US006670796B2

(12) **United States Patent**
Mori

(10) **Patent No.: US 6,670,796 B2**
(45) **Date of Patent: Dec. 30, 2003**

(54) **ULTRA FAST AND HIGH EFFICIENCY INDUCTIVE COIL DRIVER**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/154,642**

(22) Filed: **May 24, 2002**

(65) **Prior Publication Data**

US 2003/0218451 A1 Nov. 27, 2003

(51) **Int. Cl.**[7] **H03K 17/687**

(52) **U.S. Cl.** **323/282**; 327/108; 327/110; 307/270; 307/571

(58) **Field of Search** 323/282; 327/108, 327/110; 307/270, 571

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,947,776 A * 3/1976 Stevens et al. 327/374
4,661,766 A * 4/1987 Hoffman et al. 323/287
5,126,647 A * 6/1992 Blackburn et al. 318/599
5,338,977 A * 8/1994 Carobolante 327/110
6,351,162 B1 * 2/2002 Schwartz 327/110
6,507,177 B2 * 1/2003 Flock et al. 323/285

* cited by examiner

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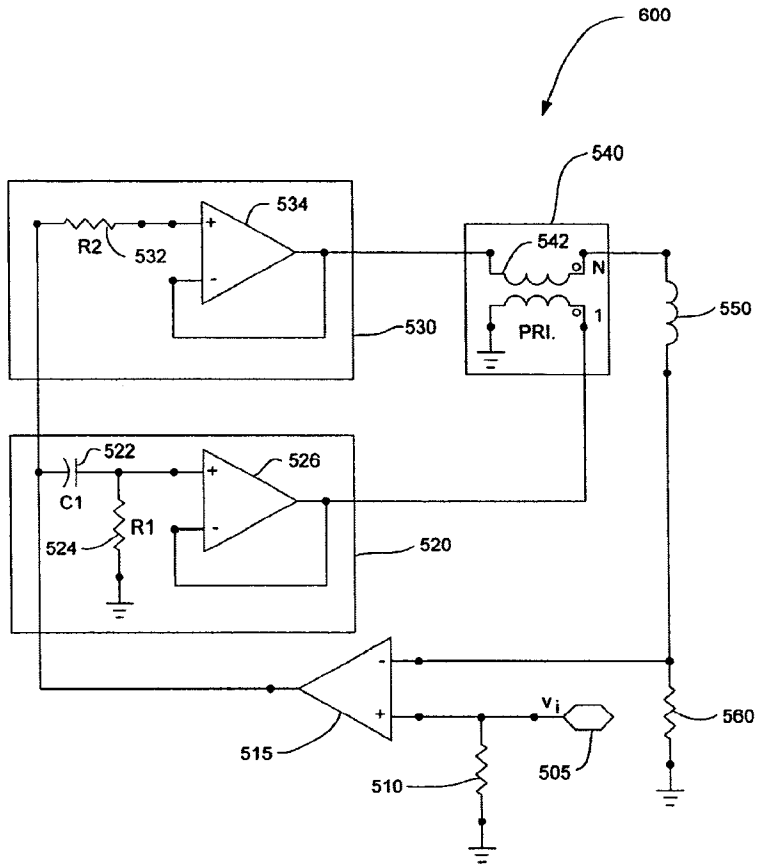
(57) **ABSTRACT**

A circuit for driving an inductive load includes a high frequency driver and low frequency driver. A low frequency component and a high frequency component is taken from an input signal. The separate low and high signal components are driven by a low frequency driver and high frequency driver, respectively. The outputs of the low frequency and high frequency drivers are combined by combination circuitry. The high frequency component is amplified by the combination circuitry in addition to being combined. The output of the combination circuitry drives an inductive load at fast speeds. The driver circuit of the present invention may be configured to provide low noise at low frequencies, pass band limitations at the load terminal, different AC and DC open loop gains, and other characteristics depending upon system requirements.

43 Claims, 10 Drawing Sheets



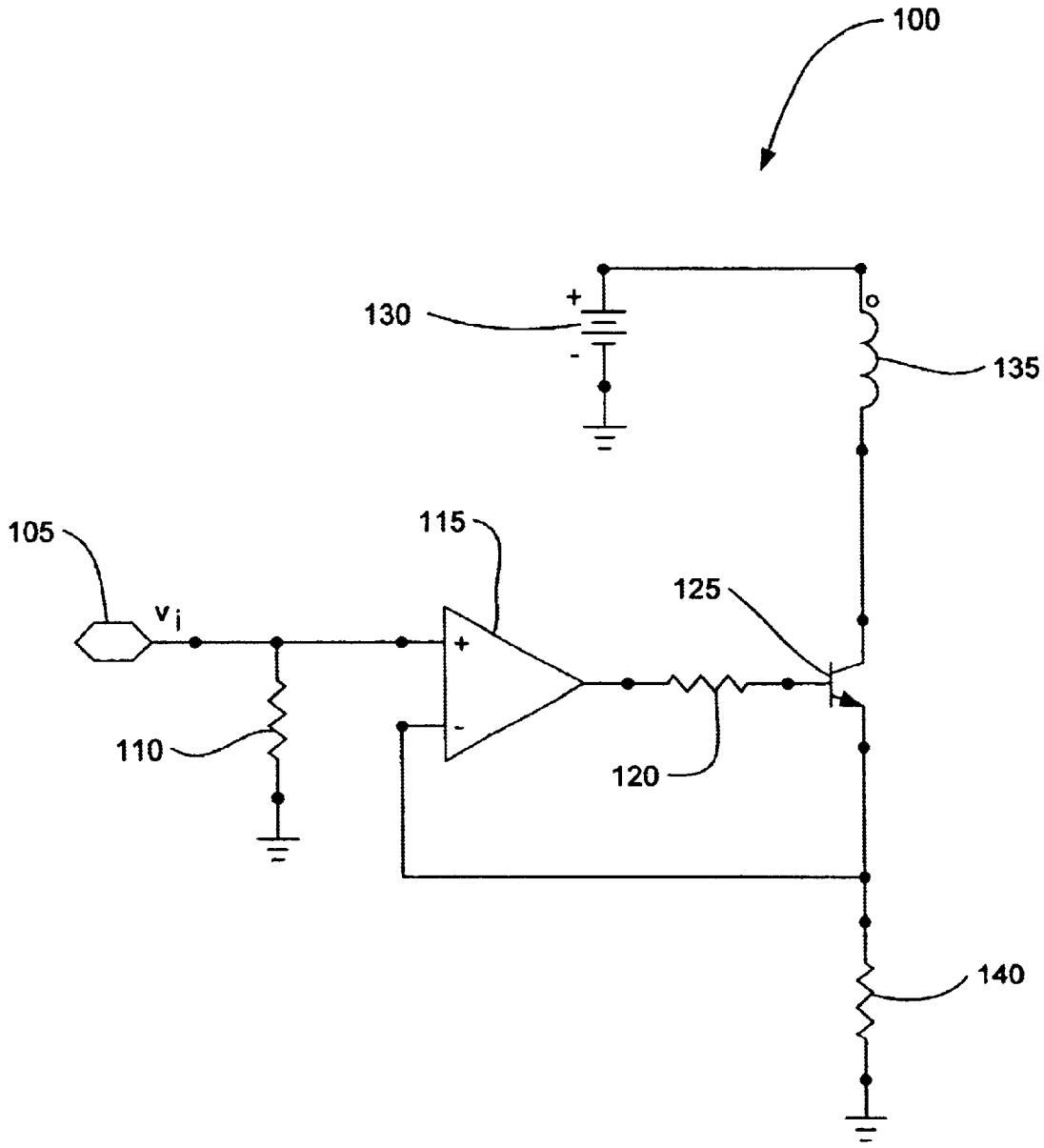


FIG. - 1
(PRIOR ART)

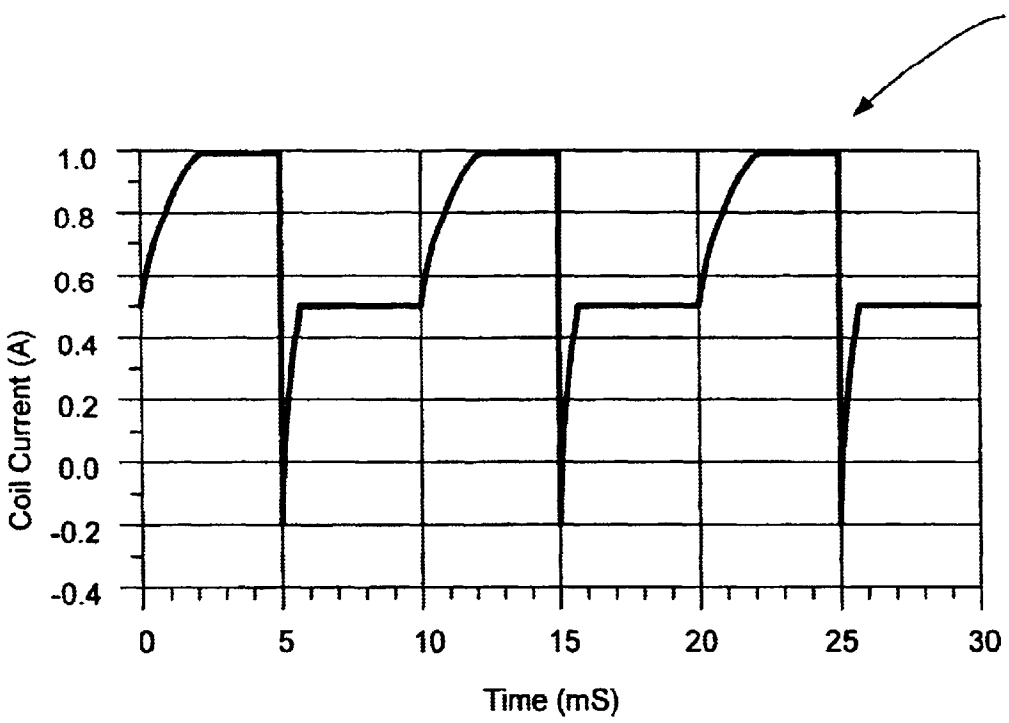


FIG. - 2
(PRIOR ART)

