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(54) NOISE CANCELING APPARATUS FOR A POWER CONVERTER

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(22) Filed: **Jul. 25, 2000**

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(52) **U.S. Cl.** **363/39**
(58) **Field of Search** 363/39, 40, 45, 363/46, 47

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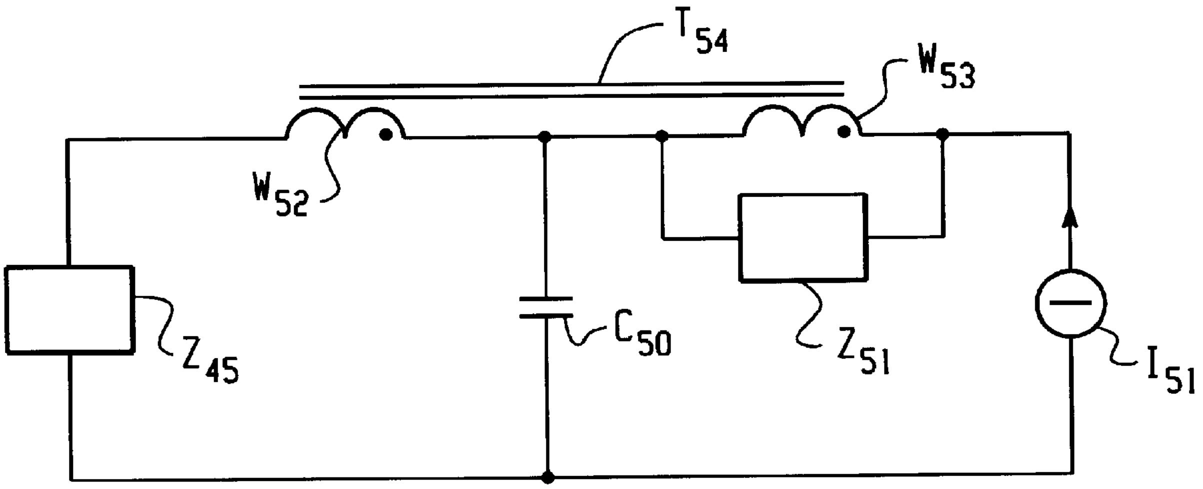
(57) ABSTRACT

A noise canceling apparatus is provided that uses magnetically-coupled windings to cancel noise currents or noise voltages from a power converter. The apparatus may include a series voltage source or a shunt current source that is placed at input or output terminals of a power converter to eliminate the noise generated from the power converter.

48 Claims, 7 Drawing Sheets



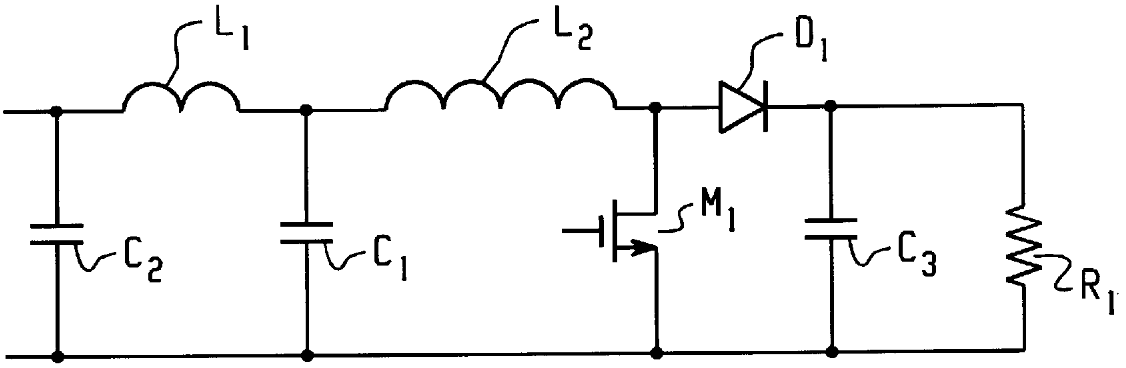


Fig. 1
(PRIOR ART)

