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Systems and Devices of Isolated Voltage Regulators

Abstract

According to an implementation, a circuit includes a trio of first switches, a pair of second switches, a pair of inductors including a primary inductor and a secondary inductor, and a first capacitor, where: the circuit is configured to regulate a load. According to an implementation, a circuit includes a voltage balancer and two or more stages. Each stage of the two or more stages includes: a two-phase isolated voltage regulator (IVR) including at least a pair of inversely coupled dual inductors and a differential voltage input, and a respective Zener diode and capacitor combination coupled to the voltage balancer and the first two-phase IVR. In certain aspects, the two or more stages are coupled in series.

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Background/Summary

FIELD

[0001] This disclosure pertains to systems and devices involving isolated voltage regulator (IVR) circuits.

DESCRIPTION OF RELATED ART

[0002] This section is intended to provide information relevant to understanding various technologies described herein. As the section's heading implies, this is a discussion of related art that in no way implies that the discussion is prior art. Generally, related art may or may not be considered prior art. Any statement in this section should be read in this light, and not as admission of prior art.

[0003] In the context of electrical or electronic design, a voltage regulator (VR) is an integrated circuit (IC) or a component within an electronic device responsible for maintaining a stable and specific voltage level within the device or a particular subsystem. For example, when an input voltage varies due to fluctuations in the power supply or environmental conditions, a VR can provide a steady and regulated output voltage to power various components of a device. Furthermore, the output voltage regulation can ensure proper and reliable operation of electronic circuits, for example, in sensitive components like microprocessors, memory modules, or other integrated circuits. Additionally, VRs can be useful, for example, working with microcontrollers, power management ICs, or various other electronic devices to dynamically adjust or statically locate a proper voltage applied to them to achieve certain performance (e.g., to be able to run certain application with certain clock frequency) or power consumption.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Implementations of various techniques are described herein with reference to the accompanying drawings. The accompanying drawings illustrate various implementations described herein and are not meant to limit implementations of various techniques described herein.

[0005] FIG. 1A is a diagram, in accordance with certain implementations.

[0006] FIG. 1B is a diagram, in accordance with certain implementations.

[0007] FIG. 2 is a diagram, in accordance with certain implementations.

[0008] FIG. 3A is a diagram, in accordance with certain implementations.

[0009] FIG. 3B is a diagram, in accordance with certain implementations.

[0010] FIG. 4A is a diagram, in accordance with certain implementations.

[0011] FIG. 4B is a diagram, in accordance with certain implementations.

[0012] FIG. 5A is a diagram, in accordance with certain implementations.

[0013] FIG. 5B is a diagram, in accordance with certain implementations.

[0014] FIG. 6A is a diagram, in accordance with certain implementations.

[0015] FIG. 6B is a diagram, in accordance with certain implementations.

[0016] Reference is made in the following detailed description to accompanying drawings, that form a part hereof, wherein like numerals may designate like parts throughout that are corresponding and/or analogous. It will be appreciated that the figures have not necessarily been drawn to scale, such as for simplicity and/or clarity of illustration. For example, dimensions of some aspects may be exaggerated relative to others. Further, it is to be understood that other implementations may be utilized. Furthermore, structural and/or other changes may be made without departing from claimed subject matter. References throughout this specification to “claimed subject matter” refer to subject matter intended to be covered by one or more claims, or any portion thereof, and are not necessarily intended to refer to a complete claim set, to a particular combination of claim sets (e.g., method claims, apparatus claims, and the like), or to a particular claim. It should also be noted that directions and/or references, for example, such as up, down, top,

bottom, and so on, may be used to facilitate discussion of drawings and are not intended to restrict application of claimed subject matter. Therefore, the following detailed description is not to be taken to limit claimed subject matter and/or equivalents.

DETAILED DESCRIPTION

[0017] According to one implementation of the present disclosure, a circuit (i.e., isolated voltage regulator (IVR) architecture) includes a trio of first switches, a pair of second switches, a pair of (e.g., coupled) inductors including a primary inductor and a secondary inductor, and a first capacitor, where: the circuit is configured to regulate a load.

[0018] According to another implementation of the present disclosure, a circuit (i.e., two-phase IVR having dual coupled inductors) includes a differential voltage input (e.g., at an input side of the circuit) including first and second nodes, where the first and the second nodes can be configured to receive respective first and second voltages. The circuit further includes a first isolated voltage regulator (IVR) including a first pair of (e.g., coupled) inductors, and a second IVR including a second pair of (e.g., coupled) inductors, where the first and the second pair of (coupled) inductors (e.g., share a magnetic core) can be inversely coupled (e.g., can be configured to reduce magnetic core loss and to reduce output voltage ripple noise).

[0019] According to another implementation of the present disclosure, a circuit (i.e., input stacked Voltage Regulator architecture (SIVR)) includes a voltage balancer and two or more stages. Each stage of the two or more stages includes: a two-phase isolated voltage regulator (IVR) including at least a pair of inversely coupled dual inductors and a differential voltage input, and a respective Zener diode and capacitor combination coupled to the voltage balancer and the first two-phase IVR. In certain aspects, the two or more stages are coupled in series.

[0020] Schemes and techniques outlined herein pertain to innovative IVR circuits for input-stacking that converts ‘high’ input voltages (i.e., greater than 2 volts) to a chip-level voltage (i.e., less than or equal to 2 volts). In certain implementations, advantageously, the innovative IVR circuits are designed for but not limited to ‘per-core regulation’, allowing for independent individual control and adjustment of voltage for each core or specific sections within a chip. In certain implementations, the innovative IVRs can be paired, stacked, and interconnected in series to achieve a “large” “conversion ratio” with “good” efficiency exceeding 95%, since the stacking of the input voltages of the IVRs substitutes the conversion and regulation of their input voltages in a traditional cascaded power supply system. Beneficially, this configuration ensures ‘good’ energy density, signifying efficient energy utilization within a compact physical footprint. Further, this efficiency can outperform traditional buck converters while occupying a notably smaller space or volume. Advantageously, this reduction in space utilization is notably significant when compared to other traditional cascaded power supply system used in, for example, servers, PCIE cards, accelerator cards, and similar devices, where the power conversion components and related circuits may occupy over 50% of the board area and limits the functionality of the product.