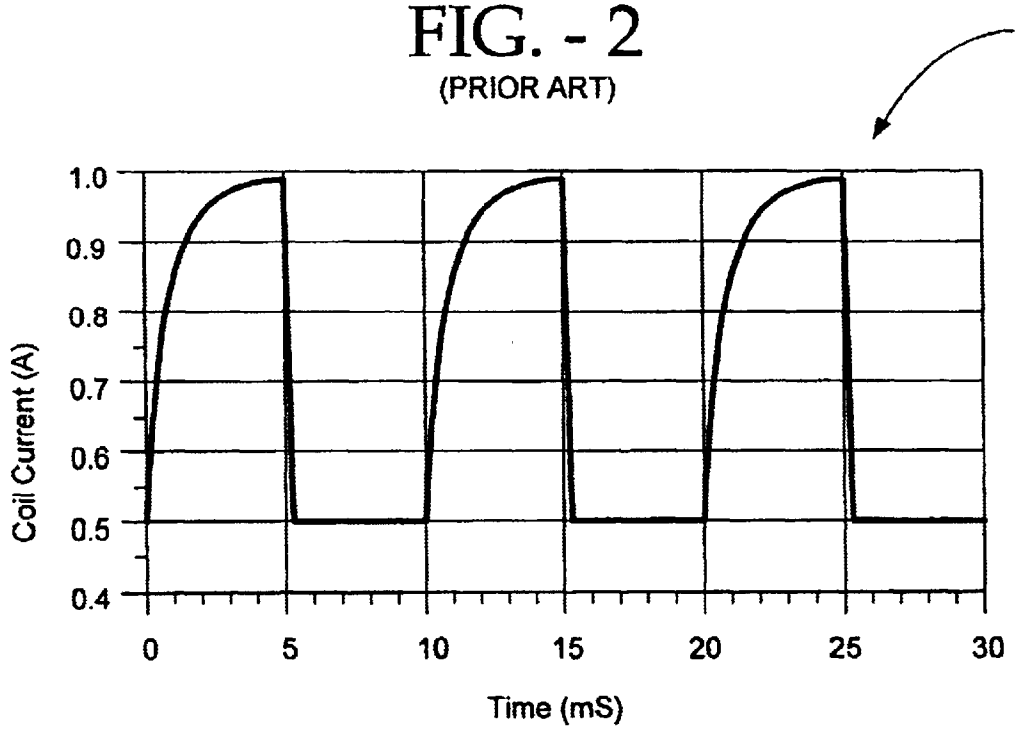


FIG. - 4
(PRIOR ART)

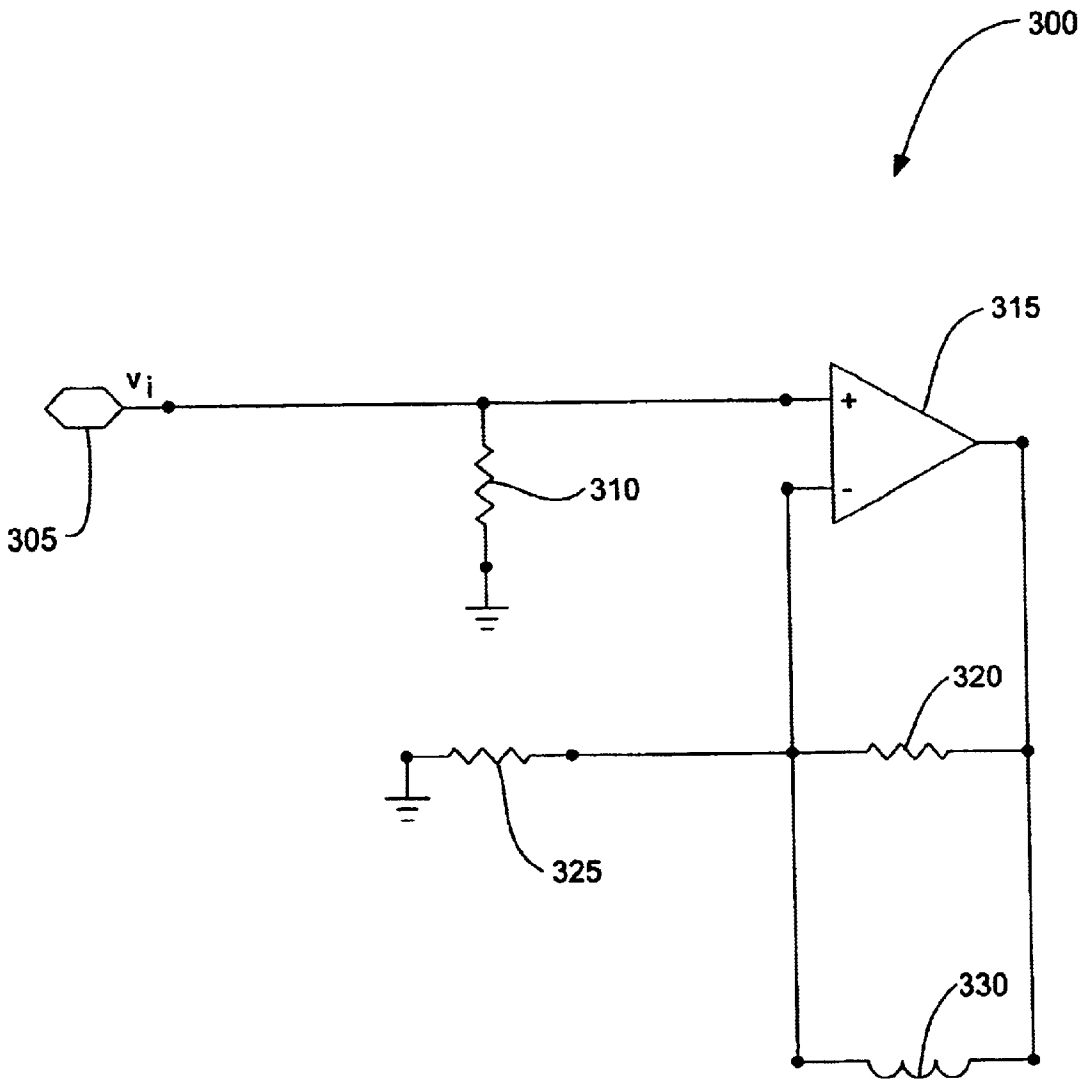


FIG. - 3
(PRIOR ART)