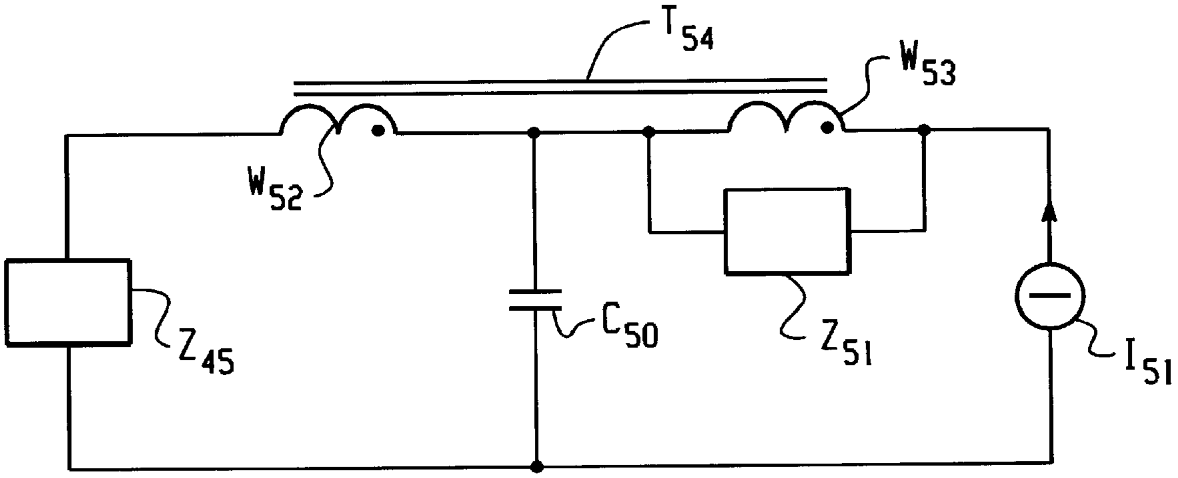


Fig. 3

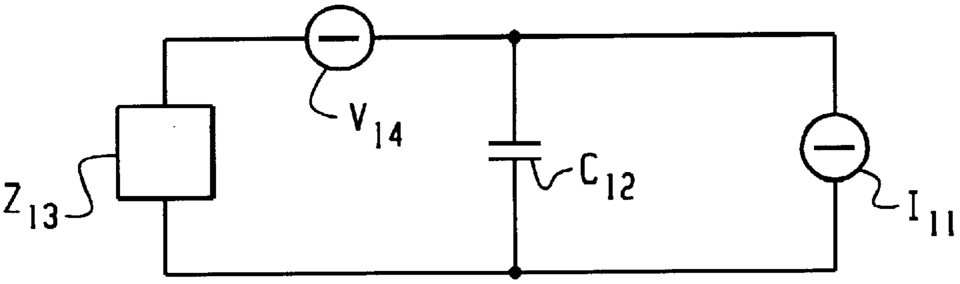


Fig. 2A

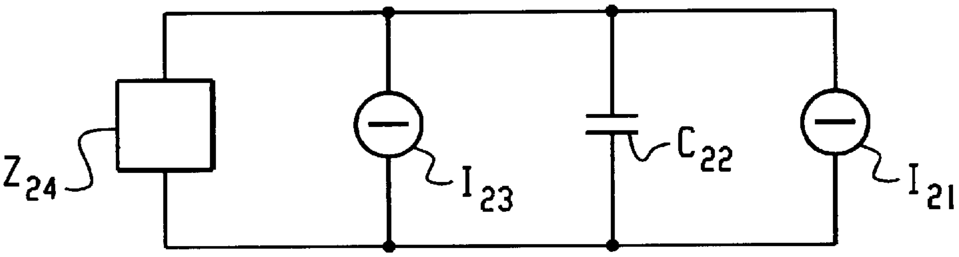


Fig. 2B

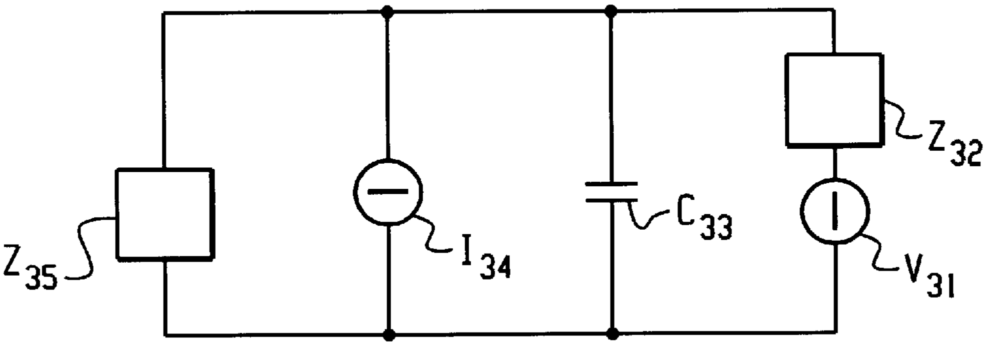


Fig. 2C

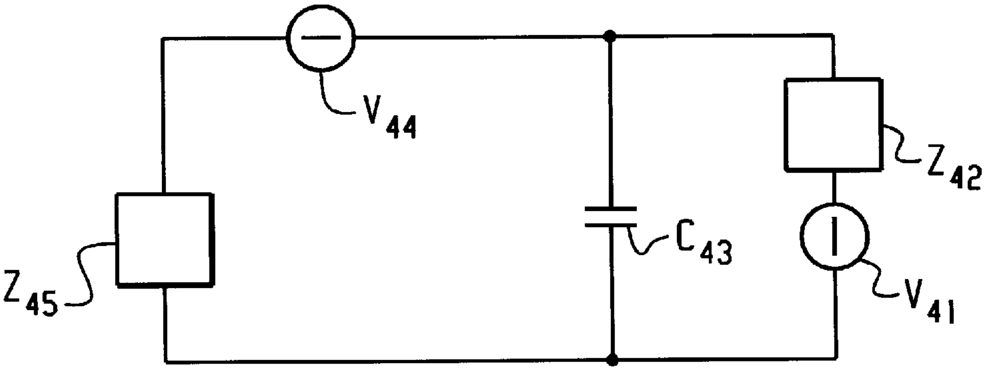


Fig. 2D

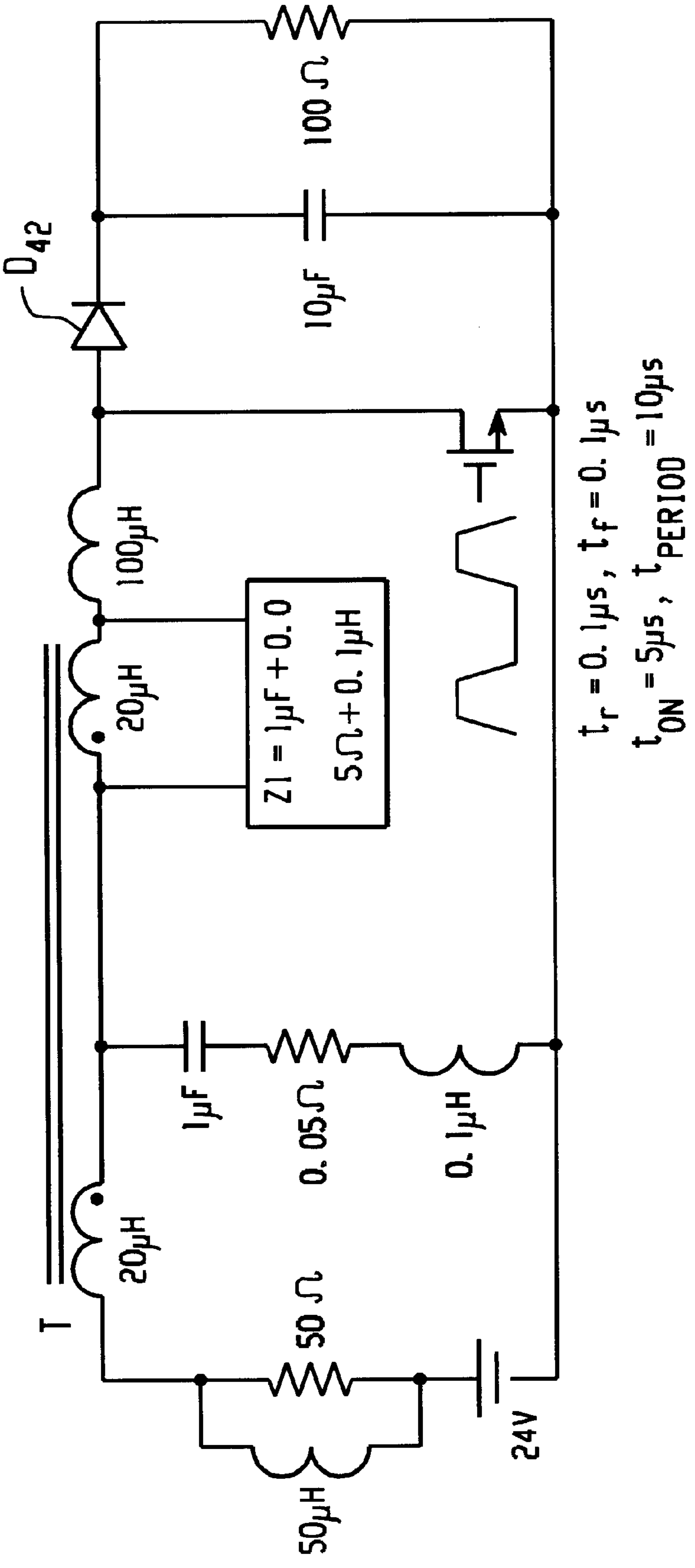

D$_{42}$
100 Ω
10µF
100µH
20µH
Z1 = 1µF + 0.0
5Ω+0. 1µH
1µF
0. 05Ω
0. 1µH
20µH
T
50 Ω
50µH
24V
$t_r = 0.1 \mu s$, $t_f = 0.1 \mu s$
$t_{ON} = 5 \mu s$, $t_{PERIOD} = 10 \mu s$

