



(51) International Patent Classification:

H02M 7/48 (2007.01) *H02M 1/44* (2007.01)

(21) International Application Number:

PCT/US2017/057540

(22) International Filing Date:

20 October 2017 (20.10.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/413,476 27 October 2016 (27.10.2016) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,

(54) Title: LOOP NOISE BALANCE TECHNIQUE FOR CM EMI NOISE REDUCTION OF THE FULL BRIDGE LLC RESONANT CONVERTER

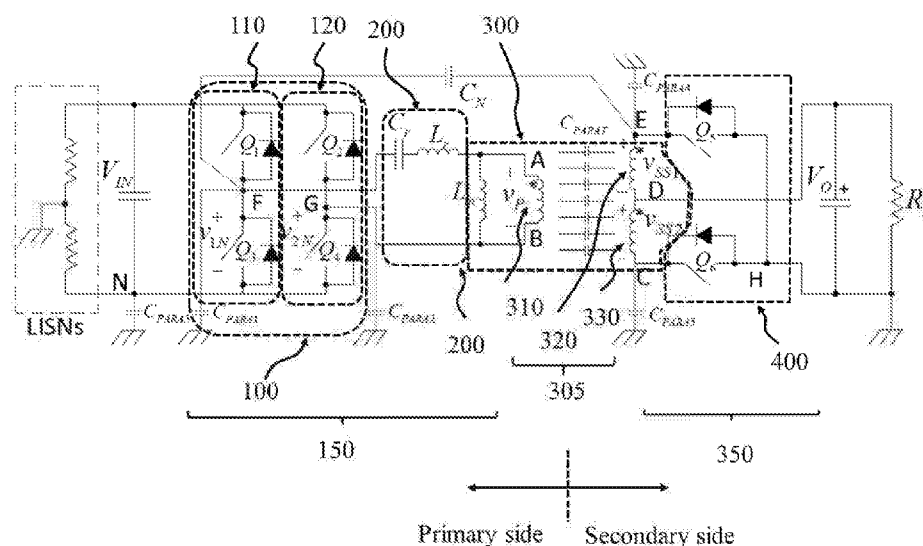


Figure 3

(57) Abstract: A full bridge LLC resonant converter can include: a full bridge circuit including a first input node and a second input node; a LLC resonant tank circuit connected to the first input node and the second input node; a transformer winding part connected to the LLC resonant tank circuit; a rectifier circuit connected to the transformer through a first output node and a second output node; and a capacitor connected between the first input node and the first output node. The LLC resonant tank circuit can include a resonant capacitor connected to the first input node, a resonant inductor connected to the resonant capacitor, and a magnetizing inductance connected between the resonant inductor and the second input node.



EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

DESCRIPTION

LOOP NOISE BALANCE TECHNIQUE FOR CM EMI NOISE REDUCTION OF THE
FULL BRIDGE LLC RESONANT CONVERTER

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CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application Serial No. 62/413,476, filed October 27, 2016, which is incorporated herein by reference in its entirety, including any figures, tables, and drawings.

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BACKGROUND OF INVENTION

LLC resonant converters have several desired features, such as high power, high power density, and high efficiency, thereby broadening the appeal of these converters. Existing LLC resonant converters can be classified as a half bridge resonant converter or a full bridge resonant converter according to a switching input circuit. While the number of switches in the half bridge resonant converter is half of that in the full bridge resonant converter, the half bridge resonant converter has twice the current of the full bridge resonant converter. Thus, the half bridge resonant converter is widely used in flat panel TVs and personal computers, and the full bridge resonant converter is used in application requiring high primary currents, such as photovoltaic applications and solar micro inverters. However, LLC resonant converters generate large common mode (CM) electromagnetic interference (EMI), which is a big drawback in a variety of applications.

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BRIEF SUMMARY

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Embodiments of the subject invention provide novel and advantageous full bridge resonant converters that include a capacitor connecting an input node of a full bridge circuit with respect to a resonant tank circuit (e.g., an LC circuit) to an output node of a transformer.

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In an embodiment of the present invention, a full bridge resonant converter can include: a full bridge circuit receiving an input signal; a resonant tank circuit connected to the full bridge circuit; a transformer connected to the resonant tank circuit; a rectifier circuit connected to the transformer and producing an output signal; and a capacitor connecting an

input node of the full bridge circuit with respect to the resonant tank circuit to an output node of the transformer.

In another embodiment of the present invention, a resonant converter can include: a primary side input circuit receiving an input signal; a transformer connected to the primary side input circuit; a secondary side output circuit connected to the transformer and providing an output signal; and a capacitor connecting the primary side input circuit to the secondary side output circuit.

In another embodiment of the present invention, a full bridge LLC resonant converter can include: a full bridge circuit including a first input node and a second input node; an LLC resonant tank circuit connected to the first input node and the second input node; a transformer winding part connected to the LLC resonant tank circuit; a rectifier circuit connected to the transformer winding part through a first output node and a second output node; and a capacitor connected between the first input node and the first output node.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 shows a full bridge LLC resonant converter.

Figure 2 shows noise sources of a full bridge LLC resonant converter.

Figure 3 shows a full bridge LLC resonant converter according to an embodiment of the subject invention.

Figure 4 shows equivalent circuits with regard to a full bridge LLC resonant converter according to an embodiment of the subject invention.

Figure 5 shows measurement results for a full bridge LLC resonant converter according to an embodiment of the subject invention.

Figure 6 shows circulating current loop of a full bridge LLC resonant converter according to an embodiment of the subject invention.

Figure 7 shows simulation results for circulating current loop of a full bridge LLC resonant converter according to an embodiment of the subject invention.

DETAILED DISCLOSURE

Embodiments of the subject invention provide novel and advantageous full bridge LLC resonant converters including a full bridge circuit, an LLC resonant tank circuit

connected to the full bridge circuit, a transformer winding part connected to the LLC resonant tank circuit, and a rectifier circuit connected to the transformer winding part. By connecting a capacitor between an input node of the full bridge circuit with respect to the LLC resonant tank circuit and an output node of the transformer winding part, the full bridge LLC resonant converter can make loop noise and reduce the common mode (CM) electromagnetic interference (EMI).

Figure 1 shows a full bridge LLC resonant converter including a full bridge circuit and an LLC resonant tank circuit. Referring to Figure 1, the full bridge LLC resonant converter comprises a full bridge circuit **100** receiving an input signal V_{IN} , an resonant tank circuit **200** connected to the full bridge circuit **100**, a transformer **300** connected to the resonant tank circuit **200**, and a rectifier circuit **400** connected to the transformer **300** and providing an output signal V_O .