[0021] Favorably, according to inventive aspects, the innovative IVR circuit provides isolation for logic gates operating at low voltages in contrast with previous on-die voltage stacking schemes where logic gates remained exposed to high input voltages, where at least three problems occur: first, the PDN (power distribution network) of each core or section of the IC is weakened, especially for the ground net (or return path of the circuit), introducing more risk of ground bounce; second, level shifting circuits are required to enable communication between cores or different sections of the IC, making the digital design more complex; third, there will still be logic gates facing high voltages, limiting either the number of stacked stages or the process technology node. Additional inventive schemes and techniques center around an innovative IVR design featuring inductors significantly ‘smaller’ (i.e., an order of magnitude; 10×) in size compared to conventional buck converters. Suitably, this implementation can provide for an in-package or in-PCB solution (i.e., integrating or incorporating specific components, functionalities, or systems within a single packaging substrate or printed circuit board or other types of enclosure). Additionally, the reduced

size of the inductors can translate to a faster response when addressing voltage droops.

Alternatively stated, smaller inductors can offer benefits in managing voltage fluctuations due to faster load transients which occur more often in high-end computing circuits.

[0022] Certain definitions have been provided herein for reference. Power integrity in circuit design refers to the ability of a circuit or system to consistently deliver stable and ‘clean’ power to components. Further, power integrity can encompass various aspects related to ensuring that the voltage levels across the circuitry remain within specified tolerances and that the power supply noise and fluctuations may be minimized. Additionally, power integrity and power supply design (i.e., the process of creating and implementing systems that provide electrical power to various devices, equipment, or circuits) can be considered together in decision-making for determining and delivering chip voltage.

[0023] In systems with multiple cores in a limited space, power density (i.e., the amount of power (i.e., usually measured in watts) that can be generated or handled per unit of volume or surface area) are dramatically increasing. Further, the current in the power delivery path (i.e., the route or trace within an electronic circuit or system through which electrical power can be supplied from a power source (i.e., such as a battery or a power supply) to the various components and subsystems that use electrical power) can increase as well. As the power density and current in the power delivery path increase, at least two problems can occur. First, the direct current (DC) loss (i.e., the loss of electrical power or voltage that can occur within a system or a circuit as DC travels through various components or transmission lines) would increase. Second, VRs may not respond fast enough to a ‘large’ load step (i.e., a significant and sudden change or variation in the electrical load in the computation core, when running certain code or software), causing a ‘large’ voltage drop or surge which may even stops the system.

[0024] In certain aspects, advantageously, innovative IVR schemes, as described herein, can convert high voltage to chip-level low voltage ‘close to’ the load. Therefore, most of the path from the innovative IVR to the load logic gates can be delivered with higher voltage, less current, and less current load steps. Furthermore, the innovative IVRs also help to enable per-core DVFS (i.e., Dynamic Voltage and Frequency Scaling; a power management technique used in electronic systems, such as, for example, processors and integrated circuits, to optimize energy efficiency and performance by dynamically adjusting the operating voltage and clock frequency based on workload demands) so that each core can operate at the core's best performance per watt depending on workloads.

[0025] One issue with traditional integrated VRs (e.g., herein ‘integrated’ corresponds to the VR that is located together with silicon and packaging substrate) is the ‘large’ power loss in both on-board (e.g., from 12V/48V to 1.8V) conversions for the integrated VR input and chip-level low voltage conversions (e.g., from 1.8V to logic). In specific scenarios where enhancing efficiency or maintaining the same conversion ratio is the goal, a tradeoff occurs; namely, increasing the conversion ratio or preserving efficiency might demand sacrificing energy density. Such a tradeoff is undesirable since maximizing board space could be a priority, and the “tightness” (e.g., scarcity) of available board space poses challenges.

[0026] FIG. 1A is a diagram of an example IVR circuit **100**, in accordance with some implementations. As illustrated in FIG. 1A, the example IVR circuit **100** can include a differential voltage input, where the differential voltage input can be configured to provide a differential voltage as an input voltage (i.e., usable by the example IVR circuit **100** to regulate and stabilize an output voltage). Further, the differential voltage can include a first node **104** and a second node **106**, where the first node **104** and the second node **106** can be configured to receive respective first and second voltages. Also, the example IVR circuit **100** can include: a trio of switches **108A**, **108B**, and **108C**, a pair of switches **110A** and **110B**, a pair of coupled inductors **102** including a primary inductor **112A** and a secondary inductor **112B**, and a fly capacitor **114A**. Additionally, the example IVR circuit **100** can be configured to output a regulated differential voltage to a load **118**.

[0027] As illustrated in FIG. 1A, the example IVR circuit **100** can provide an output voltage to a stabilizing capacitor **114B** that can be configured to stabilize the output voltage by ‘smoothing out’ ripples and variations in the output voltage. Further, the stabilizing capacitor **114B** can be coupled to a third voltage (i.e., a ground **116**), the secondary inductor **112B** and the load **118**.

[0028] In certain implementations, the switches **108A**, **108B**, **110A**, and **110B** as well as the fly capacitor **114A** can create a 1:1 switch capacitor (SC) converter **126**. The 1:1 SC voltage converter **126** can be a type of voltage conversion circuit that maintains a 1:1 ratio between the input voltage (i.e., the differential voltage) and output voltage (i.e., the fly capacitor voltage). In this configuration, the differential voltage can be stored temporarily in the fly capacitor **114A** during switching cycles. As an example, it would not be required to have a time duration that the combination of switch **108A** and **108B** is “on” be equal to the time duration that the combination of switch **110A** and **110B**.

[0029] In an example operation of the example IVR circuit **100**, when the switches **108A** and **108B** closed, a first conductive pathway can be established. The first conductive pathway can include the first node **104**, the switch **108A**, the fly capacitor **114A**, the switch **108B**, and the second node **106**. As the fly capacitor **114A** is connected between the first node **104** (i.e., the first voltage) and the second node **106** (i.e., the second voltage), the fly capacitor **114A** can recharge from the differential voltage. When the switches **108A** and **108B** open, the first conductive pathway can be disrupted. Further, the final voltage across the fly capacitor **114A** can at least approximately equate to the differential voltage between the first node **104** and the second node **106**.

[0030] Continuing with an example operation, when the switches **108A** and **108B** are closed, switch **108C** in the example IVR circuit **100** also closes (i.e., synchronous with the switches **108A** and **108B**), and a second conductive pathway can be established. The second conductive pathway can include a third voltage (i.e., the ground **116**), the primary inductor **112A**, the switch **108C**, the secondary inductor **112B**, and the stabilizing capacitor **114B** or the load **118**. When the switch **108C** is closed, current would flow through the pathway comprising the primary inductor **112A**, the switch **108C**, and the secondary inductor **112B**. Since the voltage input of this loop is 0 (as connected to ground) and the output is the load voltage, the current through this pathway will decrease, and the decrease rate is dependent on the total inductance of the primary inductor **112A**, secondary inductor **112B**, and the mutual (coupled) inductance due to the magnetic core **124**.