Fig. 4

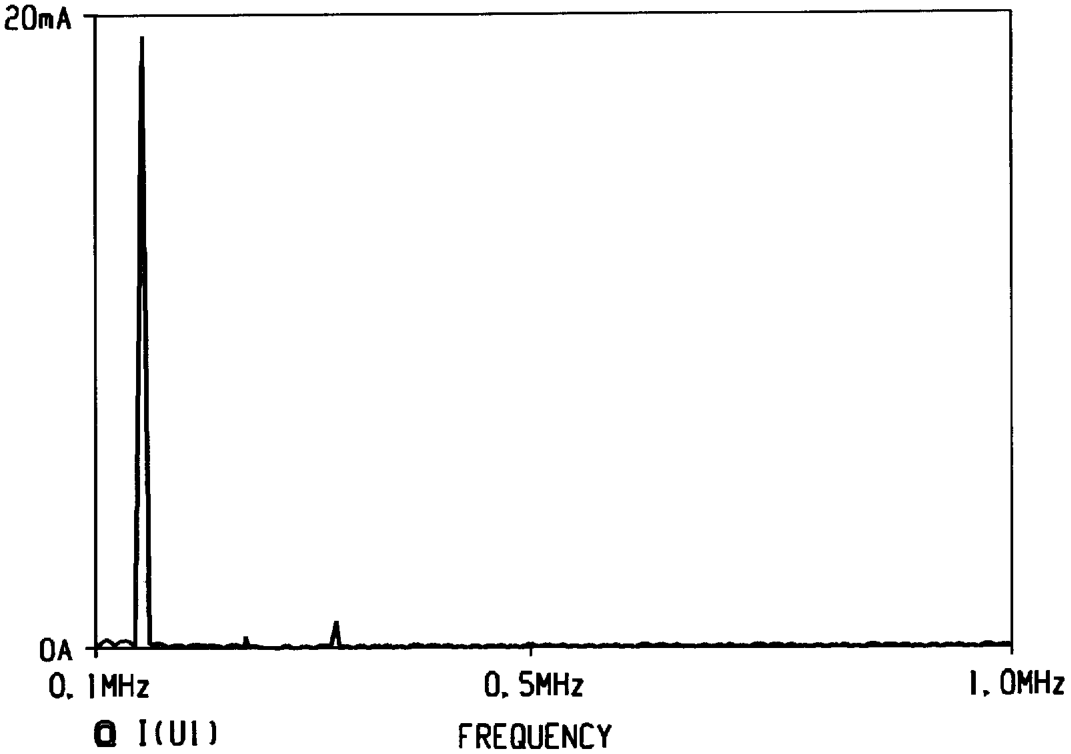

20mA
0A
0.1MHz
0.5MHz
1.0MHz
□ I(U1)
FREQUENCY

Fig. 5A

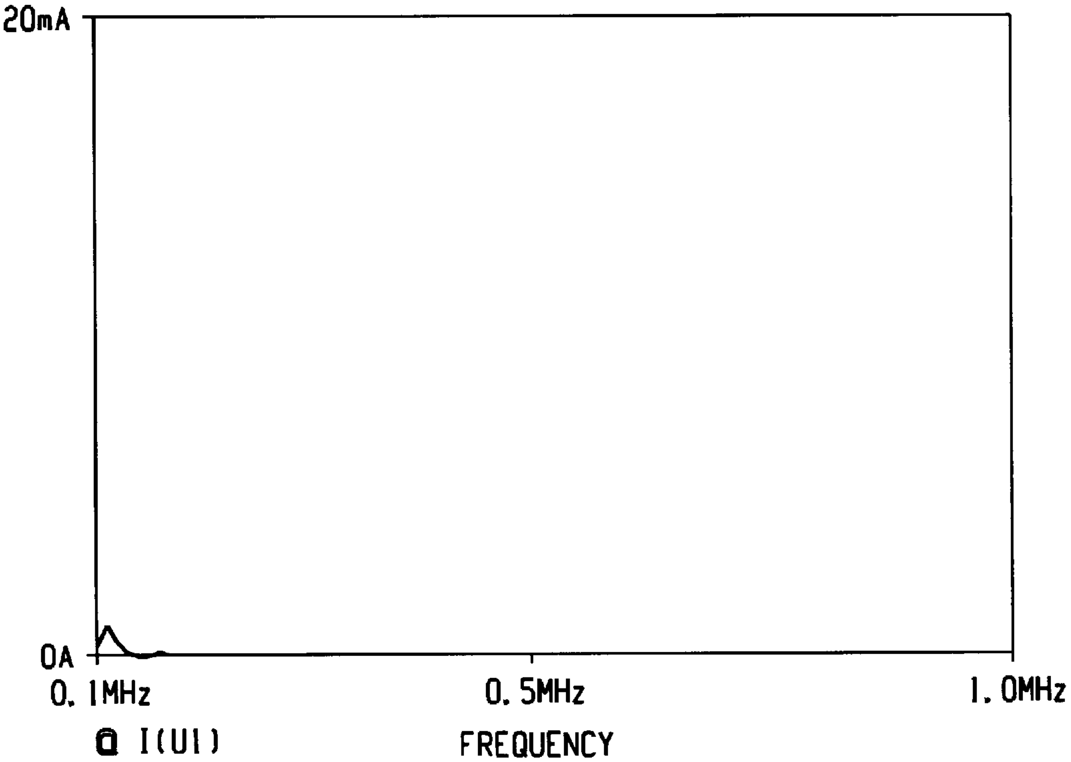

20mA
0A
0.1MHz
0.5MHz
1.0MHz
□ I(U1)
FREQUENCY

Fig. 5B

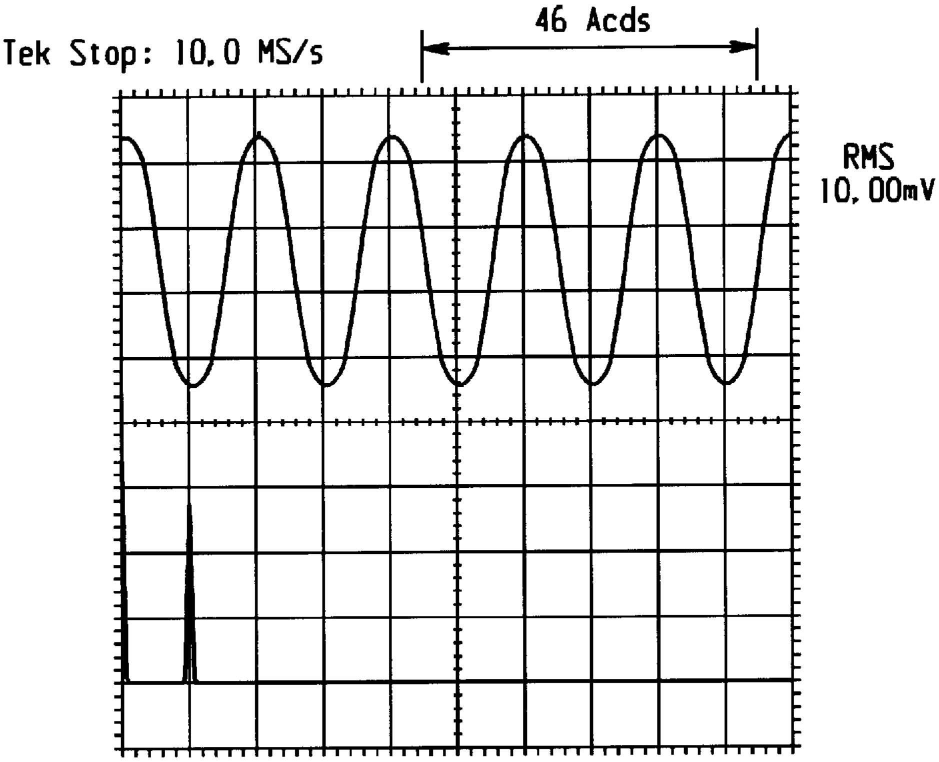

46 Acds
Tek Stop: 10.0 MS/s
RMS
10.00mV

Fig. 6A

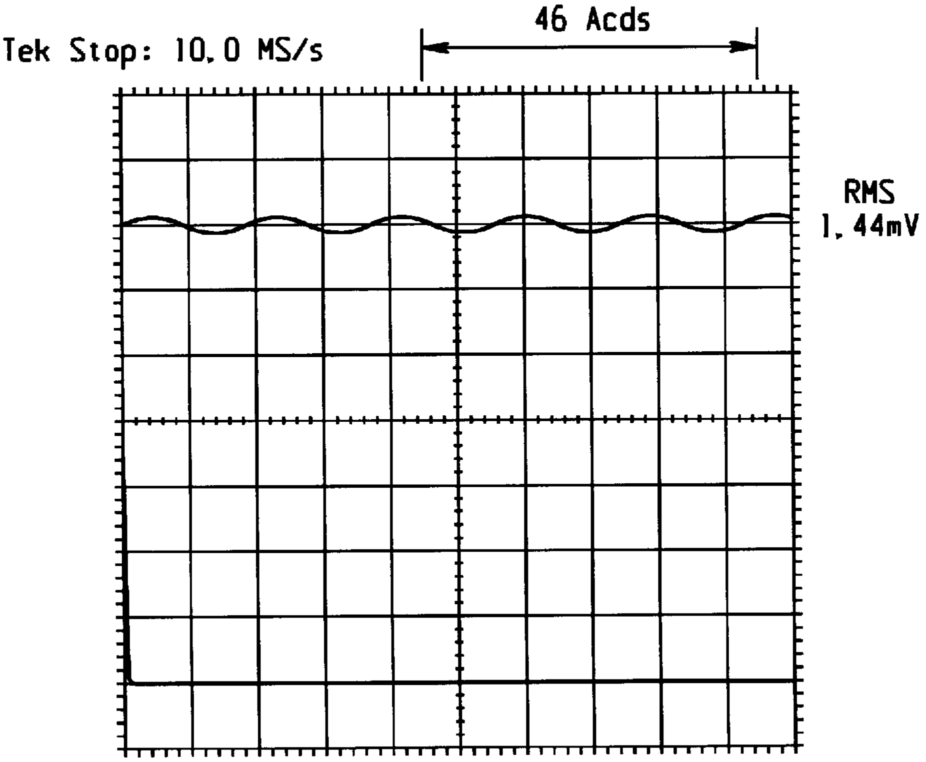

46 Acds
Tek Stop: 10.0 MS/s
RMS
1.44mV

Fig. 6B

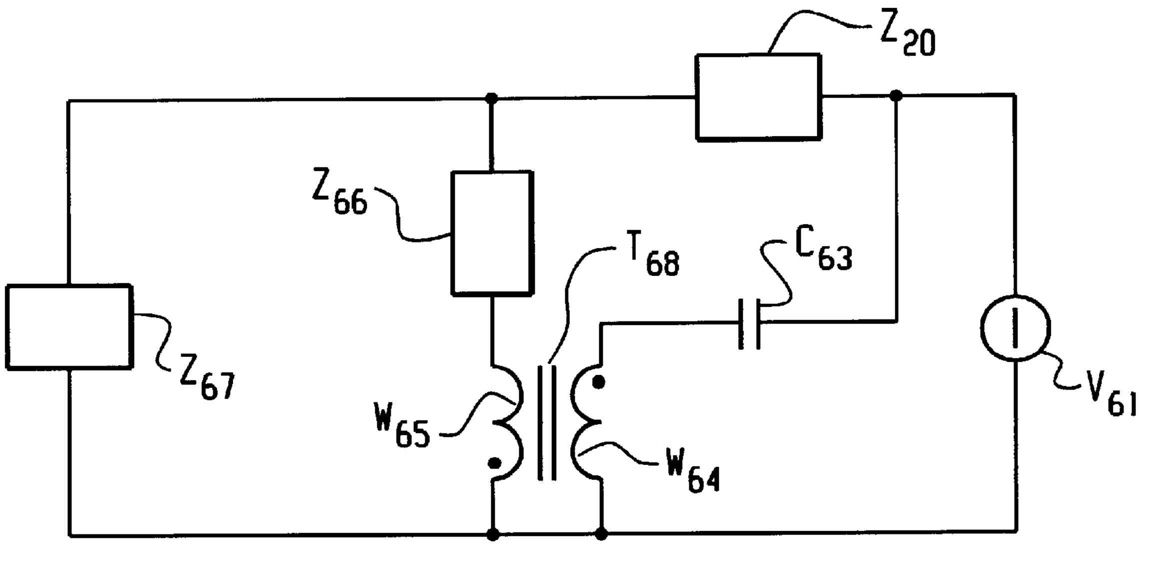

Z20
Z66
T68
C63
Z67
W65
W64
V61

Fig. 7

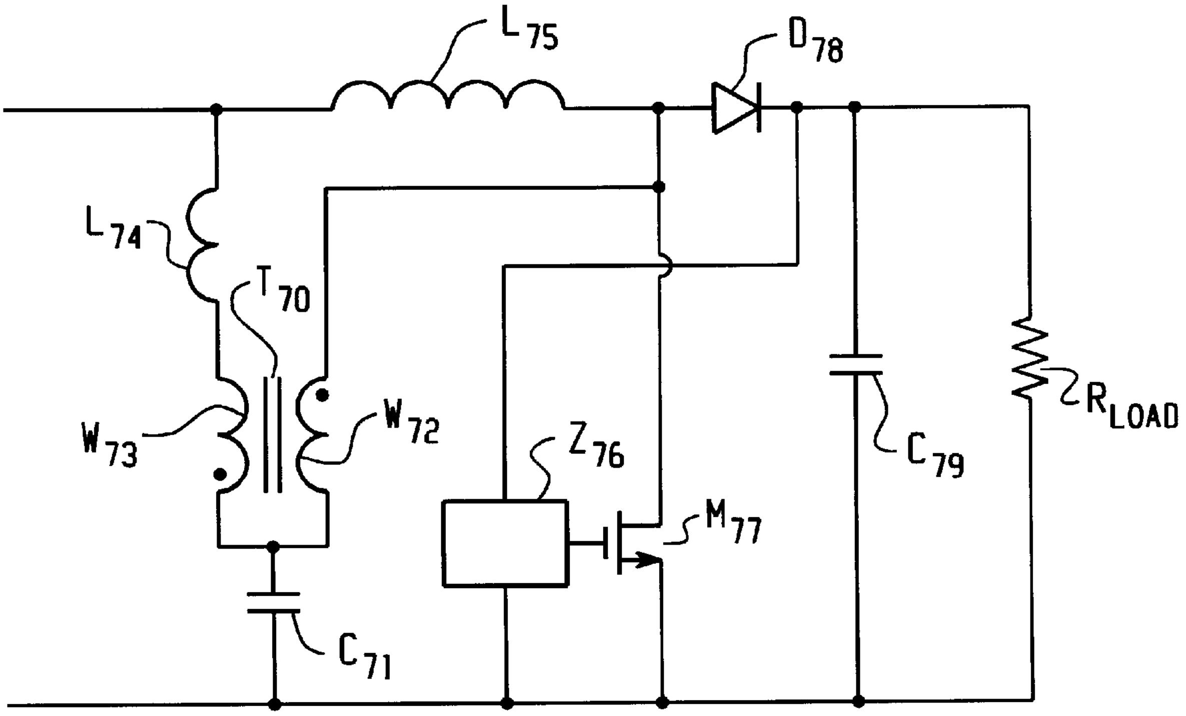

L75
D78
L74
T70
W73
W72
Z76
M77
C79
RLOAD
C71

Fig. 8

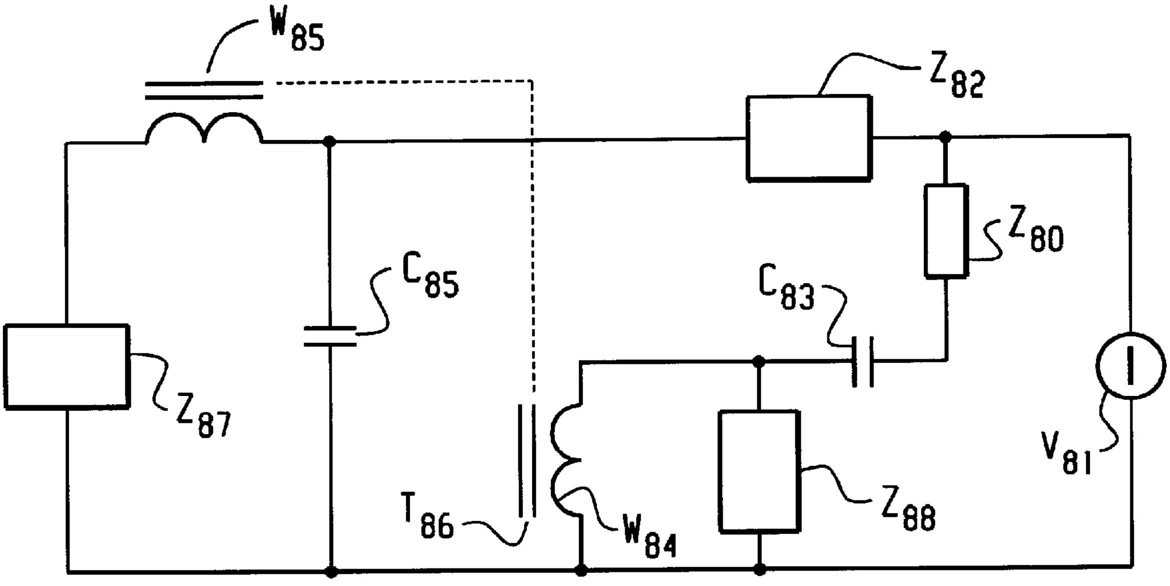

W_{85}
Z_{82}
Z_{80}
C_{85}
C_{83}
Z_{87}
V_{81}
T_{86}
W_{84}
Z_{88}

Fig. 9

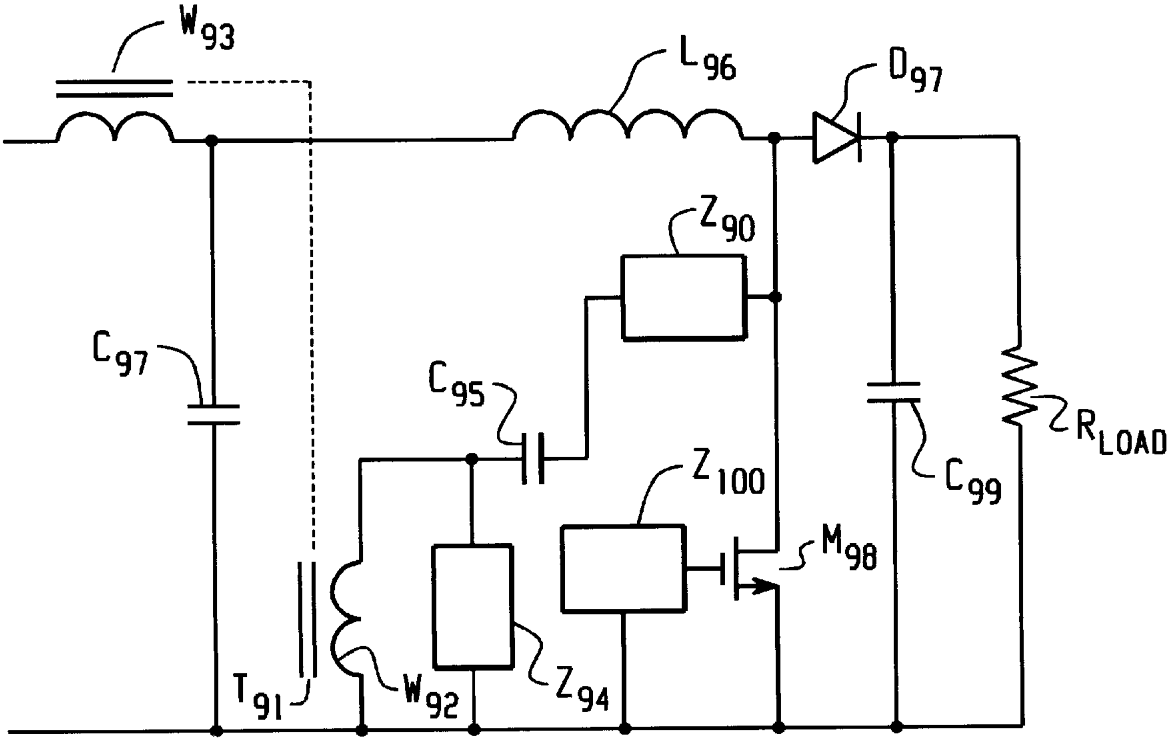

W_{93}
L_{96}
D_{97}
Z_{90}
C_{97}
C_{95}
R_{LOAD}
Z_{100}
C_{99}
M_{98}
T_{91}
W_{92}
Z_{94}

Fig. 10

NOISE CANCELING APPARATUS FOR A POWER CONVERTER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention generally relates to the field of power converters. More specifically, the invention relates to the field of reducing noise in power converters such as AC to DC converters, DC to AC converters or DC to DC converters.

2. Background of the Invention

A modern switching-mode power converter is light weight and provides high efficiency power conversion. One of the problems with this type of converter, however, is that it generates undesirable switching noise. This switching noise manifests itself as a ripple voltage or ripple current that is generated by the switching-mode at the input or output side of the converter. Reduction of such ripple voltage or current becomes a necessary design requirement in order to comply with international standards. Some prior art provides a means to reduce such ripple current. For example, a traditional means to suppress ripple voltage or current is by implementing a passive filter. As shown in FIG. **1**, a prior art converter implements a simple LC circuit. A pair of inductors, L_1 and L_2 are coupled to a pair of capacitors C_1 and C_2. Together, these components are coupled to a converter that is modeled as a diode D_1, a capacitor C_3, a resistor R_1 and a transistor M_1 that acts as