The full bridge circuit **100** comprises a first switch **Q1**, a second switch **Q2**, a third switch **Q3**, and a fourth switch **Q4**, such that the current resonates in a positive direction through the first switch **Q1** and the fourth switch **Q4**, and the current resonates in the negative direction through the second switch **Q2** and the third switch **Q3**. The full bridge circuit **100** is configured to be connected to a Line Impedance Stabilization Network (LISN) through a negative node N.

The resonant tank circuit **200** comprises a resonant capacitor C_r connected to the full bridge circuit **100** and a resonant inductor L_r connected to the resonant capacitor C_r . The resonant capacitor C_r is connected to the first switch **Q1** and the third switch **Q3**, and the resonant inductor L_r is coupled to the second switch **Q2** and the fourth switch **Q4**.

The transformer **300** comprises a magnetizing inductance L_m , a primary winding **310**, a first secondary winding **320**, and a second secondary winding **330**. The magnetizing inductance L_m is connected between the resonant inductor L_r and the full bridge circuit **100**, thereby making an LLC resonant tank circuit including the resonant capacitor C_r , the resonant inductor L_r , and the magnetizing inductance L_m connected in series. The primary winding **310** is connected to the resonant tank circuit **200** through a primary upper node **A** and a primary lower node **B**. The first secondary winding **320** is connected between a first output node **E** and a middle output node **D**, and the second secondary winding **330** is connected between the middle output node **D** and a second output node **C**.

The rectifier circuit **400** comprises a fifth switch **Q5** connected to the first output node **E** and a sixth switch **Q6** connected to the second output node **C**. The rectifier circuit **400** is configured to be connected to a load R_L and provide the output signal V_O .

The full bridge LLC resonant converter divides a primary side and a secondary side with regard to the transformer **300**. That is, the full bridge circuit **100** and the resonant tank circuit **200** are placed at the primary side, and the rectifier circuit **400** is placed at the secondary side. In addition, the full bridge LLC resonant converter has several parasitic capacitances including C_{PARA1} - C_{PARA5} and C_{PARAT} .

Figure 2 shows several noise sources of a full bridge LLC resonant converter. Referring to Figure 2, the full bridge LLC resonant converter has several noise sources because of high voltage slew rate (dv/dt). For example, in case a winding ratio of the primary winding **310**, the first secondary winding **320**, and the second secondary winding **330** is $n:1:1$, the v_{IN} voltage of the third switch **Q3**, the v_{2N} voltage of the fourth switch **Q4**, and the v_P voltage of the primary winding **310** could be noise sources in the primary side. In addition, the v_{SS1} voltage of the first secondary winding **320** and the v_{SS2} voltage of the second secondary winding **330** could be noise sources in the secondary side, wherein the noise sources meet the following two conditions.

$$v_{1N} = -v_{2N}$$

$$v_P = nv_{SS1} = nv_{SS2}$$

The noise source v_{2N} of the fourth switch **Q4** and the noise source v_P of the primary winding **310** make a noise loop and generate all CM noise. That is, this noise loop by the noise source v_{2N} voltage and the noise source v_P voltage becomes a main noise loop.

In embodiments of the subject invention, the CM noise generated by the main noise loop can be solved by connecting a capacitor between the primary side and the secondary side of the transformer. Figure 3 shows a full bridge LLC resonant converter according to an embodiment of the subject invention. Referring to Figure 3, the full bridge LLC resonant converter can comprise a full bridge circuit **100** receiving an input signal V_{IN} , an resonant tank circuit **200** connected to the full bridge circuit **100**, a transformer **300** connected to the resonant tank circuit **200**, a rectifier circuit **400** connected to the transformer **300** and providing an output signal V_O , and a capacitor C_N connecting a first input node **F** and a first output node **E**.

A primary side input circuit **150** placed at the primary side from the transformer **300** can comprise the full bridge circuit **100** and the resonant tank circuit **200**, wherein the primary side input circuit **150** receives the input signal V_{IN} .

The full bridge circuit **100** can comprise a plurality of switches. For example, the plurality of switches can include a first switch **Q1**, a second switch **Q2**, a third switch **Q3**, and a fourth switch **Q4**, such that the first switch **Q1** and the third switch **Q3** are connected in series through the first input node **F**, and the second switch **Q2** and the fourth switch **Q4** are connected in series through a second input node **G**. A first pair **110** of the first switch **Q1** and the third switch **Q3** can be connected in parallel to a second pair **120** of the second switch **Q2** and the fourth switch **Q4**. The input signal V_{IN} can be connected to both ends of the first pair **110** and both ends of the second pair **120**. In addition, each of the first to fourth switches can be embodied as a MOSFET.

The resonant tank circuit **200** can comprise a resonant capacitor C_r connected to the first input node **F** of the full bridge circuit **100** and a resonant inductor L_r connected to the resonant capacitor C_r . The resonant capacitor C_r can be connected to the first switch **Q1** and the third switch **Q3** of the first pair **110** through the first input node **F**, and the resonant inductor L_r can be coupled to the second switch **Q2** and the fourth switch **Q4** of the second pair **120** through the second input node **G**. That is, the first input node **F** of the full bridge circuit **100** and the second input node **G** of the full bridge circuit **100** can function as input nodes with respect to the resonant tank circuit **200**.

The transformer **300** can comprise a magnetizing inductance L_m and a transformer winding part **305** including a primary winding **310**, a first secondary winding **320**, and a second secondary winding **330**. The primary winding **310** can be connected to the resonant tank circuit **200** through a primary upper node **A** and a primary lower node **B** in such a manner that the primary winding **310** is connected in parallel to the magnetizing inductance L_m . The first secondary winding **320** can be connected between the first output node **E** and a middle output node **D**, and the second secondary winding **330** can be connected between the middle output node **D** and a second output node **C** such that the first **320** and second **330** secondary windings are connected in series.

The magnetizing inductance L_m of the transformer **300** is connected between the resonant inductor L_r and the second input node **G**. As a result, the resonant capacitor C_r of the resonant tank circuit **200**, the resonant inductor L_r of the resonant tank circuit **200**, and

the magnetizing inductance L_m of the transformer **300** are connected in series, thereby accomplishing an LLC resonant tank circuit.

A secondary side output circuit **350** placed at the secondary side from the transformer **300** can comprise the rectifier circuit **400** and can provide the output signal V_O . The rectifier circuit **400** can comprise a fifth switch **Q5** connected between the first output node **E** and a common output node **H** and a sixth switch **Q6** connected between the second output node **C** and the common output node **H**. The rectifier circuit **400** can be configured to provide the output signal V_O between the middle output node **D** and the common output node **H**. In addition, each of the fifth switch **Q5** and sixth switch **Q6** can be a diode.