[0031] Continuing with an example operation, when the switch **108A**, **108B**, and **108C** opens, the switch **110A** and **110B** are closed. A third pathway is then formed by the primary inductor **112A**, the switch **110B**, the capacitor **114A**, the switch **110A**, the secondary inductor **112B**, and the load. Because the voltage on the capacitor **114A** is larger than the voltage on the load, the current in the loop will increase, and the increase rate would be dependent on the total inductance of the primary inductor **112A**, secondary inductor **112B**, and the mutual (coupled) inductance due to the magnetic core **124**.

[0032] Continuing with an example operation, the alterations in the positions of the combination of switches **108A**, **108B**, **108C** and the combination of switches **110A** and **110B** controls the time duration of the current flowing through the inductors **112A** and **112B** to be increasing or decreasing. For instance, the percentage of the time duration of the inductor current to be increasing is regarded as the duty cycle. The load voltage at **118** would be approximately the same percentage as the duty cycle of the input voltage between **104** and **106**. In this way, a control of the duty cycle, taking the output voltage as the input to a feedback, can regulate the load voltage at **118**.

[0033] Continuing with an example operation, the fly capacitor **114A** can accumulate charge from the differential voltage input through the switches **108A** and **108B** that connect the fly capacitor **114A** to the first and second nodes **104** and **106**. However, when the duty cycle is “too large”, corresponding to the time duration for the switches **108A** and **108B** to be closed being “too short”, the parasitic inductance inside the routing and the capacitor **114A** would not allow enough charges to conductor to recharge the fly capacitor **114A**. Accordingly, this can appear as a voltage drop on

the fly capacitor cycle by cycle (but finally maintain at some level when the voltage difference between the input **104** and **106** and the fly capacitor **114A** is large enough for each cycle), and so the conversion efficiency can be impacted. To overcome this, the best way is to choose the fly capacitor to be low-equivalent series inductance (low-ESL) and low equivalent series resistance (low-ESR), and minimize the parasitic inductance and resistance between input **104** and **106** and the fly capacitor **114A**. The ideal implementation of such capacitor is to have an integrated circuit (IC) with all the switches (**108A**, **108B**, **110A**, **110B**, and **108C**) and use a metal-insulator-metal (MIM) capacitor or a deep-trench capacitor (DTC) integrated together with such an IC.

[0034] Continuing with an example operation, duty cycle can be controlled to follow the reference voltage from dynamic voltage and frequency scaling (DVFS). DVFS is a technique used in computing systems, particularly in CPUs, GPUs, and other integrated circuits, to dynamically adjust the operating voltage and clock frequency to optimize power consumption and performance based on the current workload or demand. Through scaling operating voltage and clock frequency, the example IVR circuit **100** can save power during idle or low-demand periods and ramp up performance when needed, thereby balancing energy efficiency with computational requirements. DVFS can allow individual processor cores or components within a chip (e.g., a load, such as the load **118**) to adjust their operating voltage and frequency based on specific workload demands. By tailoring the voltage and frequency to the needs of each core, DVFS optimizes performance per watt for each unit. For example, during low-demand periods, DVFS can reduce the voltage and frequency of specific cores that are not heavily utilized. Advantageously, this can help reduce the total system power consumption. Alternatively, when a core faces a high-demand workload or targeting at a high computing performance, DVFS can increase voltage and frequency. This adaptive approach can ensure that each core operates optimally in terms of performance and power consumption, collectively maximizing the overall efficiency of the system.

[0035] Continuing with an example operation, a computational core that requires a stable voltage input, together with its own decoupling capacitor **114B**, may be represented by the load **118** connected to the coupled inductors **102**. Additionally, the load **118** can be a component or system that relies on the regulated voltage output from the example IVR circuit **100** to function properly. Further, and advantageously, the operations of the load **118** in the example IVR circuit **100** can involve drawing power from the example IVR circuit **100** to perform the core's designated tasks. Moreover, the regulation and stability of the voltage output can ensure proper functionality of the core. Additionally, within a circuit, a load **118** may represent a specific component or functional block that requires power to operate. Further, the load **118** can be a section of a larger system that performs, for example, computational tasks, processes data, or manages certain functionalities. In the context of a processor or chip, the core can refer to an individual processing unit within the larger chip.

[0036] FIG. **1B** is a diagram representation of an example 2-phase IVR circuit **150** having dual coupled inductors **102A** and **102B**, in accordance with some implementations. As illustrated in FIG. **1B**, similar elements to those of FIG. **1A** may not be discussed again for the sake of brevity and conciseness. For example, the operations and configurations of switches **108D**, **108E**, **110C**, **110D**, and **108F** in FIG. **1B** may be identical to that of switches **108A**, **108B**, **110A**, **110B**, and **108C**, as described with reference FIG. **1A**, respectively; and the operations and configurations of capacitor **114C** may be identical to that of capacitor **114A**. Indeed, in various implementations, individually, the operations and configurations of the second IVR circuit **100B** may be identical to that of the first IVR circuit **100A**.

[0037] As illustrated in FIG. **1B**, the example 2-phase IVR circuit **150** includes a differential voltage input that includes the first node **104** and the second node **104**. Further, the example 2-phase IVR circuit **150** includes a first IVR circuit **100A** that includes coupled inductors **102A**. Additionally, the example 2-phase IVR circuit **150** also includes a second IVR circuit **100B** that also includes coupled inductors **102B**. Furthermore, the pair of coupled inductors **102A** and **102B**

can share a magnetic core **124** and can be inversely coupled. When the pair of coupled inductors **102A** and **102B** are inversely coupled and share the magnetic core **124**, changes in a first pair of coupled inductors can induce voltages in the second pair of coupled inductors in a manner that opposes the initial change in the first pair of coupled inductors. Alternatively said, alterations in the current passing through one pair of coupled inductors, such as the coupled inductors **102A**, generate a magnetic field that can affect the other pair of coupled inductors, such as the coupled inductors **102B**, through the shared magnetic core **124**. The induced voltage in the second pair of coupled inductors, such as the coupled inductors **102B**, opposes the initial change in current, exerting an influence that helps stabilize and/or regulate the behavior of each set of the coupled inductors **102A**, **102B**.

[0038] Advantageously, according to inventive aspects, the inversely coupled pairs of inductors provide specific advantages. As may be appreciated, such an inventive design can mitigate certain unwanted effects (e.g., electromagnetic interference or voltage fluctuations) and/or provide better control over the energy transfer within the circuit. By inducing opposing voltages in one pair of inductors, advantageously, the magnetic fields introduced by the opposing voltages would cancel out, and so, the output ripple current and voltage can be greatly reduced. Additionally, when a load increase happens, the increment current in one pair of the inductors will incur increment current in the other pair, no matter which pair is applied with input voltage. Accordingly, the transient performance (i.e., the voltage droop during the load increase or voltage surge during load reduction) can be improved.

