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Chen et al.

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(45) **Date of Patent: Aug. 21, 2012**

(54) **TIME DIVISION MULTIPLEXING A DC-TO-DC VOLTAGE CONVERTER**

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(73) Assignee: **Alcatel Lucent**, Paris (FR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 268 days.

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(22) Filed: **Jan. 22, 2008**

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(51) **Int. Cl.**
H05B 37/02 (2006.01)
G05F 1/00 (2006.01)

(52) **U.S. Cl.** .... **315/307**; 315/185 R; 315/294; 323/282

(58) **Field of Classification Search** .... 315/185 R, 315/224, 291, 294, 307–308; 323/207, 282, 323/315; 363/21.04, 21.12, 159
See application file for complete search history.

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(57) **ABSTRACT**

An apparatus includes a DC-to-DC voltage converter. The DC-to-DC voltage converter has a plurality of pairs of outputs and is configured to apply voltages across the pairs of outputs in a time division multiplexed manner.

18 Claims, 8 Drawing Sheets

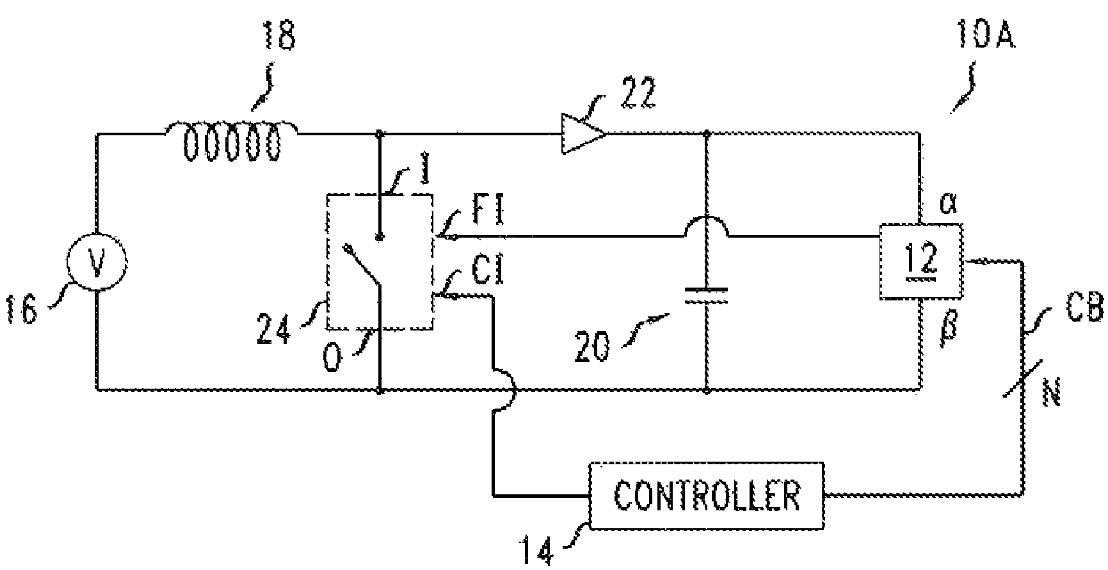

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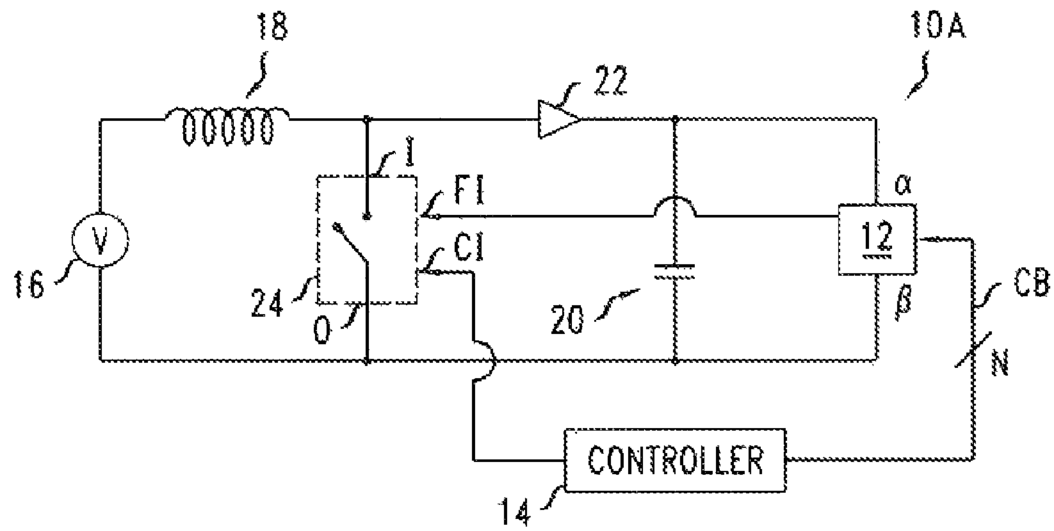
FIG. 1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α
12
β
CB
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V
16
24
O
20
CONTROLLER
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FIG. 2

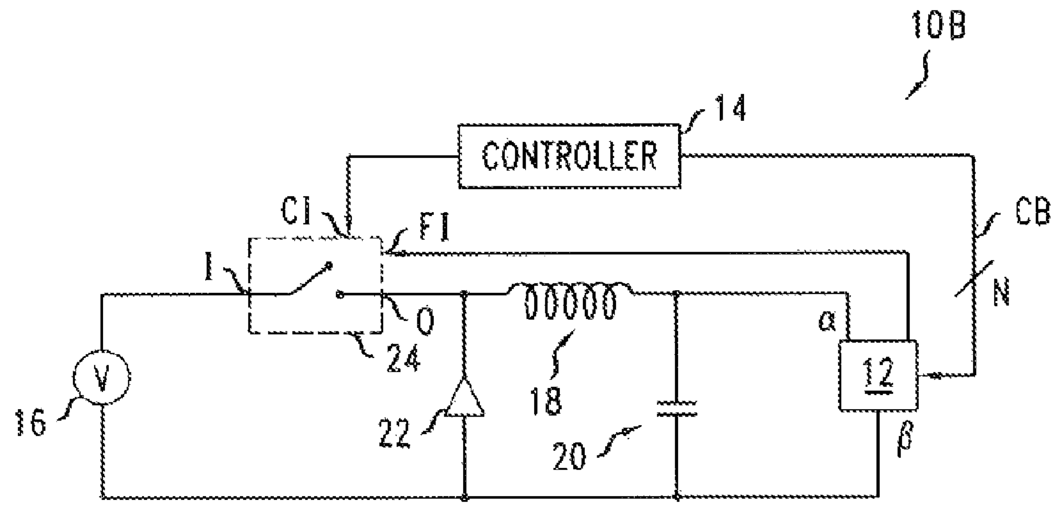
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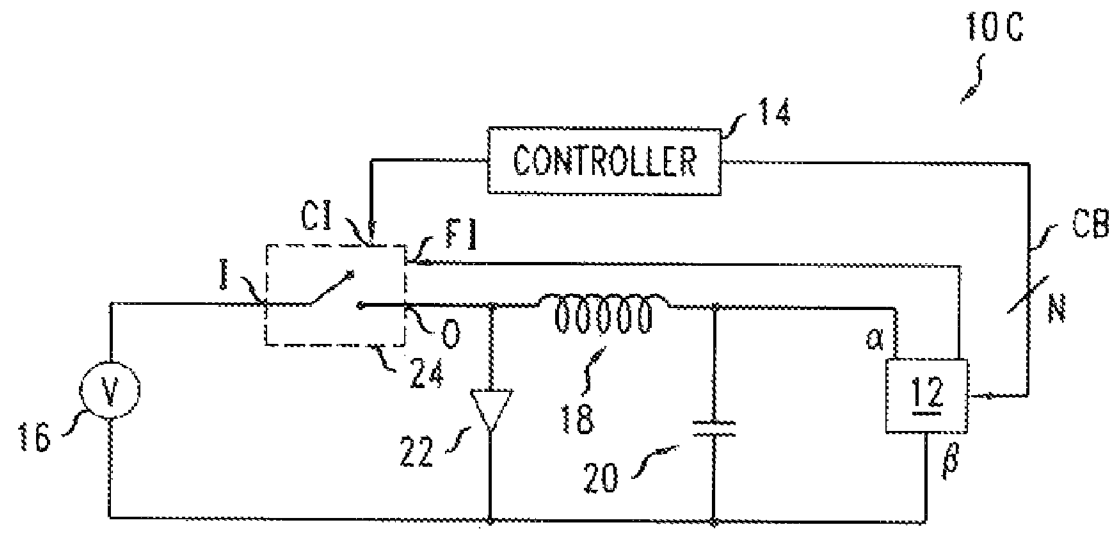
FIG. 3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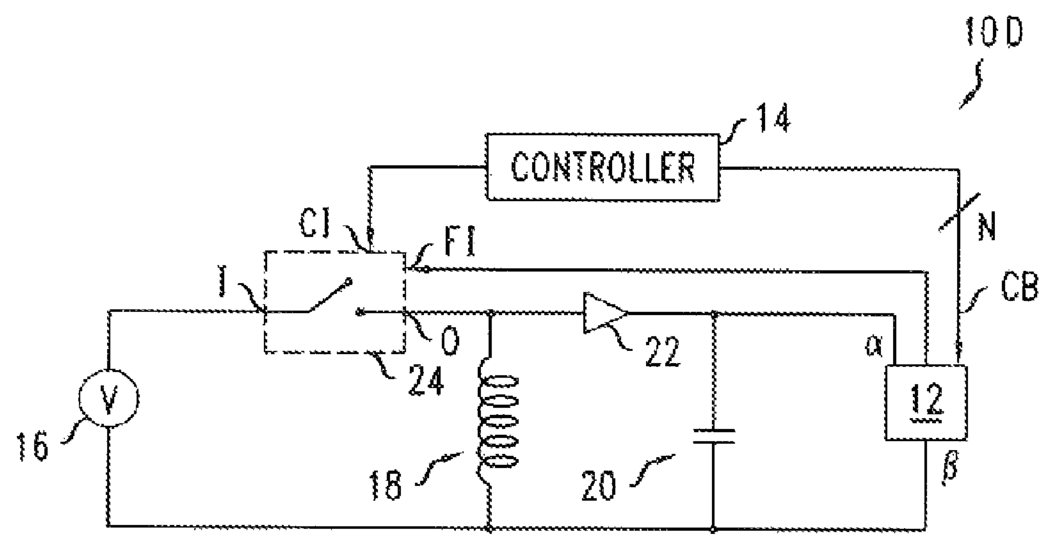
β

