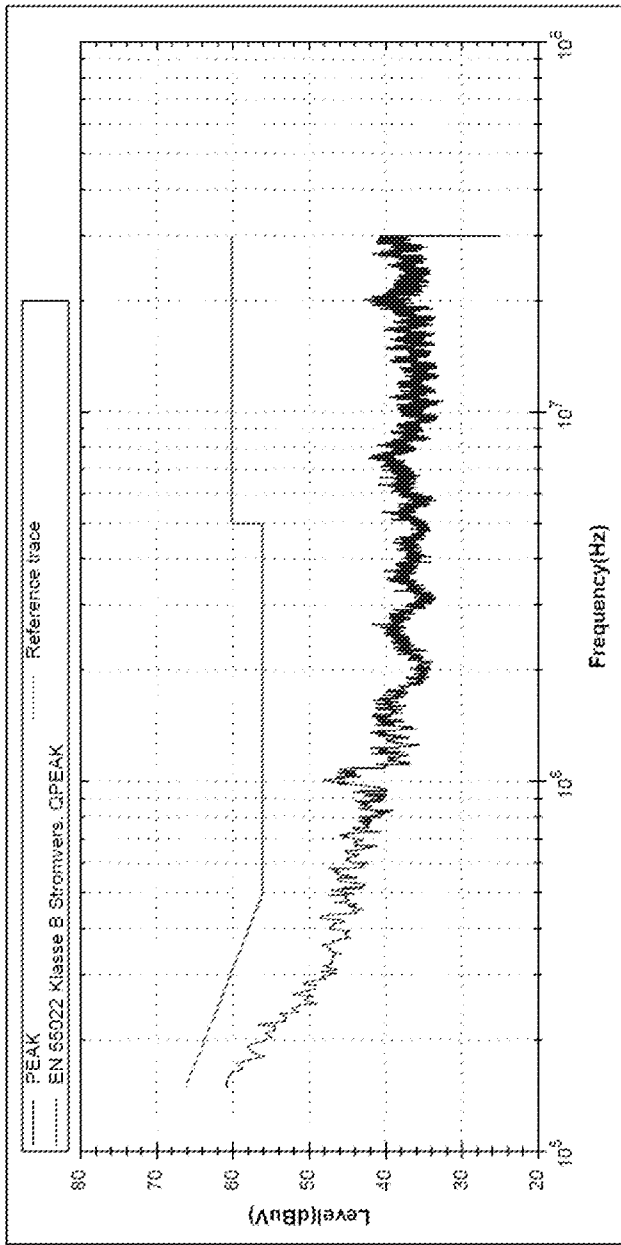


Fig. 12A

Fig. 12B

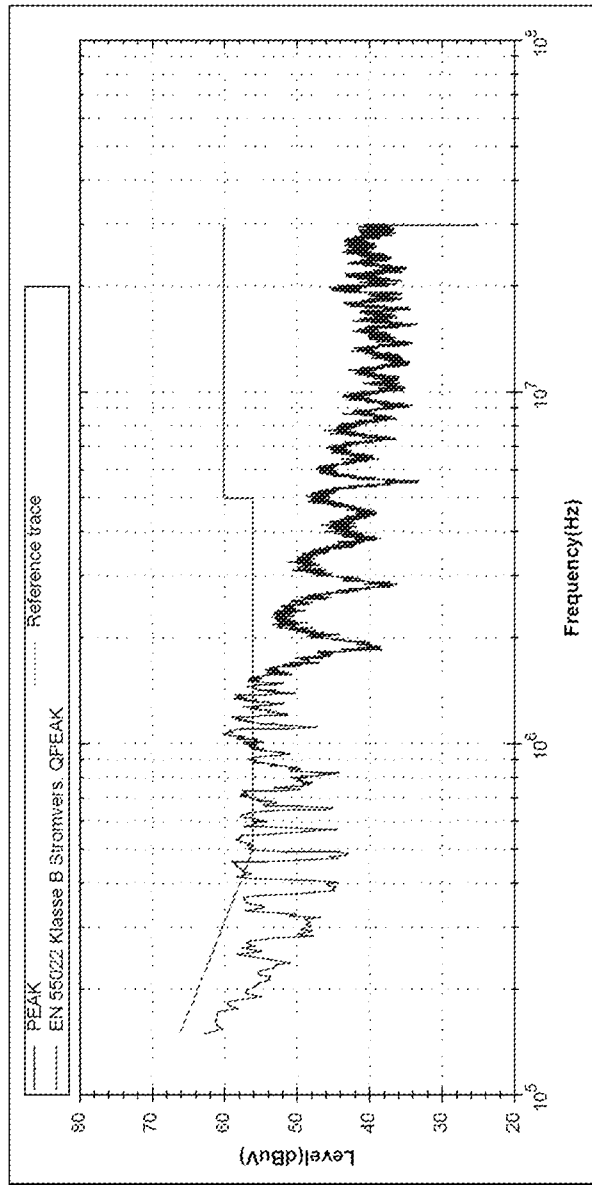


Fig. 13

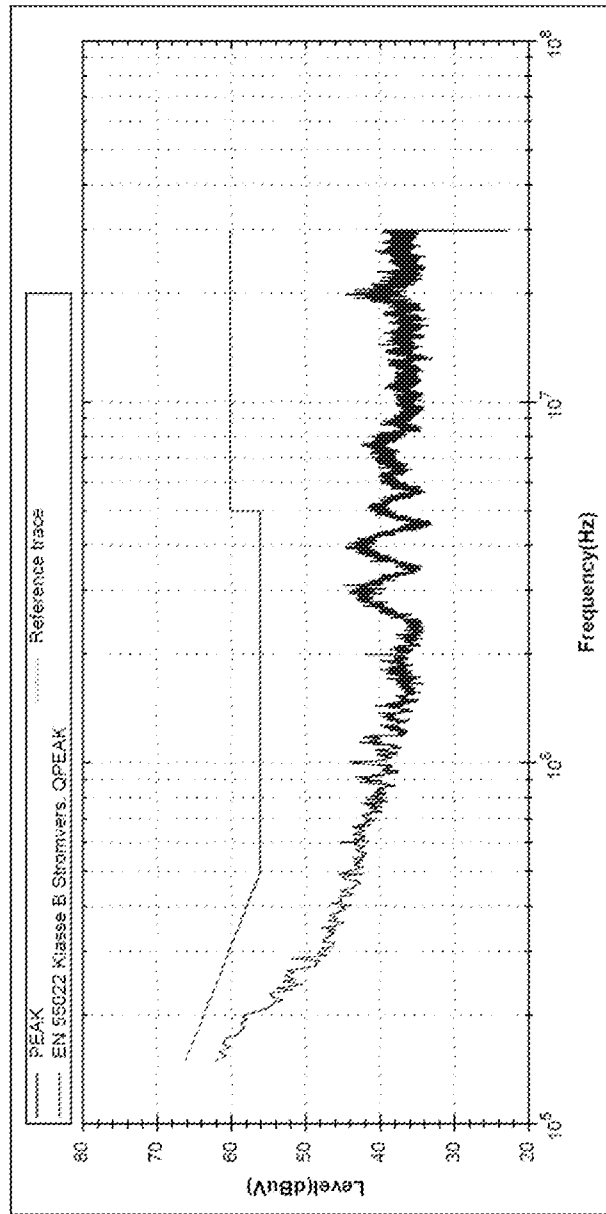


Fig. 14