[0039] In an example operation of the example 2-phase IVR circuit **150**, switches **108A**, **108B**, and **108C** should be at least approximately 180 degrees out of phase with switches **108D**, **108E**, and **108F**. The switches **108D** and **108E** should be closed after the switches **108A** and **108B** are closed by at least approximately half of a clock period. Also, the switches **110C** and **110D** should be at least approximately 180 degrees out-of-phase with switches **110A** and **110B**. Further, the duty cycle of the switches **110A** and **110B** is at least substantially the same and the duty cycle of the switches **110C** and **110D**. This modulation can regulate the average current through the inductors delivered to the load **118**, filtered by the decoupling capacitor **114B** associated with the load **118**; hence, effectively controlling the output voltage. Through varying the duration of time, advantageously, by the closing of the switches **110A**, **110B**, **110C**, and **110D** (e.g., according to the duty cycle), the example 2-phase IVR circuit **150** can maintain or adjust the output voltage level as needed.

[0040] In another advantage, utilizing the shared magnetic core **124** for the inversely coupled inductors **102A** and **102B** can reduce the physical size and weight of the example 2-phase IVR circuit **150**. While generally a larger inductance value would require a larger core size, advantageously, according to inventive aspects, the magnetic fields and ripple current in the two loops may largely be canceled out with each other. Hence, in such inventive aspects, the inductance value needed would be reduced. Further, the efficiency in space utilization is particularly helpful in compact circuit designs or applications where minimizing the physical footprint is helpful.

[0041] In another advantage, the arrangement of the dual coupled inductors **102A** and **102B** with inverse coupling and the shared magnetic core **124** contributes to better voltage regulation, assists in managing voltage fluctuations, and aids in maintaining a stable output voltage despite variations in input or load conditions.

[0042] FIG. 2 is a diagram representation of an example stacked multi-phase IVR circuit **200**, in accordance with some implementations. As may be appreciated, while the stacked units are shown as 2-phase IVRs in FIG. 2, the phases may be of different quantities in other implementations. For instance, the number of phases for each stage can be 2, 4, 6, . . . N number of stages. As illustrated in FIG. 2, the example stacked 2-phase IVR circuit **200** (i.e., Stacked-input Voltage Regulator, SIVR) includes a first stage **230A** including a first two-phase IVR **240A**. In various implementations, the first two-phase IVR **240A** can include a first IVR circuit **200A** and a second IVR circuit **200B** with a first pair of inversely coupled dual inductors (not shown). Advantageously,

the operations and configurations of the first and second IVR circuits **200A**, **200B** may be identical to that of the IVR circuits **100A**, **100B** (as described with reference to FIG. 1B). Additionally, each IVR, such as two-phase IVR **240A** and two-phase IVR **240B**, is a multi-phase isolated converter. Further, the first two-phase IVR **240A** can be coupled to a first differential voltage input **242A** that includes a first voltage at a first node **204** and a second voltage at a second node **206**. Further, the example stacked 2-phase IVR circuit **200** can include a second stage **230B** that includes a second two-phase IVR **240B**. The second two-phase IVR **240B** can include a first IVR circuit **200C** and a second IVR circuit **200D** that can include a second pair of inversely coupled dual inductors (not shown). Advantageously, the operations and configurations of the first and second IVR circuits **200C**, **200D** may be identical to that of the first and second IVR circuits **200A**, **200B**. Further, the second two-phase IVR **240B** can be coupled to a second differential voltage input **242B** that includes the second voltage at the second node **206** and a third voltage at a third node **208**. Additionally, the first stage **230A** can be coupled in series to the second stage **230B**.

[0043] In an example operation of the example stacked 2-phase IVR circuit **200**, the first differential voltage input **242A** and the second differential voltage input **242B** can be approximately half of the input voltage. Therefore, as the first differential voltage input **242A** to the first stage **230A** and the second differential voltage input **242B** to the second stage **230B** can be approximately half the voltage input (not shown), then the first voltage can be equal to the voltage input, the second voltage can be equal to half of the voltage input, and the third voltage can be ground potential or zero volts.

[0044] As shown, the example stacked 2-phase IVR circuit **200** can include a voltage balancer **252** (i.e., a circuit designed to ensure equal voltage distribution or balance among multiple stages within an electrical system, commonly realized with switched-capacitor topologies). Further, the example stacked 2-phase IVR circuit **200** can include the first stage **230A** including the first two-phase IVR **240A** (that can include the IVRs **200A** and **200B** with the first pair inversely coupled dual inductors (not shown)). Additionally, the first stage **230A** can include the first differential voltage input **242A**, a protective (Zener) diode **254A** (i.e., to allow current to flow in the forward direction (like a regular diode) but also permit current to flow in the reverse direction when the voltage reaches a specific value known as the ‘Zener voltage’), and a decoupling capacitor **256A** coupled to a voltage input **258** and voltage balancer **252**.

[0045] As further illustrated in FIG. 2, the second stage **230B** can include the second two-phase IVR **240B** (that can include the second pair of IVRs **200C** and **200D** with inversely coupled dual inductors (not shown)). Moreover, the second stage **230B** can include the second differential voltage input **242B**, a protective (Zener) diode **254B**, and a decoupling capacitor **256B** coupled to the voltage input **258** and the voltage balancer **252**. As illustrated in FIG. 2, the first stage **230A** can be coupled in series to the second stage **230B**, and the second stage **230B** can be coupled in series with the next stage, and such a coupling can continue to the N-1 stage **230(N-1)** and the N stage **230N**. As may be appreciated, each of the stages **230** may be identical in circuit operation and configurations. As one example, for the two-phase IVR **240N**, the operations and configurations of its respective first and second IVR circuits **200N-1**, **200N-2** may be identical that of the first and second IVR circuits **200A**, **200B**.

[0046] In an example operation, assuming the voltage input **258** to be 12V (i.e., a general input voltage), the differential voltage at each stage of the N-stage example where N is equal to 6 can be 2V. Each stage in the series configuration of the example is a 2-phase IVR circuit **250** which is same as circuit **150**, providing output voltage (**218A**, **218B**, . . . , **218N**) regulation to each load. The output voltages (**218A**, **218B** . . . **218N**) to each load will be close to half of the input voltages (**242A**, **242B**, . . . , **242N**).

[0047] In certain aspects, the differential voltage **242A** in the first stage **230A** can be connected to the protective Zener diode **254A** and the decoupling capacitor **256A** in parallel. Meanwhile, the decoupling capacitor **256A**, in conjunction with the protective Zener diode **254A**, can help stabilize

the output voltage and smooth any ripples or fluctuations caused by load variations and switching activity inside the voltage balancer **252**. Further, the voltage balancer **252** can ensure the uniformity of the differential input voltage across the different stages.