FIG. 4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16
V
18
20
β

FIG. 5

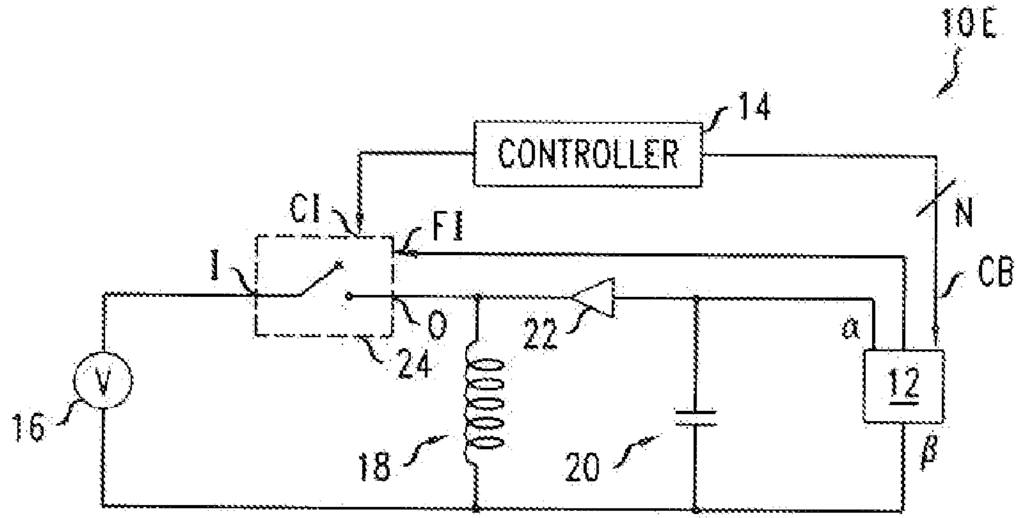
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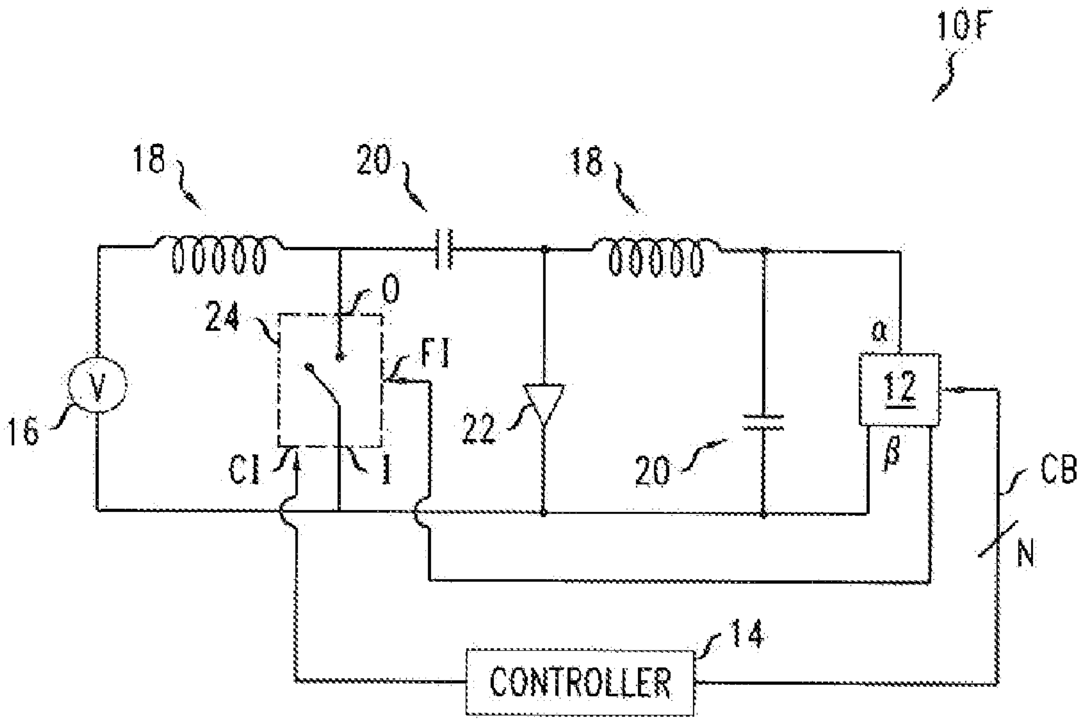
FIG. 6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18
20
18
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24
FI
V
22
12
α
16
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β
CI
I
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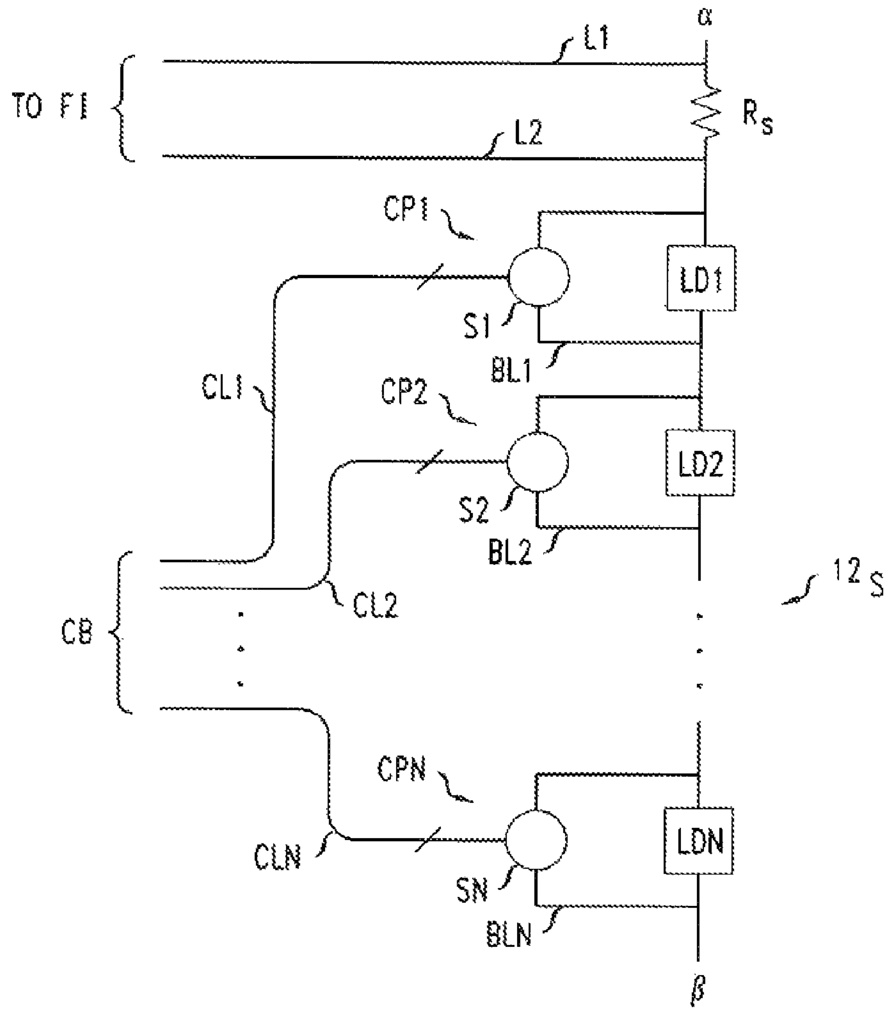
N
CONTROLLER
14