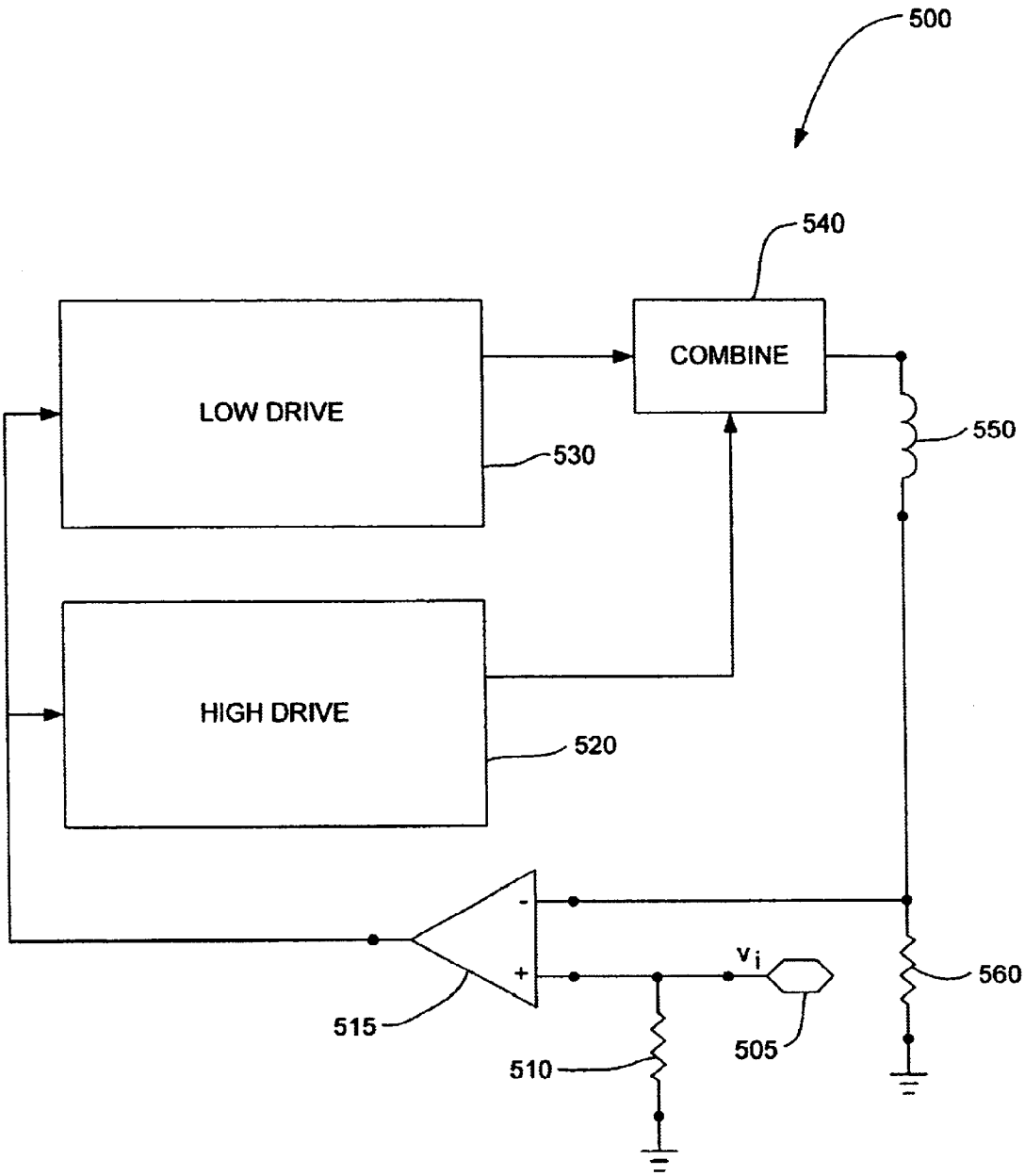

500
540
COMBINE
LOW DRIVE
530
550
HIGH DRIVE
520
-
+
v_i
560
515
505
510

FIG. - 5

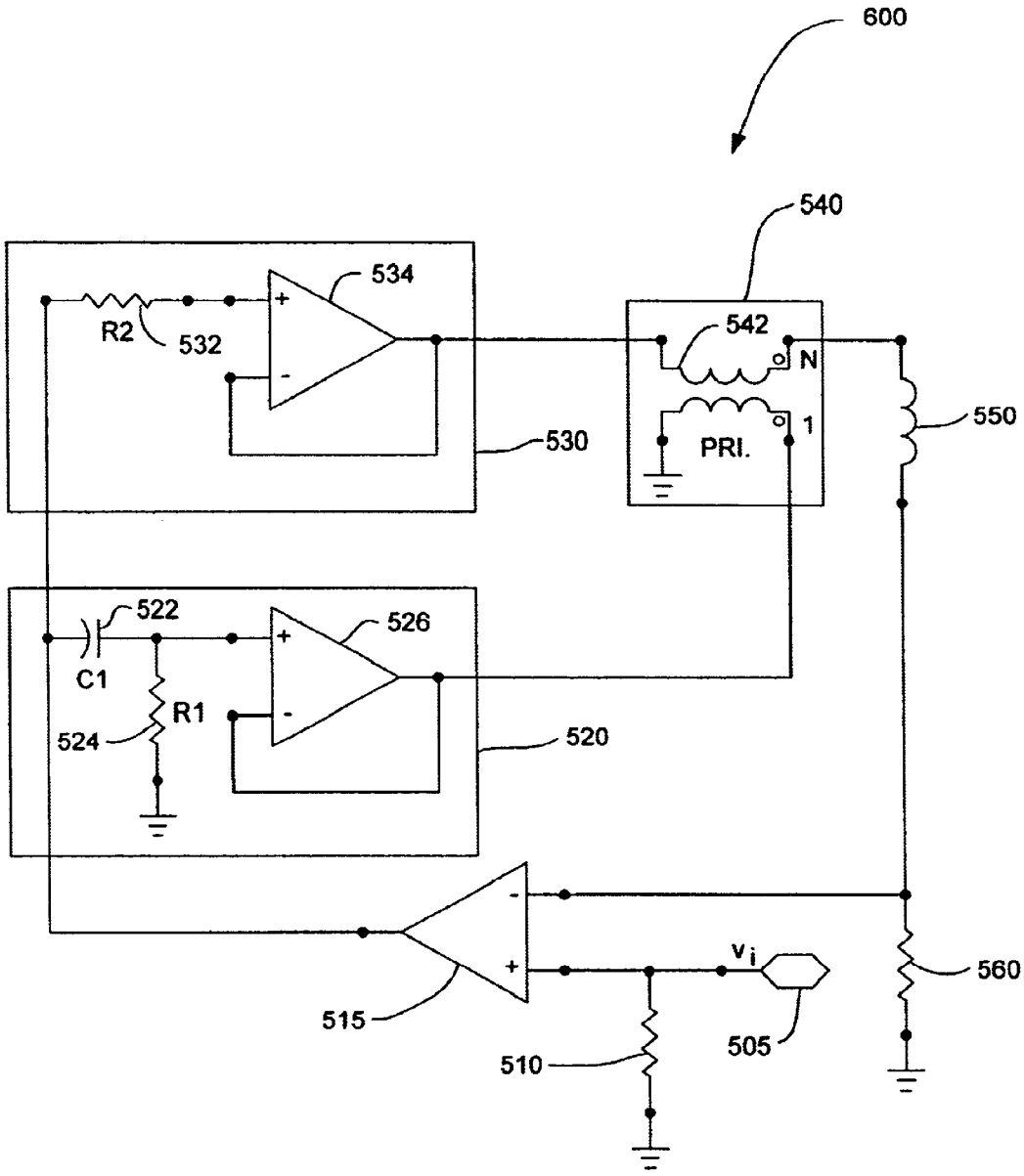

600
540
534
R2
532
542
N
1
PRI.
530
550
522
526
C1
R1
524
520
515
v_i
560
505
510