[0048] Continuing an example operation, assume the scenario where one load is unbalanced compared to the other loads, for example, loads **218A**, . . . , **218(N-1)**, and **218N** can be drawing approximately 2 amps at approximately 0.75V, but load **281B** is drawing approximately 7 amps at approximately 1V. In this case, ignoring the power loss to understand how the circuit would operate, at the first stage **230A**, the input current **244A** (I1) is approximately 0.75 amps. The current flowing into the second stage (I2), will be approximately 3.5 amps. The current **244B** is I2-I1 (i.e., 3.5 amps-0.75 amps) that is approximately 2.75 amps. The current flowing into the third stage is the same as the first stage which is 0.75 amps since their load currents and load voltages are the same. Then, the current **244C** is I3-I2 (i.e., 0.75 amps-3.5 amps) that is -2.75 amps. The currents **244B** and **244C** will discharge the capacitor **256B** with a current of 2.75 amps. Then, the voltage balancer would need to output 2.75 amps to the capacitor **256B** to maintain its voltage.

[0049] In a more general case, all stages can have different output voltages and load currents. Such case can be illustrated by a superposition of the example of one stages has additional input current, as stated in paragraph [0048].

[0050] In addition, the protective Zener diodes **254A**, **254B**, . . . , **254N** can act as protective devices that limits the voltages across the capacitors to protect them from over-voltage.

[0051] In one advantage, compared to parallel configurations in the traditional cascaded power supply systems, the output current from the voltage balancer, as described in paragraph [0048], is only 2.75 amps, where in parallel configurations the output current from the VR that converts input voltage 12 volts to the input voltage of each stage 2V is the sum of all input currents into the stages (0.75 amps*5+3.5 amps) which is 7.25 amps. In fact, the voltage balancer would only need to [0052] input the current difference between adjacent stages. Therefore, as stated in paragraph [0020], the described stacking mechanism will offer a much larger energy density in conversion as well as efficiency.

[0053] Continuing an example operation, in certain implementations, the last stage, the N stage **230N**, can be replaced with multiple low dropout regulators (e.g., one or more low dropout regulators) (e.g., LDOs can be voltage regulators designed to maintain a steady output voltage level between the input and output, even when the input voltage is only slightly higher than the desired output voltage). For example, the last stage, the N stage **230N**, can be used to power single or multiple low-noise applications. LDOs can introduce less noise compared to multi-stage IVR circuits. Therefore, in low-noise applications, using LDOs can supply cleaner power delivery to sensitive components. Further, LDOs, especially those designed for low noise, can often incorporate better filtering mechanisms. Thus, improving the stability and reducing high-frequency noise in the system and enhancing performance in noise-sensitive applications like precision analog circuits or sensitive sensors. Additionally, while LDOs can offer lower noise, LDOs might sacrifice some efficiency compared to the multi-stage IVRs. In scenarios where noise is not desired, but power efficiency is not a primary concern, LDOs can be a favorable choice for the last stage **230N**.

[0054] In one example, the last stage, the N stage **230N**, can be used to directly feed high voltage applications (i.e., I/O voltage). LDOs can be designed to provide stable output voltages even with varying input voltages. Thus, using LDOs to directly feed high voltage applications can ensure a more stable voltage source, which is desirable for the proper functioning of sensitive electronics. Further, LDOs often come with built-in protection mechanisms, safeguarding the downstream system from voltage fluctuations and potential damage due to overvoltage or other irregularities.

[0055] In one example, the last stage, the N stage **230N**, LDOs can be used as inputs for an active capacitor, sometimes also called a voltage stabilizer (e.g., since LDOs do not use fly capacitors). In such an implementation, the LDO or a MOSFET with a controlled gate voltage can aid a certain number of loads to reduce the output noise by providing additional regulation when necessary. In

certain implementations, the multiple LDOs can be configured in parallel for the above-described schemes.

[0056] FIG. 3A, is a graphical diagram **300** of an output current (I_{out1}) over time in microseconds of an example stage of an example stacked 2-phase IVR circuit, in accordance with some implementations. As illustrated in FIG. 3A, a load step **304** can increase the amperage draw from the example stage from 2.5 amps to 6.5 amps, and then after the load step **304** back down to 2.5 amps. As illustrated, the Y-axis can represent the output current in amperes (A) and the X-axis can represent the time in microseconds (μs).

[0057] The graph **300** can show three distinct phases. At 2.5 amps, the example stage of the example stacked 2-phase IVR circuit operates in a steady state **308**. The output steady state **308** can indicate a consistent output current before the load step change. When the load steps up from 2.5 amps to 6.5 amps, there can be a transient response **310**. Initially, the output current might drop slightly due to the sudden load increase, showing a dip or a sudden decrease in the current graph. Next, the stage's control mechanisms react to accommodate the load step **304**, and the graph would gradually rise to reach the 6.5 amps output level. When the load steps back down from 6.5 amps to 2.5 amps, there can be another transient response **312**. The output current can decrease from 6.5 amps back to 2.5 amps, potentially showing a temporary overshoot or undershoot before stabilizing back to the steady state **308** of 2.5 amps.

[0058] The steady state output of 2.5 Amps can represent the typical operating condition where the output stage of the example stage of the example stacked 2-phase IVR circuit supplies a constant load of 2.5 amps. Further, this level can indicate the normal, continuous current the output stage of the example stage of the example stacked 2-phase IVR can be designed to deliver to the load without fluctuations. Additionally, the load step **304** of 6.5 amps can represent the common draw or the typical load experienced by a core or a specific component within the output stage of the example stage of the example stacked 2-phase IVR. Further, this can indicate the maximum load that a particular core or component handles during certain operating conditions.

[0059] FIG. 3B is a graphical diagram **350** of an output voltage (V_{out1}) of the example stage of the example stacked 2-phase IVR circuit over time in microseconds in response to the load step **304** in FIG. 3A, in accordance with some implementations. As illustrated in FIG. 3B, the Y-axis can represent the output voltage in millivolts (mV) and the X-axis can represent time in microseconds (μs). At an initial State **302**, an output voltage can initially ripple between 850 mV and 840 mV, with a 10 mV threshold and 1.2% variation of the output voltage. In the context of the example stage of the example stacked 2-phase IVR, voltage ripple at the output can indicate the deviation of the output voltage from an intended level. The fluctuation can occur due to the

[0060] switching action of components, as whose behaviors are described in paragraphs [0026]-[0031], for example, and can be mitigated by the energy storage and release into or out of capacitors and inductors, as described in paragraphs [0026]-[0032].