FIG. 7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TO F1
Rs
L2
CP1
LD1
S1
BL1
CL1
CP2
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S2
BL2
CL2
12s
CB
CPN
LDN
CLN
SN
BLN
β

FIG. 9

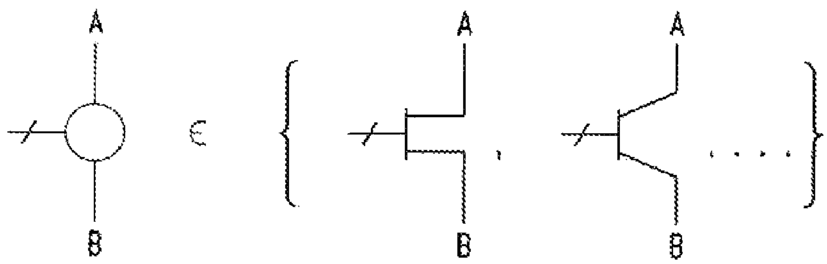
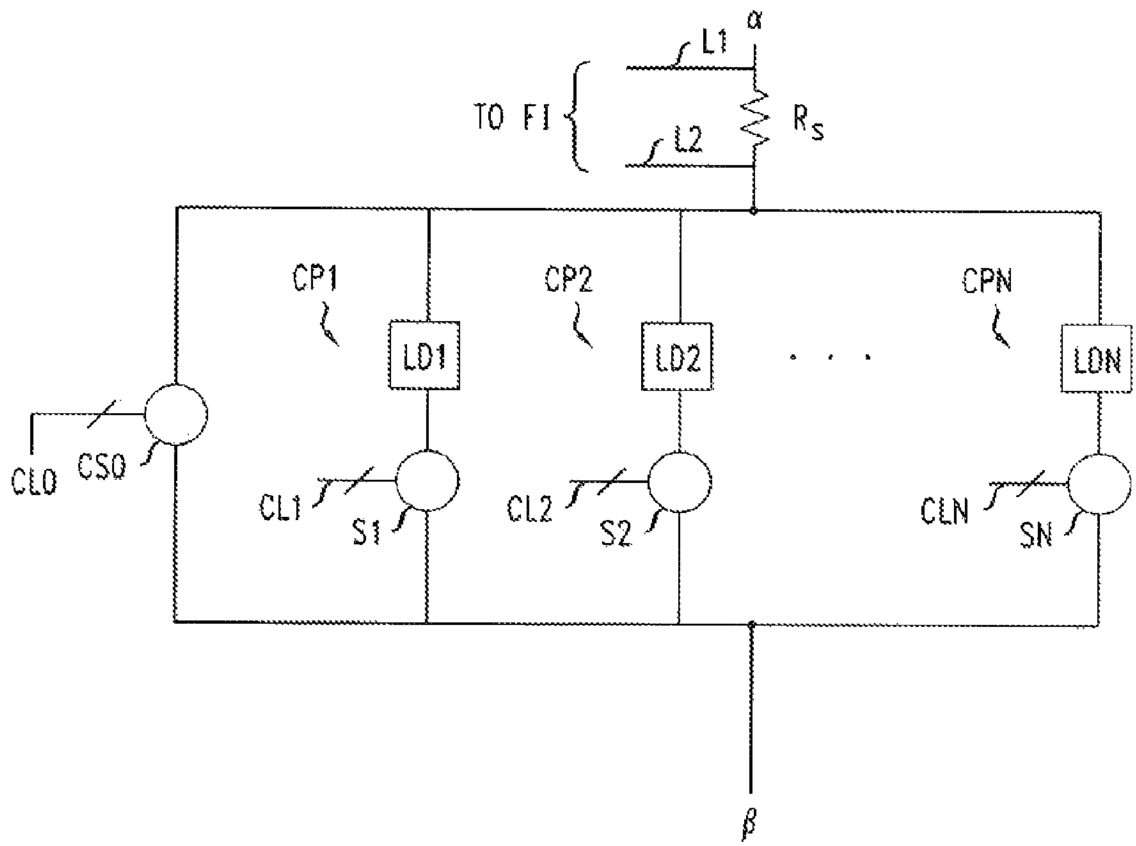

A
B
∈
A
B
A
B

FIG. 8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L1
TO F1
Rs
L2
CP1
CP2
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LD2
LDN
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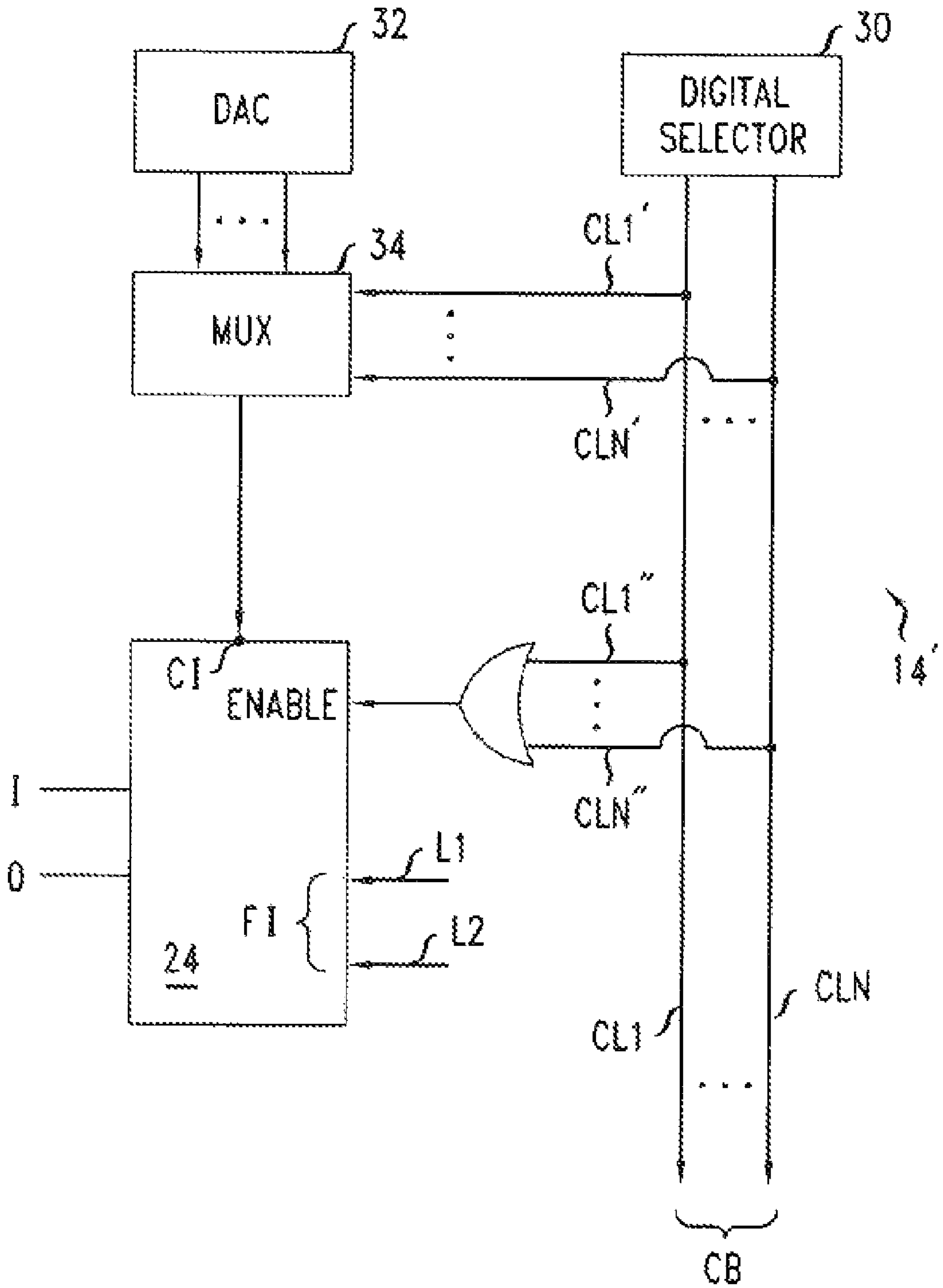
CS0
CL1
S1
CL2
S2
CLN
SN
β