FIG. - 6

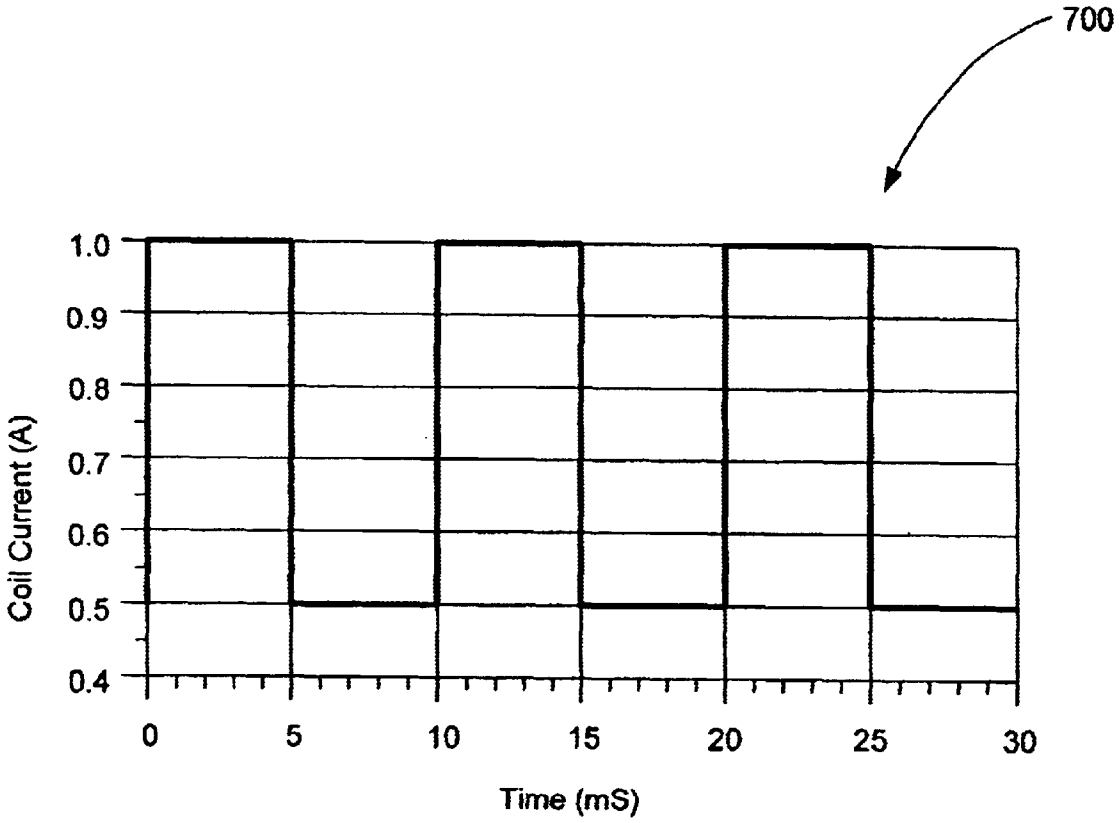


FIG. - 7

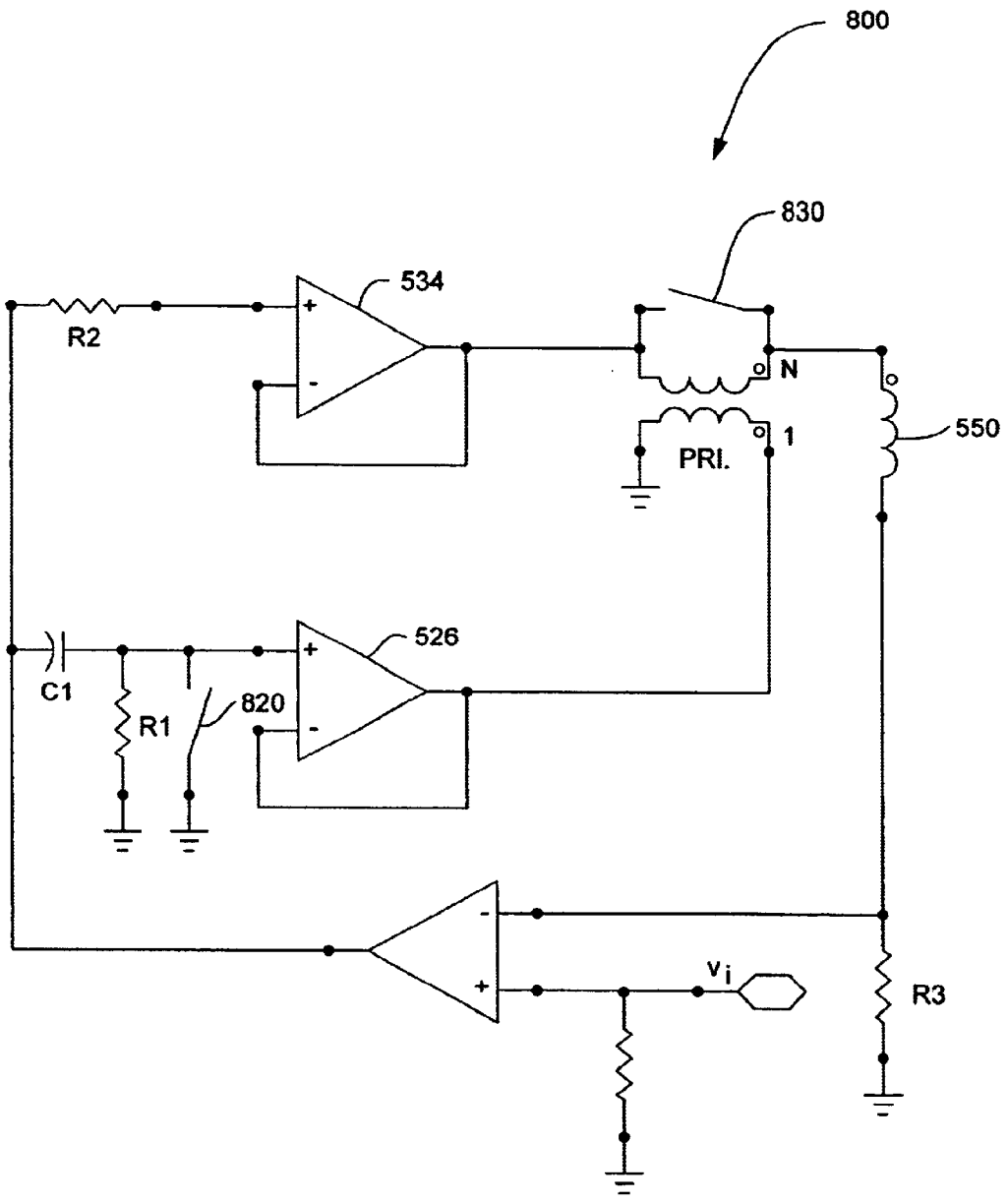


FIG. - 8

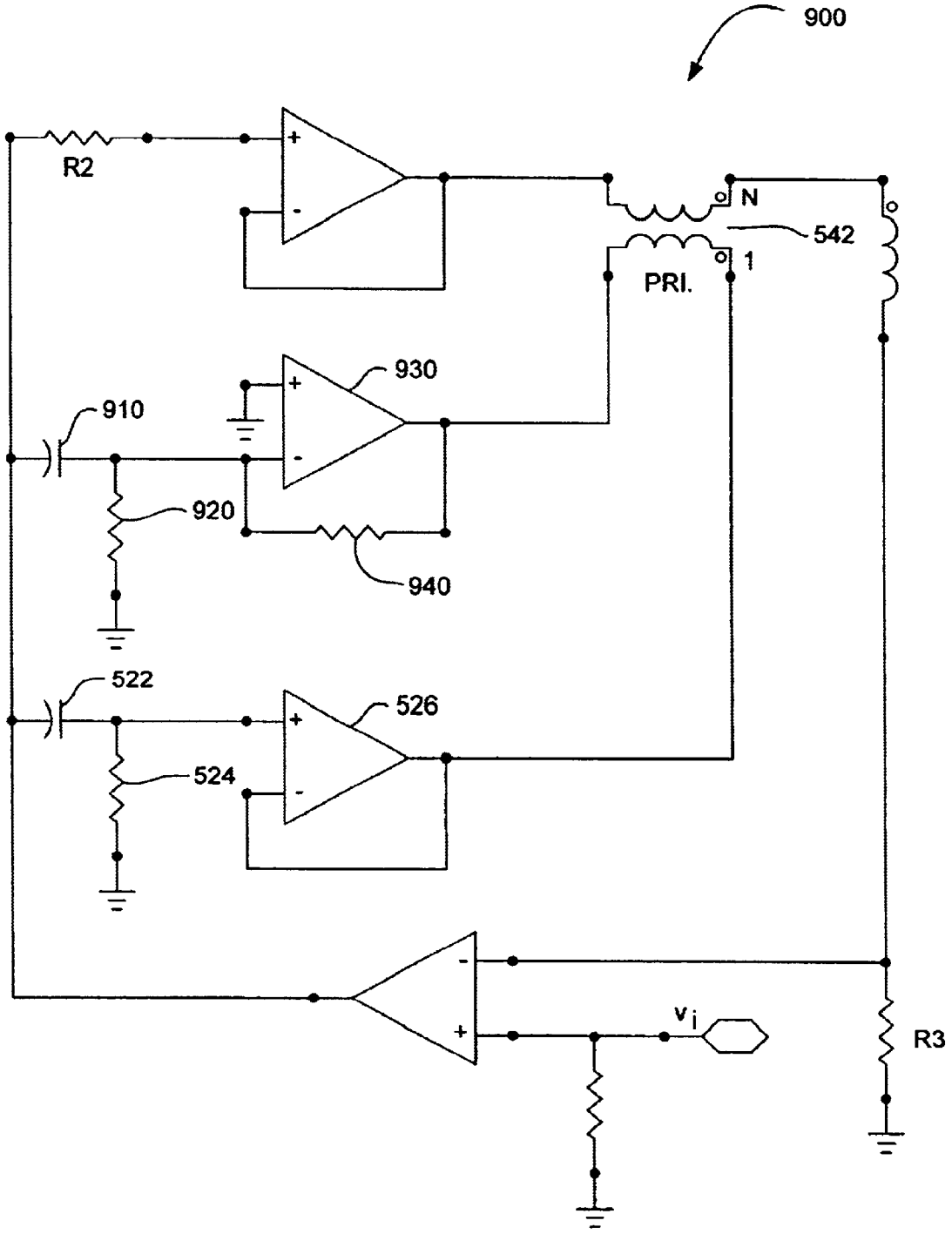


FIG. - 9

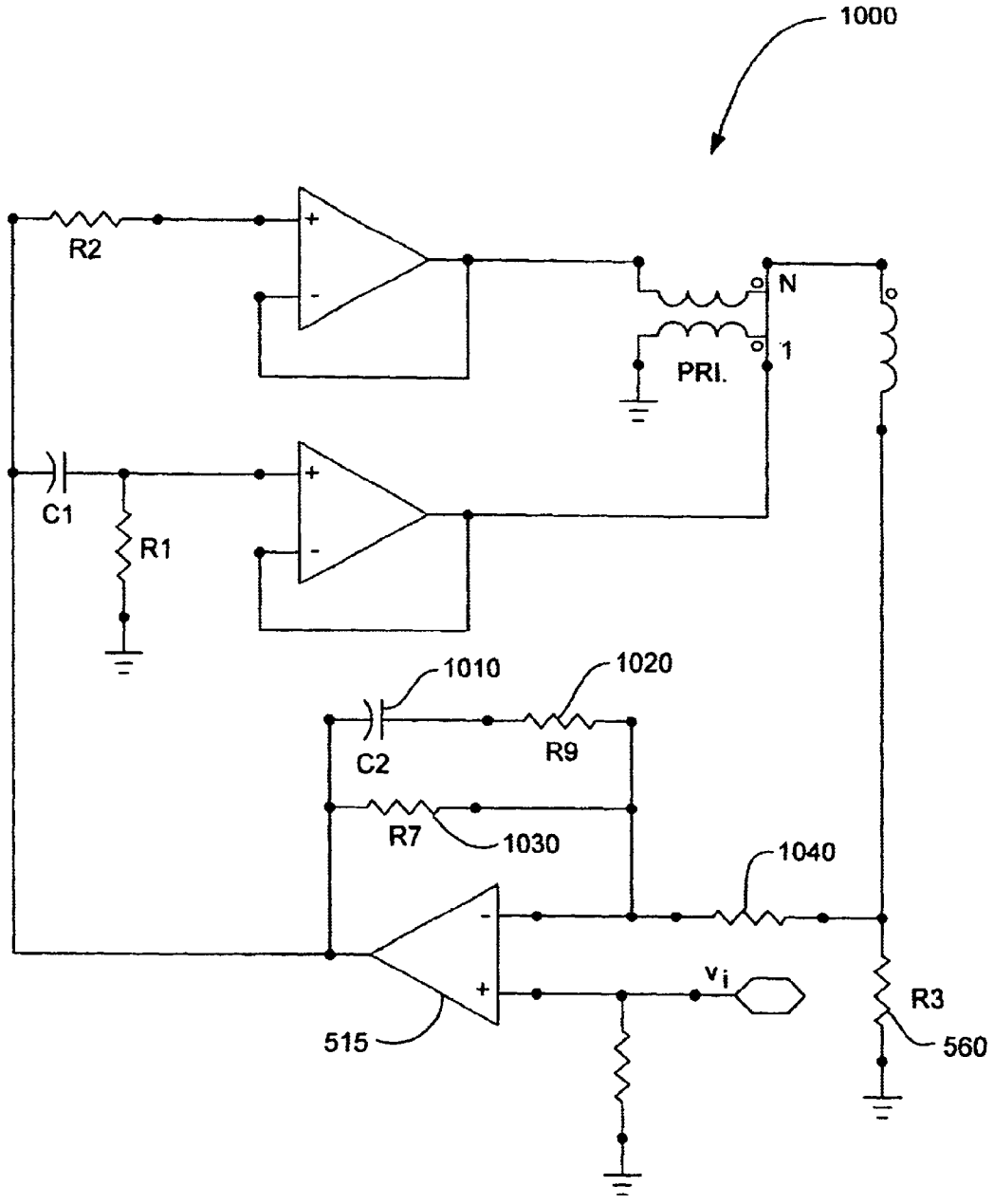


FIG. - 10

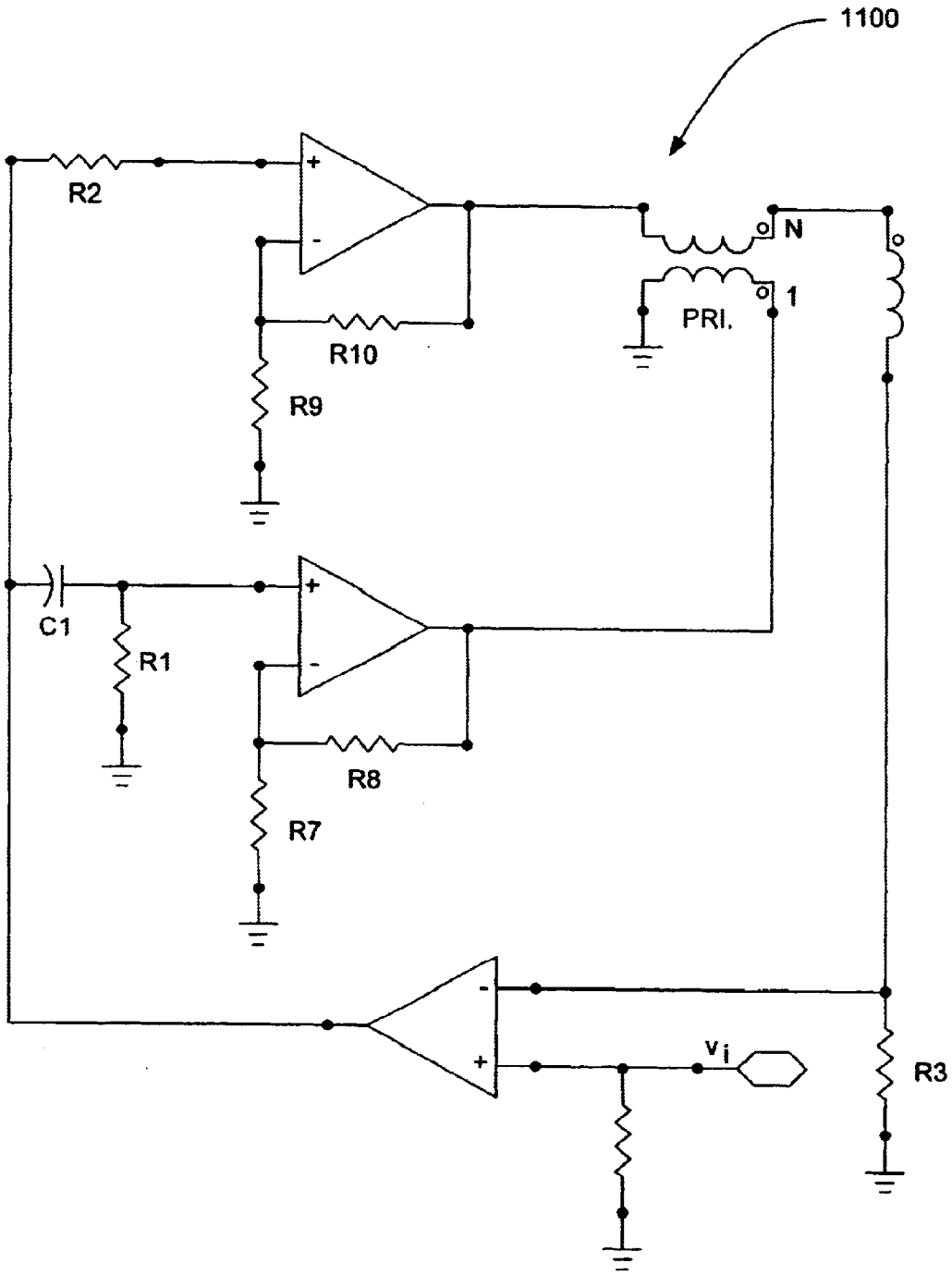


FIG. - 11

ULTRA FAST AND HIGH EFFICIENCY INDUCTIVE COIL DRIVER

FIELD OF THE INVENTION

The present invention relates to driver circuits. More particularly, the present invention relates to driver circuits with an inductive load.

BACKGROUND

Current driver circuits and other driver circuits are generally known and used for many applications. A basic current driver circuit **100** of the prior art is shown in FIG. **1**. The driver circuit **100** has a signal input **105**. The signal input **105** is connected to the positive terminal of amplifier **115** and to one end of resistor R1 **110**. The other end of resistor **110** is connected to ground. The output of amplifier **115** is connected to one end of driver resistor **120**. The other end of resistor **120** is connected to the base of transistor **125**. The negative terminal of amplifier **115** is connected to the emitter of amplifier **125** and to one end of current sensor resistor **140**. The other end of resistor **140** is connected to ground. A voltage source **130** is connected to one end of an inductance load **135**. The other end of the inductance load **135** is connected to the collector of transistor **125**.

In operation, transistor **125** of the current driver sinks a current through the inductive load **135**. Signal input **105** applies input signal v_i to the positive terminal of amplifier **115** and to resistor **110**. The voltage at the negative terminal of amplifier **115** is approximately equal to the voltage applied to the positive terminal of the amplifier. The voltage at the emitter of the transistor is applied to the negative terminal of the amplifier, which in turn sets the voltage at the base of the transistor. In one