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Takatsuji et al.

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(54) **SWITCHING POWER-SUPPLY UNIT**

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H02M 3/335 (2006.01)
H02M 1/00 (2006.01)
H02M 1/12 (2006.01)

(52) **U.S. Cl.**
CPC ***H02M 3/33523*** (2013.01); ***H02M 1/0064*** (2021.05); ***H02M 1/123*** (2021.05)

(58) **Field of Classification Search**
CPC H02M 3/33523; H02M 1/0064; H02M 1/123; H02M 1/008; H02M 3/158; H02M 3/33507; H02M 1/08; H02M 1/143; H02M 1/0006
See application file for complete search history.

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(57) **ABSTRACT**

A switching power-supply unit includes a power conversion circuit, a control circuit, a class-Y capacitor, and a common-mode choke coil. The control circuit has a direct electrical connection to the power conversion circuit. The class-Y capacitor is connected to the power conversion circuit on its side of a direct-current power supply, and is connected to the ground potential. The common-mode choke coil is connected to the control circuit on its side of a direct-current power supply. A noise balancing circuit is formed of a closed circuit including the power conversion circuit, the control circuit, the class-Y capacitor, and the common-mode choke coil. The noise balancing circuit causes common-mode currents to be confined and canceled out each other. The common-mode currents serve as switching noise generated in multiple parts of the closed circuit due to a switching operation of power-conversion switching devices.

20 Claims, 15 Drawing Sheets

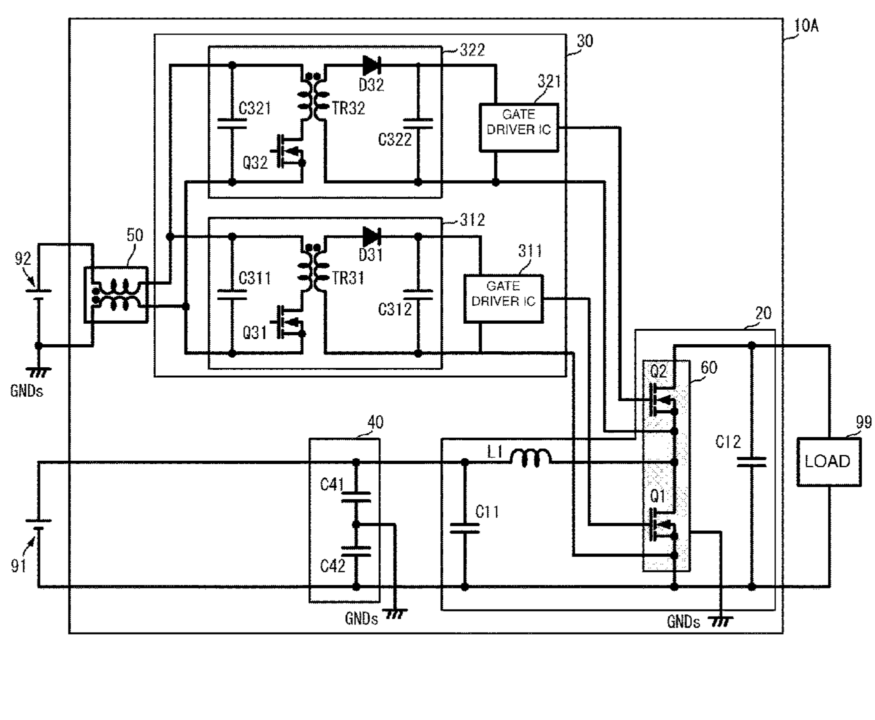
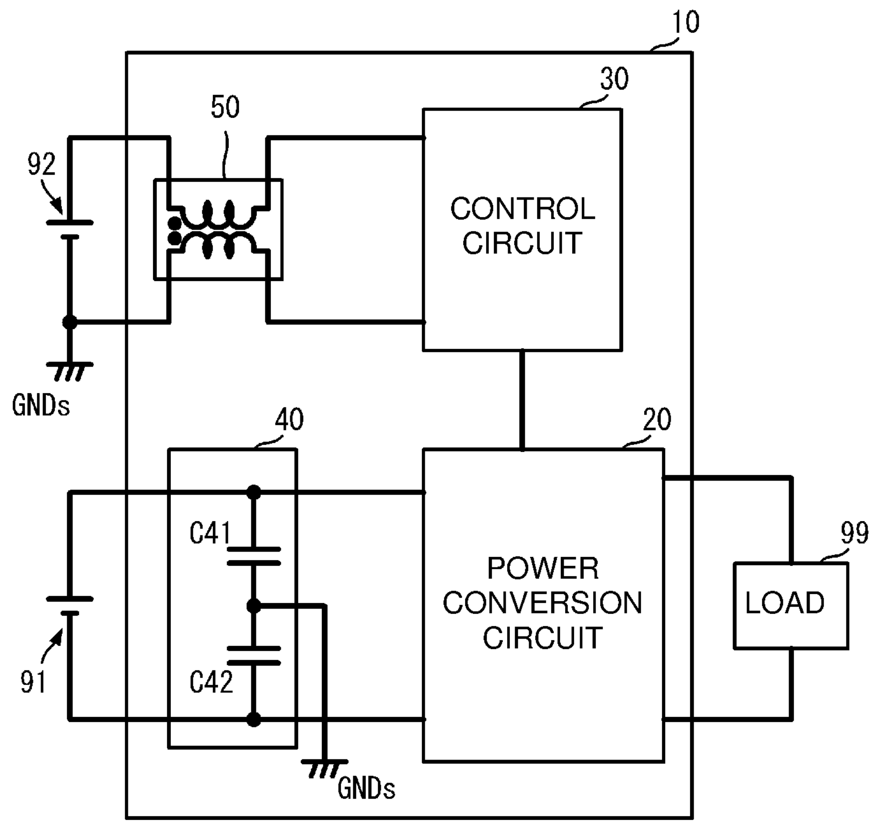


FIG. 1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30
50
92
CONTROL CIRCUIT
GNDs
40
20
C41
99
POWER CONVERSION CIRCUIT
LOAD
91
C42
GNDs

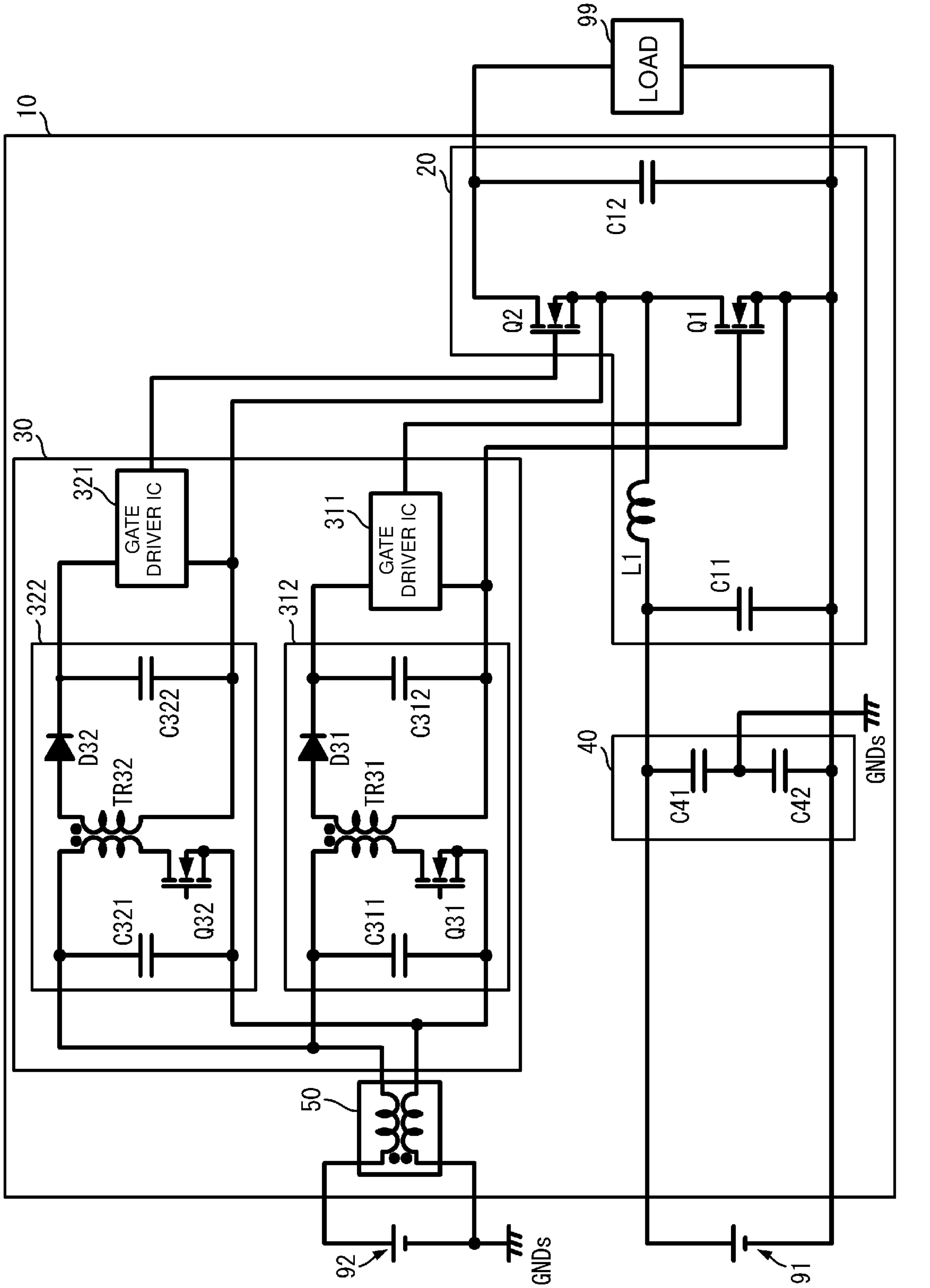
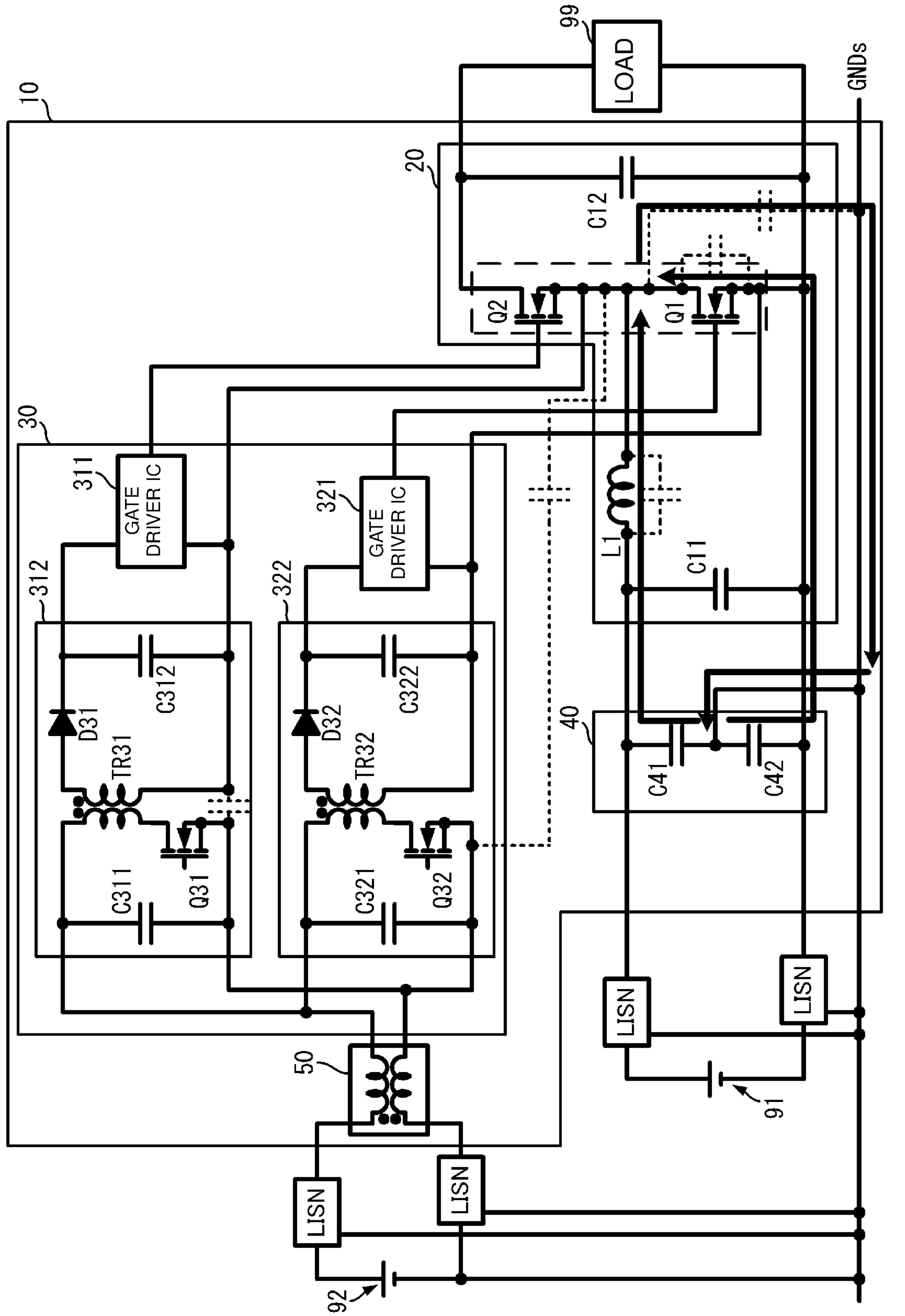
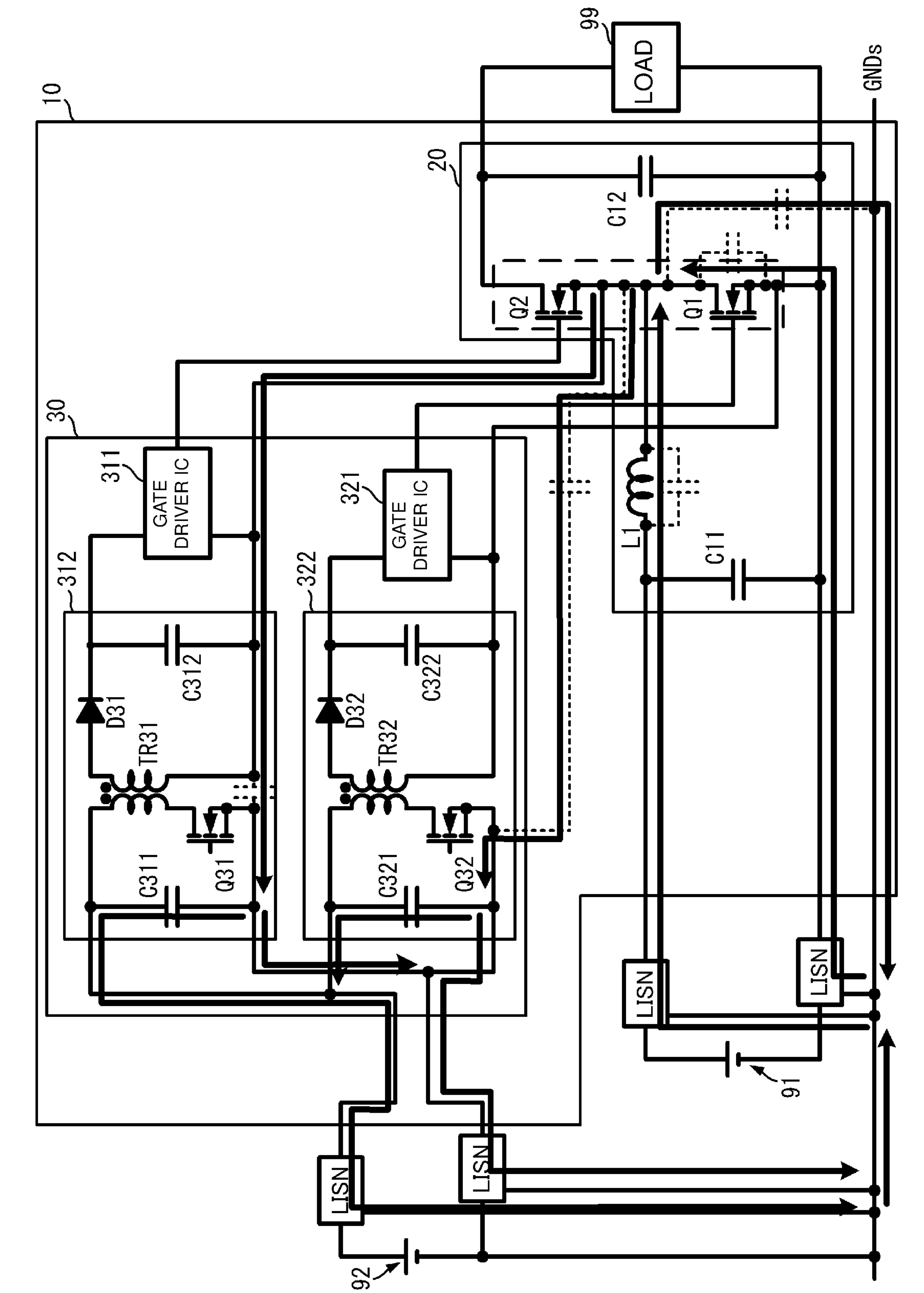