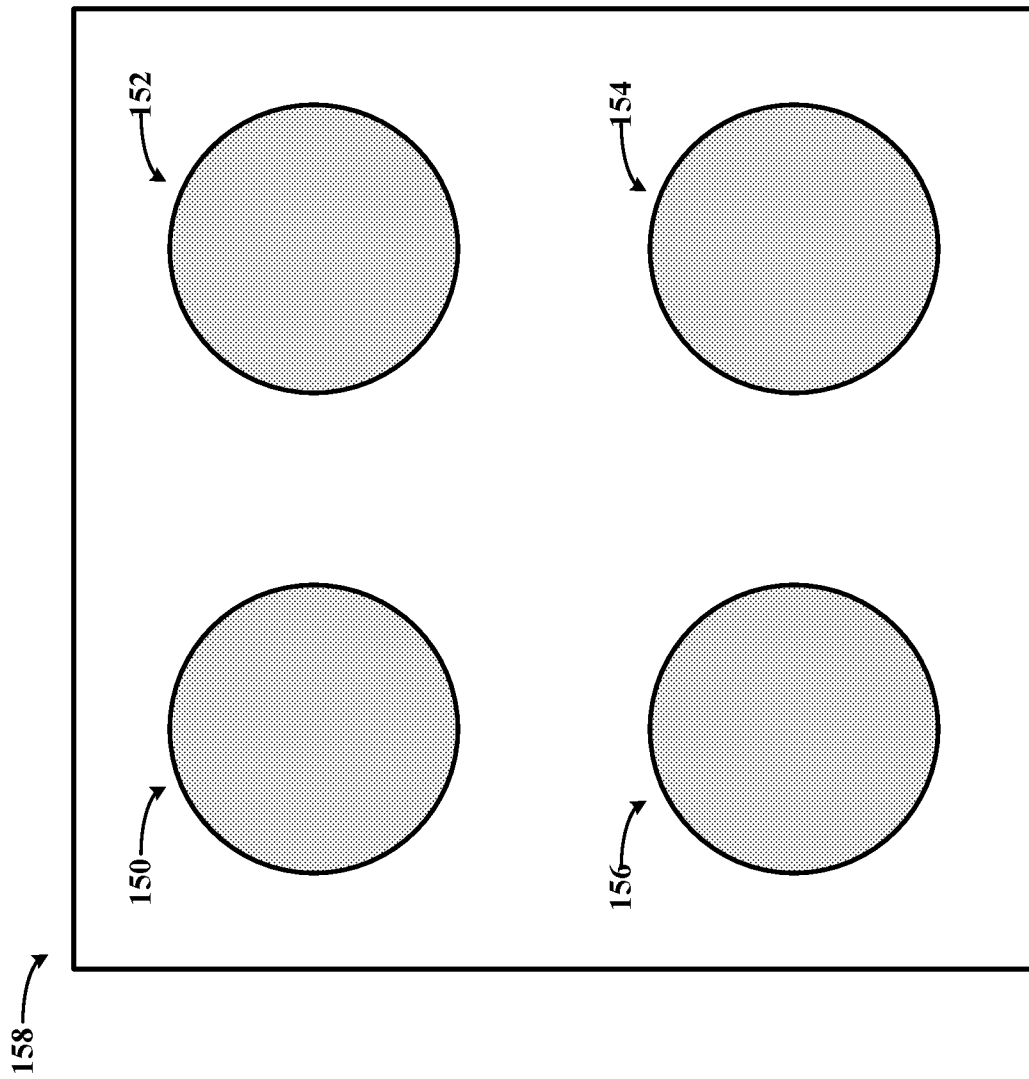


Fig. 15A

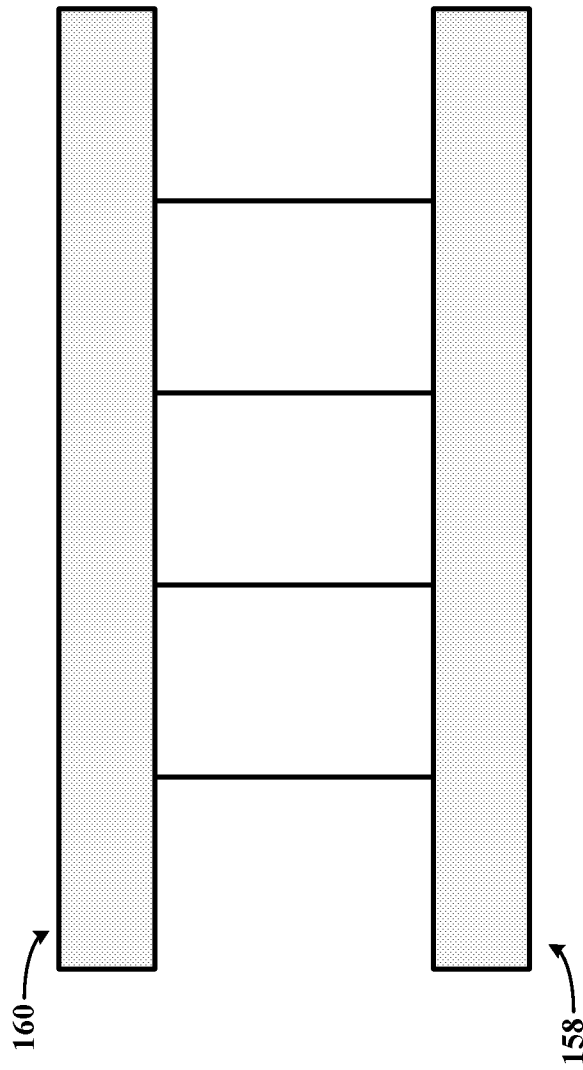


Fig. 15B

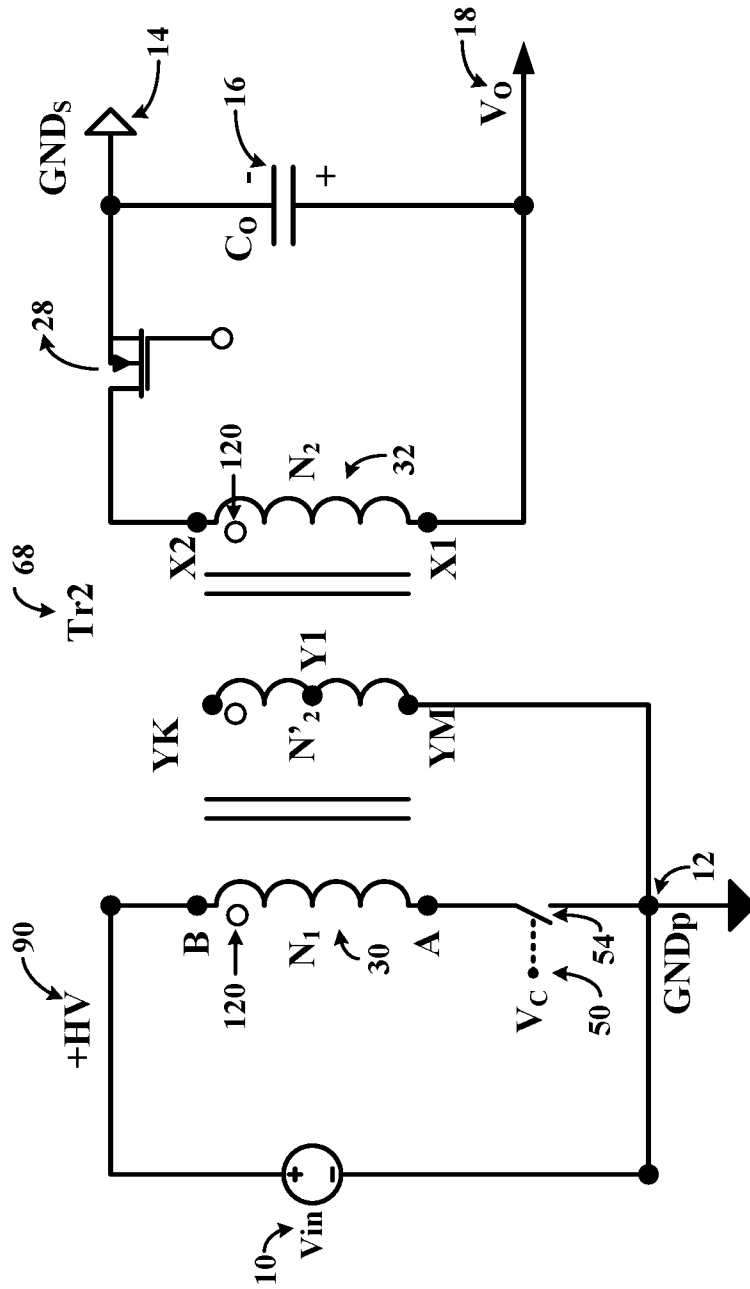


Fig. 15C

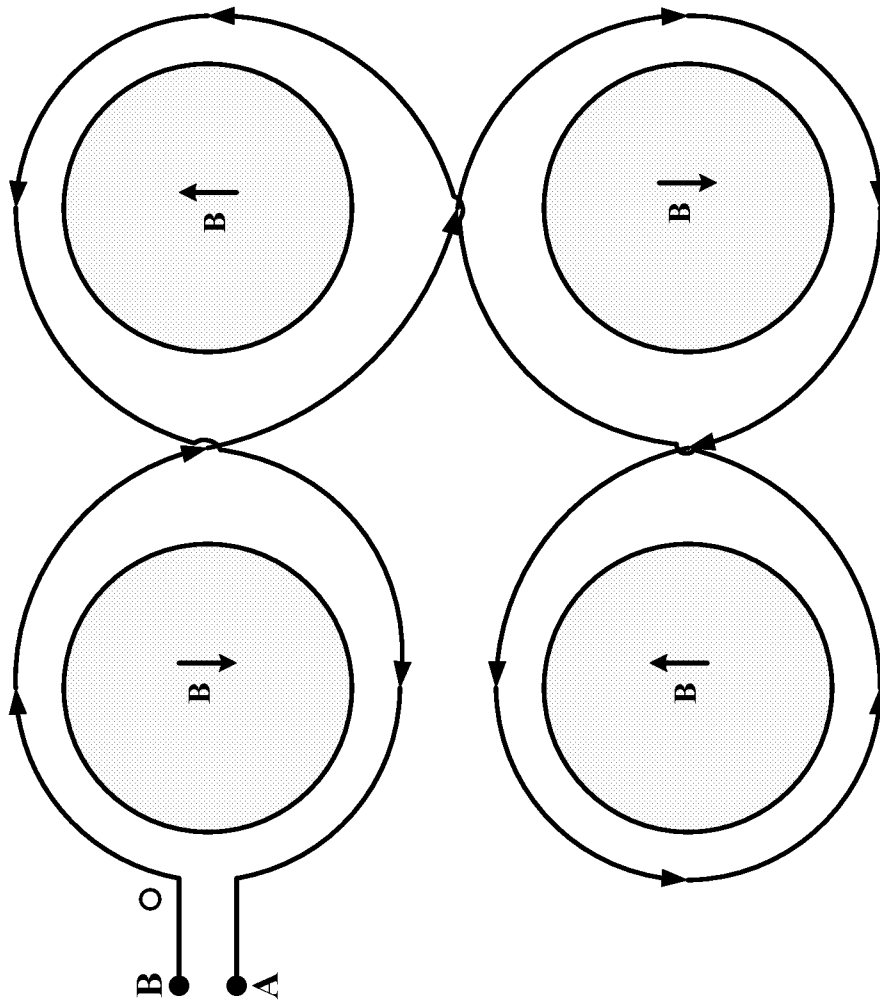