FIG. 10


32
DAC
30
DIGITAL SELECTOR
34
MUX
CL1'
CLN'
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ENABLE
I
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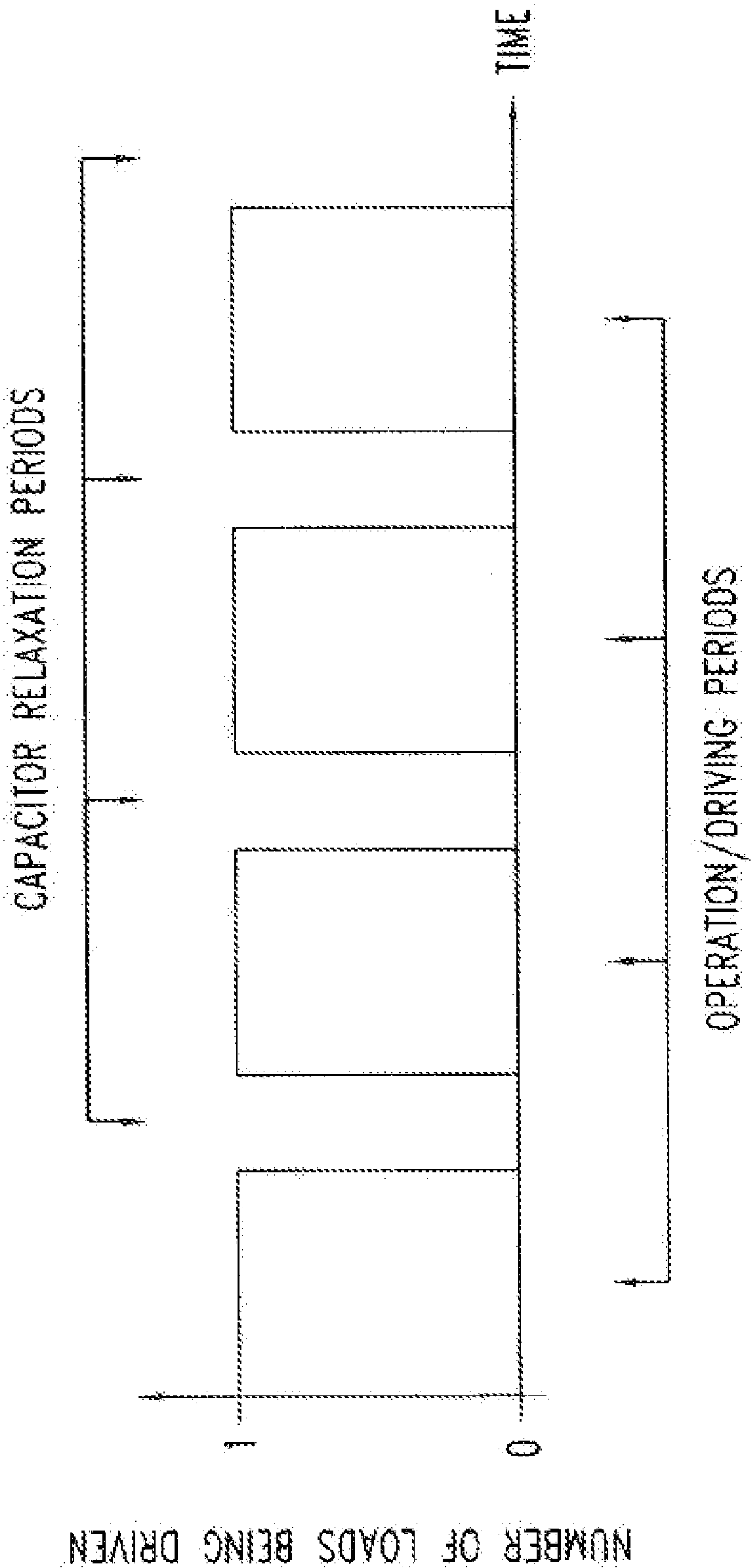
FI
L1
L2
24
CL1
CLN
CB

FIG. 11


CAPACITOR RELAXATION PERIODS
OPERATION/DRIVING PERIODS
TIME
1
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NUMBER OF LOADS BEING DRIVEN

FIG. 12

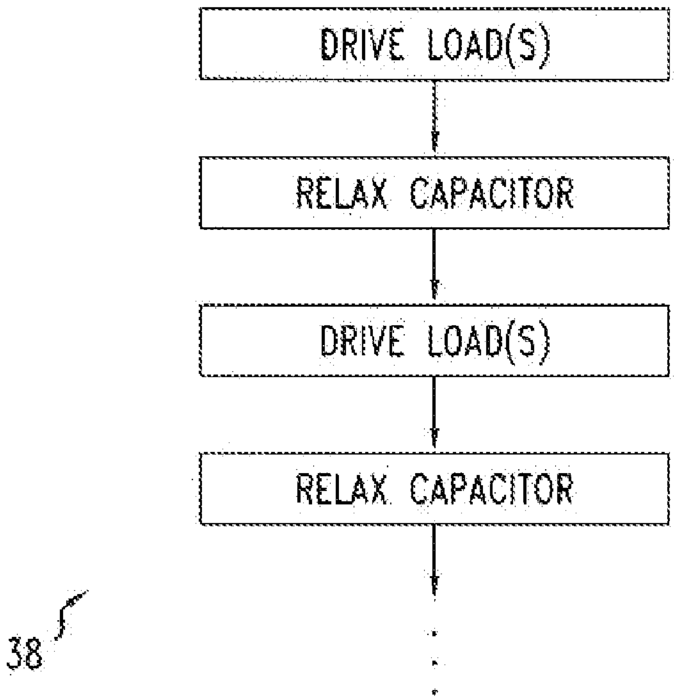
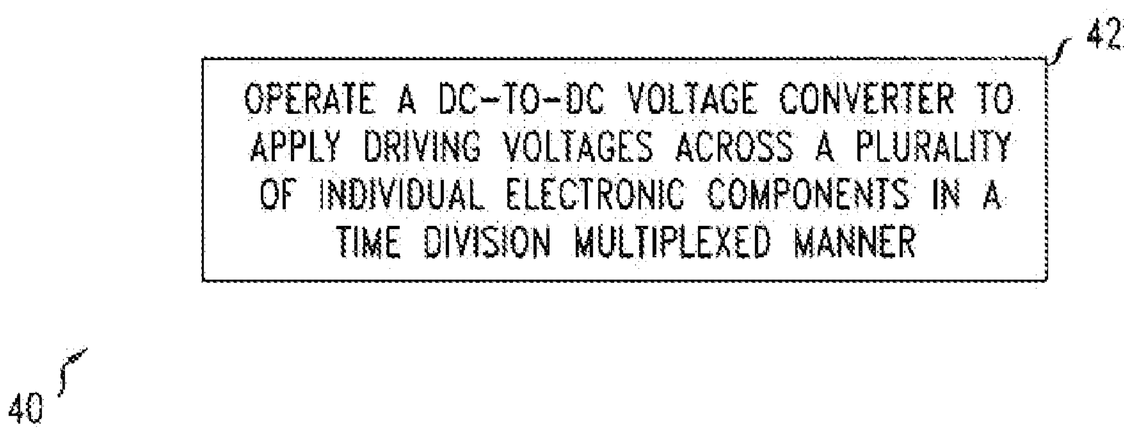

DRIVE LOAD(S)
RELAX CAPACITOR
DRIVE LOAD(S)
RELAX CAPACITOR
38

FIG. 13


42
OPERATE A DC-TO-DC VOLTAGE CONVERTER TO APPLY DRIVING VOLTAGES ACROSS A PLURALITY OF INDIVIDUAL ELECTRONIC COMPONENTS IN A TIME DIVISION MULTIPLEXED MANNER
40

TIME DIVISION MULTIPLEXING A DC-TO-DC VOLTAGE CONVERTER

BACKGROUND

1. Field of the Invention

The invention relates generally to direct current-to-direct current (DC-to-DC) voltage converters and to apparatus and methods that use DC-to-DC voltage converters.