10
20
30
40
50
99
LOAD
C12
Q2
Q1
L1
C11
321
GATE DRIVER IC
311
GATE DRIVER IC
322
312
C322
C312
D32
D31
TR32
TR31
C321
Q32
C311
Q31
C41
C42
GNDs
92
GNDs
91

FIG. 2



10
20
30
40
50
91
92
99
LOAD
GNDs
C12
Q2
Q1
L1
C11
C41
C42
311
GATE DRIVER IC
321
GATE DRIVER IC
312
322
C312
C322
D31
D32
TR31
TR32
C311
C321
Q31
Q32
LISN
LISN
LISN
LISN

FIG. 3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C312
C322
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Q32
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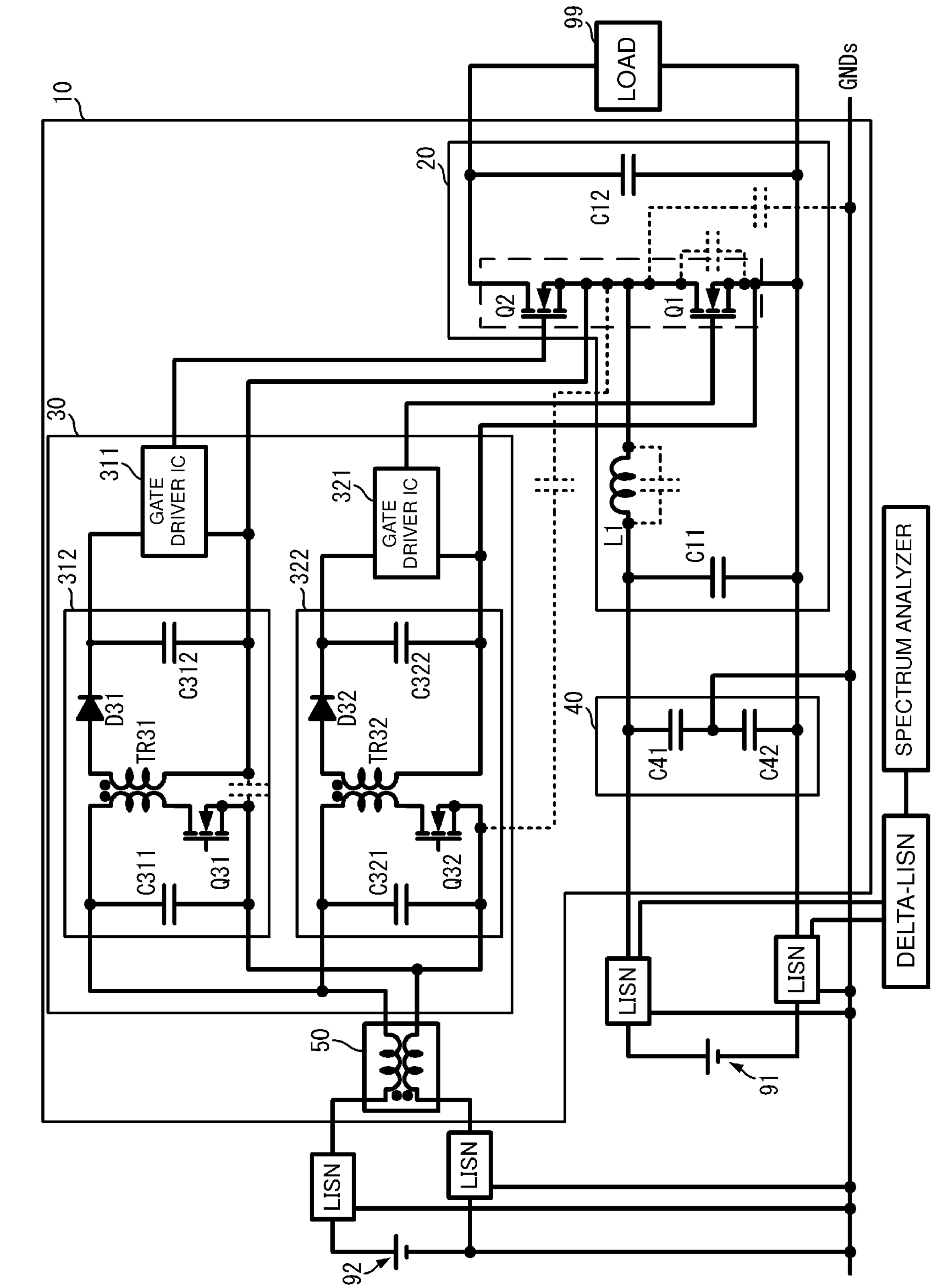
LISN
LISN
91
92

FIG. 4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LOAD
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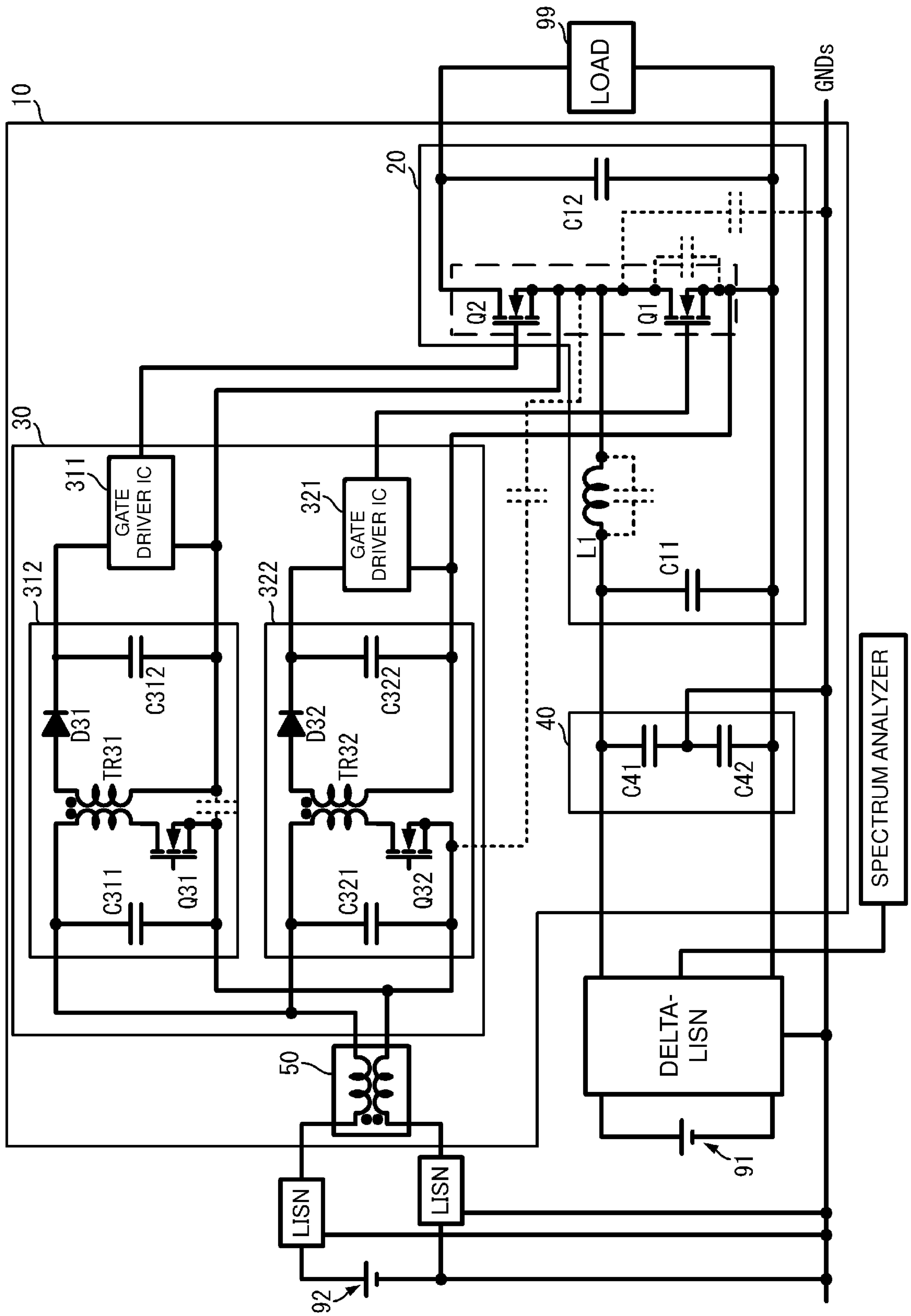
10
20
C12
Q2
Q1
30
311
GATE DRIVER IC
321
GATE DRIVER IC
312
322
C312
D31
TR31
C311
Q31
C322
D32
TR32
C321
Q32
L1
C11
40
C41
C42
SPECTRUM ANALYZER
DELTA-LISN
LISN
LISN
91
50
LISN
LISN
92