embodiment, the voltage at the base of the transistor is approximately 0.7 volts more than the emitter. Assuming operation in the active state for transistor **125**, when the input signal v_i is low, a voltage difference is applied across resistor **120** inducing a base current i_B. When the base current i_B is induced at the base, a current i_C is induced at the collector whereby $i_B=((1-\alpha)/\alpha)^* i_C$, where α is a constant for the particular transistor. The collector current i_C drives the inductive load **135**. When the input signal v_i goes high, the voltage difference across resistor **120** increases and induces a larger current i_B. This induces a larger i_C current to flow through the inductive load **135**.

The current response to driver circuit **100** is shown in FIG. **2** and displays several disadvantages of drive circuit **100**. As shown in FIG. **2**, the driver circuit **100** displays a slow rise time and a slow recovery time. A faster rise time can be achieved by increasing the amplifier supply voltage **130**. However, increasing the supply voltage results in decreasing the efficiency of the driver circuit. The current response of FIG. **2** also displays a large negative spike voltage characteristic. Such a negative spike voltage of the driver circuit **100** may damage the drive transistor unless a capacitor or diode is used to eliminate it.

Another type of driver of the prior art is a current push/pull driver. A basic current push/pull driver circuit **300** is shown in FIG. **3**. An input signal is connected to resistor **310** and the positive terminal of driving amplifier **315**. The output of amplifier **315** is applied to one terminal of resistor **320** and inductive load **330**. The negative terminal of the amplifier **315** is connected to the other terminal of resistor **320**, inductive load **330**, and to one terminal of current sensing resistor **325**. The other terminal of current sensing resistor **325** is connected to ground.