2. Discussion of the Related Art

This section introduces aspects that may help facilitate a better understanding of the inventions. Accordingly, the statements of this section are to be read in this light and are not to be understood as admissions about what is prior art or what is not prior art.

There are various types of DC-to-DC voltage converters. Examples of DC-to-DC voltage converters include the buck DC-to-DC voltage converter, the boost DC-to-DC voltage converter, the buck-boost DC-to-DC voltage converter, the cuk DC-to-DC voltage converter, the flyback DC-to-DC voltage converter, and the forward DC-to-DC voltage converter. Typical DC-to-DC voltage converters include one or more inductors, one or more capacitors, a switching circuit, and a DC voltage source.

Herein, a switching circuit opens and closes a connection in an approximately periodic manner. Examples include a transistor switch that is controlled by alternating current (AC). Herein, a closed circuit or path conducts a DC current, and an open circuit or path does not conduct a DC current.

In a DC-to-DC voltage converter, the switching circuit brings the DC-to-DC voltage converter to an approximate steady-state in which the output voltage has an average value that is determined by the duty cycle of the switching circuit and the DC source voltage. In the steady state, some DC-to-DC voltage converters step up the DC source voltage, some DC-to-DC voltage converters step down the DC source voltage, and some other DC-to-DC voltage converters can either step up or step down the DC source voltage.

Some devices include an array of electronic components that need to be driven by regulated DC power supplies. A regulated DC power supply can be achieved with an array of DC-to-DC voltage converters in which each DC-to-DC voltage converter drives a corresponding one of the electronic components.

SUMMARY

Various embodiments provide DC-to-DC voltage converters that are configured to time division multiplex their output voltages among individual electronic components of an array.

One embodiment features a first apparatus that includes a DC-to-DC voltage converter. The DC-to-DC voltage converter has a plurality of pairs of outputs and is configured to apply voltages across the pairs of outputs in a time division multiplexed manner.

In some embodiments of the first apparatus, the DC-to-DC voltage converter further includes a plurality of shunt circuit paths. Each shunt circuit path connects between the outputs of a corresponding one of the pairs of outputs and has a switch there along. In some such embodiments, the DC-to-DC voltage converter may also include an electronic controller configured to operate the switches on the shunt circuit paths. The electronic controller may be configured to open only one of the switches at a time during operation. In some such embodiments, the shunt circuit paths may be electrically connected in series.

In other embodiments of the first apparatus, the DC-to-DC voltage converter further includes circuit paths connected in parallel. Each circuit path has a corresponding one of the pairs of outputs there along and has a controllable switch there along.

Some embodiments of the first apparatus include a plurality of light sources. Each light source is connected across a corresponding one of the pairs of outputs. In some such embodiments, some of the light sources are, e.g., light emitting diodes, and each light source is configured to emit light of a different color, e.g., red, green, and blue.

Another embodiment features a second apparatus that includes a DC-to-DC voltage converter and a plurality of electronic loads connected to share the DC-to-DC voltage converter. The DC-to-DC voltage converter has an electronic controller and a plurality of circuit paths. The electronic loads are either connected across corresponding ones of the circuit paths or are part of corresponding ones of the circuit paths. Each circuit path includes a switch there along, and the controller is connected to operate the switches of the circuit paths.

In some embodiments of the second apparatus, the electronic controller is configured to open only one of the switches at a time during driving operation.

In some embodiments of the second apparatus, each circuit path is a shunt circuit path for the corresponding one of the electronic loads, and the circuit paths are electrically connected in series.

In some embodiments of the second apparatus, the circuit paths are electrically connected in parallel and the electronic loads are part of corresponding ones of the circuit paths.

In some embodiments of the second apparatus, the DC-to-DC voltage converter is one of a boost DC-to-DC voltage converter, a buck DC-to-DC voltage converter, a buck-boost DC-to-DC voltage converter, and a CUK DC-to-DC voltage converter.

Some embodiments of the second apparatus further include a plurality of light sources. Each light source is one of the electronic loads.

In some embodiments of the second apparatus, the DC-to-DC voltage converter is configured to apply a first voltage across a first of the electronic loads and to apply a different second voltage across a second of the electronic loads.

Another embodiment features a method of electrically driving a plurality of electronic components. The method includes operating a DC-to-DC voltage converter in a shared manner in which the DC-to-DC voltage converter applies voltages across the electronic components in a time division multiplexed manner.

In some embodiments of the method, the act of operating includes having the DC-to-DC voltage converter apply a first voltage across one of the electronic components and apply a different second voltage across another of the electronic components.

In some embodiments of the method, the act of operating includes causing a shunt circuit path around each one of the electronic components to close when the DC-to-DC voltage converter is not applying a voltage to the one of the electronic components.

In some embodiments of the method, the act of operating includes simultaneously causing a circuit path with one of the electronic components to close and causing the one or more circuit paths with any other of electronic components to open when applying a voltage to the one of the electronic components. In such embodiments, the circuit paths are connected in parallel.

In some embodiments, the method further includes then, discharging a capacitor while the electronic components are not being driven and then, repeating the operating step. Charges on the capacitor drive the electronic components during the operating steps.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** is a circuit diagram for an embodiment of a boost DC-to-DC voltage converter in which a DC voltage source and inductive, capacitive, and switching circuit elements are temporally shared by multiple electronic loads;

FIG. **2** is a circuit diagram for an embodiment of a buck DC-to-DC voltage converter in which a DC voltage source and inductive, capacitive, and switching circuit elements are temporally shared by multiple electronic loads;

FIG. **3** is a circuit diagram for an embodiment of an alternate buck DC-to-DC voltage converter in which a DC voltage source and inductive, capacitive, and switching circuit elements are temporally shared by multiple electronic loads;

FIG. **4** is a circuit diagram for an embodiment of a buck-boost DC-to-DC voltage converter in which a DC voltage source and inductive, capacitive, and switching circuit elements are temporally shared by multiple electronic loads;

FIG. **5** is a circuit diagram for an alternate embodiment of a buck-boost DC-to-DC voltage converter in which a DC voltage source and inductive, capacitive, and switching circuit elements are shared by multiple electronic loads;

FIG. **6** is a circuit diagram for an embodiment of a CUK DC-to-DC voltage converter in which a DC voltage source and inductive, capacitive, and switching circuit elements are temporally shared by multiple electronic loads;

FIG. **7** is a circuit diagram illustrating a series-type embodiment of an output driver circuit path for the DC-to-DC voltage converters of FIGS. **1-6**;

FIG. **8** is a circuit diagram illustrating a parallel-type embodiment of an output driver circuit path for the DC-to-DC voltage converters of FIGS. **1-6**;

FIG. **9** illustrates circuits for exemplary 3-terminal switches for the output driver circuit paths of FIGS. **7-8**;

FIG. **10** is a circuit diagram illustrating one embodiment of a controller for the DC-to-DC voltage converters of FIGS. **1-6**;

FIG. **11** is a timing diagram illustrating a method of operating DC-to-DC voltage converters, e.g., the DC-to-DC voltage converters of FIGS. **1-6**;

FIG. **12** is a flow chart illustrating the method of FIG. **11**; and

FIG. **13** illustrates a method of operating DC-to-DC voltage converters that temporally share output voltages among different electronic loads, e.g., the DC-to-DC voltage converters FIGS. **1-6**.

In the Figures, similar reference numbers refer to features with substantially similar functions and/or structures.

In some of the Figures, relative dimensions of some features may be exaggerated to more clearly illustrate the structures shown therein.

While the Figures and the Detailed Description of Illustrative Embodiments describe some embodiments, the inventions may have other forms and are not limited to those described in the Figures and the Detailed Description of Illustrative Embodiments.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Various embodiments provide systems and method in which DC-to-DC voltage converters can drive electronic components in a temporally multiplexed manner. Substantial parts of the circuits of the DC-to-DC voltages converter are temporally shared to drive the different electronic components. The temporally shared components may include, e.g., inductor(s), capacitor(s), a switching circuit, and a DC voltage source. By such sharing configurations, some such DC-to-DC voltage converters can be constructed in more compact architectures and/or at lower costs than systems in which each electronic component is driven by a corresponding DC-to-DC voltage converter.

Various embodiments herein may, e.g., drive multi-color light sources, e.g., sources with three diodes, lasers and/or laser diodes of different colors, and may be used, e.g., in multi-color image projectors and/or image projection methods as described in co-filed U.S. patent application Ser. No. 12/009,991 titled "MULTI-COLOR LIGHT SOURCE" by Gang Chen and Roland Ryf; co-filed U.S. patent application Ser. No. 12/017,440 titled "DIFFUSER CONFIGURATION FOR AN IMAGE PROJECTOR" by Gang Chen and Roland Ryf; and/or co-filed U.S. patent application Ser. No. 12/017,984 titled "SYSTEM AND METHOD FOR COLOR-COMPENSATING A VIDEO SIGNAL HAVING REDUCED COMPUTATIONAL REQUIREMENTS" by Gang Chen and Roland Ryf. The above three patent applications are being filed on the same day as the present application and are incorporated herein by reference in their entirety.