The capacitor C_N can connect the primary side input circuit **150** and the secondary side output circuit **350**, thereby making an additional noise loop and canceling the CM noise generated by the main noise loop. The capacitor C_N can be connected to the first input node **F** of the primary side input circuit **150** and the first output node **E** of the secondary side output circuit **350**, thereby connecting the primary side and the secondary side.

Figure 4 shows equivalent circuits with regard to a full bridge LLC resonant converter according to an embodiment of the subject invention. Referring to Figure 4, by connecting the capacitor C_N to the first input node **F** and the first output node **E**, the noise source v_{IN} of the third switch **Q3** and the noise source v_{SS1} of the first secondary winding **320** can make an additional noise loop that would become a new CM noise loop. The noise sources of the full bridge LLC resonant converter can satisfy the following conditions.

$$V_{1N} = -V_{2N} \quad V_P = nV_{SS1} = nV_{SS2}$$

Therefore, it is possible to have the main CM noise generated by the main noise loop and the additional CM noise generated by the additional noise loop made by the capacitor C_N to cancel each other by adjusting their loop impedances. That is, the noise cancelation can be accomplished by adjusting a capacitance C_{AD} between the primary upper node **A** and the middle output node **D** and/or a capacitance C_{BD} between the primary lower node **B** and the middle output node **D** in such a manner that a ratio of a sum of the capacitance C_{AD} and the capacitance C_{BD} to the capacitance C_{AD} is $n:1$, wherein n is a winding ratio of the primary winding **310** to the first secondary winding **320** or the second secondary winding **330**. A capacitance C_N can be used to represent the sum of the capacitance C_{AD} and the capacitance C_{BD} . The adjusting condition to cancel the CM noise can be as follows:

$$\frac{C_{AD}}{C_{AD} + C_{BD}} = \frac{1}{n}, \quad C_N = C_{AD} + C_{BD}$$

The subject invention includes, but is not limited to, the following exemplified embodiments.

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Embodiment 1. A full bridge resonant converter, comprising:

a full bridge circuit receiving an input signal;

a resonant tank circuit connected to the full bridge circuit;

a transformer connected to the resonant tank circuit;

10 a rectifier circuit connected to the transformer and producing an output signal; and

a capacitor connecting an input node of the full bridge circuit with respect to the resonant tank circuit to an output node of the transformer.

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Embodiment 2. The full bridge resonant converter according to embodiment 1, wherein the resonant tank circuit is connected to the full bridge circuit through the input node, and wherein the rectifier circuit is connected to the transformer through the output node of the transformer.

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Embodiment 3. The full bridge resonant converter according to any of embodiments 1-2, wherein the resonant tank circuit comprises a resonant capacitor and a resonant inductor.

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Embodiment 4. The full bridge resonant converter according to any of embodiments 1-3, wherein the transformer includes a magnetizing inductance, and the resonant capacitor, the resonant inductor, and the magnetizing inductance are connected in series.

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Embodiment 5. The full bridge resonant converter according to any of embodiments 1-4, wherein the full bridge circuit includes a first switch, a second switch, a third switch, and a fourth switch, wherein the first switch and the third switch are connected

to each other in series, the second switch and the fourth switch are connected to each other in series, and a first pair comprising the first and third switches and a second pair comprising the second and fourth switches are connected to each other in parallel.

5 Embodiment 6. The full bridge resonant converter according to embodiment 5, wherein the first switch and the third switch are connected to the capacitor through the input node.

10 Embodiment 7. The full bridge resonant converter according to any of embodiments 5-6, wherein each of the first, second, third, and fourth switches is a MOSFET.

15 Embodiment 8. The full bridge resonant converter according to any of embodiments 1-7, wherein the transformer further includes a primary winding at a primary side, a first secondary winding at a secondary side, and a second secondary winding connected in series to the first secondary winding at the secondary side.

20 Embodiment 9. The full bridge resonant converter according to embodiment 8, wherein the first secondary winding is connected to the capacitor through the output node of the transformer.

25 Embodiment 10. The full bridge resonant converter according to any of embodiments 1-9, wherein the rectifier circuit includes a fifth switch and a sixth switch, wherein the fifth switch is connected to the output node of the transformer.

 Embodiment 11. The full bridge resonant converter according to embodiment 10, wherein each of the fifth switch and the sixth switch is a diode.

30 Embodiment 12. A resonant converter, comprising:
a primary side input circuit receiving an input signal;
a transformer connected to the primary side input circuit;

a secondary side output circuit connected to the transformer and providing an output signal; and

a capacitor connecting the primary side input circuit to the secondary side output circuit.

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Embodiment 13. The resonant converter according to embodiment 12, wherein the primary side input circuit comprises a full bridge circuit receiving the input signal and a resonant tank circuit connected to the full bridge circuit through a first input node and a second input node.

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Embodiment 14. The resonant converter according to embodiment 13, wherein the capacitor is connected to the first input node.

Embodiment 15. The resonant converter according to any of embodiments 13-14, wherein the full bridge circuit comprises a first switch, a second switch, a third switch, and a fourth switch, the first switch is connected to the third switch through the first input node, and the second switch is connected to the fourth switch through the second input node.

Embodiment 16. The resonant converter according to any of embodiments 13-15, wherein the resonant tank circuit includes a resonant capacitor connected to the first input node and a resonant inductor connected to the resonant capacitor.

Embodiment 17. The resonant converter according to any of embodiments 12-16, wherein the transformer comprises a magnetizing inductance connected between the resonant inductor and the second input node, a primary winding connected to the magnetizing inductance, a first secondary winding connected to a first output node, and a second secondary winding connected to the first secondary winding through a middle output node.

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Embodiment 18. The resonant converter according to embodiment 17, wherein a winding direction of the primary winding is the same as that of the first secondary winding and that of the second secondary winding.

5 Embodiment 19. The resonant converter according to any of embodiments 12-18, wherein the secondary side output circuit comprises a rectifier circuit comprising a fifth switch connected to the transformer through the first output node and a sixth switch connected to the transformer through a second output node.

10 Embodiment 20. The resonant converter according to embodiment 19, wherein the fifth switch is connected to the sixth switch through a common output node.

Embodiment 21. The resonant converter according to any of embodiments 17-20, wherein the capacitor is connected to the first output node.

15 Embodiment 22. The resonant converter according to any of embodiments 20-21, further comprising a load configured to be connected between the middle output node and the common output node.