FIG. 5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Q1
30
311
GATE DRIVER IC
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GATE DRIVER IC
L1
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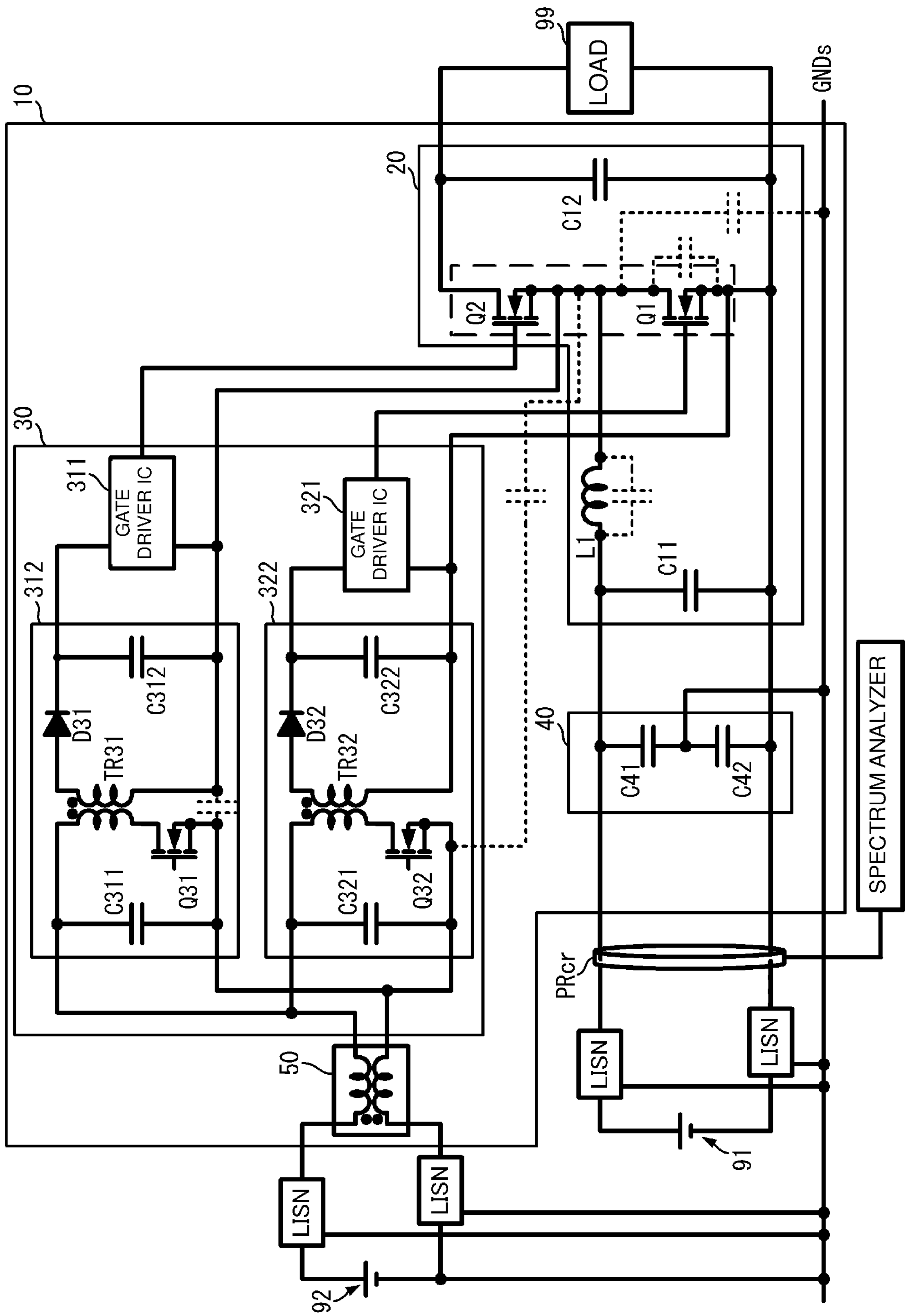
322
C312
C322
D31
D32
TR31
TR32
C311
Q31
C321
Q32
40
C41
C42
SPECTRUM ANALYZER
DELTA-LISN
50
91
LISN
LISN
92

FIG. 6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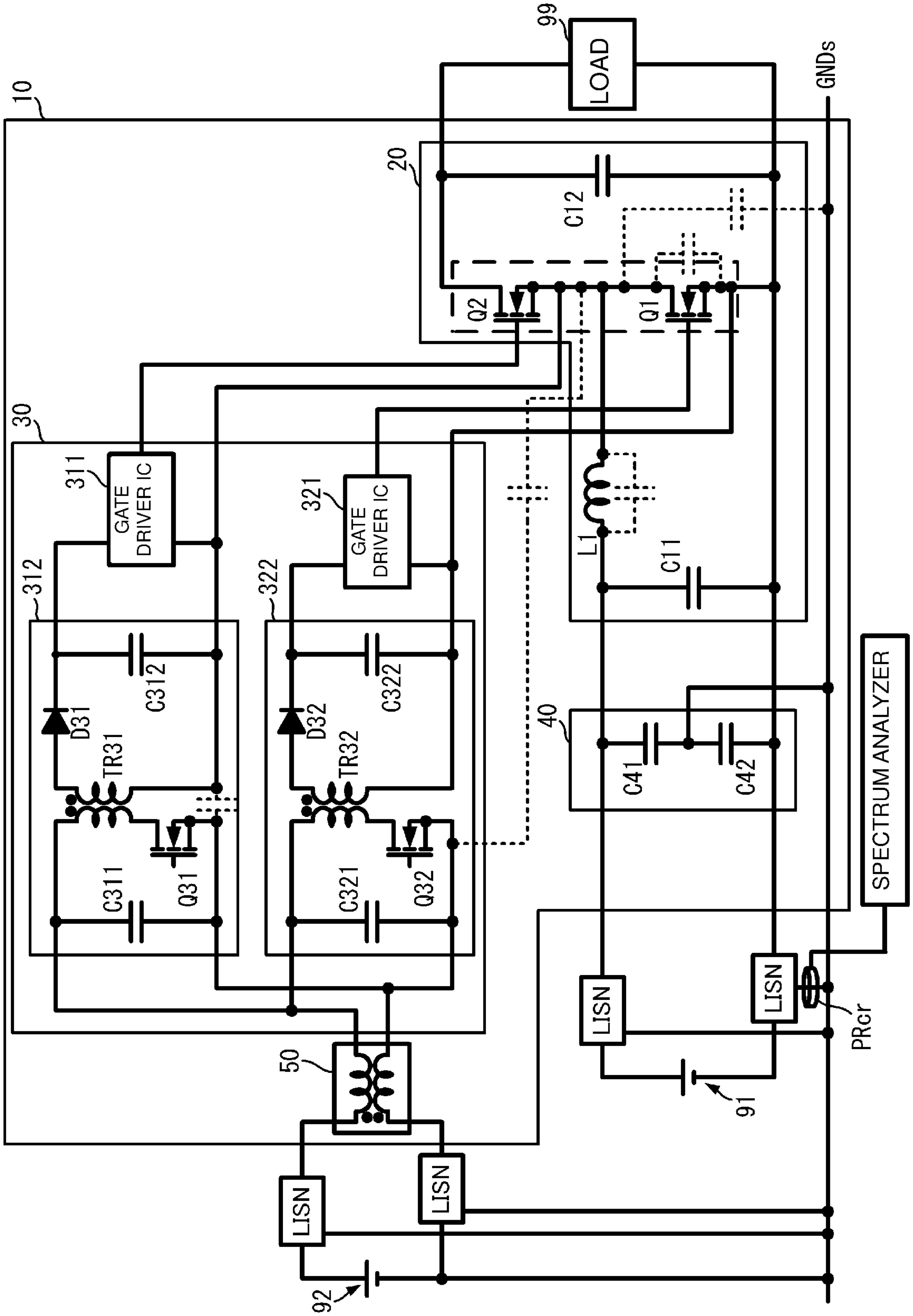
99
LOAD
GNDs
20
C12
Q2
Q1
30
311
GATE DRIVER IC
321
GATE DRIVER IC
L1
C11
312
322
C312
C322
D31
D32
TR31
TR32
40
C41
C42
SPECTRUM ANALYZER
C311
Q31
C321
Q32
PRcr
LISN
LISN
50
91
LISN
LISN
92

FIG. 7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LOAD
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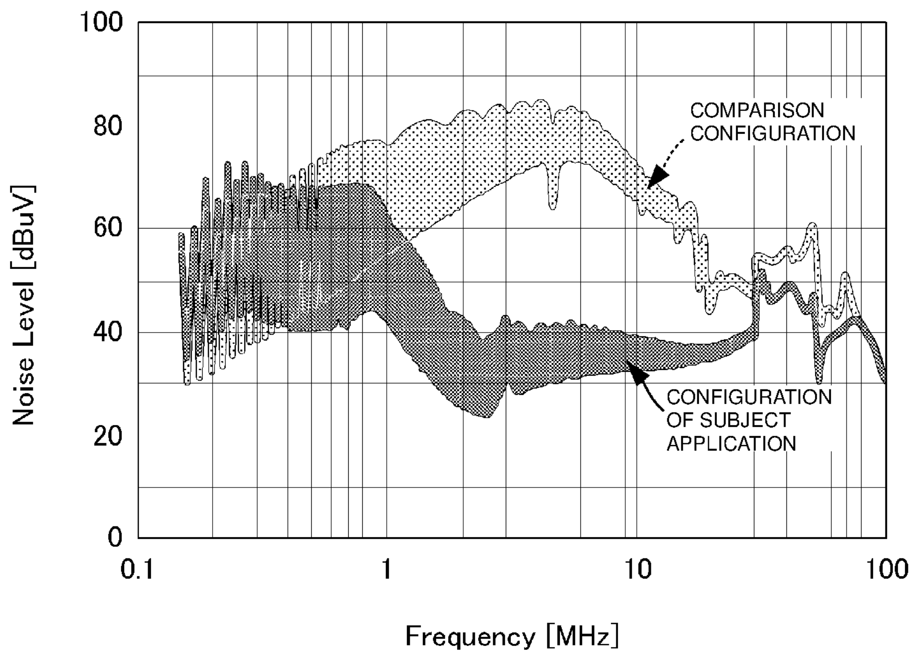
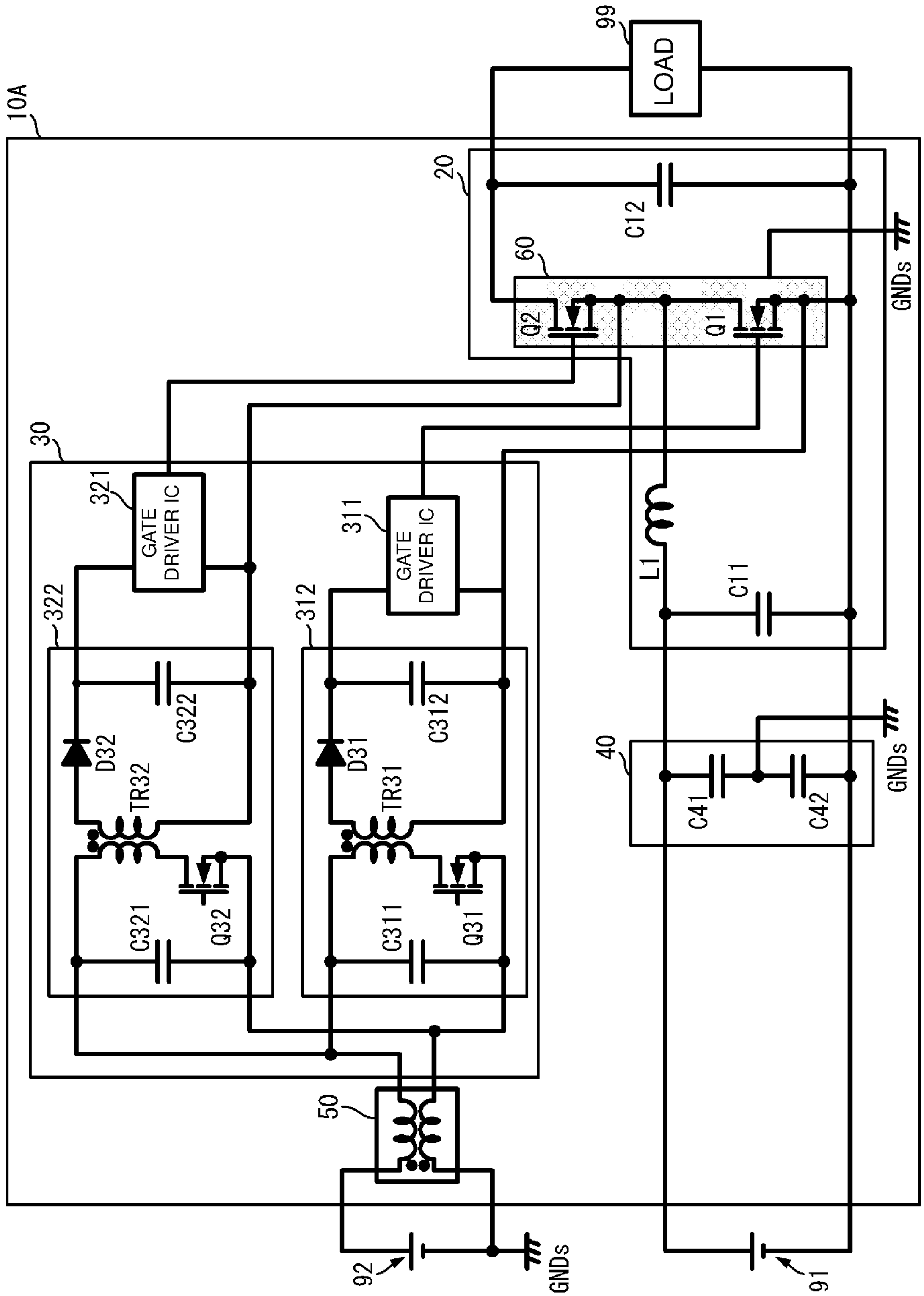
20
C12
Q2
Q1
GNDs
30
311
GATE DRIVER IC
321
GATE DRIVER IC
L1
C11
312
322
C312
C322
D31
D32
TR31
TR32
40
C41
C42
SPECTRUM ANALYZER
C311
Q31
C321
Q32
LISN
LISN
PRcr
91
50
LISN
LISN
92