a switch for the converter. A passive filter, however, requires bulky components that take up the limited space within the power converter. Other prior art work implements active cancellation techniques to reduce the ripple noise. For example, in U.S. Pat. No. 4,274,133 to Cuk a converter is disclosed that cancels ripple current by matching a coupling coefficient of two inductors within the converter. In U.S. Pat. No. 5,038,263 to Marrero a circuit is disclosed with a winding coupled to the main transformer of the converter for diverting ripple current to a capacitor. The coupling ratio of the transformer windings reduces the ac ripple current input switching. In Marrero, an inductor is coupled in series with the input to provide constant current. This inductor, however, is bulky and adds an extra component in the power conversion path. In U.S. Pat No. 6,008,999 also to Marrero a converter is disclosed having an additional winding that effects the output inductance of the converter. The coupling ratio of the additional winding and output winding reduces input and output switching ripple.

These prior art methods have drawbacks that limit the utility of the power converter. For example, traditional passive filters require bulky inductors and capacitors that increase component count and space requirements. Known active noise cancellation techniques reduce component size and count, but require careful magnetic coupling between each winding in the main magnetic component. The cancellation effect is not achieved in these circuits without a tightly-coupled magnetic field. The main magnetic component must be made precisely to satisfy both power conversion and noise cancellation requirements. This becomes an added constraint to the design and increases the difficulty to manufacture the converter.

SUMMARY OF THE INVENTION

The present invention provides a general solution for canceling ripple current generated by a power converter. In general, two methods are provided, a series voltage source or a shunt current source, which are placed at the input terminals of a power converter to eliminate ripple current generated by the converter. This noise