Fig. 15D

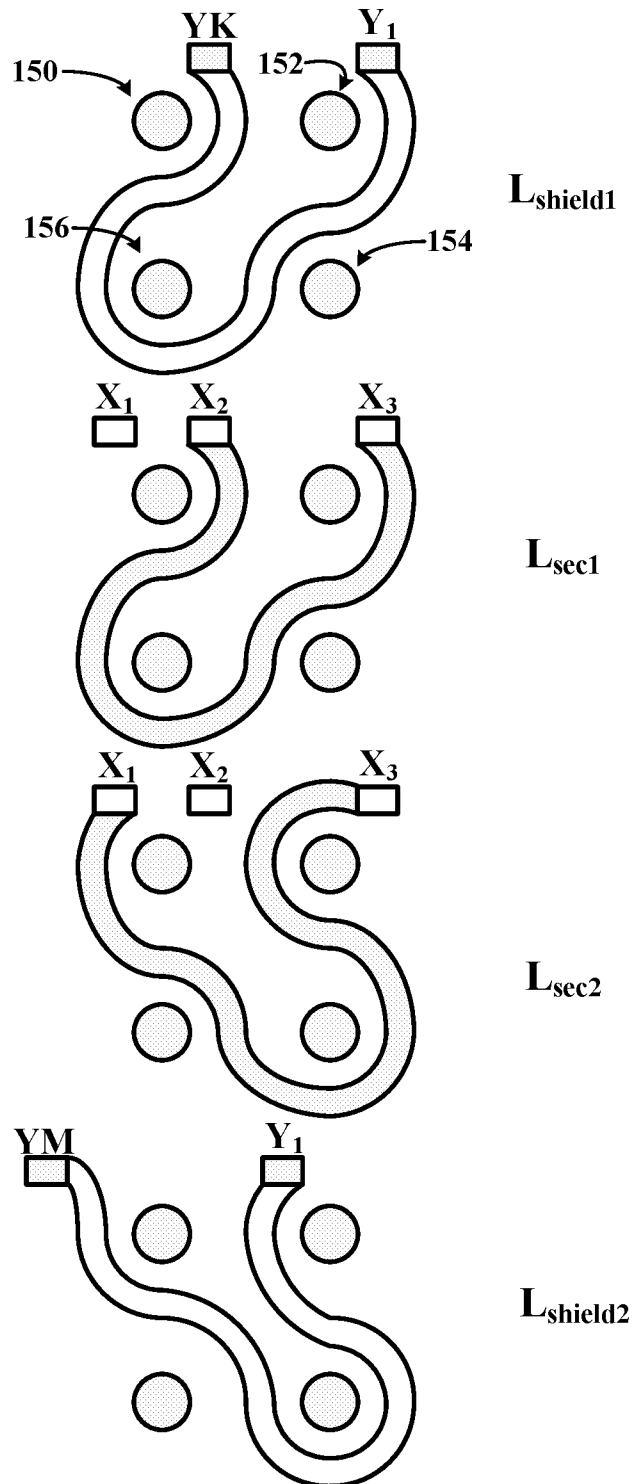


Fig. 15E

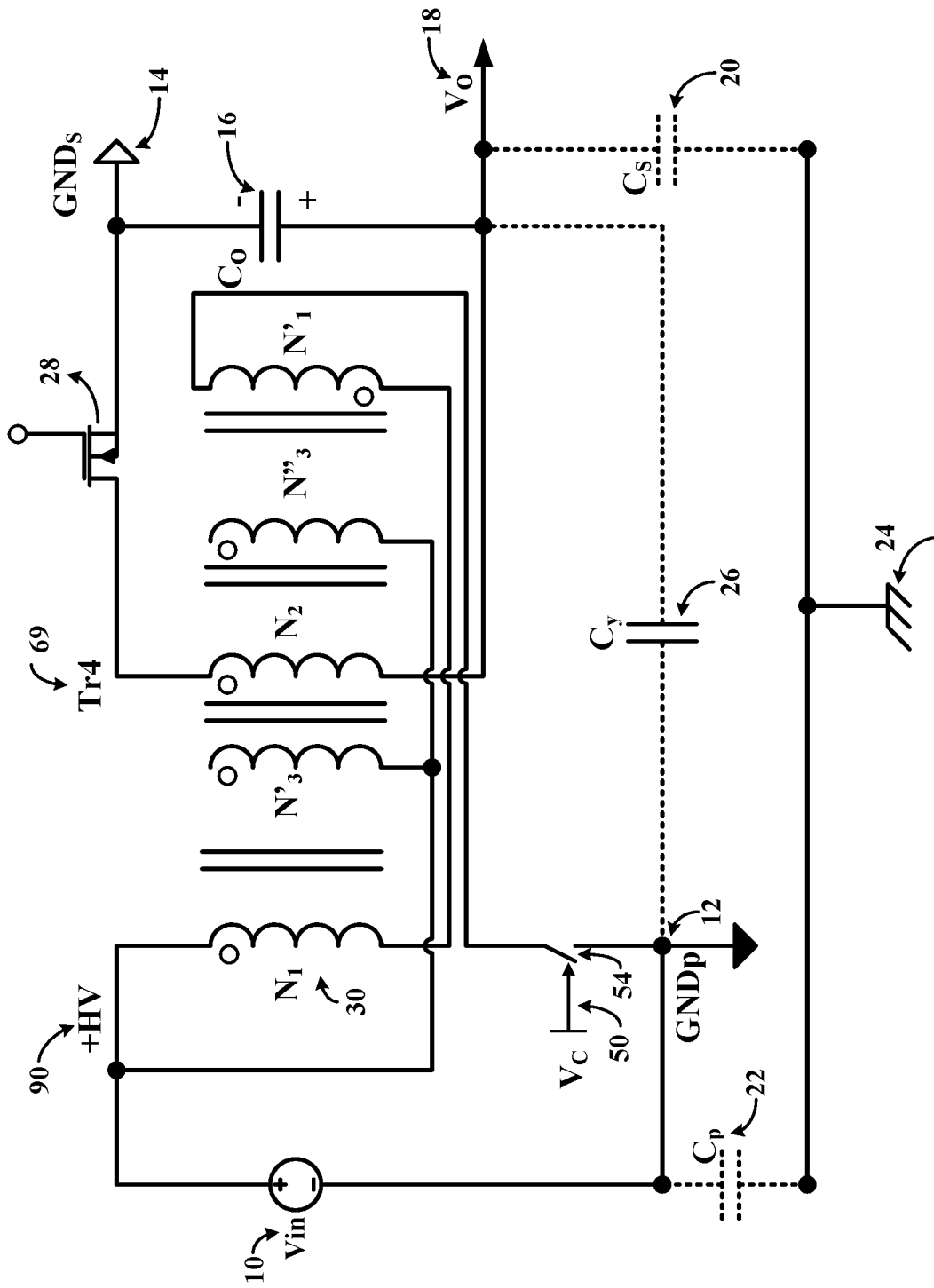


Fig. 16A

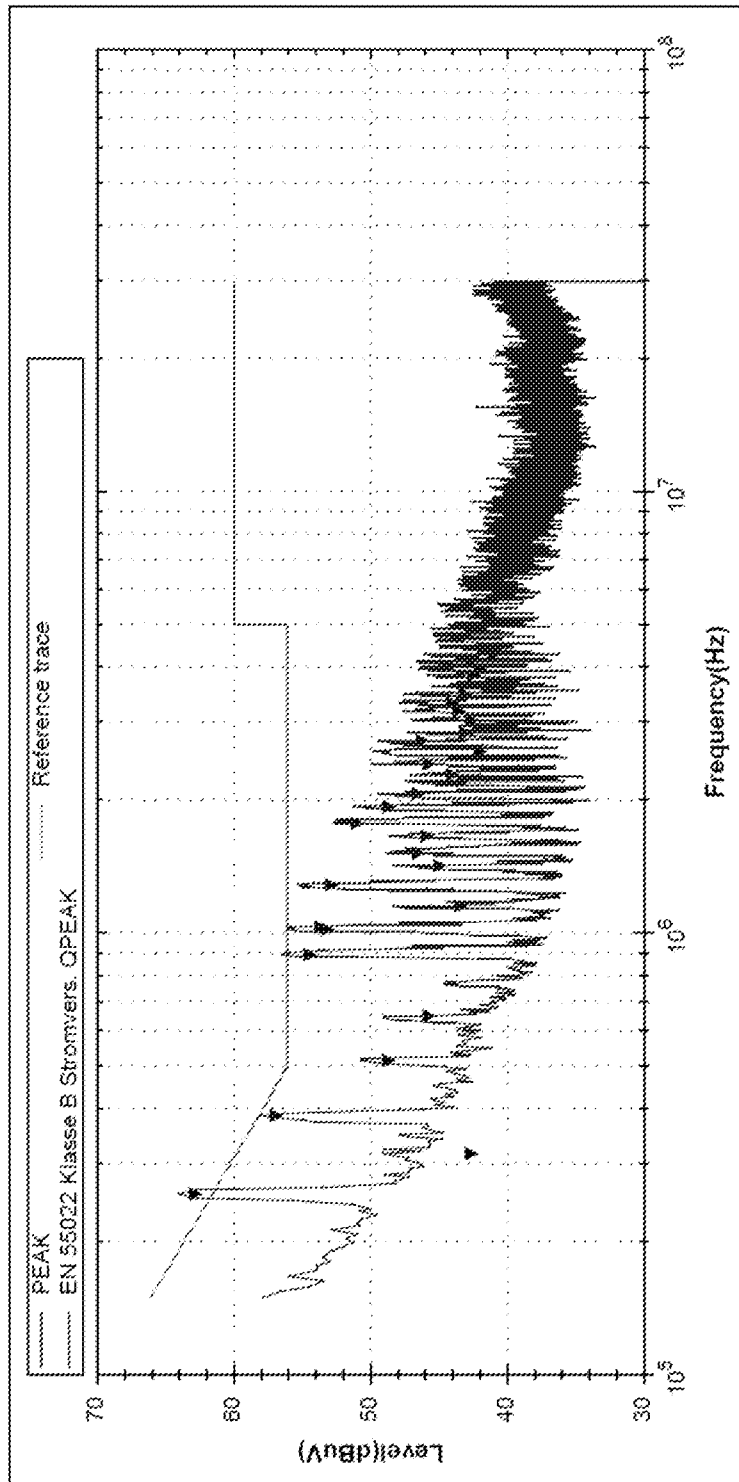


Fig. 16B