FIG. 8

FIG. 9


100
80
60
40
20
0
Noise Level [dBuV]
0.1
1
10
100
Frequency [MHz]
COMPARISON CONFIGURATION
CONFIGURATION OF SUBJECT APPLICATION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99
LOAD
20
C12
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Q2
Q1
GNDs
30
321
GATE DRIVER IC
311
GATE DRIVER IC
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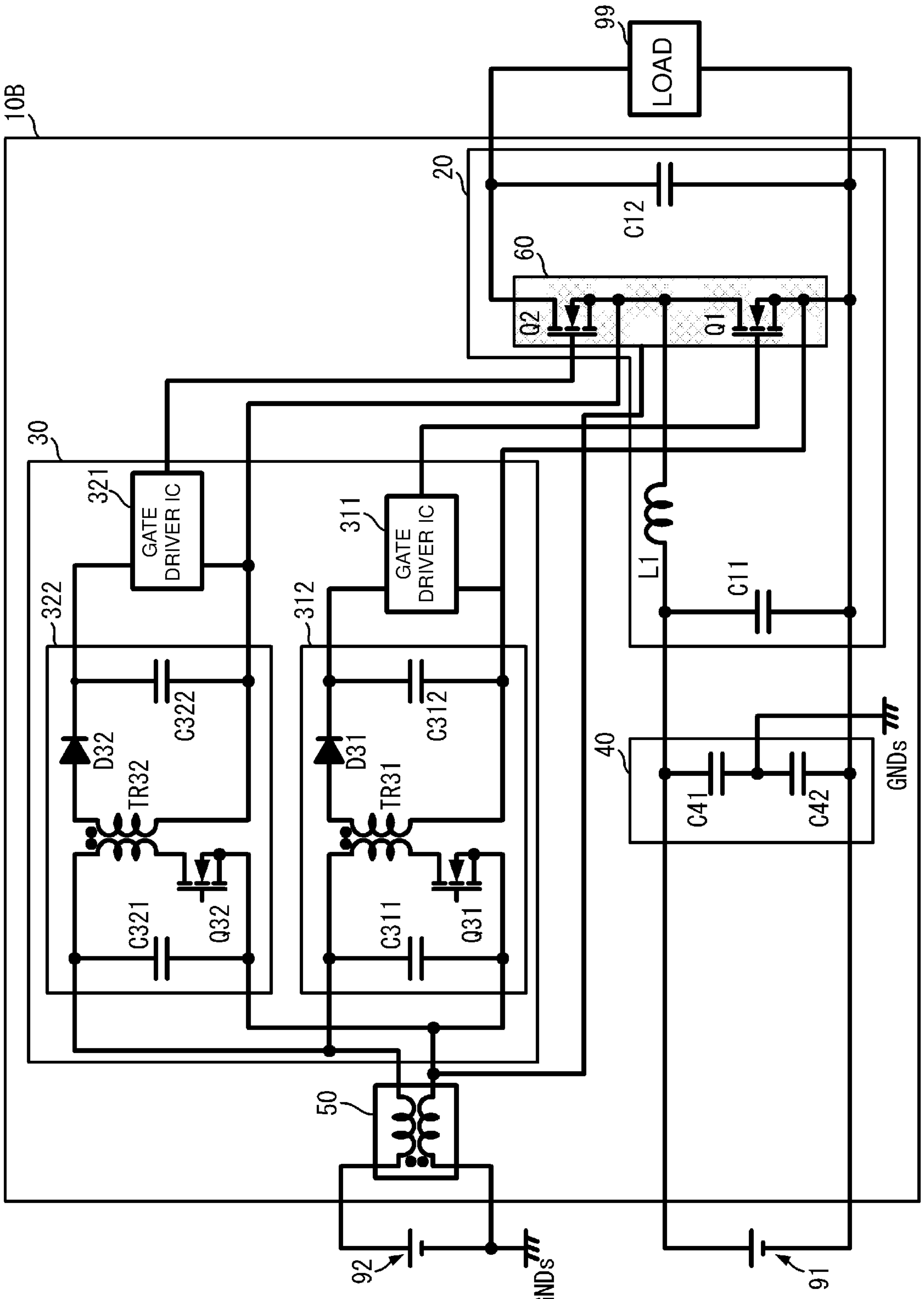
322
312
C322
C312
D32
D31
TR32
TR31
40
C41
C42
GNDs
C321
Q32
C311
Q31
50
92
GNDs
91

FIG. 10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LOAD
20
C12
60
Q2
Q1
30
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GATE DRIVER IC
311
GATE DRIVER IC
322
312
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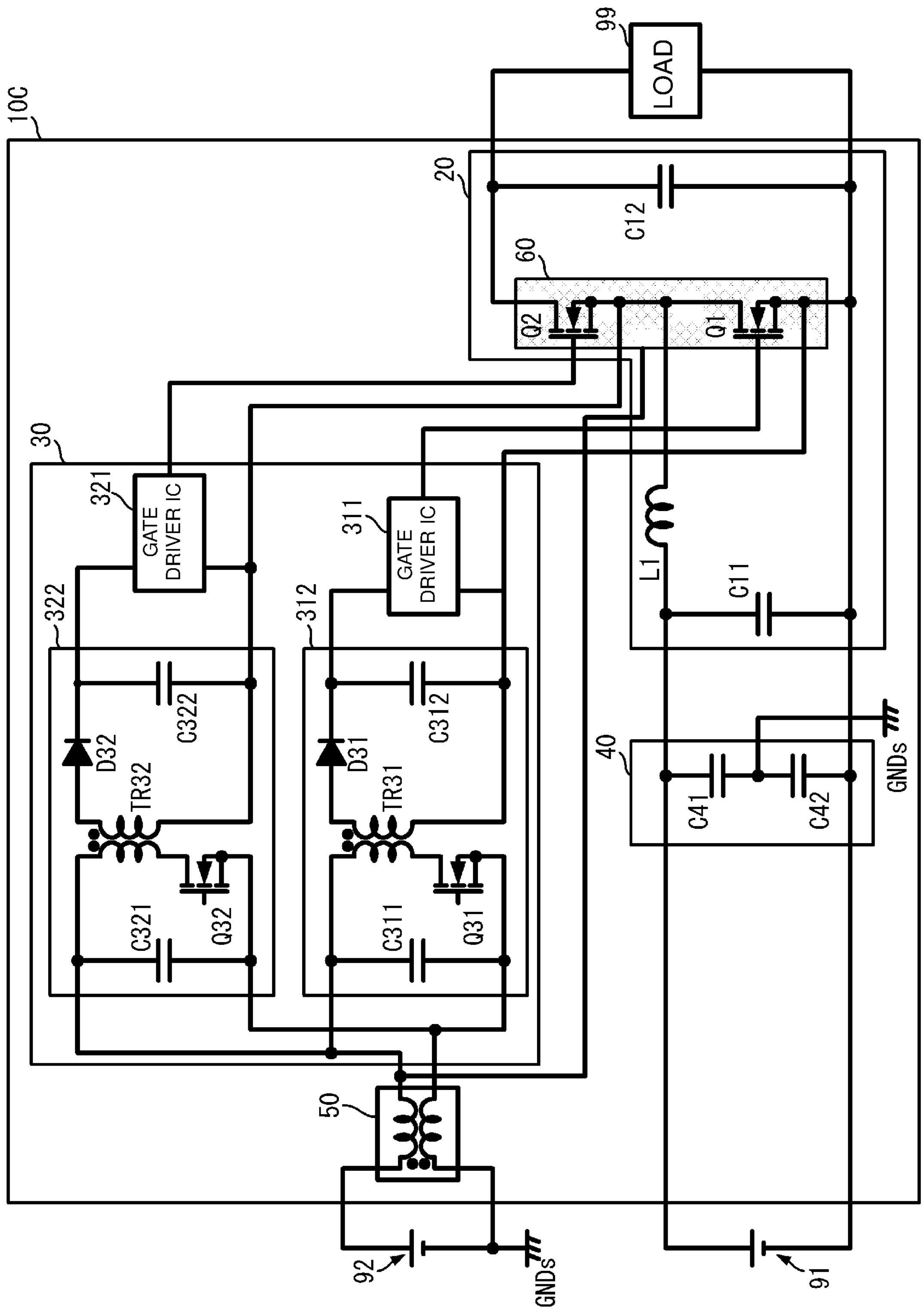
C312
D32
D31
TR32
TR31
C321
C311
Q32
Q31
L1
C11
40
C41
C42
GNDs
50
92
91
GNDs