20 Embodiment 23. A full bridge LLC resonant converter, comprising:
a full bridge circuit including a first input node and a second input node;
an LLC resonant tank circuit connected to the first input node and the second input node;
a transformer winding part connected to the LLC resonant tank circuit;
25 a rectifier circuit connected to the transformer winding part through a first output node and a second output node; and
a capacitor connected between the first input node and the first output node.

30 Embodiment 24. The full bridge LLC resonant converter according to embodiment 23, wherein the LLC resonant tank circuit comprises a resonant capacitor connected to the first input node, a resonant inductor connected to the resonant capacitor,

and a magnetizing inductance connected between the resonant inductor and the second input node.

Embodiment 25. The full bridge LLC resonant converter according to any of
embodiments 23-24, wherein the transformer winding part comprises a primary winding
connected to the magnetizing inductance through a primary upper node and a primary lower
node, a first secondary winding connected between the first output node and a middle
output node, and a second secondary winding connected between the middle output node
and the second output node.

Embodiment 26. The full bridge LLC resonant converter according to
embodiment 25, wherein a sum capacitance of a first capacitance between the primary
upper node and the middle output node and a second capacitance between the primary lower
node and the middle output node is the same as a capacitance of the capacitor between the
first input node and the first output node.

Embodiment 27. The full bridge LLC resonant converter according to any of
embodiments 25-26, further comprising an assistance capacitor between the primary lower
node and the middle output node such that the sum capacitance of the first capacitance
between the primary upper node and the middle output node and the second capacitance
between the primary lower node and the middle output node is the same as the capacitance
of the capacitor between the first input node and the first output node.

Embodiment 28. The full bridge LLC resonant converter according to any of
embodiments 26-27, wherein a first ratio of the sum capacitance to the first capacitance is N
to 1, and a second ratio of a primary winding voltage between the primary upper node and
the primary lower node to a first secondary winding voltage between the first output node
and the middle output node is N to 1.

Embodiment 29. The full bridge LLC resonant converter according to any of
embodiments 23-28, wherein the full bridge circuit comprises a first switch, a second
switch, a third switch, and a fourth switch, the first switch is connected to the third switch

through the first input node, and the second switch is connected to the fourth switch through the second input node.

Embodiment 30. The full bridge LLC resonant converter according to
5 embodiment 29, wherein a first input voltage of the third switch and a second input voltage of the fourth switch have the same absolute value but different signs (positive or negative).

A greater understanding of the present invention and of its many advantages may be
had from the following example, given by way of illustration. The following example is
10 illustrative of some of the methods, applications, embodiments, and variants of the present invention. It is, of course, not to be considered as limiting the invention. Numerous changes and modifications can be made with respect to the invention.

EXAMPLE 1 - Full Bridge LLC Resonant Converter

15 The full bridge LLC resonant converter described in Figures 1 and 2 can have a winding ratio n of 4, a capacitance C_{AD} of 2.72 nF (nanoFarad), and a capacitance C_{BD} of 4.08 nF. With respect to this full bridge LLC resonant converter, by adding a capacitance of 4.08 nF between the primary lower node **B** and the middle output node **D** and adding capacitor C_N of 10.88 nF between the first input node **F** and the first output node **E**, the
20 adjusting condition can be satisfied and the CM noise can be reduced or canceled. The addition capacitance between the primary lower node **B** and the middle output node **D** can be accomplished by adding an additional capacitor between the primary lower node **B** and the middle output node **D**.

Figure 5 shows measurement results for a full bridge LLC resonant converter
25 according to an embodiment of the subject invention. Referring to Figure 5, the EMI noise was reduced by more than 20 dBs at switching frequency when comparing CM EMI 1 (without capacitor C_N) with CM EMI 2 (with capacitor C_N). However, referring to Figure 6, the capacitor C_N connecting the primary side and the secondary side inevitably made a circulating current loop and caused a loop impedance. Therefore, the performance of the
30 full bridge LLC resonant converter can be improved by decreasing the loop inductance.

Figure 7 shows simulation results for circulating current loop of a full bridge LLC resonant converter according to an embodiment of the subject invention. Referring to

Figure 7, simulation 1 was tested at a loop inductance of 0.035 μH (microHenry) and simulation 2 was tested at a loop inductance of 1 nH (nanoHenry), where the CM noise of simulation 2 decreased sharply. The reduction of the loop inductance was mainly determined by the loop area; therefore, the loop inductance can be reduced by rearranging the PCB layout.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application.

All patents, patent applications, provisional applications, and publications referred to or cited herein are incorporated by reference in their entirety, including all figures and tables, to the extent they are not inconsistent with the explicit teachings of this specification.

CLAIMS

What is claimed is:

1. A full bridge resonant converter, comprising:
a full bridge circuit receiving an input signal;
a resonant tank circuit connected to the full bridge circuit;
a transformer connected to the resonant tank circuit;
a rectifier circuit connected to the transformer and producing an output signal; and
a capacitor connecting an input node of the full bridge circuit with respect to the resonant tank circuit to an output node of the transformer.
2. The full bridge resonant converter according to claim 1, wherein the resonant tank circuit is connected to the full bridge circuit through the input node and the rectifier circuit is connected to the transformer through the output node of the transformer.
3. The full bridge resonant converter according to any of claims 1-2, wherein the resonant tank circuit comprises a resonant capacitor and a resonant inductor.
4. The full bridge resonant converter according to claim 3, wherein the transformer comprises a magnetizing inductance, and the resonant capacitor, the resonant inductor, and the magnetizing inductance are connected in series.
5. The full bridge resonant converter according to any of claims 1-4, wherein the full bridge circuit comprises a first switch, a second switch, a third switch, and a fourth switch, wherein the first switch and the third switch are connected in series, the second switch and the fourth switch are connected in series, and a first pair comprising the first and third switches and a second pair comprising the second and fourth switches are connected to each other in parallel.
6. The full bridge resonant converter according to claim 5, wherein the first switch and the third switch are connected to the capacitor through the input node.

7. The full bridge resonant converter according to any of claims 5-6, wherein each of the first, second, third, and fourth switches is a metal oxide semiconductor field effect transistor (MOSFET).

8. The full bridge resonant converter according to any of claims 1-7, wherein the transformer comprises a primary winding at a primary side, a first secondary winding at a secondary side, and a second secondary winding connected in series to the first secondary winding at the secondary side.

9. The full bridge resonant converter according to claim 8, wherein the first secondary winding is connected to the capacitor through the output node of the transformer.