In operation, the signal input **305** applies signal v_i to resistor **310** and to the positive terminal of driving amplifier **315**. The output of the amplifier **315** is applied to one end of resistor **320** and one end of the inductive load **330**. The voltage at the negative terminal of driving amplifier **315** is approximately the same as the voltage at the positive terminal of driving amplifier **315**. The voltage at the negative terminal of the drive amplifier applies a voltage to one terminal of current sensing resistor **325**. The voltage difference across current sensing resistor **325** induces a current through resistor **325** towards the grounded terminal of the resistor and through resistor **320** towards resistor **325**. Resistor values for resistor **320** and **325** are chosen such that the current driven through resistor **325** will be more or less than the current through resistor **320** depending on whether the input signal goes high or low. When input signal v_i is low, the voltage difference across resistor **320** induces a current across resistor **320** towards node **340**. This provides a current across resistor **320** smaller than the current drawn by current sensor resistor **325**. As a result, current is pushed through inductor **330** towards node **340**. When input signal v_i is high, the voltage difference placed across resistor **320** is now higher then when v_i was low and higher than the current drawn by current resistor **325** away from node **340**. As a result, current is pulled through inductor **330** away from node **340**.

The current response of the push/pull driver circuit **300** is shown in FIG. **4**. The current response of circuit **300** is improved over the current response of circuit **200**. The negative spike voltage characteristic has been eliminated due to the push/pull characteristic of circuit **300**. The push/pull operation to the inductive load operates to remove some of the energy stored in the inductive load. Current driver **300** still possess a slow rise time characteristic is shown in FIG. **4**. Though the rise time of circuit **300** could be improved by increasing the supply voltage, this would decrease efficiency and require additional elements such as heat sink components.

What is needed is an improved circuit for driving an inductive load. The circuit should generate a high enough voltage to drive an inductive load at high speeds and display a favorable rise time. Further, a driving circuit is needed that can provide a low level of noise, high frequency capability, and be otherwise configurable to meet different system requirements as needed.

SUMMARY

A driving circuit for driving an inductive load in accordance with the present invention includes a high frequency driver and low frequency driver. A low frequency component and high frequency component is taken from an input signal. The separate low and high signal components are input to a low frequency driver and high frequency driver, respectively. The outputs of the high frequency and low frequency drivers are combined by combination circuitry. In one embodiment of the present invention, the high frequency component is also amplified by the combination circuitry. The combined signals generate a high voltage signal that drives an inductive load at fast speeds. The driver circuit of the present invention may be configured to provide low noise at low frequencies, pass band frequency response at the load terminal, different AC and DC open loop gains, and other characteristics depending upon system requirements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of a typical inductance current driver circuit of the prior art.

FIG. **2** is a diagram of the driver current response of the driver circuit of FIG. **1**.

FIG. **3** is a diagram of a typical inductance current push/pull driver circuit of the prior art.

FIG. **4** is a diagram of the driver current response of the push/pull driver circuit of FIG. **3**.

FIG. **5** is a diagram of a inductance driver circuit in accordance with one embodiment of the present invention.

FIG. **6** is a diagram of an inductance driver circuit with low frequency and high frequency circuitry in accordance with one embodiment of the present invention.

FIG. **7** is a diagram of the driver current response of the driver circuit of FIG. **6**.

FIG. **8** is a diagram of a low noise inductance driver circuit in accordance with one embodiment of the present invention.

FIG. **9** is a diagram of a inductance driver circuit having an increased efficiency high frequency driver in accordance with one embodiment of the present invention.

FIG. **10** is a diagram of an inductance driver circuit with a frequency band limiter in accordance with one embodiment of the present invention.

FIG. **11** is a diagram of an inductance driver circuit with a different closed loop gain for a low frequency driver and high frequency driver in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION

A driving circuit for driving an inductive load in accordance with the present invention includes a low frequency driver, one or more high frequency drivers, and combination circuitry. A low frequency component and high frequency component are taken from an input signal. The separate low and high signal components are input to a low frequency driver and high frequency driver, respectively. The outputs of the low frequency and high frequency drivers are combined by combination circuitry. In one embodiment of the present invention, the high frequency component is amplified by the combination circuitry in addition to being combined. The combined signals generate a high voltage signal that drives an inductive load at fast speeds. The driver circuit of the present invention may be configured to provide low noise at low frequencies, pass band frequency response at the load terminal, different AC and DC open loop gains, and other characteristics depending upon system requirements.

High frequency amplifiers, such as amplifiers over 4 kHz, generally are used in amplifier circuits having lower resistor values. As a result of the lower resistance values, the open loop gain is lower and current accuracy is decreased. A fast amplifier normally requires higher current and resistors having higher values. The higher resistance values are generally associated with poor noise performance. Thus, a trade-off is usually made between circuit speed and noise.

The present invention addresses the trade-off requirement by generating a different circuit topology for the two amplifiers. Inductive load applications do not require high speed and low noise performance simultaneously. Thus, a high gain, low noise, slow speed amplifier is used as a low frequency amplifier and moderate gain, moderate noise, fast speed amplifier is used as a high frequency amplifier. As a result, the present invention embodies a higher performance inductive driver circuit.

A driving circuit **500** for an inductive load in accordance with the present invention is shown in FIG. **5**. As shown in FIG. **5**, driving circuit **500** includes a signal input **505** connected to resistor **510** and the positive terminal of amplifier **515**. The output of amplifier **515** is connected to high frequency driver **520** and a low frequency drive circuit **530**. The outputs of the low frequency and high frequency drivers are input into combining circuitry **540**. The output of combining circuitry **540** drives the inductive load **550**. The inductive load **550** is coupled to current sense resistor **560** and the negative terminal of amplifier **515**. The other end of the current sensing resistor is connected to ground.

In operation, the reference signal input applies reference signal v_i to resistor **510** and amplifier **515**. An amplified signal is then output from the amplifier and applied to the input of high frequency driver **520** and low frequency driver **530**. In one embodiment, the amplified signal contains different frequency components. Low frequency components of the spectrum are processed by a low frequency amplifier and high frequency components of the spectrum are processed by a high frequency amplifier or are otherwise suppressed by filters. The high frequency driver **520** is configured to drive the high frequency portion of input signal v_i. If a signal contains mostly high frequency components, then perhaps 60–90% of the signal may be processed by the high frequency driver. In one embodiment, the high frequency driver may include a high pass or band pass filter in order to separate the desired frequency signal from the input signal v_i. In another embodiment, the high frequency driver may include a low pass filter and an amplifier using negative feedback circuits. The high frequency driver may also include amplifier circuitry to amplify the high frequency portion as needed. The high frequency driver outputs the high frequency component into combining circuitry **540**. The low frequency driver is configured to drive the low frequency component of the input signal v_i. In one embodiment, if the input signal v_i has a slow rise time, then a larger portion of input signal v_i may be processed by the low frequency driver. The low frequency driver may include a low pass filter or other type of filter depending on the circuit topology. In general, the low frequency driver circuitry will have a frequency response having a low pass characteristic shape to retrieve the desired DC and/or low frequency signal from the input signal. The low frequency driver may also include amplifier circuitry to amplify the low frequency portion as needed. The output of the low frequency driver is provided to combining circuitry **540**. The combining circuitry combines the low and high frequency components and provides an output signal or driving signal having an output signal voltage better shaped to drive inductive load **550**. A current is driven through inductive load **550** as determined by the difference between the combining circuitry output voltage and the voltage at the current sensor resistor.

A driver circuit **600** with low frequency drive circuitry, high frequency drive circuitry, and combining circuitry in accordance with one embodiment of the present invention is shown in FIG. **6**. In FIG. **6**, high frequency drive circuitry **520** includes a capacitor **522**, resistor **524**, and amplifier **526**. In the embodiment shown, capacitor **522** and resistor **524** act as a high pass or band pass RC filter to allow certain frequencies above DC to pass. In another embodiment, a band pass filter allows frequencies between 1 kHz and 4 kHz to pass through to amplifier **534**. Those skilled in the art will understand that the band pass range will vary depending on the particular circuit requirements. The scope of the current invention is not intended to be limited by the band pass range of the high drive circuitry. The band pass circuitry then provides a signal to the positive terminal of amplifier **526**.

The amplifier could be configured as a non-inverting amplifier to amplify the signal as shown or act as a buffer for the signal depending on system requirements. Low frequency drive circuitry **530** includes a resistor **532** and an amplifier **534**. The amplifier **534** in conjunction with the inductive load **550** and **542** act as a low pass circuit.

In general, a rapid change in the current through the inductive load requires a higher voltage supply to amplifier **534**. A limited power supply for amplifier **534** effects the current supply to the inductive load. Applying a high frequency component to an amplifier with a limited voltage power supply will not produce a voltage higher than the voltage supply. Thus, from Ohm's law (V=IR), the limitation of the bandwidth will be determined by the inductance value of the inductors and the power supply voltages. Thus, if an input signal to an amplifier exceeds a certain value, the frequency response will be lost. This characteristic is the low pass filter response. Normally, the bandwidth of amplifier **534** and **526** are wider than the cross over frequency of the system. The frequency response may not be wider if inductive loads are located at the amplifier output.