FIG. 11


10C
99
LOAD
20
C12
60
Q2
Q1
30
321
GATE DRIVER IC
311
GATE DRIVER IC
L1
C11
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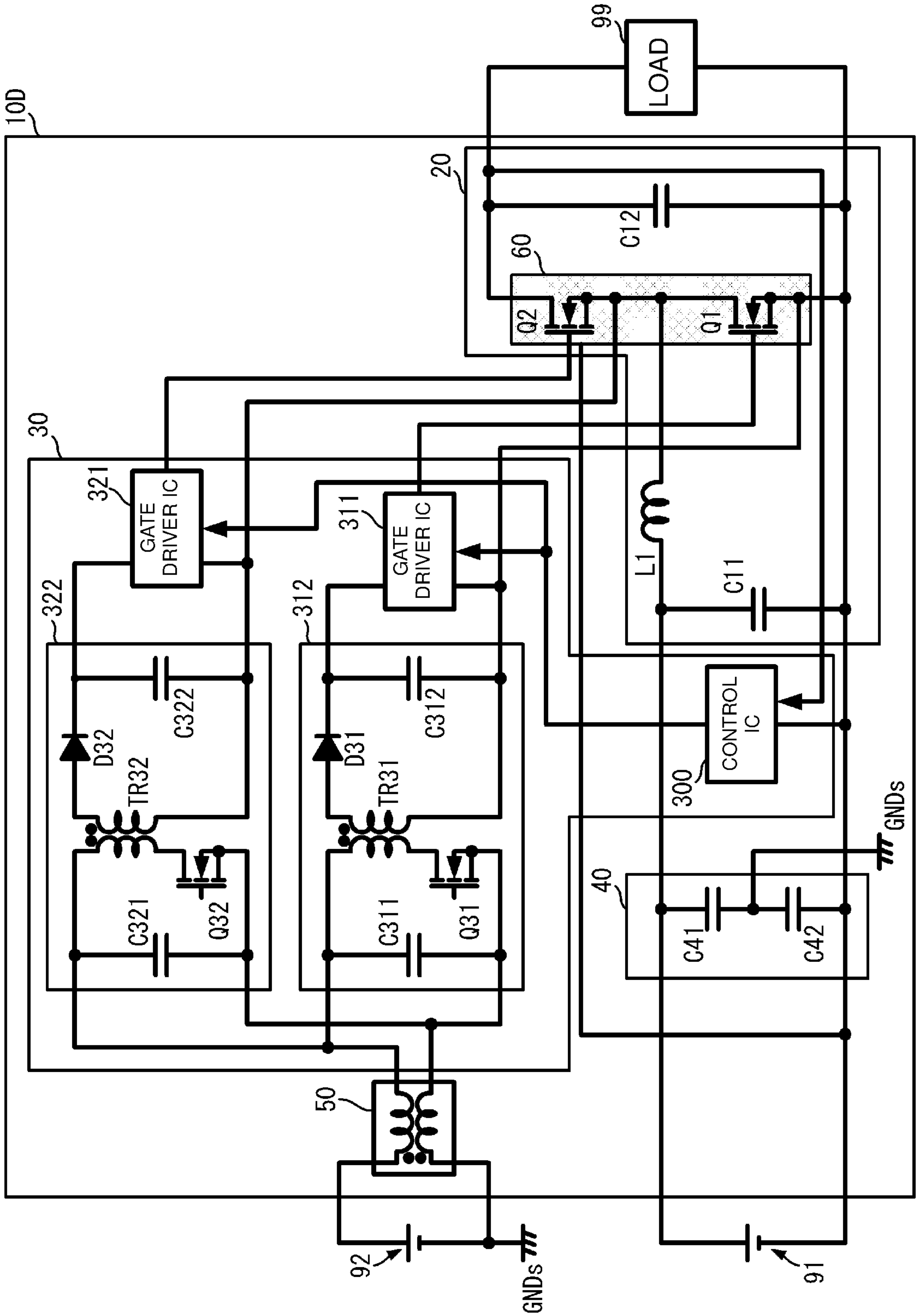
C322
C312
D32
D31
TR32
TR31
40
C41
C42
GNDs
C321
Q32
C311
Q31
50
92
GNDs
91

FIG. 12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LOAD
20
C12
60
Q2
Q1
30
321
GATE DRIVER IC
311
GATE DRIVER IC
L1
C11
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C322
C312
D32
D31
TR32
TR31
CONTROL IC
300
GNDs
40
C41
C42
C321
C311
Q32
Q31
50
92
91
GNDs

FIG. 13

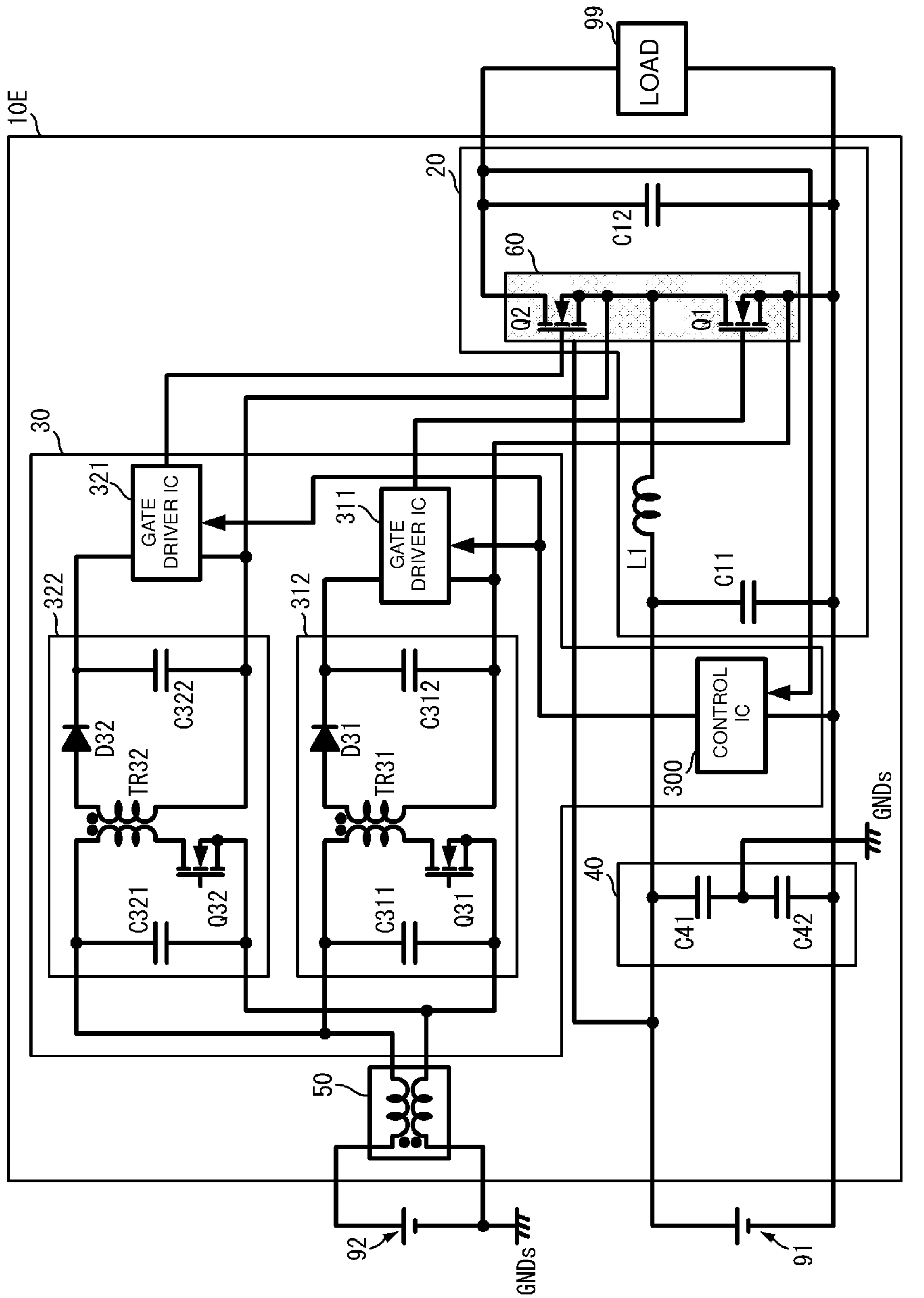
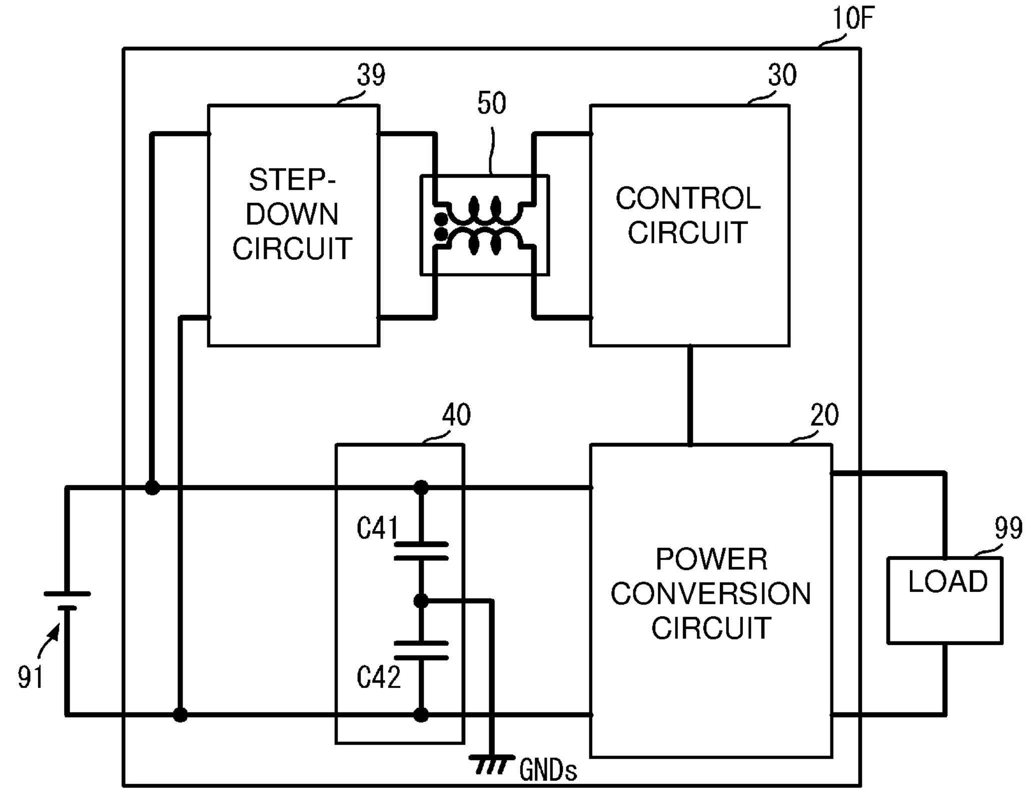

10E
99
LOAD
20
C12
60
Q2
Q1
30
321
GATE DRIVER IC
311
GATE DRIVER IC
L1
C11
322
312
C322
C312
D32
D31
TR32
TR31
CONTROL IC
300
GNDs
40
C321
Q32
C311
Q31
C41
C42
50
92
GNDs
91

FIG. 14

FIG. 15


10F
39
50
30
STEP-DOWN CIRCUIT
CONTROL CIRCUIT
40
20
C41
C42
POWER CONVERSION CIRCUIT
99
LOAD
91
GNDs

SWITCHING POWER-SUPPLY UNIT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of priority to Japanese Patent Application No. 2023-009496, filed Jan. 25, 2023, and to Japanese Patent Application No. 2022-049348, filed Mar. 25, 2022, the entire content of each is incorporated herein by reference.

BACKGROUND

Technical Field

The present disclosure relates to a switching power-supply unit which converts power by using a switching device.

Background Art

Switching power-supply units have a problem of common-mode noise generated by switching devices for power conversion. In particular, as in switching power-supply units included in electrically driven vehicles, a large electromagnetic interference (EMI) noise, mainly common-mode noise, occurs in use of a high power, causing a problem of electromagnetic interference.

The power supply unit described in Japanese Unexamined Patent Application Publication No. 2006-271135 has a configuration, for reducing occurrence of common-mode noise, in which a power conversion circuit is connected, on its input side and its output side, to common-mode choke coils and class-Y capacitors. That is, in the power supply unit described in Japanese Unexamined Patent Application Publication No. 2006-271135, both a common-mode choke coil and a class-Y capacitor are connected between an external direct-current power supply and the power conversion circuit.

However, to suppress common-mode noise, a large-size common-mode choke coil, which is capable of flowing a large current having high-impedance characteristics, needs to be used.

When a common-mode choke coil having a high impedance is connected to a wiring line connected to a power conversion circuit through which a large current flows, a problem of an increase of heat generation and power loss of the common-mode choke coil arises.

SUMMARY

Accordingly, the present disclosure provides a switching power-supply unit which achieves suppression of heat generation and power loss and which achieves a reduction of occurrence of common-mode noise.

A switching power-supply unit provided by the present disclosure includes a power conversion circuit, a control circuit, a class-Y capacitor, and a common-mode choke coil. The power conversion circuit includes a first input capacitor, a power-conversion switching device, and a first output capacitor, and converts, for output to a load, power supplied from a first direct-current power supply. The control circuit has a direct electrical connection to the power conversion circuit. The control circuit includes a second input capacitor and a switching drive circuit, and generates a drive signal for the power-conversion switching device by using power supplied from a second direct-current power supply. The

class-Y capacitor is connected to the power conversion circuit on its first direct-current power supply side, and is connected to the ground potential. The common-mode choke coil is connected to the control circuit on its second direct-current power supply side. A noise balancing circuit is formed of a closed circuit including the power conversion circuit, the control circuit, the class-Y capacitor, and the common-mode choke coil. The noise balancing circuit causes common-mode currents to be confined and canceled out each other. The common-mode currents serve as switching noise generated in multiple parts of the closed circuit due to a switching operation of the power-conversion switching device.