10. The full bridge resonant converter according to any of claims 1-9, wherein the rectifier circuit comprises a fifth switch and a sixth switch, wherein the fifth switch is connected to the output node of the transformer.

11. The full bridge resonant converter according to claim 10, wherein each of the fifth switch and the sixth switch is a diode.

12. A resonant converter, comprising:
a primary side input circuit receiving an input signal;
a transformer connected to the primary side input circuit;
a secondary side output circuit connected to the transformer and providing an output signal; and
a capacitor connecting the primary side input circuit to the secondary side output circuit.

13. The resonant converter according to claim 12, wherein the primary side input circuit comprises a full bridge circuit receiving the input signal and a resonant tank circuit connected to the full bridge circuit through a first input node and a second input node.

14. The resonant converter according to any of claims 12-13, wherein the capacitor is connected to the first input node.

15. The resonant converter according to any of claims 13-14, wherein the full bridge circuit comprises a first switch, a second switch, a third switch, and a fourth switch, wherein the first switch is connected to the third switch through the first input node, and wherein the second switch is connected to the fourth switch through the second input node.

16. The resonant converter according to any of claims 13-15, wherein the resonant tank circuit comprises a resonant capacitor connected to the first input node and a resonant inductor connected to the resonant capacitor.

17. The resonant converter according to any of claims 12-16, wherein the transformer comprises: a magnetizing inductance connected between the resonant inductor and the second input node; a primary winding connected to the magnetizing inductance; a first secondary winding connected to a first output node; and a second secondary winding connected to the first secondary winding through a middle output node.

18. The resonant converter according to claim 17, wherein a winding direction of the primary winding is the same as that of the first secondary winding and that of the second secondary winding.

19. The resonant converter according to any of claims 12-18, wherein the secondary side output circuit comprises a rectifier circuit comprising a fifth switch connected to the transformer through the first output node and a sixth switch connected to the transformer through a second output node.

20. The resonant converter according to claim 19, wherein the fifth switch is connected to the sixth switch through a common output node.

21. The resonant converter according to any of claims 17-20, wherein the capacitor is connected to the first output node.

22. The resonant converter according to any of claims 20-21, further comprising a load configured to be connected between the middle output node and the common output node.

23. A full bridge LLC resonant converter, comprising:
a full bridge circuit including a first input node and a second input node;
an LLC resonant tank circuit connected to the first input node and the second input node;
a transformer winding part connected to the LLC resonant tank circuit;
a rectifier circuit connected to the transformer winding part through a first output node and a second output node; and
a capacitor connected between the first input node and the first output node.

24. The full bridge LLC resonant converter according to claim 23, wherein the LLC resonant tank circuit comprises a resonant capacitor connected to the first input node, a resonant inductor connected to the resonant capacitor, and a magnetizing inductance connected between the resonant inductor and the second input node.

25. The full bridge LLC resonant converter according to any of claims 23-24, wherein the transformer winding part comprises a primary winding connected to the magnetizing inductance through a primary upper node and a primary lower node, a first secondary winding connected between the first output node and a middle output node, and a second secondary winding connected between the middle output node and the second output node.

26. The full bridge LLC resonant converter according to claim 25, wherein a sum capacitance of a first capacitance between the primary upper node and the middle output node and a second capacitance between the primary lower node and the middle

output node is the same as a capacitance of the capacitor between the first input node and the first output node.

27. The full bridge LLC resonant converter according to any of claims 25-26, further comprising an assistance capacitor between the primary lower node and the middle output node such that the sum capacitance of the first capacitance between the primary upper node and the middle output node and the second capacitance between the primary lower node and the middle output node is the same as the capacitance of the capacitor between the first input node and the first output node.

28. The full bridge LLC resonant converter according to any of claims 26-27, wherein a first ratio of the sum capacitance to the first capacitance is N to 1, and a second ratio of a primary winding voltage between the primary upper node and the primary lower node to a first secondary winding voltage between the first output node and the middle output node is N to 1.

29. The full bridge LLC resonant converter according to any of claims 23-28, wherein the full bridge circuit comprises a first switch, a second switch, a third switch, and a fourth switch, wherein the first switch is connected to the third switch through the first input node, and wherein the second switch is connected to the fourth switch through the second input node.

30. The full bridge LLC resonant converter according to claim 29, wherein a first input voltage of the third switch and a second input voltage of the fourth switch have the same absolute value with different signs.