cancellation apparatus can be applied to any power converter because it is a separate unit that captures the noise signal and generates a cancellation signal equal in magnitude, but opposite in phase to the noise signal, in order to reduce the undesirable noise, such as switching voltage or ripple current of a switching-mode power supply.

According to one aspect of the invention, an AC voltage can be inserted in series with the input terminal of the power converter to reduce the noise voltage. The AC voltage is equal in magnitude but opposite in phase to the noise voltage generated by an AC noise current, or the equivalent of an AC noise current, coupled to the input impedance of the power converter. The noise voltage at the input is thus cancelled.

According to another aspect of the invention, a shunt AC current source can be inserted in parallel with the input terminal of a power converter. If the shunt AC current has equal magnitude, but opposite phase, of the noise current generated by the power converter, then the AC current flow into the input terminal is cancelled.

According to yet another aspect of the invention, an AC voltage can be inserted in series with the input terminal of a power converter. This voltage source can be derived from a noisy voltage node or its equivalent within the converter. Voltage scaling is provided by impedance networks and this voltage source can cancel out noise at the converter input.

The design of these cancellation circuits, unlike traditional filter designs, is not dependent on converter input source impedance. The noise cancellation can also be incorporated with a traditional filter to further reduce the noise level associated with the ripple current and voltage.

Accordingly, it is an object of the present invention to provide noise cancellation circuits for power converters. The noise cancellation circuits can be placed on the input terminals or output terminals of the power converter. The noise reduction apparatus can reduce the noise of different topologies of power converters. Furthermore, the noise reduction apparatus has a low component count and reduces the size of the components in the design.