In this configuration, the common-mode choke coil is connected to the control circuit which has a direct electrical connection to the power conversion circuit and which operates at a power lower than that of the power conversion circuit. The power conversion circuit is connected to the class-Y capacitor. Therefore, the class-Y capacitor suppresses a leak of common-mode noise currents from the power conversion circuit to the first direct-current power supply side. The common-mode choke coil suppresses a leak of a common-mode noise current from the power conversion circuit through the control circuit to the second direct-current power supply side. Thus, common-mode currents, which serve as common-mode noise, are confined in the noise balancing circuit, and are canceled out. The common-mode choke coil is not connected to wiring lines connected to the power conversion circuit through which a large current flows, and is connected to wiring lines connected to the control circuit which operates at a low power. Thus, heat generation and power loss of the common-mode choke coil are suppressed.

The present disclosure achieves a reduction of occurrence of common-mode noise currents while suppressing heat generation and power loss.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a circuit block diagram illustrating a schematic configuration of a switching power-supply unit according to a first embodiment of the present disclosure;

FIG. **2** is a circuit diagram illustrating an exemplary circuit configuration of a switching power-supply unit according to the first embodiment of the present disclosure;

FIG. **3** is a schematic diagram illustrating flows of common-mode currents in the configuration of the disclosure of the subject application;

FIG. **4** is a schematic diagram illustrating flows of common-mode currents in a comparison configuration;

FIG. **5** is a diagram illustrating a circuit example in measurement of common-mode noise using a Delta-LISN;

FIG. **6** is a diagram illustrating a circuit example in measurement of common-mode noise using a Delta-LISN;

FIG. **7** is a circuit diagram illustrating the case in which a current probe PRcr is disposed around a cable on High side and a cable on Low side;

FIG. **8** is a circuit diagram illustrating the case in which a current probe PRcr is disposed around a cable connecting a LISN to a chassis;

FIG. **9** is a graph illustrating the noise level in the configuration of the subject application and that in a comparison configuration;

FIG. **10** is a circuit diagram illustrating an exemplary circuit configuration of a switching power-supply unit according to a second embodiment of the present disclosure;

FIG. **11** is a circuit diagram illustrating an exemplary circuit configuration of a switching power-supply unit according to a third embodiment of the present disclosure;

FIG. **12** is a circuit diagram illustrating an exemplary circuit configuration of a switching power-supply unit according to a fourth embodiment of the present disclosure;

FIG. **13** is a circuit diagram illustrating an exemplary circuit configuration of a switching power-supply unit according to a fifth embodiment of the present disclosure;

FIG. **14** is a circuit diagram illustrating an exemplary circuit configuration of a switching power-supply unit according to a sixth embodiment of the present disclosure; and

FIG. **15** is a circuit block diagram illustrating a schematic configuration of a switching power-supply unit according to a seventh embodiment of the present disclosure.

DETAILED DESCRIPTION

First Embodiment

A switching power-supply unit according to a first embodiment of the present disclosure will be described by referring to figures. FIG. **1** is a circuit block diagram illustrating a schematic configuration of the switching power-supply unit according to the first embodiment of the present disclosure. FIG. **2** is a circuit diagram illustrating an exemplary circuit configuration of the switching power-supply unit according to the first embodiment of the present disclosure.

Schematic Configuration and Schematic Operation of a Switching Power-Supply Unit **10**

As illustrated in FIGS. **1** and **2**, a switching power-supply unit **10** includes a power conversion circuit **20**, a control circuit **30**, a class-Y capacitor **40**, and a common-mode choke coil **50**.

In a schematic configuration, the power conversion circuit **20** is connected, at its input end, to a direct-current power supply **91**. The direct-current power supply **91** is a high-voltage power supply, and is, for example, a direct-current power supply from 100 V to 1000 V. The direct-current power supply **91** corresponds to a "first direct-current power supply" in the embodiment of the present disclosure.

The class-Y capacitor **40** is connected between the input end of the power conversion circuit **20** and the direct-current power supply **91**. The class-Y capacitor **40** is connected to the ground potential GNDs. The ground potential GNDs is different from the potential obtained through grounding to the earth, and is the reference potential, for example, of an electrically driven vehicle including the switching power-supply unit **10**. The ground potential GNDs is, for example, the same as that of the chassis of the electrically driven vehicle.

The power conversion circuit **20** is connected, at its output end, to a load **99**.

The control circuit **30** is connected, at its input end, to a direct-current power supply **92**. The direct-current power supply **92** has a voltage lower than that of the direct-current power supply **91**, and is, for example, a direct-current power supply from 12 V to 14 V. The negative electrode of the direct-current power supply **92** is connected to the ground potential GNDs. The direct-current power supply **92** corresponds to a "second direct-current power supply" in the embodiment of the present disclosure.

The common-mode choke coil **50** is connected between the input end of the control circuit **30** and the direct-current power supply **92**.

The control circuit **30** is connected to the power conversion circuit **20**. Here, the control circuit **30** has a direct electrical connection to the power conversion circuit **20**. "A direct electrical connection" means that the control circuit **30** is connected to the power conversion circuit **20** without other electric circuit devices connected in between.

The control circuit **30** is supplied with power from the direct-current power supply **92**. The control circuit **30** generates drive signals for power-conversion switching devices Q**1** and Q**2**, which are used for power conversion, of the power conversion circuit **20**, and outputs the generated signals to the power-conversion switching devices Q**1** and Q**2**.

The power conversion circuit **20** exerts control so that the power-conversion switching devices Q**1** and Q**2** are switched on/off by using the drive signals from the control circuit **30**. Thus, the power conversion circuit **20** converts the input voltage, which is supplied from the direct-current power supply **91**, to an output voltage for the load **99**, and outputs the resulting voltage to the load **99**.

The switching operation of the power-conversion switching devices Q**1** and Q**2** causes common-mode noise in accordance with the switching frequency to be generated.

As described above, in the switching power-supply unit **10**, the power conversion circuit **20** is connected, at its input end, to the class-Y capacitor **40** which is connected to the ground potential GNDs. Further, in the switching power-supply unit **10**, the control circuit **30** is connected, at its input end, to the common-mode choke coil **50**.

Thus, the power conversion circuit **20**, the control circuit **30**, the class-Y capacitor **40**, and the common-mode choke coil **50** form a closed circuit (noise balancing circuit) for common-mode noise. Therefore, the common-mode noise, which is generated by the power-conversion switching devices Q**1** and Q**2** of the power conversion circuit **20**, does not leak to the direct-current power supply **91** side and the direct-current power supply **92** side of the switching power-supply unit **10**, and is confined in the noise balancing circuit. The common-mode noise confined in the noise balancing circuit has different phases, and is thus canceled out.

As a result, the switching power-supply unit **10** may reduce occurrence of common-mode noise. The common-mode choke coil **50** is connected to the input end of the control circuit **30**. That is, the common-mode choke coil **50** is connected, not to wiring lines on the high power side, but to wiring lines on the low power side. Therefore, heat generation and power loss of the common-mode choke coil **50** may be suppressed. Further, the withstand voltage of the common-mode choke coil **50** may be decreased, achieving a small-size and inexpensive common-mode choke coil **50**. This achieves a small-size and inexpensive switching power-supply unit **10**.

Exemplary Specific Circuit Configuration of the Switching Power-Supply Unit **10**

As illustrated in FIG. **2**, the power conversion circuit **20** includes an input capacitor C**11**, an inductor L**1**, the power-conversion switching devices Q**1** and Q**2**, and an output capacitor C**12**. The input capacitor C**11** corresponds to a "first input capacitor" in the embodiment of the present disclosure. The output capacitor C**12** corresponds to a "first output capacitor" in the embodiment of the present disclosure.

The input capacitor C**11** is connected, at its first terminal, to the positive electrode of the direct-current power supply **91**. The input capacitor C**11** is connected, at its second terminal, to the negative electrode of the direct-current power supply **91**. The inductor L**1** is connected, at its first terminal, to the positive electrode of the direct-current power supply **91**. The inductor L**1** is connected, at its second terminal, to a node between the drain of the power-conversion switching device Q**1** and the source of the power-conversion switching device Q**2**.

The source of the power-conversion switching device Q**1** is connected to the negative electrode of the direct-current power supply **91** and a negative-side output terminal of the switching power-supply unit **10**. The drain of the power-conversion switching device Q**2** is connected to a positive-side output terminal of the switching power-supply unit **10**. The output capacitor C**12** is connected between the positive-side output terminal and the negative-side output terminal of the switching power-supply unit **10**. The load **99** is connected between the positive-side output terminal and the negative-side output terminal.

The gate of the power-conversion switching device Q**1** and the gate of the power-conversion switching device Q**2** are connected to a gate driver integrated circuit (IC) **311** and a gate driver IC **321** of the control circuit **30**. More specifically, the gate of the power-conversion switching device Q**1** has a direct electrical connection to the gate driver IC **311**. The gate of the power-conversion switching device Q**2** has a direct electrical connection to the gate driver IC **321**.

The control circuit **30** includes the gate driver IC **311**, an isolated converter **312**, the gate driver IC **321**, and an isolated converter **322**. Each of the gate driver IC **311** and the gate driver IC **321** corresponds to a "switching drive circuit" in the embodiment of the present disclosure.

The isolated converter **312** is connected, at its input terminal, to the common-mode choke coil **50**. The isolated converter **312** is connected, at its output terminal, to the gate driver IC **311**. The isolated converter **322** is connected, at its input terminal, to the common-mode choke coil **50**. The isolated converter **322** is connected, at its output terminal, to the gate driver IC **321**.

The isolated converter **312** includes a capacitor C**311**, a capacitor C**312**, a switching device Q**31**, an insulating transformer TR**31**, and a rectifier device D**31**. The isolated converter **312** converts the direct-current voltage of the direct-current power supply **92** to the direct-current drive voltage for the gate driver IC **311**, and provides the resulting voltage to the gate driver IC **311**. The capacitor C**311** corresponds to a "second input capacitor" in the embodiment of the present disclosure.

The isolated converter **322** includes a capacitor C**321**, a capacitor C**322**, a switching device Q**32**, an insulating transformer TR**32**, and a rectifier device D**32**. The isolated converter **322** is connected between the common-mode choke coil **50** and the gate driver IC **321**. The isolated converter **322** converts the direct-current voltage of the direct-current power supply **92** to the direct-current drive voltage for the gate driver IC **321**, and provides the resulting voltage to the gate driver IC **321**. The capacitor C**321** corresponds to a "second input capacitor" in the embodiment of the present disclosure.

The class-Y capacitor **40** includes a capacitor C**41** and a capacitor C**42**. The capacitor C**41** is connected to the capacitor C**42** in series. The series circuit of the capacitor C**41** and the capacitor C**42** is connected between a positive-side wiring line, for power conversion, which is connected to the positive electrode of the direct-current power supply **91**, and a negative-side wiring line, for power conversion, which is connected to the negative electrode of the direct-current power supply **91**. A node between the capacitor C**41** and the capacitor C**42** is connected to the ground potential GNDs.

The common-mode choke coil **50** is connected between the direct-current power supply **92** and the control circuit **30**.

The switching power-supply unit **10** having such a configuration schematically operates as follows. The gate driver IC **311** is driven by using power supplied from the direct-current power supply **92** through the common-mode choke coil **50** and the isolated converter **312**, and generates a drive signal for the power-conversion switching device Q**1**. The gate driver IC **321** is driven by using power supplied from the direct-current power supply **92** through the common-mode choke coil **50** and the isolated converter **322**, and generates a drive signal for the power-conversion switching device Q**2**. The gate driver IC **311** is synchronized with the gate driver IC **321**. The gate driver IC **311** and the gate driver IC **321** are set so that the ON period of the drive signal, which is output by the gate driver IC **311**, does not overlap that of the drive signal, which is output by the gate driver IC **321**, and the ON voltage of the gate driver IC **311** and that of the gate driver IC **321** are output alternately.

The switching of the power-conversion switching device Q**1** of the power conversion circuit **20** is controlled by the drive signal from the gate driver IC **311**. The switching of the power-conversion switching device Q**2** is controlled by the drive signal from the gate driver IC **321**. Thus, the power conversion circuit **20** converts the direct-current voltage of the direct-current power supply **91** to the output voltage for the load **99**, and supplies the resulting voltage to the load **99**.

In such a configuration, the switching operation of the power-conversion switching device Q**1** and the power-conversion switching device Q**2** is a main cause of occurrence of common-mode noise.

However, the switching power-supply unit **10**, which has the configuration described above, may reduce occurrence of common-mode noise.