Various embodiments herein may also be used to drive multi-color light sources used in optical projectors, optical projection methods, and/or speckle reduction methods and/or apparatus as described in: U.S. patent application Ser. No. 11/713,207 filed Mar. 2, 2007 by Randy C. Giles et al; U.S. patent application Ser. No. 11/681,376 filed Mar. 2, 2007 by Vladimir A. Aksyuk et al; U.S. patent application Ser. No. 11/713,155 filed Mar. 2, 2007 by Vladimir A. Aksyuk et al; and/or U.S. patent application Ser. No. 11/713,483 filed Mar. 2, 2007 by Gang Chen et al. These four patent applications are also incorporated herein by reference in their entirety.

Various other embodiments herein may be used to drive a variety of other types of electrical components, e.g., an array of electrical components that can be individually driven. For example, various embodiments provide apparatus and methods for driving electronic components under constant DC voltage conditions and/or constant DC current conditions. The embodiments are not intended to be limited, e.g., to drivers and driving of the light emitters of multi-color light sources.

FIGS. **1-6** illustrate DC-to-DC voltage converters **10**A, **10**B, **10**C, **10**D, **10**E, **1** OF that include a output driver circuit path **12** and an electronic controller **14**.

The various DC-to-DC voltage converters **10**A, **10**B, **10**C, **10**D, **10**E, **10**F have different output and input characteristics. The DC-to-DC voltage converter **10**A is in a boost type DC-to-DC voltage converter that steps up a voltage of a DC voltage source **16**. The DC-to-DC voltage converters **10**B-**10**C are buck type DC-to-DC voltage converters that step down the voltage of the DC voltage source **16**. The DC-to-DC voltage converters **10**D-**10**E are buck-boost DC-to-DC voltage converters that can, e.g., be operated to either step up or step down the voltage of the DC voltage source **16**. The DC-to-DC voltage converter **10**F is in a CUK DC-to-DC voltage converter that that can, e.g., be operated to either step up or step down the voltage of the DC voltage source **16** and can temporally smooth the current flows from the DC voltage source **16** and to the output driver circuit path **12**.

The output driver circuit path **12** has contacts α and β across which the DC-to-DC voltage converters **10**A-**10**F apply an output voltage, V_0. The output driver circuit path **12** is operated by the electronic controller **14** to drive an array of N electronic loads with the output voltage, V_0, in a time division multiplexed manner. The output driver circuit path **12** can have a first form or a second form. In the first form, the output driver circuit path **12** includes a serially connected array of controllable circuit paths, and each electronic load connects across the ends of a corresponding one of the controllable circuit paths. In the second form, the output drive circuit path **12** includes a parallel connected array of controllable circuit paths, and each circuit path includes a corresponding one of the electronic loads.

The electronic controller **14** controls the output driver circuit path **12**. In particular, the electronic controller **14** includes circuitry that configures the output drive circuit path **12** to selectively drive one of the electronic loads of the array and to selectively not drive other electronic loads of the array at a particular time. Thus, the electronic controller **14** can cause the output driver circuit path **12** to drive the electronic loads in time division multiplexed manner, e.g., so that only one of the electronic loads is driven at any one time.

Each DC-to-DC voltage converter **10**A-**10**F also includes the DC voltage source **16**, one or more conventional inductors **18**, one or more conventional capacitors **20**, one or more diodes **22**, and a conventional switching circuit **24**. The DC voltage source **16** supplies a preset DC source voltage, V_S. The inductor(s) **18** and capacitor(s) **20** are conventional circuit devices whose forms can affect transient characteristics of DC-to-DC voltage converters **10**A-**10**F and boundaries between discontinuous-mode and continuous-mode steady-state operation regions thereof. The one or more diode(s) **22** are also conventional circuit device, e.g., Schottky diodes. The switching circuit **24** is configured to open and close the electrical connection between its input, I, and its output, O, at a preselected frequency thereby enabling the DC-to-DC voltage regulators **10**A-**10**F to convert the DC source voltage, V_S, to an approximately constant DC output voltage, V_O, when steady state operation is achieved. Exemplary switching circuits **24** include a switching voltage source and a switch whose control input, e.g., a gate of a field effect transistor switch or a base of a bipolar transistor switch as shown in FIG. **8**, is driven by the switching voltage source. The switching voltage source includes an alternating current (AC) component, e.g., a saw tooth component, and may include a DC component that enables regulation of the duty value, D, of the switching circuit **24**. Herein, the ratio of the time per cycle that a switching circuit is closed over the total length of the switching circuit's operating cycle, i.e., a cycle to open and close, is the duty value, D, of the switching circuit.

In some embodiments, the electronic controller **14** may control and/or regulate the duty value, D, of the switching circuit **24**, and/or the duty value of the switching circuit **24** may be auto adjusted based on a voltage value fedback from the output driver circuit path **12**. For example, the electronic controller **14** may be connected to apply a DC offset to the control input of a switching transistor in the switching circuit, e.g., the gate of an FET switch or the base of a bipolar transistor switch, thereby adjusting the duty value, D, of the switching circuit **24**.

Commercially available integrated circuits (ICs) may be suitable for the switching circuit **24** and parts of the electronic controller **14**. For example, Linear Technologies Inc of 1630 McCarthy Blvd., Milpitas, Calif. 95035-7417 (www.linear.com) sells products with identification numbers LT3518, LT3477, and LT3478, and these products may be suitable for the switching circuit **24** and parts of the electronic controller **14**. Some such ICs may have feedback inputs, FI, for feeding back a voltage drop over a sense resistor, R_S, e.g., as shown in FIGS. **7**-**8**, to regulate the switching circuit **24**. The switching circuit **24** can use such a fedback voltage to adjust its duty value in a manner that stabilizes the current in the output driver circuit **12** to a preselected value as described below. Some such ICs may also have a control input (CI) to apply a DC bias voltage to regulate the duty value, D, of the switching circuit **24**.

The duty value, D, of the switching circuit **24** approximately defines the relation between the DC output voltage, V_O, of the DC-to-DC voltage converter and its DC source voltage, V_S, at steady state operation. In the continuous current mode, the current in the inductor(s) of the DC-to-DC voltage converters **10**A-**10**F do not go to zero. For the exemplary DC-to-DC voltage converters **10**A-**10**F, the relations between V_O and V_S are shown in the below Table 1 for the continuous current mode at steady state operation.

TABLE 1

Source and Output Voltage relations in continuous current mode

DC-to-DC voltage converter	Relation between V_o and V_s
Boost	$V_o \cong V_s/(1 - D)$
Buck	$V_o \cong D \cdot V_s$
Buck-Boost	$V_o \cong -D \cdot V_s/(1 - D)$
CUK	$V_o \cong -D \cdot V_s/(1 - D)$

Thus, various embodiments of the DC-to-DC voltage converters **10**A-**10**F may use the electronic controller **14** to adjust the duty value, D, of the switching circuit **24** to operate in a manner substantially consistent with the relations of Table 1 to produce desired output voltages, V_O.

In the DC-to-DC voltage converters **10**A-**10**F, the output driver circuit path **12** may be, e.g., in a series embodiment $\mathbf{12}_S$, as shown in FIG. **7**, or a parallel embodiment $\mathbf{12}_P$, as shown in FIG. **8**. In both embodiments $\mathbf{12}_S$, $\mathbf{12}_P$, N, individual electronic loads LD**1**, LD**2**, . . . , LDN either connect across corresponding circuit paths CP**1**, CP**2**, . . . , CPN or form parts of said circuit paths CP**1**, . . . , CPN. The electronic loads LD**1**, . . . , LDN are driven by the DC-to-DC voltage converters **10**A-**10**F in a time-interleaved manner, i.e., a time division multiplexed manner. Here, the integer N is greater or equal to two, e.g., 2, 3, 4, or 5.