The low pass signal in circuit **530** is applied to the positive terminal of amplifier **534**. The amplifier could be configured as a non-inverting amplifier to amplify the signal as shown or act as a buffer for the signal depending on system requirements in FIG. **6**.

In accordance with the embodiment of the present invention shown in FIG. **6**, the outputs of the high frequency drive and low frequency drive circuits are combined using a transformer **542**. In FIG. **6**, the low frequency driver applies a signal to the secondary coil of the transformer. The high frequency driver applies a signal to the primary coil of the transformer. In the embodiment shown in FIG. **6**, the primary coil has fewer wire turns than the secondary coil. The transformer acts to combine the signals and amplify the high frequency component according to the transformer ratio N to **1** as shown. The voltage V_{LOAD} at the output of the combining circuitry **540** and applied to the inductive load **550** can be described as

$$V_{LOAD}=V_{LD}+V_{PC}+V_1,$$

where V_{LD} is the voltage output of the low frequency drive circuit, V_{PC} is the voltage increase (or decrease) at the secondary coil, and V_1 is the voltage induced from the secondary side of the transformer. The voltage increase at the secondary coil can be described as $V_{PC}=L(di_{LD}/dt)$ where L is the inductance of the coil and i_{LD} is current output of the low frequency driver. The induced voltage V_1 can be described as $V_1=M(di_{HD}/dt)$, where M is the mutual inductance of the transformer and i_{HD} is the current output from the high frequency driver circuit applied to the primary coil of the transformer. The mutual inductance M may be derived from the transformer ratio, which is chosen according to the requirements of the system. In this case, the transformer may have a ratio of 5 to 1, 10 to 1, 20 to 1, or some other ratio.

The transformer ratio can be changed dynamically in accordance with the present invention depending on the requirements of the system. A lower ratio transformer operates at a lower current and a lower speed. A transformer with a higher ratio may operate more quickly or over a wider frequency band, but requires a higher current. Different transformer ratios may be used depending on the system in which the inductance driver is implemented in. Such implementations are hereby considered within the scope of the present invention.

The current induced through the inductive load **550** is determined by the difference between the load voltage and the current sensor voltage. As shown, current sense resistor **560** is connected between one end of load **550** and a ground terminal. The load voltage may be determined by transformer **542** as discussed above. The current sensor voltage of circuit **600** is determined by the inductive load current through current sense resistor **560**.

An advantage of the circuit of FIG. **6** is that amplifier **526** of the high frequency driver may be used to drive a high current without using a higher voltage output amplifier. Amplifier **526** is only required to drive the transformer **542** and may operate at lower power supply voltage levels. In contrast to amplifier **526**, amplifier **534** can be a medium current and medium voltage amplifier. Amplifier **534** may also be chosen to have low noise characteristics because it does not require a higher current. The performance of amplifier **534** determines the DC and low frequency performance that is important in phase locked loops. The current response of the driver circuit of FIG. **6** is shown in FIG. **7**. The current response is improved over systems of the prior art in that the rise time, negative spike voltage, and recovery time characteristics are all improved over the current response of drive circuits **100** and **300** of the prior art.

Another advantage of the inductance driver circuit of the present invention is that the circuit does not require a high current at all times. The primary side of the transformer is driven using current. For a short time, the higher current is used to generate a higher voltage on the secondary side of the transformer. The higher current is only needed when the coil current is changing rapidly. In one embodiment of the present invention, the input signal may be a burst wave form. Thus, the high current is only needed for a short time when a burst appears in the signal. In one embodiment, a capacitor may be used to store power and supply current to the high frequency amplifier. Thus, the power supply only needs to drive an average current load. In this embodiment of the present invention, a high current power supply is not needed.

The circuit of FIG. **6** may be manipulated into many configurations to meet the requirements of different systems. A few examples of the many possible configurations are shown in FIGS. **8**–**11**. In FIG. **8**, a driver circuit **800** is shown for systems that require low noise in accordance with one embodiment of the present invention. Most of the noise introduced in the inductive load is from the high frequency driver. Switches may be used to reduce the noise introduced by the high frequency driver. As shown in FIG. **8**, switches may be used in the high frequency driver circuitry and the combining circuitry. When the high pass driver circuitry switch **820** is in the closed position, a short is created between the positive terminal of amplifier **526** and ground. The short created by switch **820** prevents a significant portion of the high frequency signal from being applied to amplifier **526**. When the combining circuitry switch **830** is in the closed position, a short is created between the output of amplifier **534** and inductive load **550**. The short created by switch **830** prevents a significant portion of the signal output from the high pass driver circuit from being combined with the low pass driver circuit. When the switches are closed, allowing the high frequency signal to proceed, most of the noise introduced to the inductive load is from the high frequency component. Thus, when either one or both of switch **820** and **830** are closed, only a small portion of the high frequency component and corresponding noise element is pushed through the inductive load **550**. This allows the circuit to operate with a lower noise floor capability. In one embodiment, at least one of switch **820** or **830** is closed when the input signal is characterized by low frequency energy.

Some driver circuit applications may be configured for a more efficient high frequency drive circuit. This may be achieved by using multiple lower voltage amplifiers in the high frequency drive component of the present invention. A driver circuit **900** with a more efficient high frequency drive component in accordance with one embodiment of the present invention is shown in FIG. **9**. Circuit **900** of FIG. **9** is similar to circuit **600** of FIG. **6** except for the addition of capacitor **910**, resistor **920**, amplifier **930**, and resistor **940**. Capacitor **910** and resistor **920** operate as a high pass RC filter. A high frequency signal is provided from the RC high pass filter to the inverting input of amplifier **930**. The non-inverting input is coupled to ground. The output of the inverting amplifier is connected to resistor **940**, which is then connected to the inverting input terminal of the amplifier, and to one end of the primary coil of transformer **542**. In FIG. **9**, a more efficient drive capability is accomplished in the high frequency driver by implementing a balanced terminal load circuit around the primary coil of the transformer. One terminal of the secondary coil is coupled to the output of non-inverting amplifier **526**. The other terminal of the secondary coil is connected to the output of inverting amplifier **930**. The outputs of amplifiers **930** and **526** are 180° out phase with each other at the secondary coil terminals. As a result, a voltage difference is placed across the secondary coil of transformer **542** using the two amplifiers that is approximately twice as large as the voltage applied across the secondary coil terminals if only one such amplifier were used.

Some driver systems require or may benefit from a frequency band limiter. Band limiting circuitry may operate to suppress high voltage and surge voltages. A driver circuit **1000** implementing a frequency band limitation circuit in accordance with one embodiment of the present invention is shown in FIG. **10**. One terminal of resistor **1030** is connected to the output of amplifier **515**. The other terminal of resistor **1030** is connected to the negative terminal of amplifier **515**. A capacitor **1010** and resistor **1020** are connected in series. The other end of capacitor **1010** is coupled to the output of amplifier **515** . The other end of resistor **1020** is coupled to the negative terminal of amplifier **515**. Resistor **1040** is coupled between the negative terminal of the amplifier and the current sensor resistor **560**. The voltage at the current sensor resistor **560** is determined by the inductive load current and may be limited during a DC signal inputs using resistors **1030** and **1040**. During an AC signal input, the voltage at current sensor resistor **560** is determined by resistors **1030** and **1040** and additionally by resistor **1020** and capacitor **1010**. In operation, the frequency band limitation circuitry operates as a low pass filter. The frequency band limitation circuitry does not allow a signal above a desired frequency cut-off into the driver circuit. In one embodiment, the desired frequency cut-off is about 10 kHz or 20 kHz. However, those skilled in the art will realize the filter characteristics of circuit **1000** can be adjusted to meet the requirements of a particular system.

The drive circuit of the present invention can be configured to implement a different closed loop gain for the low frequency driver and the high frequency driver. Different closed loop gains can be used to implement gain phase margins that prevent oscillations and establish driver circuit stability. There are many ways to implement a closed loop gain for a driving circuit. High frequency driver and low frequency driver circuit configurations having different closed loop gains in accordance with one embodiment of the present invention are shown in driver circuit **1100** of FIG. **11**. The closed loop gain for high frequency driver circuitry in circuit **1100** can be expressed as $V_{OH}=V_{IH}$ (1+R**8**/R**7**), where V_{OH} is the output voltage for the high frequency driver amplifier and the V_{IH} is the input voltage to the high frequency driver amplifier. The closed loop gain for low frequency driver circuitry of circuit **1100** can be expressed as $V_{OL}=V_{IL}$ (1+R**10**/R**9**), where V_{OL} is the output voltage for the low frequency driver amplifier and the V_{IL} is the input voltage to the low frequency driver amplifier. By adjusting the values of resistors R**7**, R**8**, R**9**, and R**10**, the closed loop gain can be adjusted for either the low frequency driver amplifier or the high frequency driver amplifier. The open loop gain of both the high frequency and low frequency drive amplifiers may be determined by the particular amplifier circuit topologies and will differ from application to application.