These and other objects of the present invention will become apparent to those skilled in the art from the following detailed description of the invention and from the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1**(Prior Art) is a simplified equivalent circuit of a boost converter with a filtering circuit at the input terminal;

FIG. **2**A is a schematic diagram of a circuit showing a series voltage noise canceling source controlled by converter noise current;

FIG. **2**B is a schematic diagram of a circuit showing a parallel noise canceling source controlled by converter noise current;

FIG. **2**C is a schematic diagram of a circuit showing a parallel noise canceling source controlled by converter noise voltage;

FIG. **2**D is a schematic diagram of a circuit showing a series voltage noise canceling source controlled by converter noise voltage;

FIG. **3** is a preferred embodiment of the present invention using a series voltage source to reduce noise created by ripple;

FIG. **4** is an example circuit of the preferred embodiment of FIG. **3** coupled to a boost converter;

FIG. **5**A is an example input noise spectrum of a boost converter without noise cancellation;

FIG. **5**B is an example input noise spectrum of the boost converter with noise cancellation of FIG. **4**;

FIG. **6**A is a plot showing the measured input ripple current of the boost converter without noise cancellation in the time domain and in the frequency domain;

FIG. **6**B is a plot showing the measured input ripple current of the boost converter with noise cancellation in the time domain and in the frequency domain;

FIG. **7** is another preferred embodiment of the present invention coupling a parallel current source derived from the noise voltage to a converter in order to reduce ripple;

FIG. **8** is an example circuit of the embodiment of FIG. **7** coupled to a boost converter;

FIG. **9** is another preferred embodiment of the present invention coupling a series voltage source derived from the noise voltage to a converter in order to reduce ripple; and

FIG. **10** is an example circuit of the embodiment of FIG. **9** coupled to a boost converter.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In general, noise detected at the input of a switching power converter is generated by a pulsating current or a pulsating voltage within the converter. Each of these noise sources is present in switching power converters, but which noise source dominates the noise signal depends on the converter. If the converter includes high pulsating current, then the pulsating current model may be the most appropriate model for noise reduction. If the converter includes a high pulsating voltage, however, then the pulsating voltage model may be the most appropriate model for noise reduction. These models form the basis for the generation of cancellation signals to eliminate noise at the input.

FIG. **2**A is a schematic diagram of a circuit showing a series voltage noise-canceling source controlled by converter noise current. The current-based noise source is modelled by a switching current source I_{11}. An input capacitor C_{12} is in parallel to the input and functions as an energy storage element. A series impedance of the input, Z_{13}, is the modeled impedance of the converter. In order to eliminate noise at Z_{13}, an active voltage source, V_{14}, is put in series with the input. This voltage source is matched to the current change such that the voltage source changes oppositely to the ripple voltage across capacitor C_{12}, thus canceling the AC voltage that would have appeared across Z_{13} and eliminating input noise. A direct method for matching the voltage source to the noise is to couple the current change at I_{11} to the series voltage source V_{14}.

FIG. **2**B is a schematic diagram of a circuit showing a parallel noise canceling source controlled by converter noise current. A switching source I_{21} represents a current-based noise source. An input capacitor C_{22} is in parallel to the input and functions as an energy storage element. A series impedance of the input, Z_{24}, is the modeled impedance of the converter. In order to eliminate noise at $Z_{24,}$ an active current source, I_{23}, is coupled in parallel to the input. This current source produces a current opposite to that of the noise source I_{21} so that the input impedance Z_{24} does not see any ripple current.

FIG. **2**C is a schematic diagram of a circuit showing a parallel noise canceling source controlled by converter noise voltage. A voltage based noise source is represented by pulsating voltage source V_{31} in series with an impedance Z_{32}. A capacitor C_{33} is parallel to the input. A series impedance of the input, Z_{35}, is the modeled impedance of the converter. In order to eliminate noise at Z_{35}, an active current source I_{34} is coupled in parallel to the input. The current source I_{34} produces a current opposite to that drawn by the noise source V_{31}. The impedance Z_{35} does not see any ripple current. A method for matching the voltage noise source to the current source I_{34} is to directly couple the current source I_{34} to the noise source V_{31}.

FIG. **2**D is a schematic diagram of a circuit showing a series voltage noise canceling source controlled by converter noise voltage. A voltage based noise source is represented by pulsating voltage source V_{41} in series with an impedance Z_{42}. A capacitor C_{43} is parallel to the input. A series impedance of the input, Z_{35}, is the modeled impedance of the converter. In order to eliminate noise at Z_{35}, an active voltage source V_{44} is coupled in series to the impedance Z_{45}. This voltage source is matched to the current change such that the voltage source changes oppositely to the ripple voltage across capacitor C_{43}, thus canceling the AC voltage that would have appeared across Z_{45} and eliminating input noise. The voltage source V_{44} produces a voltage opposite to that of the noise source V_{41} so that the input impedance Z_{24} does not see any ripple voltage.

The schematic diagrams of FIGS. **2**A through **2**D represent the idealized control mechanism for reducing ripple noise by using either a shunt current (FIGS. **2**B and **2**C) or by using a voltage source (FIGS. **2**A and **2**D). The use of the shunt current or voltage source as a controller is applicable to a circuit where the ripple noise is modeled as a current noise source (FIGS. **2**A and **2**B) or as a voltage noise source (FIGS. **2**C and **2**D).

Turning now to FIG. **3**, a preferred embodiment of the present invention is shown in which a series voltage source is used to reduce noise created by ripple. This noise canceling apparatus is an embodiment of the idealized voltage source/ripple current configuration of FIG. **2**A. The apparatus includes a transformer T_{54} that is coupled to a pair of windings, W_{52} and W_{53}. The winding W_{53} is in parallel to an impedance Z_{51}. Both the W_{53} winding and the Z_{51} impedance are in series with a ripple noise current source I_{51}. An input impedance Z_{45} is in series with the W_{52} winding and an energy storing capacitor C_{50}. The energy storing capacitor C_{50} is, in turn, in series with the W_{53} winding and the current source I_{51}.

A cancellation voltage is generated by detecting the voltage drop across the impedance Z_{51} measured across the winding W_{53} caused by the switching ripple current I_{51}. The cancellation voltage across W_{52} is determined by the transformer ratio of T_{54} and the impedance Z_{51}, because the turn ratio of W_{52} and W_{53} is unity.

The following equations show the mathematical relationship between voltage drops across components in the circuit,

$$v(C_{50})=i(I_{51}).Z(C_{50}) \tag{1}$$

$$v(C_{50})=v(W_{52}) \tag{2}$$

$$v(W_{52})=i(I_{51}).(Z_{51}//Z_{LT1}) \tag{3}$$

where, Z_{LT1} is the input impedance of the transformer T_{54} at winding W_{53}.

Solving the above equations, Z_{51} can be found for zero input noise as:

$$Z_{51} = \frac{Z(C_{50})Z_{LT1}}{Z_{LT1} - Z(C_{50})} \tag{4}$$

Assuming $Z_{LT1} \gg Z(C_{50})$, hence Z_{51} can be approximated as,

$$Z_{51} = Z(C_{50}), \tag{5}$$

The above assumption and the result shows that a component that has an impedance equal to that of the primary filter capacitor (C_{50}) and coupled in parallel to winding W_{53} of transformer T_{54} can provide cancellation of the noise voltage. If the components of the filter include components other than a capacitor, the impedance Z_{51} is modeled as the total impedance of the primary filter components.

If Z_{51} is equal to $Z(C_{50})$, then the voltage drop on both impedances are equal because the parallel impedance of T_{54} is large. Transformer T_{54} thus provides an equal amplitude, but opposite-phase, waveform across the W_{52} winding to cancel out the voltage change across C_{50} due to the noise current source I_{51}.

In a more general case where the turn ratio of W_{52} and W_{53} is not equal to one, the condition for noise cancellation is

$$\frac{Z_{51}}{Z(C_{50})} = \frac{N(W_{53})}{N(W_{52})} \tag{6}$$

where $N(W_{53})$ is the number of turns of winding W_{53} and $N(W_{52})$ is the number of turns of winding W_{52}.