Referring to FIG. **7**, the series embodiments $\mathbf{12}_s$ connect the circuit paths CP**1**, . . . , CPN in series to form the output driver circuit paths **12** of FIGS. **1**-**6**. Each circuit path CP**1**, CP**2**, . . . , CPN is a shunt circuit path that includes a switch Sl, S**2**, . . . , SN there along. The electronic loads LD**1**, . . . , LDN connect across ends of corresponding circuit paths CP**1**, . . . , CPN. Thus, each pair of ends of a circuit path CP**1**, . . . , CPN functions as a pair of outputs of the DC-to-DC voltage converters **10**A-**1**OF in the series embodiments $\mathbf{12}_s$. The switches SI, S**2**, . . . , SN open and close the shunt circuit paths in response to control voltages applied thereto. The control voltages are configured to have one of two values where the corresponding circuit path CP**1**, . . . , CPN is open for one value and closed for the other value. Thus, an output current flows substantially only through the circuit path CP**1**, . . . , CPN if the path's switch S**1**, . . . , SN is closed and flows substantially only through the corresponding electronic load LD**1**, . . . , LDN if the path's switch S**1**, . . . , SN is open.

During typical driving operation of the series embodiments $\mathbf{12}_S$, the electronic controller **14** applies control voltages to the switches S**1**, S**2**, . . . , SN via the control lines CL**1**, CL**2**, . . . , CLN of a control-line bundle CB. The control voltages determine which of the corresponding circuit paths CP**1**, . . . , CPN will be open and which will be closed. In particular, the electronic controller **14** typically applies a set of control voltages that simultaneously cause N-1 of the switches S**1**, . . . , SN to be closed and causes the remaining one switch S**1**, . . . , SN to be open during driving operation. Thus, only one of the N electronic loads LD**1**, . . . , LDN is typically driven by the output voltage, V_O, of the DC-to-DC voltage converters **10**A-**10**F at any one time in the series embodiment $\mathbf{12}_S$. The electronic controller **14** alternates the form of the set of control voltages so that different ones of the electronic loads LD**1**, . . . , LDN are driven at different times. That is, the electronic controller **14** controls the output driver circuit path $\mathbf{12}_S$ in a manner that time division multiplexes the driving of the electronic loads LD**1**, . . . , LDN.

Referring to FIG. **8**, the parallel embodiments $\mathbf{12}_P$ connect the circuit paths CP**1**, . . . , CPN in parallel to form the output driver circuit path **12** of FIGS. **1**-**6**. Each circuit path CP**1**, CP**1** . . . , CPN includes a corresponding switch S**1**, S**2**, . . . , SN and a corresponding electronic load LD**1**, LD**2**, . . . , LDN there along. Thus, two points on each circuit path CP**1**, . . . , CPN function as a pair of outputs of the DC-to-DC voltage converters **10**A-**10**F in the parallel embodiments $\mathbf{12}_P$. The switches S**1**, . . . , SN open and close in response to applied control voltages. That is, each control voltages has one of two values so that the corresponding circuit paths CP**1**, . . . , CPN is open for one value and is closed for the other value. An output drive current flows to one of the electronic loads LD**1**, . . . , LDN only if the switch S**1**, . . . , SN on the same circuit path CP**1**, . . . , CPN is closed.

During typical driving operation of the parallel embodiments $\mathbf{12}_P$, the electronic controller **14** applies the control voltages to the switches S**1**, S**2**, . . . , SN via the control lines CL**1**, CL**2**, . . . , CLN of the control line bundle CB. The control voltages determine which of the corresponding circuit paths CP**1**, . . . , CPN is closed. In particular, the electronic controller **14** applies a set of control voltages that simultaneously cause N-1 of the switches S**1**, . . . , SN to be open and that cause the remaining one switch S**1**, . . . , SN to be closed. Thus, only one of the N electronic loads LD**1**, . . . , LDN is typically driven by the output voltage, V_O, of the DC-to-DC voltage converters **10**A-**10**F at any one time. In the parallel embodiment $\mathbf{12}_P$, the electronic controller **14** again alternates the forms of the set of control voltages so that different ones of the electronic loads LD**1**, . . . , LDN are driven at different times. That is, the electronic controller **14** controls the output driver circuit path **12** in a manner that time division multiplexes the driving of the electronic loads LD**1**, . . . , LDN.

The parallel embodiment $\mathbf{12}_P$ of the output driver circuit paths **12** may optionally include an additional shunt circuit path CP**0** that is controlled by a switch S**0**. The shunt circuit path CP**0** can be closed by a control voltage applied to control line CL**0** via the electronic controller **14** so that the parallel embodiment $\mathbf{12}_P$ of the output driver circuit path **12** can function as a shunt circuit path without passing any current through the electronic loads LD**1**, . . . , LDN. Such shunting may be useful to discharge charges on the capacitor(s) **20** of the DC-to-DC voltage converters **10**A-**10**F as further described below.

Both the series and parallel embodiments $\mathbf{12}_S$, $\mathbf{12}_P$ of the output driver circuit paths **12** may also optionally include a small sense resistor, e.g., of less than about **1** ohm. In some embodiments, the voltage across the sense resistor is fedback to sensing inputs FI of the switching circuits **24** of FIGS. **1**-**6** to enable feedback control or stabilization of output voltages or currents to the N electronic loads LD**1**-LDN in the DC-to-DC voltage converters **10**A-**10**F. In particular, some of the DC-to-DC voltage converters **10**A-**10**F can vary their duty value, D, based on such a feedback measurements. Such a feedback control may be useful, e.g., to compensate for temperature variations and/or changes in the electronic loads LD**1**-LDN during operation.

FIG. **9** shows some exemplary forms for the switches S**1**, . . . , SN of the series and parallel embodiments $\mathbf{12}_S$, $\mathbf{12}_P$ of the output driver circuit paths **12**, as shown in FIGS. **7**-**8**. The switches S**1**, . . . , SN may be field-effect transistors (FETs) so that the control inputs are gates of the FETs. The switches S**1**, . . . , SN may be field effect transistor switch circuits. The switches S**1**, . . . , SN may also be bipolar transistor switches so that the control inputs are bases of the bipolar transistors. Other embodiments of the switches S**1**, . . . , SN may be based on other conventional circuits for controllable ON/OFF types of switches.

FIG. **10** shows an exemplary embodiment **14'** for the electronic controller **14** of FIGS. **1**-**6**. The electronic controller **14'** includes a digital selector circuit **30** and optionally includes a digital-to-analog converter (DAC) **32**, an Mx1 multiplexer (MUX) **34**, and an optional N-to-1 OR gate **36**.

The digital selector **30** produces the sets of N binary valued voltages that operate the N switches S**1**-SN of the output driver circuit path **12**. In particular, each set of voltages typically causes the N switches S**1**-SN to selectively apply the output voltage, V_0, of the DC-to-DC voltage converters **10**A-**10**F to one electronic load LD**1**-LDN at a time. The digital selector **30** selects the order and timing with which the N electronic loads LD**1**-LDN are driven.

The optional DAC **32** produces a different voltage value on each of its M outputs. Here, M is less than or equal to N. Each output of the DAC connects to one of the inputs of the Mx1 MUX **34**. The Mx1 MUX **34** has an output that applies a control voltage to an optional control input, CI, of the switching circuit **24**. The control voltage controls the duty value, D, of the switching circuit **24**, e.g., by fixing a DC bias applied to a gate or base of a transistor switch. By fixing the duty value, D, of the switching circuit **24**, the control voltage determines the output voltage, V_0, such embodiments of the DC-to-DC voltage converters **10**A-**10**F of FIGS. **1**-**6** during steady state operation. Thus, by controlling the MUX **34**, the digital selector **30** is able, e.g., to cause the DC-to-DC voltage converters **10**A-**10**F to apply different output voltages, V_0, across or send different currents through different ones of the electronic loads LD**1**-LDN.

In an alternative embodiment, a single DAC can replace, e.g., the DAC **32** and the MUX **34**. In such embodiments, the digital selector **30** would send a corresponding a digital value directly to the single DAC, which would present a desired voltage output to the control input, CI, of the switching circuit **24**.

The optional N-to-1 OR gate **36** applies a digital control signal to an optional enable input on the switching circuit **24**. For example, the N-to-1 OR gate **36** may enable the switching circuit **24** whenever any of the electronic loads LD**1**-LDN of FIGS. **7** and **8** is configured to be driven by the DC-to-DC voltage converters **10**A-**10**F. Of course, other embodiments may use other conventional methods to enable the switching circuit **24** when the output driver circuit path **12** is configured to drive one of the N electronic loads connected thereto.