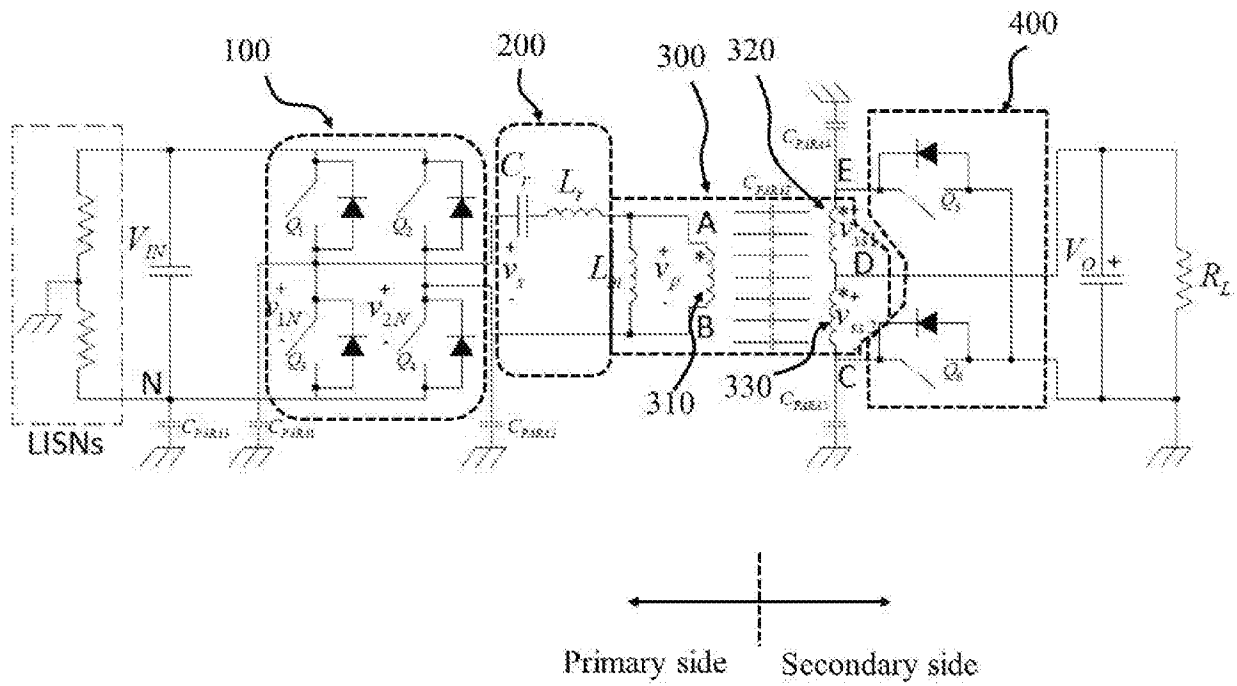


Figure 1

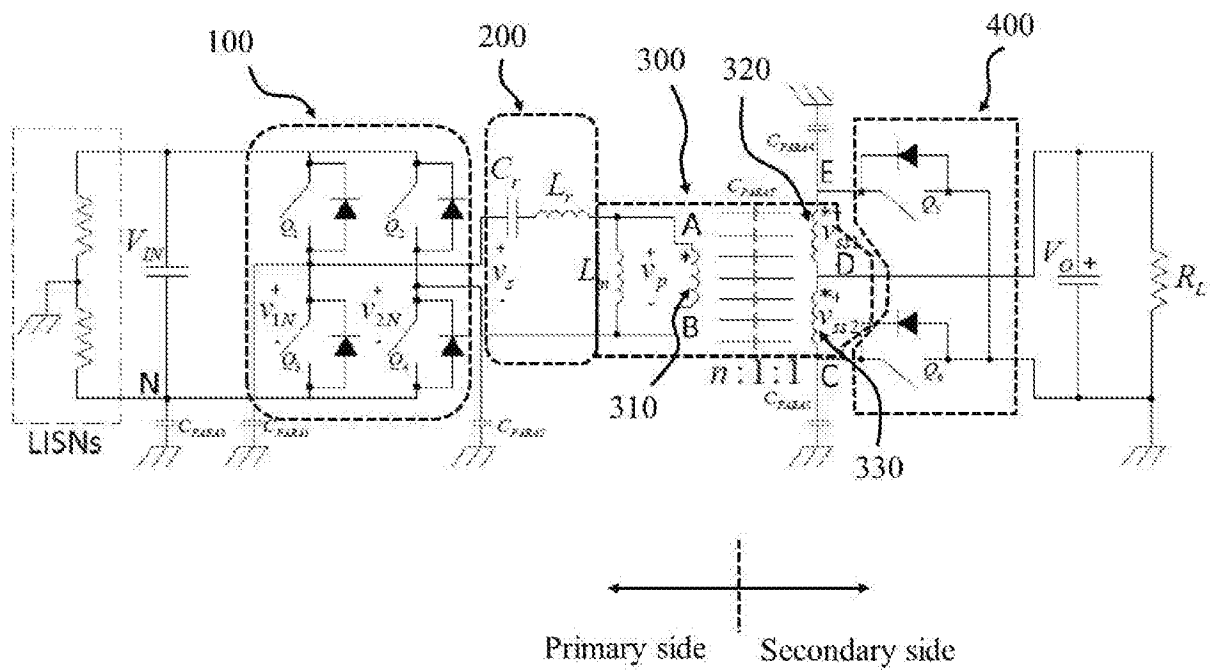


Figure 2

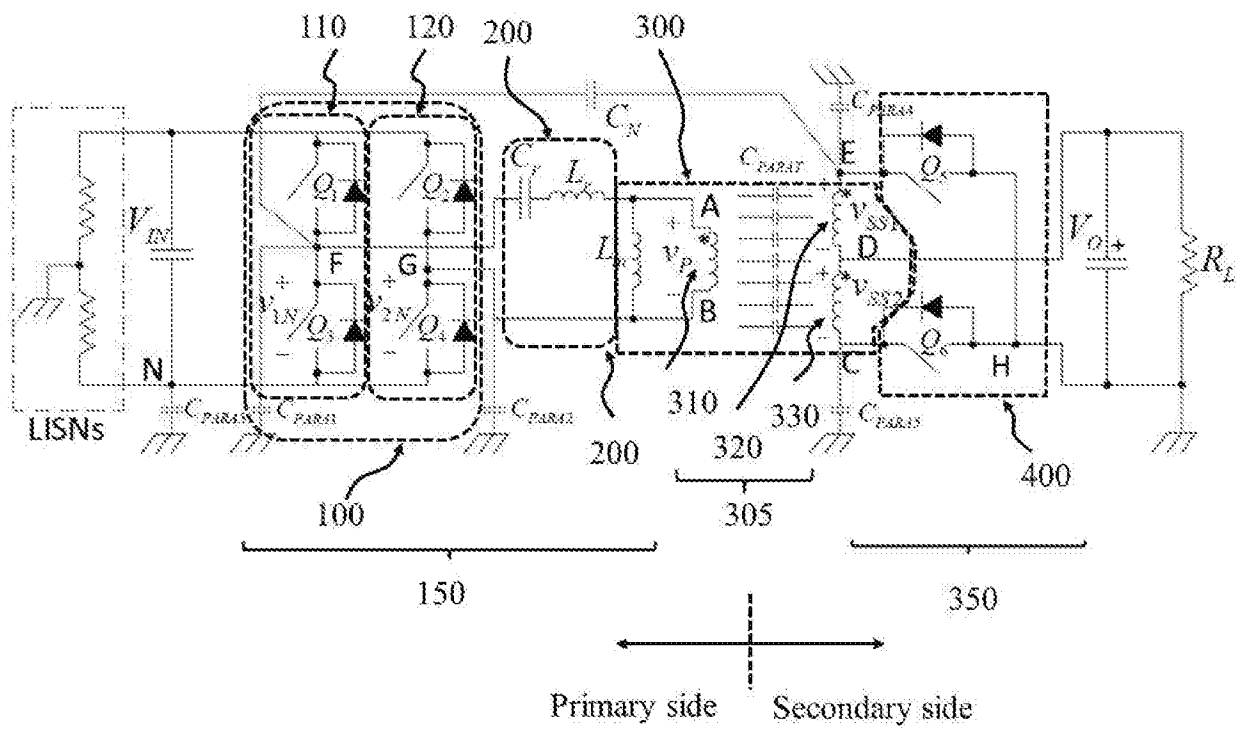


Figure 3

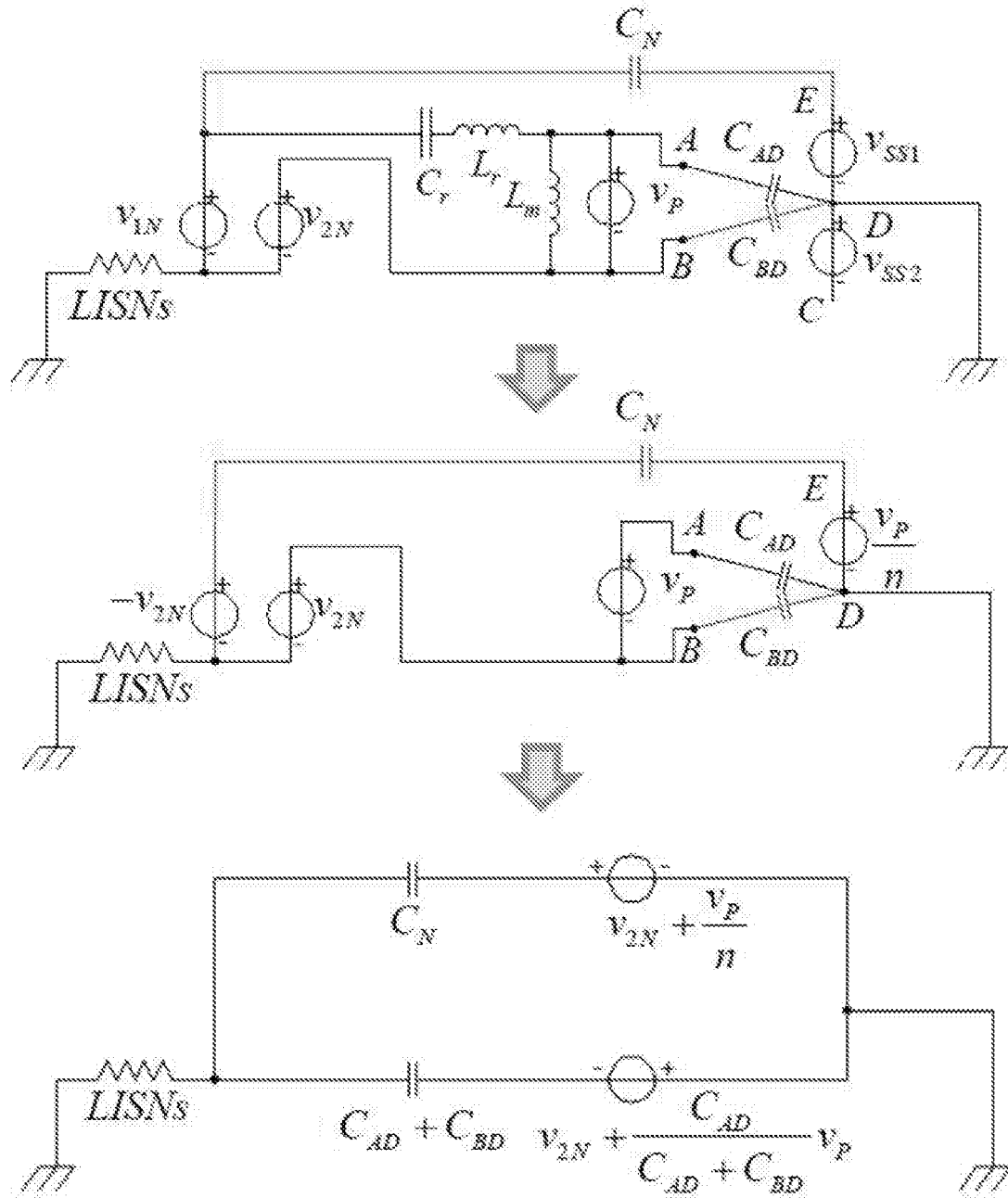


Figure 4

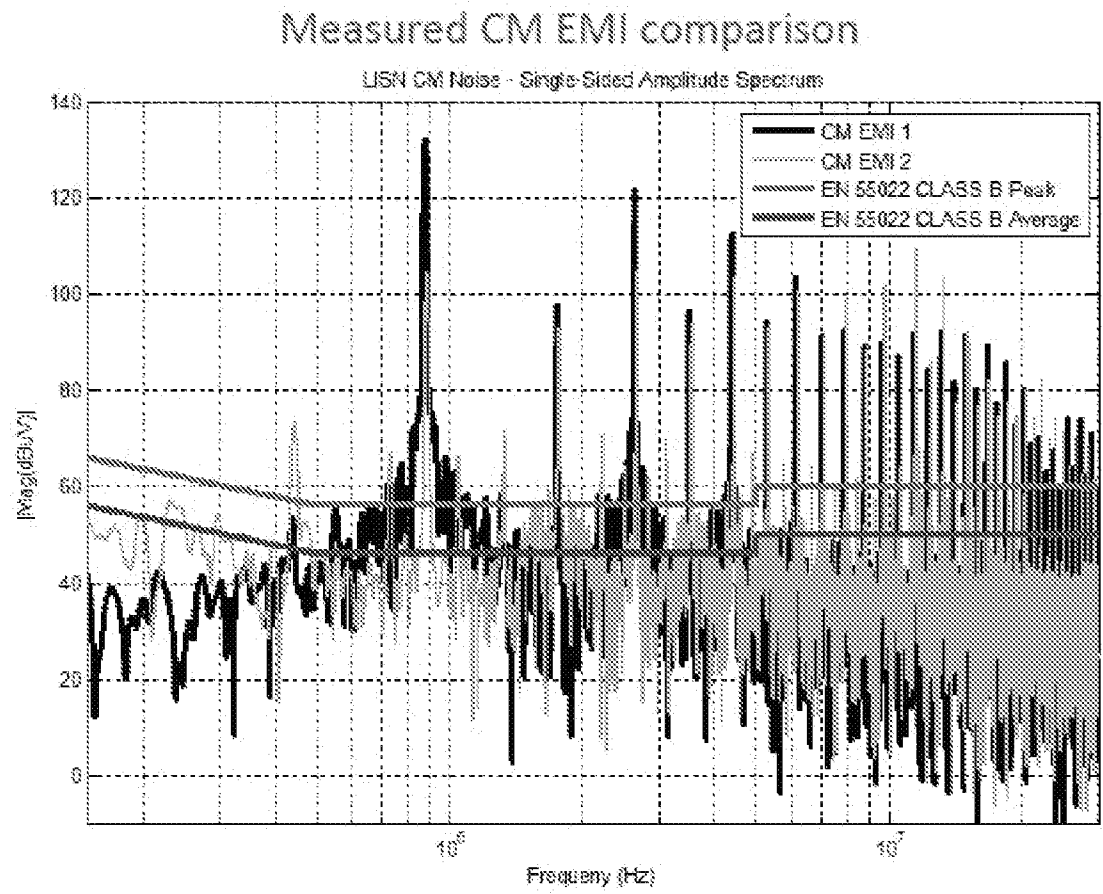


Figure 5

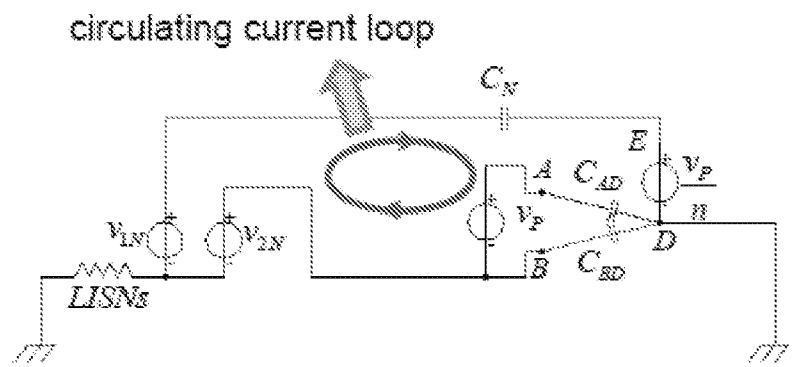


Figure 6

Simulated CM EMI comparison

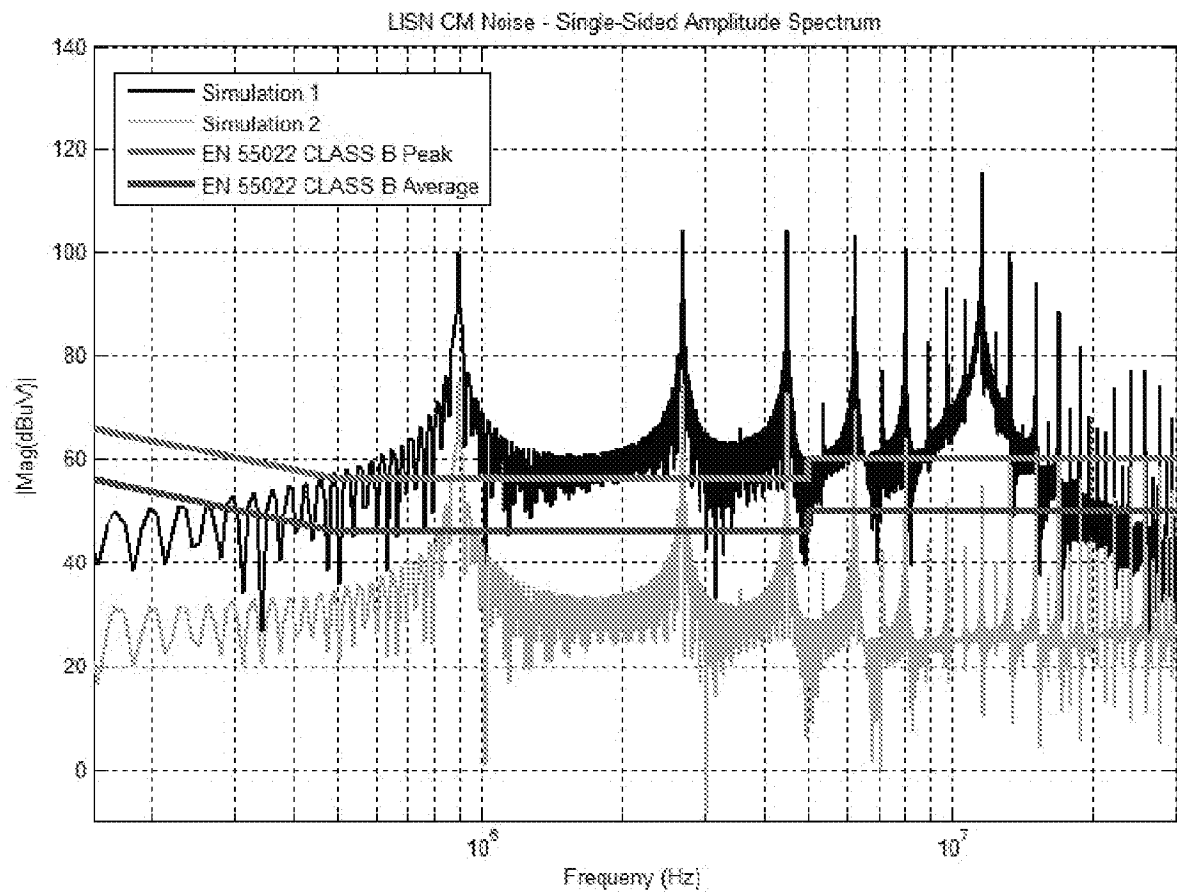


Figure 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/057540

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 6, 9, 11, 18, 20, 30
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claims 6, 9, 11, 18, 20, 30 are regarded to be unclear because the claims refer to multiple dependent claims which do not comply with PCT Rule 6.4(a).