[0061] As an example, when the load steps up, there can be the initial transient response **306**, such as a rapid drop in voltage to a threshold of 800 mV (i.e., a 50 mV decrease) within a threshold of the first 200 ns (i.e., 5.9% of the output voltage). Correspondingly, the voltage can then rise to another threshold of 830 mV within the threshold of 200 ns (i.e., 2.4% of the output voltage). Further, after 1 microsecond, the voltage returns to another threshold of 840 mV (i.e., 1.2% of the output voltage).

[0062] Moreover, following the load step decrease, another transient response **314** can occur, showing a rise to a threshold voltage of 890 mV (i.e., a 40 mV increase) within the threshold of 200 ns (i.e., 4.7% of the output voltage). Correspondingly, the voltage can 'quickly' fall back to another threshold voltage of 860 mV within 200 ns (i.e., 1.2% of the output voltage). Finally, the output voltage stabilizes back to the initial output voltage of 850 mV after a threshold of 600ns.

[0063] FIG. 4A is a diagram of an example PCB (Printed Circuit Board) **402** as seen from a bottom view for an example voltage balancer **400**, in accordance with some implementations. As illustrated

in a top or plan view of FIG. 4A, in one implementation of the example voltage balancer **400**, the example PCB **402** can be coupled to the package substrate **438** (e.g., as illustrated in FIG. 4B) through metal traces **434** (i.e., conductive pathways made of metal (typically copper) that can be deposited or etched onto a circuit board's surface; FIG. 4B), the vias through the PCB **420A** and **420B**, solder balls array **436**, and the metal traces inside the package substrate **444** (i.e., package **444**) (e.g., **444A**, **444B** as illustrated in FIG. 4B). On the example PCB **402**, there can be a metal plane **404** that can provide the voltage input to the system as V_{in} **258**. Meanwhile, on the example PCB **402**, there can be a metal plane **412** that can provide ground of the system and return path of the total input current. Further, coupled to the metal planes **404** and **412**, cells of capacitors **406A** and **406B** (i.e., standard, or predefined functional units that can serve as building blocks for designing ICs or digital systems) can be configured for voltage balancing purposes within the example voltage balancer **400**. Additionally, coupled to the metal layer **404** and **412** and to the cells of capacitors **406A** and **406B**, cells **408A** and **408B** including FETs (i.e., Field-Effect Transistors can be components used in digital circuit design and integrated circuits commonly used in digital circuits are Metal-Oxide-Semiconductor FETs (MOSFETs)) can be responsible for managing or controlling the voltage balancing operation (e.g., in certain implementations, can include each of the respective Zener diode and capacitor combinations coupled to an example voltage balancer). Furthermore, coupled to the metal planes **404** and **412**, the cells of capacitors **406A** and **406B**, and the cells **408A** and **408B** can be a cell of decoupling capacitors **410** for each stage in a stacked 2-phase IVR circuit that can provide a stable input voltage to each stage. Additionally, the example voltage balancer **400** can include other metal layers and planes for circuitry around that is routed inside the PCB **402**.

[0064] In an example operation, the example voltage balancer **400** can be responsible for managing voltage balancing for each stage of a stacked 2-phase IVR circuit. Further, the example voltage balancer **400** can utilize the cells of capacitors **406A** and **406B** and the cells of FETs **408A** and **408B** to balance the input voltage for the stacked 2-phase IVR circuits. Additionally, the cells of capacitors **406A** and **406B** can stabilize voltage levels, while the cells of FETs **408A** and **408B** can control or manage the voltage distribution across the different stages of the stacked 2-phase IVR circuit. Further, the cells of decoupling capacitors **410** can stabilize and filter the input voltage, reduce noise, and ensure smooth consistent power supply to each stage. Moreover, the metal layer **412** can provide a reference potential and serve as a return path for current flow in the example voltage balancer **400** as well as contributing to stable and safe electrical operation. The example PCB **402** of the example voltage balancer **400** can be dedicated to managing voltage regulation, balancing, and ensuring stable power delivery for each stage of the stacked 2-phase IVR circuit.

[0065] FIG. 4B is a diagram of an example stacked 2-phase IVR circuit layout **450**, in accordance with some implementations. As illustrated in an isometric view of FIG. 4B, the example voltage balancer **400** can include the capacitors **406A** and **406B**, and the switching cells **408A** and **408B**, as mentioned in paragraph [0061]. The decoupling capacitors **410** for each stage may be identical to decoupling capacitors **256A**, **256B**, . . . , **256N** in FIG. 2. The protective Zener diodes **254A**, **254B**, . . . , **254N** can be placed adjacent to the decoupling capacitors or integrated in the FET cells **408A** and **408B**. The 2-phase IVR **424**, also shown as in FIG. 1A and FIG. 1B, includes the integrated circuit **416** configured to integrate switches **108A**, **108B**, **108D**, **108E**, **110A**, **110B**, **110C**, **110D**, **108C**, **108F**, and fly capacitors **114A**, **114C** together. The inversely coupled inductors **112A-112D** are formed by the structure of **426** (as illustrated herein). Central Processing Unit (CPU)₁ **414A** and CPU₂ **414B** (i.e., core 1 and core 2 **414A**, **414B**; first and second processing units) are representative of the load **218A**, **218B** and so forth as similarly shown in FIG. 2.

[0066] As illustrated in FIG. 4B, the example stacked 2-phase IVR circuit layout **450** can be optimized for delivering stable and efficient power to individual computing cores, such as core 1 **414A** and core 2 **414B**, within a larger processing unit, in certain implementations (not shown). Further, the example stacked 2-phase IVR circuit layout **450** can be optimized for powering

individual cores or CPUs, such as core 1 **414A** and core 2 **414B**, within the larger processing unit. Additionally, the example stacked 2-phase IVR circuit layout **450** can include multiple IVR circuits, such as the IVR **424**, stacked one upon the other.

[0067] Additionally, the via **420A** can route a first voltage and the via **420B** can route a second voltage where the difference between the first and second voltage is a differential voltage as the differential input voltage into each stages **242A**, **242B**, . . . , **242N** as in FIG. 2.

[0068] Coupled through metal traces **442** and vias **430** to the cell of IVR FETs **416** can be coupled inductors **422A** and **422B**. As illustrated in FIG. 4B, the coupled inductors **422A** and **422B** can be part of the IVR **424** and can be electromagnetically coupled to a magnetic core **426** within a metal layer **428**. Further, the coupled inductors **422A** and **422B** can output Vdd for the core 1 **414A** through vias **430**. Moreover, the Vdd can be coupled to a stabilizing capacitor **432** interfaced between the coupled inductors **422A** and **422B** and the core 1 **414A** through the vias **430**. In various implementations, the stabilizing capacitor **432** can be a D2D SiCap (Direct-to-Die Silicon Capacitor) that is a component integrated directly onto the silicon of the chip or die. Further, the D2D SiCap can be designed to provide localized or on-chip capacitance, enhancing power delivery efficiency and stability, especially in scenarios where rapid power fluctuations can be to be managed, such as in high-performance processors. In some implementations, the D2D SiCap can be around 1 microfarad (1 uF) D2D silicon capacitor at the output stage.