FIG. **11** is a timing diagram for an exemplary method **38** of operating the DC-to-DC voltage converters **10**A-**10**F of FIGS. **1**-**6**. In this method, the DC-to-DC voltage converters **10**A-**10**F are operated to alternate between being in driving periods and being in relaxation periods as illustrated by the flow chart of FIG. **12**. During each driving period, the electronic controller **14** configures the output driver circuit path **12** to apply a driving voltage across one or more of the N electronic loads, e.g., the loads LD**1**-LDN of FIGS. **7** and **8**, and also typically configures the output driver circuit path **12** to not apply a driving voltage across the remaining N-1 electronic loads. In some embodiments, the electronic controller **14** may sequentially drive a plurality of the electronic loads. For example, the electronic controller **14** may drive all N of the electronic loads LD**1**-LDN, i.e., one load at a time. In alternate embodiments, the electronic controller **14** may drive only one electronic load or, at least, less than all N of the electronic loads in the single driving period. During each relaxation period, the electronic controller **14** configures the output driver circuit path **12** to not apply a driving voltage across any of the N electronic loads. Instead, in these periods, the electronic controller **14** configures the output driver circuit path **12** to enable any capacitor(s) **20** to discharge stored charges without driving any of the electronic loads. In the series embodiment $\mathbf{12}_S$, the electronic controller **14** would close all N switches S**1**-SN during the relaxation period. In the parallel embodiment $\mathbf{12}_P$, the electronic controller **14** would open all N switches S**1**-SN and close the switch S**0** for the shunt circuit path during the relaxation period. The method **38** includes repeating the performance of the driving and relaxation periods, e.g., to drive more of the electronic loads and/or to drive the same electronic loads again.

Each relaxation period enables the capacitor(s) **20** to discharge charges that are too high for driving the next electronic load to-be-driven. By using such relaxation periods, the DC-to-DC voltage converters **10**A-**10**F can drive the electronic loads of arrays in which one or more of the electronic loads could be damaged by voltage and/or current values needed to drive other(s) of the electronic loads.

For capacitors **20** of moderate size, the relaxation periods can even be orders of magnitude shorter than the driving periods thereby not wasting substantial amounts of driving time.

In the method **38** the sequence of driving periods (DPs) and relaxation periods (RPs) may be arranged to minimize the amount of relaxation needed. For example, the DPs may be ordered so that the charge stored on capacitor(s) **20** increases monotonically over one cycle in which all of the electronic loads are driven one time. In such an embodiment, the capacitor(s) discharge(s) only at the end of the whole cycle. Such an embodiment eliminates the need to discharge the capacitor(s) **20**, e.g., so that a single drive cycle of all of the electronic loads can proceed without performing a relaxation to discharge the capacitor(s) **20**. For example, in the parallel embodiment $\mathbf{12}_P$ of FIG. **8**, the controller **14** would, e.g., only close the switch SO of the output driver circuit path **12** to discharge the capacitor(s) at the end of a cycle over which all N electronic loads LD**1**-LDN have been driven.

FIG. **12** illustrates a method **40** of operating a temporally-shared DC-to-DC voltage converter to drive a plurality of N electronic loads, e.g., the DC-to-DC voltage converters **10**A-**10**F of FIGS. **1-6**. The method **40** includes operating the DC-to-DC voltage converter to apply driving voltages across individual electronic loads of the plurality during a sequence of time periods so that the loads are driven in a time division multiplexed manner (step **42**). The operating step **42** may include closing shunt circuit path(s), e.g., N-1 of the circuit paths CP**1**-CPN of FIG. **7**, to cause the applied current and voltage to bypass the corresponding electronic load(s), i.e., the load(s) not being driven at that time. The operating step **42** may alternately include opening N-1 switch(es), e.g., N-1 of the circuit paths CP**1**-CPN of FIG. **8**, to cause the applied current and voltage to bypass the corresponding electronic load(s), i.e., the load(s) not being driven at that time. In the operating step **42**, one voltage may be applied across one electronic load and a different voltage may be applied across one or more other electronic loads. The method **40** may include interleaving such driving periods with capacitor relaxation periods as described in the above method **38**.

In some embodiments, the DC-to-DC voltage converters **10**A-**10**F of FIGS. **1-10** and methods **38**, **40** of FIGS. **11-13** may also be configured to simultaneously driving more than one of the electronic loads in some of the driving periods.

The invention is intended to include other embodiments that would be obvious to a person of ordinary skill in the art in light of the description, figures, and claims.

What is claimed is:

1. An apparatus for driving a plurality of electronic loads, comprising:
- a DC-to-DC voltage converter having a variable voltage output; and
- a controller, the controller being configured to:
  - select one or more of the plurality of electronic loads and a corresponding output voltage level of the variable voltage output; and
  - apply a plurality of voltage levels from the variable voltage output across the plurality of electronic loads in accordance with the correspondence and a time division multiplexed scheme;
  - wherein the correspondence is established prior to the selection, and
  - wherein the selection of one or more of the plurality of electronic loads is done by effecting a shunt across the unselected one or more of the plurality of electronic loads.

2. The apparatus of claim **1**, wherein the shunt is realizable using a plurality of shunt circuit paths, each shunt circuit path connecting between the outputs of a corresponding one of the electronic loads and having a switch there along.

3. The apparatus of claim **2**, wherein the shunt circuit paths are electrically connected in series.

4. The apparatus of claim **1**, wherein the variable voltage output further comprises circuit paths connected in parallel, each circuit path having the outputs of a corresponding one of the electronic loads there along and having a controllable switch there along.

5. The apparatus of claim **1**, wherein the electronic loads comprise a first load operable at a first voltage and a second load operable at a different second voltage.

6. The apparatus of claim **5**, wherein some of the electronic loads are light emitting diodes, each light source being configured to emit light of a different color.

7. The apparatus of claim **1**, wherein the controller is further configured to shunt all of the plurality of electronic loads during certain times according to the time division multiplexed scheme.

8. An apparatus for driving a plurality of electronic loads, comprising:
- a DC-to-DC voltage converter having a variable voltage output, the plurality of electronic loads being connected to share the DC-to-DC voltage converter over a plurality of circuit paths;
- a controller, the controller being configured to:
  - select one or more of the plurality of electronic loads and a corresponding output voltage level of the variable voltage output;
  - apply a plurality of voltage levels from the variable voltage output across the plurality of electronic loads in accordance with the correspondence and a time division multiplexed scheme; and
  - effect a shunt across all of the plurality of electronic loads during certain times according to the time division multiplexed scheme;

wherein the correspondence is established prior to the selection;

wherein the loads are either connected across corresponding ones of the circuit paths or are part of corresponding ones of the circuit paths; and

wherein each path includes a switch there along and the controller is connected to operate the switches.

9. The apparatus of claim **8**, wherein the controller is configured to open only one of the switches at a time during driving of the loads.

10. The apparatus of claim **8**, wherein each circuit path is a shunt path for the corresponding one of the electronic loads, and the circuit paths are electrically connected in series.

11. The apparatus of claim **8**, wherein the circuit paths are electrically connected in parallel and the loads are part of corresponding ones of the circuit paths.

12. The apparatus of claim **8**, wherein the DC-to-DC voltage converter is one of a boost DC-to-DC voltage converter, a buck DC-to-DC voltage converter, a buck-boost DC-to-DC voltage converter, and a CUK DC-to-DC voltage converter.

13. The apparatus of claim **8**, wherein the electronic loads comprise a first load operable at a first voltage and a second load operable at a different second voltage.

14. The apparatus of claim **8**, wherein the DC-to-DC voltage converter is configured to apply a first voltage across a first of the loads and to apply a different second voltage across a second of the loads.

15. A method of driving a plurality of electronic loads, comprising:

selecting, by a controller, one or more of the plurality of electronic loads and a corresponding output voltage level of a DC-to-DC voltage converter having a variable voltage output; and

operating, by the DC-to-DC voltage converter in combination with the controller, a plurality of voltage levels from the variable voltage output across the plurality of electronic loads in accordance with the correspondence and a time division multiplexed scheme;

wherein the correspondence is established prior to the selection, and

wherein the selecting of one or more of the plurality of electronic loads is done by effecting a shunt across the unselected one or more of the plurality of electronic loads.

16. The method of claim **15**, wherein the operating includes having the DC-to-DC voltage converter apply a first voltage across one of the electronic components and a different second voltage across another of the electronic components.

17. The method of claim **15**, wherein the operating includes simultaneously closing a circuit path with one of the electronic components and opening one or more circuit paths with any other of electronic components when the DC-to-DC voltage converter is applying a voltage to the one of the electronic components, the circuit paths being connected in parallel.

18. The method of claim **15**, further comprising:

effecting a shunt across all of the plurality of electronic components during certain times according to the time division multiplexed scheme;

then, discharging a capacitor during the certain times; and

then, repeating the operating step;

wherein charges on the capacitor drive the electronic components.

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