3. ☒ Claims Nos.: 5, 7-8, 10, 15-17, 19, 21-22, 27-29
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/057540**A. CLASSIFICATION OF SUBJECT MATTER****H02M 7/48(2007.01)i, H02M 1/44(2007.01)i**

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

B. FIELDS SEARCHEDMinimum documentation searched (classification system followed by classification symbols)
H02M 7/48; H02M 3/335; H02M 3/155; H02M 3/28; H02M 1/12; H02M 1/44Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: converter, capacitor, rectifier, transformer, winding, resonant, switch**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012-037135 A1 (HUAWEI TECHNOLOGIES CO. LTD, et al.) 22 March 2012 See page 7, line 2-page 15, line 3 and figures 1-13.	12
Y		13
A		1-4, 14, 23-26
Y	US 2015-0124488 A1 (FUTUREWEI TECHNOLOGIES, INC.) 07 May 2015 See paragraphs 25-79 and figures 1-15.	13
A	US 2016-0254755 A1 (INFINEON TECHNOLOGIES AUSTRIA AG) 01 September 2016 See the entire document.	1-4, 12-14, 23-26
A	JP 2012-034522 A (MERSTECH INC.) 16 February 2012 See the entire document.	1-4, 12-14, 23-26
A	JP 2011-050134 A (SANKEN ELECTRIC CO., LTD.) 10 March 2011 See the entire document.	1-4, 12-14, 23-26

☐ 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
07 February 2018 (07.02.2018)Date of mailing of the international search report
07 February 2018 (07.02.2018)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/057540

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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