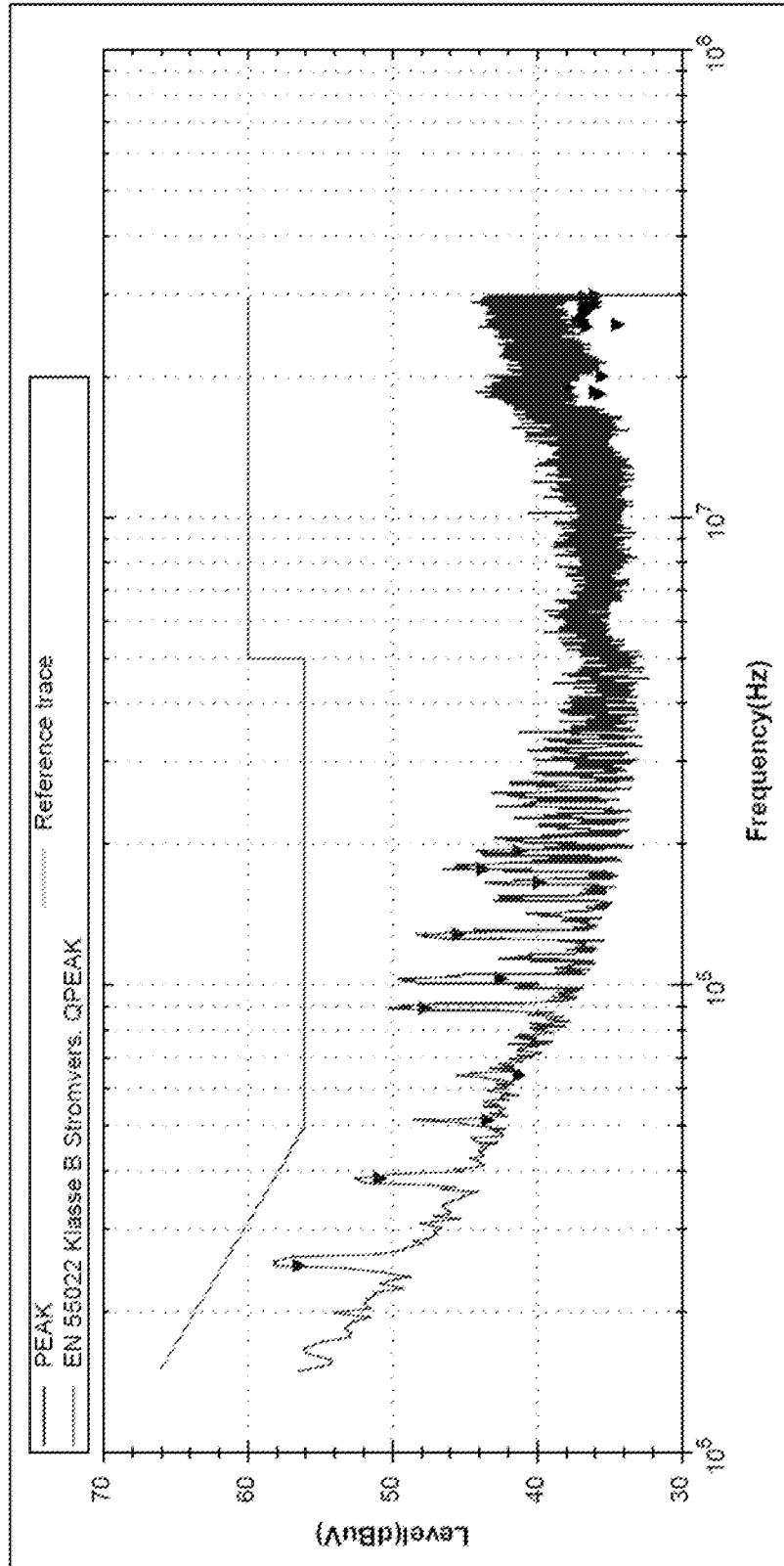


Fig. 16C

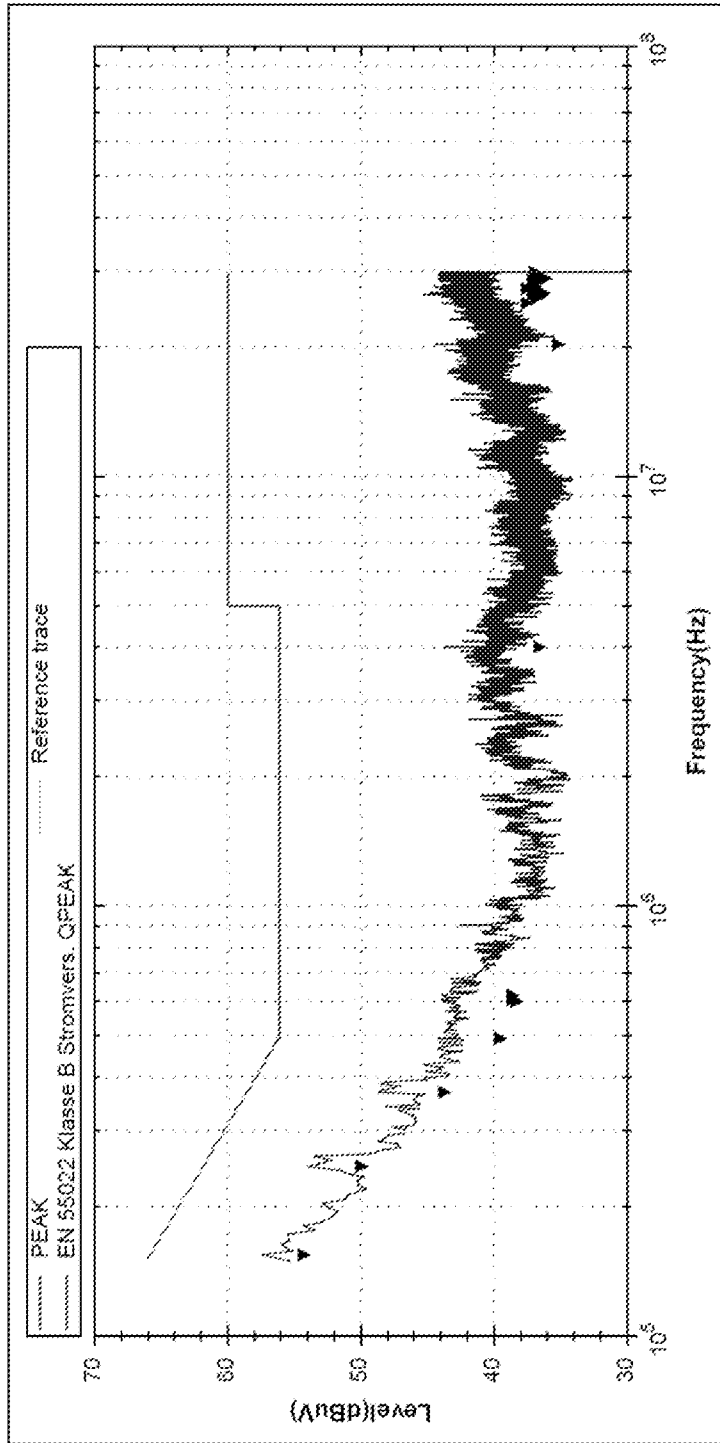


Fig. 17B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2019/069166

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H01F 27/28; H01F 27/36; H02M 1/12 (2020.01)

CPC - H01F 27/34; H01F 27/362; H02M 1/12; H02M 1/44 (2020.02)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 336/83; 336/200; 363/40 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 7,868,724 B2 (SICONG et al) 11 January 2011 (11.01.2011) entire document	1-16
A	US 6,490,181 B1 (LIU et al) 03 December 2002 (03.12.2002) entire document	1-16
A	US 2017/0181257 A1 (ROSTAMZADEH et al) 22 June 2017 (22.06.2017) entire document	1-16

 Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

02 March 2020

Date of mailing of the international search report

24 MAR 2020

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