FIG. **4** is an example circuit of the preferred embodiment of FIG. **3** coupled to a boost converter. The noise source I_{51} in FIG. **3** is replaced by the boost converter. The boost converter is modeled as a 100 uH inductor in series with an input transistor and in parallel with a 10 uF capacitor and a 100 Ω resistor through a diode D_{42}. An input waveform having a rise time of 0.1 us, a fall time of 0.1 us, a peak time of 5 us and a period of 10 us is input into the circuit through the gate of the transistor. The capacitor C_{50} is a 1 uF capacitor that is in series with a 0.05 Ω resistor and a 0.1 uH inductor. Each winding W_{52} and W_{53} is a 20 uH winding. The impedance placed in parallel to the 20 uH winding W_{53} must then be equal to the combined impedance of the 1 uF capacitor, the 0.050Ω resistor and the 0.1 uH inductor. The transformer T_{54} then generates a voltage drop in the W_{52} winding that is equal in magnitude to the sensed voltage drop across the W_{53} winding, but the voltage drop is opposite in phase.

FIG. **5**A is an example input noise spectrum of a boost converter without noise cancellation. The input current spectrum was calculated without the coupling transformer T_{54}, but with the 20 uH winding W_{53} placed in series with the boost converter. The first harmonic of the noise signal contributes most of the amplitude to the noise spectrum.

FIG. **5**B is an example input noise spectrum of a boost converter with noise cancellation as shown in FIG. **4**. The boost converter with noise cancellation has a noise spectrum that is dramatically attenuated by using a small size 20 uH 1:1 cancellation transformer T_{54} with a parallel low voltage 1 uF capacitor.

FIG. **6**A is a plot showing the measured input ripple current of the boost converter without noise cancellation in the time domain (upper plot) and frequency domain (lower plot). FIG. **6**B is a plot showing the measured input ripple current of the boost converter with noise cancellation in the time domain (upper plot) and frequency domain (lower plot). FIG. **6**A shows that a first harmonic of the switching ripple current has a large magnitude and the accompanying sinusoidal wave in the time domain is related to the large magnitude of the first harmonic. After adding the cancellation circuit to the converter, the first harmonic of the switching ripple current is reduced, as shown in FIG. **6**B. The reduction in the frequency domain corresponds to the relatively flat waveform signal in the time domain.

Turning now to FIG. **7**, another preferred embodiment of the present invention couples a parallel current source derived from the noise voltage to a converter in order to reduce ripple. This embodiment corresponds to the idealized noise cancellation method shown in FIG. **2**C. In this circuit, a noise voltage V_{61} produces noise at the input. An impedance Z_{20} is in series with the noise voltage V_{61}. A capacitor C_{63} and a winding W_{64} are in parallel with the noise voltage. A transformer T_{68} couples the winding W_{64} to a winding W_{65}. An impedance Z_{66} is placed in series with the W_{65} winding. The windings W_{64} and W_{65} are both parallel to an input impedance Z_{67}.

The transformer T_{68} detects the noise voltage V_{61} and converts it to a shunt current source. The transformer T_{68} accomplishes these functions with the windings W_{64} and W_{65}. Winding W_{64} captures the noise voltage and winding W_{65} produces the compensation current. The capacitor C_{63} is placed in series with winding W_{64} so that it picks up AC noise only and does not interfere with normal converter operation. The impedance Z_{66} is placed in series with winding W_{65} in order to produce a corresponding noise canceling current.

When a noise current is generated by the noisy voltage source V_{61} through the impedance Z_{20}, then the impedance Z_{66} drives a corresponding current which cancels the noisy current. Assuming the magnetizing impedance of sensing winding W_{64} is high, the condition for null noise current flow at the input impedance Z_{67} can be approximately related as

$$\frac{Z_{66}}{Z_{20}} = \frac{N(W_{65})}{N(W_{64})} \tag{7}$$

where $N(W_{65})$ is the number of turns of winding W_{65} and $N(W_{64})$ is the number of turns of winding W_{64}.

Impedance networks are needed in this circuit, but they may not necessarily require extra components, because the impedances may be components of the corresponding switching converter. For example Z_{20} may be the input or output inductor of a boost or buck converter, respectively.

Turning now to FIG. **8**, an example circuit of the embodiment of FIG. **7** coupled to a boost converter is set forth. The circuit is applied to a boost converter comprising an inductor L_{75}, transistor M_{77}, diode D_{78}, resistor R_{load} and output capacitor C_{79}. The transistor M_{77} is controlled through a source **76**.

The noise cancellation circuit comprises a transformer T_{70} which has two windings W_{72} and W_{73}. A sensing winding W_{72} detects noise voltage across the switch M_{77} and transfers the noise signal to a compensating winding W_{73}. A capacitor C_{71} is coupled in series with an inductor L_{74}. An inductor L_{75}, which may be the input inductor of the boost converter, is in series with the components of the boost converter. The inductor L_{74} and the capacitor C_{71} are an impedance network to match the impedance of the input inductor L_{75} and the output capacitor C_{79}. The impedance network translates the noise voltage signal derived from the sensing winding W_{72} and passed to the compensating winding W_{73} into an equal magnitude, opposite phase current signal. The current signal thus cancels out the noise at the input.

FIG. **9** is another preferred embodiment of the present invention coupling a series voltage source derived from the noise voltage to a converter in order to reduce ripple. It consists of a noise voltage source V_{81} which is connected in series with an impedance Z_{82}. An input impedance of the converter is modeled as Z_{87} and a capacitor C_{85}. The cancellation circuit consists of a transformer T_{86} coupled to a pair of windings W_{84} and W_{85}. The sensing winding W_{84} is in series with a capacitor C_{83} and an impedance Z_{80}. An impedance network Z_{88} is parallel to the sensing winding W_{84}. The compensating winding W_{85} is in series with the impedance Z_{82} and the noise voltage source V_{81}.

In this circuit, the transformer T_{86} detects the noise voltage V_{81}, and converts it to a series voltage source. The sensing winding W_{84} captures the noise voltage. The compensating winding W_{85} produces a compensating voltage in series with the noise voltage V_{81}. The capacitor C_{83} is placed in series with winding W_{84} so that it picks up AC noise only and does not interfere with normal converter operation. The impedance network Z_8 and the impedance Z_{80} adjust the noise cancellation characteristics of the circuit. Winding W_{85} is placed in series with the input so that it produces a voltage signal equal in magnitude but opposite in phase to cancel the noise voltage.

FIG. **10** is an example circuit of the embodiment of FIG. **9** coupled to a boost converter. The boost converter is modeled as a circuit and comprises an inductor L_{96}, a transistor M_{98}, a diode D_{97}, a resistor R_{load} and an output capacitor C_{99}. A source **100** controls the switching of the transistor M_{98}.

The cancellation circuit is modeled as a pair of windings W_{92} and W_{93} coupled by a transformer T_{91}. The sensing winding W_{92} is in parallel with an impedance network Z_{94} and in series with a capacitor C_{95} and an impedance Z_{90}.

Winding W_{92} detects noise voltage across the switch M_{98} and transfers the noise signal to winding W_{93}. The impedance network $Z_{94,}$ the impedance Z_{90}, and the capacitor C_{95} are tuned to couple the noise canceling voltage across the winding W_{93} to the voltage noise controlled through the switch M_{98}. These components are modeled to match the impedance of the booster converter components L_{96} and C_{99}. The voltage signal generated across the W_{93} winding is thus equal in magnitude but opposite in phase to the voltage drop generated across the transistor M_{98}.

Each of the three embodiments of the cancellation circuit described above can be applied to the input or output of a power converter. Coupling the cancellation circuit to the output cancels output ripple while coupling the cancellation circuit to the input cancels input ripple. The configuration and operating principles are the same for both input cancellation and output cancellation.

The preferred embodiments described with reference to the attached drawing figures are presented only to demonstrate certain examples of the invention. Other elements, steps, methods, and techniques that are insubstantially different from those described above and/or in the appended claims are also intended to be within the scope of the invention.