FIG. **3** is a schematic diagram illustrating flows of common-mode currents in the configuration of the disclosure of the subject application. FIG. **4** is a schematic diagram illustrating flows of common-mode currents in a comparison configuration. In FIGS. **3** and **4**, bold arrows indicate flows of common-mode currents. The comparison configuration does not include the class-Y capacitor **40** and the common-mode choke coil **50** used in the embodiment of the disclosure of the subject application. Adoption of the configuration of the disclosure of the subject application consequently suppresses the illustrated common-mode currents. However, to make the description easy to understand, FIG. **3** illustrates the flows of common-mode currents.

The common-mode currents occur at the power-conversion switching devices Q**1** and Q**2** which serve as a noise source, and flow through lines which are electrically connected to each other directly or indirectly in the frequency band of the common-mode noise. Therefore, the common-mode currents flow, not only through the power conversion circuit **20**, but also through the control circuit **30**.

As illustrated in FIG. **4**, in the comparison configuration which does not include the class-Y capacitor **40**, common-mode currents, which flow through wiring lines for power conversion, leak from the power conversion circuit **20** of the switching power-supply unit **10** to the direct-current power supply **91** side. Similarly, in the comparison configuration which does not includes the common-mode choke coil **50**, common-mode currents leak from the control circuit **30** of the switching power-supply unit **10** to the direct-current power supply **92** side. Thus, in the comparison configuration, common-mode currents leak to the outside of the switching power-supply unit **10**.

In contrast, as illustrated in FIG. **3**, in the configuration of the subject application, the common-mode choke coil **50** is connected to the control circuit **30** on its input side. Thus, a common-mode current from the control circuit **30** to the direct-current power supply **92** side is suppressed.

Further, in the configuration of the subject application, the class-Y capacitor **40** is connected to the power conversion circuit **20** on its input side, and is connected to the ground potential GNDs. Thus, the power conversion circuit **20**, the class-Y capacitor **40**, and the ground potential GNDs cause common-mode currents to flow back to the power-conversion switching devices Q1 and Q2 which serve as a noise source. At that time, the common-mode currents have different phases, and are thus canceled out. Therefore, occurrence of common-mode noise is reduced.

Thus, with use of the configuration of the subject application, the switching power-supply unit **10** uses the power conversion circuit **20**, the control circuit **30**, the class-Y capacitor **40**, and the common-mode choke coil **50** to implement a closed circuit for common-mode current, enabling the noise to be balanced. That is, the switching power-supply unit **10** may include a noise balancing circuit formed of the power conversion circuit **20**, the control circuit **30**, the class-Y capacitor **40**, and the common-mode choke coil **50**. Thus, common-mode noise, which is caused by the power-conversion switching devices Q1 and Q2 of the power conversion circuit **20**, is confined in the noise balancing circuit, suppressing leaks of the common-mode noise to the direct-current power supply **91** side and the direct-current power supply **92** side. Further, the confined common-mode noise has different phases, and is thus canceled out.

The state in which the noise balancing circuit causes common-mode currents to be confined and canceled out may be confirmed through connection of line impedance stabilization networks (LISNs) to the wiring lines on High side and the wiring lines on Low side of the noise balancing circuit (for example, see FIG. **3**).

For example, a Delta-LISN is used to measure the voltage of common-mode noise (common-mode noise voltage). FIGS. **5** and **6** are diagrams illustrating circuit examples in measurement of common-mode noise by using a Delta-LISN. In FIG. **5**, a Delta-LISN is connected to LISNs, and is connected to a spectrum analyzer. In FIG. **6**, a Delta-LISN is connected between the direct-current power supply **91** and the class-Y capacitor **40**, and is connected to a spectrum analyzer. If the common-mode noise voltage, which is measured in these measurement configurations (measurement methods), is substantially zero or sufficiently small, the state in which the noise balancing circuit causes common-mode currents to be confined and canceled out may be detected.

Alternatively, a current probe is disposed around a cable on High side and a cable on Low side or a cable connecting a LISN to the chassis. The probe is used to measure the common-mode current. FIG. **7** is a circuit diagram illustrating the case in which a current probe PRcr is disposed around a cable on High side and a cable on Low side. FIG. **8** is a circuit diagram illustrating the case in which a current probe PRcr is disposed around a cable connecting a LISN to the chassis. In each configuration in FIGS. **7** and **8**, the current probe PRcr is connected to a spectrum analyzer. If the common-mode current is substantially zero or sufficiently small in these measurement configurations (measurement methods), the state in which the noise balancing circuit causes common-mode currents to be confined and canceled out may be detected.

Therefore, the switching power-supply unit **10** may reduce occurrence of common-mode noise, and achieves suppression of electromagnetic interference (EMI) noise and power integrity (ensuring the quality of a power supply).

That is, the switching power-supply unit **10** does not need connection of the common-mode choke coil to a wiring line connected to the power conversion circuit through which a large current flows. In addition, the switching power-supply unit **10** may cancel out occurrence of noise at the noise source, and may reduce occurrence of common-mode noise currents while suppressing heat generation and power loss of the common-mode choke coil. In particular, a switching power-supply unit, such as one in an electric vehicle, which is difficult to be grounded by using the earth as the ground potential due to traveling, may effectively reduce occurrence of common-mode noise currents while suppressing heat generation and power loss of a common-mode choke coil.

FIG. **9** is a graph illustrating the noise level in the configuration of the subject application and that in the comparison configuration. As illustrated in FIG. **9**, adoption of the disclosure of the subject application achieves suppression of noise in a band from 2 MHz to 20 MHz. In particular, noise in a 5-MHz band may be effectively suppressed.

In the switching power-supply unit **10**, the common-mode choke coil **50** is not connected to wiring lines for power conversion, and is connected to wiring lines for control at a low power. This may suppress heat generation of the common-mode choke coil **50**. Therefore, the switching power-supply unit **10** may reduce occurrence of common-mode noise while suppressing heat generation and power loss.

Further, the withstand voltage of the common-mode choke coil **50** does not need to be made high, resulting in a reduction in size. Therefore, the switching power-supply unit **10** may reduce occurrence of common-mode noise while achieving a reduction in size.

In particular, the switching power-supply unit **10** is more effective when included in an electrically driven vehicle. Specifically, common-mode noise, which occurs due to the switching operation of the power conversion circuit **20**, may be conducted through the chassis (a component having the same potential as the ground potential GNDs), causing a problem of electromagnetic interference with another electronic circuit of the vehicle. For example, common-mode noise, which enters a control circuit of another electronic circuit of the vehicle, leads to a problem of a malfunction in a control operation on a switching device of the control circuit. In addition, if common-mode noise reaches another device, a problem of a malfunction occurs in the other device. Emission of common-mode noise from the chassis causes a problem of a malfunction of an electronic device outside the vehicle.

However, the configuration of the switching power-supply unit **10** achieves suppression of leaks of common-mode noise from the switching power-supply unit **10** to the outside, and achieves suppression of occurrence of problems as described above. In particular, in an electrically driven vehicle, the power conversion circuit **20** receives a very high current and voltage. Therefore, the configuration of the switching power-supply unit **10** of the present disclosure is more effective.

In the switching power-supply unit **10**, the negative electrode of the direct-current power supply **92** is connected to the ground potential GNDs, and the positive electrode and the negative electrode of the direct-current power supply **91** are not connected to the ground potential GNDs. Thus, the switching power-supply unit **10** enables the operation of the control circuit **30** to be stabilized while suppressing an adverse effect on the outside through the direct-current power supply **91** whose voltage and current are high.

In the switching power-supply unit **10**, the negative electrode of the gate driver IC **311** is connected to the source of the power-conversion switching device Q**1**, and the negative electrode of the gate driver IC **321** is connected to the source of the power-conversion switching device Q**2**. Thus, the switching power-supply unit **10** enables stabilized drive signals to be supplied to the power-conversion switching devices Q**1** and Q**2**.

The isolated converters **312** and **322** of the control circuit **30** may be replaced with non-isolated converters. However, inclusion of the isolated converters **312** and **322** achieves more reliable electrical protection of the gate driver ICs **311** and **321** from the direct-current power supply **92** side.

The isolated converter **312** of the control circuit **30** includes the switching device Q**31**, and the isolated converter **322** includes the switching device Q**32**. However, in the switching power-supply unit **10**, these switching devices Q**31** and Q**32** are present in the noise balancing circuit. Therefore, the switching power-supply unit **10** may also reduce occurrence of common-mode noise caused by the switching devices Q**31** and Q**32**.

The switching power-supply unit **10** may include another class-Y capacitor on the output side of the power conversion circuit **20**.

The configuration of the control circuit **30** is exemplary. Another configuration may be employed as long as an input capacitor and the gate driver ICs **311** and **321**, which are used for a control circuit, are included, and the drive signals described above are output to the power-conversion switching devices Q**1** and Q**2** of the power conversion circuit **20**. Similarly, the power conversion circuit **20** may have another configuration as long as the input capacitor C**11**, the power-conversion switching devices Q**1** and Q**2**, and the output capacitor C**12** are included.

Second Embodiment

A switching power-supply unit according to a second embodiment of the present disclosure will be described by referring to a figure. FIG. **10** is a circuit diagram illustrating an exemplary circuit configuration of the switching power-supply unit according to the second embodiment of the present disclosure.

As illustrated in FIG. **10**, a switching power-supply unit **10**A according to the second embodiment is different from the switching power-supply unit **10** according to the first embodiment in that a heat sink **60** is included. The other configuration of the switching power-supply unit **10**A is substantially the same as that of the switching power-supply unit **10**, and substantially the same points will not be described.

The switching power-supply unit **10**A includes the heat sink **60**. The heat sink **60** is formed of a material having a high thermal conductivity. The heat sink **60** is disposed to be close to or in contact with the power-conversion switching devices Q**1** and Q**2**. In other words, the heat sink **60** is disposed at a position where heat from the power-conversion switching devices Q**1** and Q**2** is propagated. The heat sink **60** dissipates heat generated by the power-conversion switching devices Q**1** and Q**2**.

The heat sink **60** is conductive. That is, the heat sink **60** has a high thermal conductivity and is conductive. The heat sink **60** is connected to the ground potential GNDs.

In this configuration, noise emitted from the power-conversion switching devices Q**1** and Q**2** flows to the ground potential GNDs through the heat sink **60**. Thus, the noise balancing circuit includes the heat sink **60**.

Therefore, the noise balancing circuit may balance noise including noise emitted from the power-conversion switching devices Q**1** and Q**2**. As a result, the switching power-supply unit **10**A may more effectively suppress noise which leaks to the outside. In particular, the heat sink **60** is disposed so as to overlie the power-conversion switching devices Q**1** and Q**2**. Thus, the switching power-supply unit **10** achieves further effective suppression of noise leaking to the outside.

Third Embodiment

A switching power-supply unit according to a third embodiment of the present disclosure will be described by referring to a figure. FIG. **11** is a circuit diagram illustrating an exemplary circuit configuration of the switching power-supply unit according to the third embodiment of the present disclosure.

As illustrated in FIG. **11**, a switching power-supply unit **10**B according to the third embodiment is different from the switching power-supply unit **10**A according to the second embodiment in the connection form of the heat sink **60**. The other configuration of the switching power-supply unit **10**B is substantially the same as that of the switching power-supply unit **10**A, and substantially the same points will not be described.

In the switching power-supply unit **10**B, the heat sink **60** is connected, on the negative electrode side of the common-mode choke coil **50**, to a wiring line on the control circuit **30** side.

This configuration causes noise, which is emitted from the power-conversion switching devices Q**1** and Q**2**, to flow to the noise balancing circuit through the heat sink **60** and the isolated converter **312**. The heat sink **60** and the isolated converter **312** are connected, on the negative electrode side of the common-mode choke coil **50** (the negative electrode side of the direct-current power supply **92** connected to the ground potential GNDs), to a wiring line on the control circuit **30** side. Thus, a leak of noise, which goes through the heat sink **60** and the isolated converter **312**, to the outside may be suppressed, and influence on the control circuit **30** may be suppressed.

Fourth Embodiment

A switching power-supply unit according to a fourth embodiment of the present disclosure will be described by referring to a figure. FIG. **12** is a circuit diagram illustrating an exemplary circuit configuration of the switching power-supply unit according to the fourth embodiment of the present disclosure.

As illustrated in FIG. **12**, a switching power-supply unit **10**C according to the fourth embodiment is different from the switching power-supply unit **10**A according to the second embodiment in the connection form of the heat sink **60**. The other configuration of the switching power-supply unit **10**C is substantially the same as that of the switching power-supply unit **10**A, and substantially the same points will not be described.