[0069] In an example operation, the example stacked 2-phase IVR circuit layout **450** can employ a sophisticated system of FETs, such as the cell of IVR FETs **416**, coupled inductors, such as the coupled inductors **422A** and **422B**, and capacitors, such as the stabilizing capacitor **432** to regulate voltage and the fly capacitor within the cell of IVR FETs **416**. Each stage, such as stage 1 **444A** and stage 2 **444B** (i.e., first and second packages **444A**, **444B**), of the example stacked 2-phase IVR circuit layout **450** can represent a dedicated power supply for individual computing cores, such as the core 1 **414A** and the core 2 **414B**. Further, the stages can work in concert to deliver stable and regulated power to the cores. Moreover, the isolation of the IVR cells can ensure each core receives consistent and precise voltage level for optimal computing performance. Furthermore, the use of dual inductor pairs and cells of FETs can aid in balancing and managing the voltage distribution and optimizing power delivery across the cores.

[0070] In some implementations, with reference to FIGS. 4A-4B, a printed circuit board (PCB) (e.g., PCB **400**, **420A**, **420B**) is configured to house: the voltage balancer (e.g., voltage balancer **400**); and each of the respective Zener diode (e.g., integrated in FET cells **408A**, **408B** or adjacent to decoupling capacitor **410**) and capacitor combinations (e.g., cells of capacitors **410**, **406A**, **406B**) coupled to the voltage balancer (**400**); where the PCB (e.g., PCB **400**, **420A**, **420B**) can be coupled to an integrated circuit that comprises one or more processing units (e.g., core 1 **414A**, core 2 **414B**), and a package (**444A**, **444B**) comprising each of the two-phase IVRs (**424**).

[0071] FIG. 5A is a diagram of an example PCB bottom **502** of an example combination voltage balancer and IVR circuit PCB layout **500**, in accordance with some implementations. As illustrated in a top or plan view of FIG. 5A, the example combination voltage balancer and IVR circuit PCB layout **500** can provide a sophisticated power management setup for dual-voltage (i.e., 12V/48V) applications. Further, the example combination voltage balancer and IVR circuit PCB layout **500** can include distinct sections, such as cells of capacitors **506A** and **506B** that can provide voltage balancing, cells of FETs **508A** and **508B** that can provide voltage control, and cells of IVR FETs (with decoupling capacitors) **510** that can provide stable and regulated power.

[0072] As illustrated in FIG. 5A, a metal plane **504** can represent a main power input with a dual-voltage capability, that may allow the system to handle both 12V and 48V power inputs. Further, the cells of capacitors **506A** and **506B** can represent the voltage balancer capacitors that can be configured to maintain and regulate voltage balance within the system. Moreover, the cells of FETs **508A** and **508B** can depict the voltage balancer FETs that can be configured to control and manage voltage balancing operations. Furthermore, the cells of IVR FETs **510** can represent the decoupling

capacitors and the IVRs that can be configured to stabilize the power supply and provide pre-core voltage regulation. Another metal plane **512** can represent a grounding connection that can provide a reference point and return path for the entire power delivery system.

[0073] In an example operation, the cells of capacitors **506A** and **506B** and the cells of FETs **508A** and **508B** can work in conjunction to maintain balanced voltage levels between the 12V and 48V inputs. Further, the cells of IVR FETs **510** with the decoupling capacitors can stabilize the power supply and provide regulated clean power output to the system components while ensuring isolation and efficient voltage regulation. Overall, the example combination voltage balancer and IVR circuit PCB layout **500** can provide a robust and versatile power management system capable of handling dual-voltage inputs while ensuring stable and regulated power delivery to the connected devices or systems.

[0074] FIG. **5B** is a diagram of an example package layout **550** of an example power supply module **552** coupled with an example package substrate **556** (i.e., substrate, package), in accordance with some implementations. According to certain implementations, in contrast to the system shown in FIG. **4A** and FIG. **4B**, the system in FIG. **5B** has an independent power supply module **552** that would not need to be manufactured together with the substrate **556** and load chip **560** (i.e., integrated circuit). Advantageously, this can help risk mitigation in the real product design as well as managing the supply chain. As illustrated in a front view of FIG. **5B**, the example IVR layout **552** can include embedded coupled inductors **554A** and **554B** in the PCB or substrate **558** and voltage balancer (e.g., the cells of capacitors **506A** and **506B** along with the cells of FETs **508A** and **508B**). Further, the example IVR with related switches and fly capacitors can be integrated in the IC **510**.

[0075] As illustrated in FIG. **5B**, the example IVR layout **552** with the embedded inductors **554A** and **554B** can provide a low-cost implementation where the example IVR layout **552** and load balancer, along with support circuitry, can be separate from the substrate **556**. Instead, the example IVR layout **552** with the embedded inductors **554A** and **554B** can be coupled via solder balls **564** to the vias through PCB **562** that can have substrate **556** mounted thereon.

[0076] In an example operation, the example package layout **550** would still maintain voltage regulation and load balancing but can provide the option to separate the power management components from the load IC; helping a system designer pick a desired supplier for different components and integrate them together. By doing so, costs can potentially be reduced as these elements are not integrated into the substrate **556**. Further, the example IVR layout **552**, in combination with the embedded coupled inductors **554A** and **554B** and associated circuitry, can manage voltage fluctuations and ensure simple and low-risk development of not only the power delivery to the load IC **560** on the substrate **556**, but also other signals through other components on the PCB **562** and substrate **556**.

[0077] In some implementations, with reference to FIGS. **5A-5B**, a first printed circuit board (PCB) (e.g., **500**, **558**, **562**) may house the voltage balancer; each of the respective Zener diode (e.g., integrated in FET cells **508A**, **508B** or adjacent to IVR FETS with decoupling capacitors **510**) and capacitor combinations (e.g., **506A**, **506B**); coupled to the voltage balancer; and each of two-phase IVRs (e.g., IVR FETS **510**). Also, a second PCB may house an integrated circuit (IC) comprising one or more processing units (e.g., load IC **560**). Advantageously, in such implementations, the two-phase IVRs (e.g., IVR FETS **510**) would be distinct from and not integrated in a package substrate **556**.