What is claimed is:

1. A noise canceling circuit for use with a power converter that generates a noise current, comprising:

a transformer having a first winding and a second winding that are magnetically coupled and are configured in series to the power converter;

an impedance network coupled in parallel to the first winding; and

a filter network coupled in series with the second winding and in parallel with the power converter, wherein the impedance of the impedance network and the filter network are approximately equivalent;

wherein the noise current is coupled to the first winding of the transformer, which measures a corresponding voltage drop across the first impedance network and causes the second winding to generate a noise cancellation voltage that compensates for the noise current generated by the power converter.

2. The noise canceling circuit of claim **1**, wherein the filter network comprises a single capacitor.

3. The noise canceling circuit of claim **1**, wherein the filter network comprises a capacitor coupled in series with a resistor.

4. The noise canceling circuit of claim **3**, wherein the filter network further comprises an inductor.

5. The noise canceling circuit of claim **1**, wherein the power converter includes an input port for receiving input power and an output port for providing converted power.

6. The noise canceling circuit of claim **5**, wherein the noise canceling circuit is coupled to the input port of the power converter.

7. The noise canceling circuit of claim **5**, wherein the noise canceling circuit is coupled to the output port of the power converter.

8. The noise canceling circuit of claim **5**, wherein the power converter is coupled to an input power source, and wherein the noise canceling circuit is coupled between the input power source and the input port of the power converter.

9. The noise canceling circuit of claim **1**, wherein the inductance of the first winding and the second winding are approximately equivalent.

10. The noise canceling circuit of claim **1**, wherein the noise cancellation voltage is an AC noise cancellation voltage.

11. The noise canceling circuit of claim **10**, wherein the AC noise cancellation voltage is equal in magnitude but opposite in phase to the corresponding voltage drop across the first impedance network.

12. The noise canceling circuit of claim **1**, wherein the cancellation voltage is equal in magnitude but opposite in phase to the corresponding voltage drop across the first impedance network.

13. The noise canceling circuit of claim **1**, wherein the power converter is a boost converter.

14. The noise canceling circuit of claim **1**, wherein the power converter is a buck converter.

15. The noise canceling circuit of claim **1**, wherein the power converter is a switching power converter.

16. The noise canceling circuit of claim **1**, wherein the impedance of the noise canceling circuit is substantially less than the input impedance of the power converter.

17. The noise canceling circuit of claim **1**, wherein the turn ratio of the first and second windings of the transformer is unity.

18. A noise canceling circuit for use with a power converter that generates a noise voltage, comprising:

a transformer having a first winding and a second winding that are magnetically coupled and are configured in parallel to each other, wherein the first winding is coupled in parallel to the power converter and the second winding is coupled to an internal node of the switching power converter where the noise voltage is generated; and

an impedance network coupled in series with the first winding;

wherein the second winding of the transformer measures the noise voltage at the internal node and causes the first winding to generate a noise cancellation current that compensates for the noise voltage generated by the power converter.

19. The noise canceling circuit of claim **18**, wherein the impedance network comprises a single capacitor.

20. The noise canceling circuit of claim **18**, wherein the impedance network comprises a capacitor in series with an inductor.

21. The noise canceling circuit of claim **18**, wherein the power converter includes an input port for receiving input power and an output port for providing converted power.

22. The noise canceling circuit of claim **21**, wherein the noise canceling circuit is coupled to the input port of the power converter.

23. The noise canceling circuit of claim **21**, wherein the noise canceling circuit is coupled to the output port of the power converter.

24. The noise canceling circuit of claim **21**, wherein the power converter is coupled to an input power source, and wherein the noise canceling circuit is coupled between the input power source and the input port of the power converter.

25. The noise canceling circuit of claim **18**, wherein the noise cancellation current is an AC noise cancellation current.

26. The noise canceling circuit of claim **18**, wherein a noise cancellation voltage is generated across the impedance network by the noise cancellation current, and wherein the noise cancellation voltage is equal in magnitude but opposite in phase with the noise voltage.

27. The noise canceling circuit of claim **18**, wherein the power converter is a switching converter.

28. The noise canceling circuit of claim **27**, wherein the switching converter is a boost converter.

29. The noise canceling circuit of claim **28**, wherein the boost converter includes an input port, an output port, an inductor coupled in series with the input port, a capacitor coupled in parallel with the output port, a diode coupling the input port to the output port, and a switching transistor coupled in parallel to the output port.

30. The noise canceling circuit of claim **29**, wherein the internal node is connected to the output of the switching transistor.

31. The noise canceling circuit of claim **29**, wherein the impedance of the impedance network is approximately equivalent to the impedance of the inductor and the capacitor of the switching power converter.

32. A noise canceling circuit for use with a power converter that generates a noise voltage, comprising:

a transformer having a first winding and a second winding that are magnetically coupled, wherein the first winding is coupled in series with the power converter and the second winding is coupled to an internal node of the power converter where the noise voltage is generated; and

an impedance network coupled to the second winding;

wherein the second winding of the transformer measures the noise voltage at the internal node and causes the first winding to generate a noise cancellation voltage that compensates for the noise voltage generated by the power converter.

33. The noise canceling circuit of claim **32**, wherein the impedance network comprises a single capacitor coupled in series with the second winding.

34. The noise canceling circuit of claim **32**, wherein the power converter includes an input port for receiving input power and an output port for providing converted power.

35. The noise canceling circuit of claim **34**, wherein the noise canceling circuit is coupled to the input port of the power converter.

36. The noise canceling circuit of claim **34**, wherein the noise canceling circuit is coupled to the output port of the power converter.

37. The noise canceling circuit of claim **34**, wherein the power converter is coupled to an input power source, and wherein the noise canceling circuit is coupled between the input power source and the input port of the power converter.

38. The noise canceling circuit of claim **32**, wherein the noise cancellation voltage is an AC noise cancellation voltage.

39. The noise canceling circuit of claim **32**, wherein a noise cancellation voltage is equal in magnitude but opposite in phase with the noise voltage.

40. The noise canceling circuit of claim **32**, wherein the power converter is a switching converter.

41. The noise canceling circuit of claim **40**, wherein the switching converter is a boost converter.

42. The noise canceling circuit of claim **41**, wherein the boost converter includes an input port, an output port, an inductor coupled in series with the input port, a capacitor coupled in parallel with the output port, a diode coupling the input port to the output port, and a switching transistor coupled in parallel to the output port.

43. The noise canceling circuit of claim **22**, wherein the internal node is connected to the output of the switching transistor.

44. The noise canceling circuit of claim **43**, wherein the impedance of the impedance network is approximately equivalent to the impedance of the inductor and the capacitor of the switching power converter.

45. A noise canceling circuit for use with a power converter that generates a noise current, comprising:

measurement circuitry coupled to the power converter for measuring the noise current by generating a noise measurement voltage that corresponds to the noise current; and

compensation circuitry coupled to the measurement circuitry and the power converter for generating a noise cancellation voltage in series with the power converter, wherein the noise cancellation voltage is equal in magnitude but opposite in phase with the noise measurement voltage.

46. The noise canceling circuit of claim **45**, wherein the measurement circuitry is coupled in series with the power converter and includes a first winding and an impedance network coupled in parallel, wherein the noise current is coupled to the measurement circuitry and passes through the impedance network, thus causing the first winding to measure the noise cancellation voltage.

47. The noise canceling circuit of claim **46**, wherein the compensation circuitry includes a second winding magnetically coupled to the first winding and a filter network coupled in series with the second winding and in parallel with the power converter, wherein the impedance of the filter network and the impedance network are approximately equivalent.

48. A noise canceling circuit for use with a power converter that generates a noise voltage, comprising:

measurement circuitry coupled to the power converter for measuring the noise voltage; and

compensation circuitry coupled to the measurement circuitry and the power converter for generating a noise cancellation voltage in series with the power converter, wherein the noise cancellation voltage is equal in magnitude but opposite in phase with the noise voltage.

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