In the switching power-supply unit **10**C, the heat sink **60** is connected, on the positive electrode side of the common-mode choke coil **50**, to a wiring line on the control circuit **30** side.

This configuration causes noise, which is emitted from the power-conversion switching devices Q1 and Q2, to flow to the noise balancing circuit through the heat sink **60** and the isolated converter **312**. The heat sink **60** is connected, on the positive electrode side of the common-mode choke coil **50** (the positive electrode side of the direct-current power supply **92** connected to the ground potential GNDs), to a wiring line on the control circuit **30** side, and the isolated converter **312** is connected, on the negative electrode side of the common-mode choke coil **50** (the negative electrode side of the direct-current power supply **92** connected to the ground potential GNDs), to a wiring line on the control circuit **30** side. Thus, a leak of noise, which goes through the heat sink **60** and the isolated converter **312**, to the outside may be suppressed, and influence on the control circuit **30** may be suppressed.

Fifth Embodiment

A switching power-supply unit according to a fifth embodiment of the present disclosure will be described by referring to a figure. FIG. **13** is a circuit diagram illustrating an exemplary circuit configuration of the switching power-supply unit according to the fifth embodiment of the present disclosure.

As illustrated in FIG. **13**, a switching power-supply unit **10**D according to the fifth embodiment is different from the switching power-supply unit **10**A according to the second embodiment in the connection form of the heat sink **60**. The other configuration of the switching power-supply unit **10**D is substantially the same as that of the switching power-supply unit **10**A, and substantially the same points will not be described.

In the switching power-supply unit **10**D, the heat sink **60** is connected, on the negative electrode side of the class-Y capacitor **40**, to a wiring line on the power conversion circuit **20** side.

This configuration causes noise, which is emitted from the power-conversion switching devices Q1 and Q2, to flow to the noise balancing circuit through the isolated converter **312**. The isolated converter **312** is connected, on the negative electrode side of the common-mode choke coil **50** (on the negative electrode side of the direct-current power supply **92** connected to the ground potential GNDs), to a wiring line on the control circuit **30** side. Thus, a leak of noise, which goes through the isolated converter **312**, to the outside may be suppressed, and influence on the control circuit **30** may be suppressed.

Sixth Embodiment

A switching power-supply unit according to a sixth embodiment of the present disclosure will be described by referring to a figure. FIG. **14** is a circuit diagram illustrating an exemplary circuit configuration of the switching power-supply unit according to the sixth embodiment of the present disclosure.

As illustrated in FIG. **14**, a switching power-supply unit **10**E according to the sixth embodiment is different from the switching power-supply unit **10**A according to the second embodiment in the connection form of the heat sink **60**. The other configuration of the switching power-supply unit **10**E is substantially the same as that of the switching power-supply unit **10**A, and substantially the same points will not be described.

In the switching power-supply unit **10**E, the heat sink **60** is connected, on the positive electrode side of the class-Y capacitor **40**, to a wiring line on the power conversion circuit **20** side.

This configuration causes noise, which is emitted from the power-conversion switching devices Q1 and Q2, to flow to the noise balancing circuit through the isolated converter **312**. The isolated converter **312** is connected, on the negative electrode side of the common-mode choke coil **50** (on the negative electrode side of the direct-current power supply **92** connected to the ground potential GNDs), to a wiring line on the control circuit **30** side. Thus, a leak of noise, which goes through the isolated converter **312**, to the outside may be suppressed, and influence on the control circuit **30** may be suppressed.

Seventh Embodiment

A switching power-supply unit according to a seventh embodiment of the present disclosure will be described by referring to a figure. FIG. **15** is a circuit block diagram illustrating a schematic configuration of the switching power-supply unit according to the seventh embodiment of the present disclosure.

As illustrated in FIG. **15**, a switching power-supply unit **10**F according to the seventh embodiment is different from the switching power-supply unit **10** according to the first embodiment in that direct-current power is supplied from the single direct-current power supply **91**. The other configuration of the switching power-supply unit **10**F is substantially the same as that of the switching power-supply unit **10**, and substantially the same points will not be described.

The switching power-supply unit **10**F is connected to the direct-current power supply **91**. A step-down circuit **39** is connected between the common-mode choke coil **50** and the direct-current power supply **91**. The step-down circuit **39** is, for example, a step-down DC/DC converter.

This configuration enables the switching power-supply unit **10**F to, like the switching power-supply unit **10**, reduce occurrence of common-mode noise while suppressing heat generation and power loss. The configuration of the switching power-supply unit **10**F does not need multiple direct-current power supplies having different voltages, and may use a single direct-current power supply to reduce occurrence of common-mode noise while suppressing heat generation and power loss.

The configurations of the embodiments described above may be combined with each other appropriately, enabling operation and effect in accordance with each combination to be exerted.

(1) A switching power-supply unit comprising a power conversion circuit that includes a first input capacitor, at least one power-conversion switching device for power conversion, and a first output capacitor, and that converts, for output to a load, power supplied from a first direct-current power supply; and a control circuit that includes a second input capacitor and at least one switching drive circuit, and that generates a drive signal for the at least one power-conversion switching device by using power supplied from a second direct-current power supply, the control circuit having a direct electrical connection to the power conversion circuit. The switching power-supply unit further comprises a class-Y capacitor that is connected to the power conversion circuit on the first direct-current power supply side of the power conversion circuit, and that is connected to a ground potential; and a common-mode choke coil that

is connected to the control circuit on the second direct-current power supply side of the control circuit. A noise balancing circuit is formed of a closed circuit including the power conversion circuit, the control circuit, the class-Y capacitor, and the common-mode choke coil. The noise balancing circuit causes common-mode currents to be confined and canceled out each other, and the common-mode currents serve as switching noise generated in a plurality of parts of the closed circuit due to a switching operation of the at least one power-conversion switching device.

(2) The switching power-supply unit according to (1), wherein a negative electrode of the second direct-current power supply is connected to the ground potential.

(3) The switching power-supply unit according to (1) or (2), wherein a positive electrode and a negative electrode of the first direct-current power supply are electrically isolated from the ground potential.

(4) The switching power-supply unit according to any one of (1) to (3), wherein the first direct-current power supply has a voltage higher than a voltage of the second direct-current power supply.

(5) The switching power-supply unit according to any one of (1) to (4), further comprising a heat sink that dissipates heat generated by the at least one power-conversion switching device.

(6) The switching power-supply unit according to (5), wherein the heat sink is connected to the ground potential.

(7) The switching power-supply unit according to (5) or (6), wherein the heat sink is electrically connected to a negative electrode of the second direct-current power supply, and the common-mode choke coil is connected between a point of connection between the heat sink and the second direct-current power supply, and a positive electrode of the second direct-current power supply.

(8) The switching power-supply unit according to (5) or (6), wherein the heat sink is electrically connected to a positive electrode of the second direct-current power supply, and the common-mode choke coil is connected between a point of connection between the heat sink and the second direct-current power supply, and a negative electrode of the second direct-current power supply.

(9) The switching power-supply unit according to (5) or (6), wherein the heat sink is electrically connected to a negative electrode of the first direct-current power supply.

(10) The switching power-supply unit according to (5) or (6), wherein the heat sink is electrically connected to a positive electrode of the first direct-current power supply.

(11) The switching power-supply unit according to any one of (1) to (10), wherein a negative electrode of the first direct-current power supply is electrically connected to a negative electrode of the second direct-current power supply.

(12) The switching power-supply unit according to any one of (1) to (11), wherein the at least one switching drive circuit comprises a plurality of switching drive circuits, and the at least one power-conversion switching device comprises a plurality of power-conversion switching devices. The control circuit includes an isolated converter and the plurality of switching drive circuits, and a negative electrode of each of the plurality of switching drive circuits is connected to a source potential of a corresponding one of the plurality of power-conversion switching devices.

(13) The switching power-supply unit according to any one of (1) to (12), wherein the noise balancing circuit, the first direct-current power supply, and the second direct-current power supply are included in a vehicle, and the ground potential is the same as a potential of the vehicle's chassis.

What is claimed is:

1. A switching power-supply unit comprising:

a power conversion circuit that includes a first input capacitor, at least one power-conversion switching device for power conversion, and a first output capacitor, and the power conversion circuit is configured to convert, for output to a load, power supplied from a first direct-current power supply;

a control circuit that includes a second input capacitor and at least one switching drive circuit, and control circuit is configured to generate a drive signal for the at least one power-conversion switching device by using power supplied from a second direct-current power supply, the control circuit having a direct electrical connection to the power conversion circuit;

a class-Y capacitor that is connected to the power conversion circuit on a side of the first direct-current power supply of the power conversion circuit, and that is connected to a ground potential; and

a common-mode choke coil that is connected to the control circuit on a side of the second direct-current power supply of the control circuit,

wherein a noise balancing circuit is configured of a closed circuit including the power conversion circuit, the control circuit, the class-Y capacitor, and the common-mode choke coil, and the noise balancing circuit is configured to confine common-mode currents to cancel out each other, the common-mode currents being switching noise generated in a plurality of parts of the closed circuit due to a switching operation of the at least one power-conversion switching device.

2. The switching power-supply unit according to claim **1**, wherein

a negative electrode of the second direct-current power supply is connected to the ground potential.

3. The switching power-supply unit according to claim **1**, wherein

a positive electrode and a negative electrode of the first direct-current power supply are electrically isolated from the ground potential.

4. The switching power-supply unit according to claim **1**, wherein

the first direct-current power supply has a voltage higher than a voltage of the second direct-current power supply.

5. The switching power-supply unit according to claim **1**, further comprising:

a heat sink configured to dissipate heat generated by the at least one power-conversion switching device.

6. The switching power-supply unit according to claim **5**, wherein the heat sink is connected to the ground potential.

7. The switching power-supply unit according to claim **5**, wherein

the heat sink is electrically connected to a negative electrode of the second direct-current power supply, and

the common-mode choke coil is connected between a point of connection between the heat sink and the second direct-current power supply, and a positive electrode of the second direct-current power supply.

8. The switching power-supply unit according to claim **5**, wherein

the heat sink is electrically connected to a positive electrode of the second direct-current power supply, and the common-mode choke coil is connected between a point of connection between the heat sink and the second direct-current power supply, and a negative electrode of the second direct-current power supply.

9. The switching power-supply unit according to claim **5**, wherein

the heat sink is electrically connected to a negative electrode of the first direct-current power supply.

10. The switching power-supply unit according to claim **5**, wherein

the heat sink is electrically connected to a positive electrode of the first direct-current power supply.

11. The switching power-supply unit according to claim **1**, wherein

a negative electrode of the first direct-current power supply is electrically connected to a negative electrode of the second direct-current power supply.

12. The switching power-supply unit according to claim **1**, wherein

the at least one switching drive circuit comprises a plurality of switching drive circuits, and the at least one power-conversion switching device comprises a plurality of power-conversion switching devices,

the control circuit includes an isolated converter and the plurality of switching drive circuits, and

a negative electrode of each of the plurality of switching drive circuits is connected to a source potential of a corresponding one of the plurality of power-conversion switching devices.

13. The switching power-supply unit according to claim **1**, wherein

the noise balancing circuit, the first direct-current power supply, and the second direct-current power supply are included in a vehicle, and

the ground potential is the same as a potential of a chassis of the vehicle.

14. The switching power-supply unit according to claim **2**, wherein

a positive electrode and a negative electrode of the first direct-current power supply are electrically isolated from the ground potential.

15. The switching power-supply unit according to claim **2**, wherein

the first direct-current power supply has a voltage higher than a voltage of the second direct-current power supply.

16. The switching power-supply unit according to claim **2**, further comprising:

a heat sink configured to dissipate heat generated by the at least one power-conversion switching device.

17. The switching power-supply unit according to claim **16**, wherein the heat sink is connected to the ground potential.

18. The switching power-supply unit according to claim **2**, wherein

a negative electrode of the first direct-current power supply is electrically connected to a negative electrode of the second direct-current power supply.

19. The switching power-supply unit according to claim **2**, wherein

the at least one switching drive circuit comprises a plurality of switching drive circuits, and the at least one power-conversion switching device comprises a plurality of power-conversion switching devices,

the control circuit includes an isolated converter and the plurality of switching drive circuits, and

a negative electrode of each of the plurality of switching drive circuits is connected to a source potential of a corresponding one of the plurality of power-conversion switching devices.

20. The switching power-supply unit according to claim **2**, wherein

the noise balancing circuit, the first direct-current power supply, and the second direct-current power supply are included in a vehicle, and

the ground potential is the same as a potential of a chassis of the vehicle.

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