A driving circuit for driving an inductive load in accordance with the present invention includes a high frequency driver and low frequency driver. A high frequency component and low frequency component is taken from an input signal. The separate low and high signal components are driven by a low frequency driver and high frequency driver, respectively. The outputs of the low frequency and high frequency drivers are combined by combination circuitry. In one embodiment of the present invention, the high frequency component is amplified by the combination circuitry in addition to being combined. The combined signals generate a high voltage signal that drives an inductive load at fast speeds. The driver circuit of the present invention may be configured to provide low noise at low frequencies, pass band limitations at the load terminal, different AC and DC open loop gains, and other characteristics depending upon system requirements. Though specific examples of circuit configurations are shown in these FIGS. **8–11** , it is not intended to limit the application of the basic invention to these examples. The basic concept of the present invention as shown in FIG. **5** may be applied and modified to meet the designs and specifications of many circuits. The scope of the inductance driver of the present invention is not intended to be limited by the illustrated applications of FIGS. **8–11**.

The inductance driver of the present invention may be used in several applications. For example, the inductance driver may be implemented within an electronic measuring instrument, such as a frequency spectrum analyzer. However, the inductance driver could be implemented in any circuit or instrument where an inductive load is to be driven, wherein the circuit or instrument utilizes a low voltage, high speed, and high efficiency inductance driver circuit. Use of the inductance driver of the present invention in larger circuits, instruments, and systems is within the intended scope of the present invention.

Although the present invention has been described above with particularity, this was merely to teach one of ordinary skill in the art how to make and use the invention. Additional modifications will fall within the scope of the invention, as that scope is defined by the following claims.

What is claimed is:

1. A system for driving an inductance load comprising:

a receiver configured to receive an input signal, the input signal having a high frequency portion and a low frequency portion;

a high frequency driver configured to process the high frequency portion of the input signal and provide a high frequency output;

a low frequency driver configured to process a low frequency portion of the input signal and provide a low frequency output; and

a combining circuitry configured to combine the low frequency output and the high frequency output and provide a combined output signal.

2. The system of claim 1 wherein the combining circuitry is configured to drive a load with the combined output signal.

3. The system of claim 2 wherein the load is an inductive load.

4. The system of claim 2 wherein the load is connected to a current sensing device.

5. The system of claim 1 wherein said high frequency driver includes a high pass filter and an amplifier, the amplifier configured to receive the output of the high pass filter.

6. The system of claim 2 wherein the high pass filter is a high pass RC filter.

7. The system of claim 2 wherein the high pass filter is operable to pass a frequency in the range of about 1 kHz to 4 kHz.

8. The system of claim 1 wherein said low frequency driver includes a low pass filter and an amplifier, the amplifier configured to receive the output of the low pass filter.

9. The system of claim 1 wherein the combining circuitry is a transformer having a primary coil and a secondary coil, the primary coil coupled to the high frequency output, the secondary coil coupled to the low frequency output.

10. The system of claim 1 wherein the high frequency driver includes a noise reducing device operable to reduce the amplitude of the high frequency portion and a noise present within the high frequency signal.

11. The system of claim 10 wherein the noise reducing device includes a switch operable to short the high frequency portion to ground.

12. The system of claim 1 wherein said combining circuitry includes a noise reducing device operable to reduce the proportion of the high frequency output and a noise present within the high frequency output in the combined output signal.

13. The system of claim 12 wherein the noise reducing device includes a switch operable to short the output of the low frequency device.

14. The system of claim 8 wherein said high frequency driver includes:

a first RC high pass filter coupled to a non-inverting amplifier, the non-inverting amplifier providing a first high frequency output to a first terminal of the primary coil; and

a second RC high pass filter coupled to an inverting amplifier, the inverting amplifier providing a second high frequency output to a second terminal of the primary coil, the second high frequency output 180° out of phase with the first high frequency output.

15. The system of claim 1 further including:

an amplifier, said input signal coupled to an input of the amplifier, the output of the amplifier coupled to the high frequency driver and low frequency driver; and

a frequency band limiter connected to the input and output of the amplifier; the frequency band limiter limiting a voltage applied to the inductive load.

16. The system of claim 1 wherein said high frequency driver includes a first gain circuitry operable to provide a first open loop gain to the high frequency portion, said low frequency driver includes a second gain circuitry operable to provide a second open loop gain to the low frequency portion.

17. A system for driving a load comprising:

an amplifier operable to receive a signal having a voltage and provide an amplified output;

a high frequency driver including:

a high pass filter operable to receive the amplified output and provide a filtered output; and

a high frequency amplifier operable to receive the filtered output and provide a high frequency driving signal;

a low frequency driver including:

a low pass filter operable to receive the amplified output and provide a filtered output; and

a low frequency amplifier operable to receive the filtered output and provide a low frequency driving signal; and

a transformer, the low frequency driving signal coupled to the secondary coil of the transformer, the high frequency driving signal coupled to the primary coil of the transformer, said transformer providing a combined output signal.

18. The system of claim 17 wherein the combined output signal is configured to drive an inductive load.

19. A method for driving a load comprising:

receiving an input signal, the input signal having a high frequency portion and a low frequency portion;

providing a high frequency driving signal derived from the high frequency portion;

providing a low frequency driving signal derived from the low frequency portion; and

driving a load with the high frequency driving signal and the low frequency driving signal.

20. The method of claim 19 wherein driving a load includes driving an inductive load.

21. The method of claim 19 wherein providing a high frequency driving signal includes:

receiving the input signal;

deriving the high frequency portion from the input signal;

processing the high frequency signal by an amplifier; and

providing a high frequency driving signal output from the amplifier.

22. The method of claim 21 wherein deriving a high frequency signal from the input signal includes processing the input signal by a high pass filter.

23. The method of claim 21 wherein the amplifier is configured to operate as a buffer.

24. The method of claim 20 wherein providing a low frequency driving signal includes:

receiving the input signal;

deriving the low frequency portion from the input signal;

processing the low frequency signal by an amplifier; and

providing a low frequency driving signal output from the amplifier.

25. The method of claim 24 wherein deriving a low frequency signal from the input signal includes processing the input signal by a low pass filter.

26. The method of claim 24 wherein the amplifier is configured to operate as a buffer.

27. The method of claim 19 wherein driving an inductive load with the high frequency driving signal and the low frequency driving signal includes:

providing a transformer having a mutual inductance ratio;

receiving a low frequency driving signal on one terminal of a secondary coil of the transformer;

receiving a high frequency driving signal on a primary coil of the transformer; and

providing a combined output signal to a load, the load coupled to a second terminal of the secondary coil, the

combined output signal comprising the summation of the high frequency driving signal multiplied by the mutual inductance ratio and the low frequency signal.

28. The method of claim **27** wherein the load is an inductive load.

29. The method of claim **19** further comprising:

providing a current sensor device coupled to the inductive load.

30. The method of claim **19** wherein providing a high frequency driving signal includes reducing a noise signal, the noise signal present within the high frequency signal processed by the amplifier.

31. The method of claim **30** wherein reducing the noise signal includes providing a short to connect the high frequency signal to ground.

32. The method of claim **27** wherein providing a combined output signal includes reducing a noise signal, the noise signal present in the high frequency driving signal.

33. The method of claim **32** wherein reducing the noise signal includes providing a short to connect the low frequency driving signal to the load.

34. The method of claim **27** wherein receiving a high frequency driving signal on a secondary coil of the transformer includes:

providing a first high frequency driving signal to a end of the primary coil; and

providing a second high frequency driving signal to a end of the primary coil, the first high frequency driving signal being 180° out of phase with the second high frequency driving signal.

35. The method of claim **19** further comprising:

limiting the voltage applied to the inductive load.

36. The method of claim **35** wherein limiting the voltage applied to the inductive load includes providing a low pass further to limit the frequency band applied to the inductive load.

37. The method of claim **17** wherein processing the high frequency signal by an amplifier includes applying a first open loop to the high frequency signal.

38. The method of claim **21** wherein processing the high frequency signal by an amplifier includes providing a gain circuit having a first open loop gain.

39. The method of claim **24** wherein processing the low frequency signal by an amplifier includes providing a gain circuit having a second open loop gain.

40. A method for driving an inductive load comprising:

receiving an input signal;

amplifying the input signal;

separating a low frequency component from the input signal;

providing the low frequency component to a secondary coil of a transformer;

separating a high frequency component from the input signal;

providing the high frequency component to a primary coil of the transformer;

generating a driving signal by combining the high frequency component and low frequency component at the transformer; and

driving a load with the driving signal.

41. A system for measuring a signal comprising:

an amplifier operable to receive a signal having a voltage and provide an amplified output;

a high frequency driver having a high pass frequency response, the high frequency driver operable to receive the amplified output and provide a high frequency driving signal;

a low frequency driver having a low pass frequency response the low frequency driver operable to receive the amplified output and provide a low frequency driving signal; and

a transformer, the low frequency driving signal coupled to the secondary coil of the transformer, the high frequency driving signal coupled to the primary coil of the transformer, said transformer providing a combined output signal.

42. The system of claim **41** wherein said high frequency driver includes:

a high pass filter operable to receive the amplified output and provide a filtered output; and

a high frequency amplifier operable to receive the filtered output and provide a high frequency driving signal.

43. The system of claim **41** wherein said low frequency driver includes:

a low pass filter operable to receive the amplified output and provide a filtered output; and

a low frequency amplifier operable to receive the filtered output and provide a low frequency driving signal.

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