[0078] FIG. **6A** is a diagram representation of example inversely coupled inductor pairs **600**, in accordance with some implementations. FIG. **6B** is a schematic diagram of the example inversely coupled inductor pairs **600**, in accordance with some implementations. Such inversely coupled inductor pairs **600** can be utilized in various example implementations, as described herein, e.g., with reference to FIGS. **1B**, **2A**, and **2B**. As illustrated in FIGS. **6A** and **6B**, the example inversely coupled inductor pairs **600** can feature four inductors, L1 **602**, L2 **604**, L3 **606**, and L4 **608**,

arranged in two pairs with a shared magnetic core **610A** and **610B**. In some implementations, each inductor, of inductors **L1 602**, **L2 604**, **L3 606**, and **L4 608**, measures **125** micrometers in diameter and **187.5** micrometers in height and can have an inductance range of approximately **1** to **5** nanohenries (nH).

[0079] In an example operation, the inductors, **L1 602**, **L2 604**, **L3 606**, and **L4 608**, can be paired as follows: **L1 602** and **L2 604** can form one pair, while **L3 606** and **L4 608** can form the other pair. As illustrated by the dotted arrows, current flow in the inductors **L1 602** and **L3 606** can flow from the bottom of **L1 602** and **L3 606** to the top (i.e., from node a to node b on **L1 602** and from node h to node g on **L3 606**). Correspondingly, this current flow can represent the secondary inductors providing current flow to the stabilizing capacitor/load. Conversely, current flow in the inductors **L2 604** and **L4 608** can flow from the top of the inductors to the bottom (from node c to node d on **L2** and from node f to node e on **L4**). Correspondingly, this current flow can represent the primary inductors providing current flow from ground.

[0080] Across the magnetic core **610A** and **610B**, node d aligns with node a, node c with node b, node e with node h, and node f with node g. Further, the example inversely coupled inductor pairs **600** can represent a coupled inductor configuration that can enable efficient energy transfer between the inductors, **L1 602**, **L2 604**, **L3 606**, and **L4 608**, while maintaining a smaller size compared to traditional IVRs. Moreover, the shared magnetic core **610A** and **610B** can facilitate the coupling of magnetic flux between the inductors that can aid in energy transfer and can enhance the overall performance of the system. Furthermore, the example inversely coupled inductor pairs **600** can optimize space utilization and inductor efficiency for the intended application.

[0081] The subject matter of the claims is not limited to the implementations and illustrations provided herein, the intention is that modified forms of those implementations including portions of implementations and combinations of elements of different implementations be in accordance with the claims. In the development of any such implementation, there is an appreciation as in any engineering or design project, that numerous implementation-specific decisions can be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, that vary from one implementation to another. Moreover, while such a development effort is complex and time consuming, there is an appreciation for those of ordinary skill having benefit of these implementations the development would nevertheless be a routine undertaking of design, fabrication, and manufacture.

[0082] Reference has been made in detail to various implementations, examples of that can be illustrated in the accompanying drawings and figures. In the above description, numerous specific details can be set forth to provide a thorough understanding of the implementations provided herein. However, the implementations provided herein can be practiced without these specific details. In some other instances, well-known methods, procedures, components, circuits, and networks have not been described in detail so as not to unnecessarily obscure details of the implementations.

[0083] Although the terms first, second, and the like can be used herein to describe various elements, these elements should not be limited by these terms. These terms can be used to distinguish one element from another. For example, a first element can be termed a second element, and, similarly, a second element is able to be termed a first element. The first element and the second element can be both elements, respectively, but they are not to be considered the same element.

[0084] The terminology used in the description of the implementations provided herein is for the purpose of describing implementations and is not intended to limit the implementations provided herein. As used in the description of the implementations provided herein and appended claims, the singular forms a, an, and they can be intended to include the plural forms as well, unless the context clearly indicates otherwise. The term and/or as used herein refers to and encompasses all possible combinations of one or more of the associated listed items. The terms includes, including,

comprises, and/or comprising, when used in this specification, specify a presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components and/or groups thereof.

[0085] While the foregoing is directed to implementations of various techniques described herein, other, and further implementations can be devised in accordance with the implementations herein, that may be determined by the claims that follow.

[0086] Although the subject matter has been described in language specific to structural features and/or methodological acts, the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above can be disclosed as example forms of implementing the claims.

Claims

1. A circuit comprising: a trio of first switches; a pair of second switches; a pair of inductors comprising a primary inductor and a secondary inductor; and a first capacitor, wherein: the circuit is configured to regulate a voltage to a load.
2. The circuit of claim 1, further comprising: a differential voltage input comprising first and second nodes, wherein the first and second nodes are configured to receive respective first and second voltages, wherein: the circuit is configured to regulate the voltage to the load based on a differential voltage provided by the differential voltage input.
3. The circuit of claim 1, further comprising: a second capacitor configured to stabilize an output voltage, wherein: the second capacitor is coupled to a third voltage and the secondary inductor; and the third voltage comprises 0 volts.
4. The circuit of claim 3, wherein: the secondary inductor and the second capacitor of the circuit are coupled to the load; and the pair of inductors are configured to respond to a voltage droop of an output voltage based on inductance values of the pair of inductors and the second capacitor.
5. The circuit of claim 1, wherein: the trio of the first switches and the pair of second switches are configured for distinct circuit operation; and the out-of-phase switching cycle is configured to provide independent circuit operation between the trio of the first switches and the pair of the second switches.
6. The circuit of claim 1, wherein: the first capacitor is coupled between a first switch of the trio of the first switches and a second switch of the trio of the first switches; the first switch and a second switch of the trio of the first switches is configured to provide a first electrical pathway with the first node, the first capacitor, and the second node; and a third switch of the trio of the first switches is configured to provide a second electrical pathway between the primary and the secondary inductors and the load.
7. The circuit of claim 1, wherein: the circuit is configured to control a duty cycle of the pair of the second switches to provide output voltage regulation.
8. The circuit of claim 1, wherein: the pair of second switches are configured to provide a third electrical pathway between the first capacitor, the pair of inductors and the load.
9. The circuit of claim 1, wherein: the first capacitor is configured to store a first charge in response to an activation of the trio of the first switches and a dissipation of the first charge in response to an activation of the pair of the second switches.
10. The circuit of claim 1, wherein: the load comprises one or more cores, and the one or more cores comprises a processing unit of one or more processing units.
11. A circuit comprising: a differential voltage input comprising first and second nodes, wherein the first and the second nodes are configured to receive respective first and second voltages; a first isolated voltage regulator (IVR) comprising a first pair of inductors; and a second IVR comprising a second pair of inductors, wherein the first and the second pair of inductors are inversely coupled.

- 12.** The circuit of claim 11, wherein: the first and the second pair of the inductors are configured to share a magnetic core; the magnetic core is configured to enable a magnetic field produced by the first pair of the inductors to impact a magnetic field of the second pair of the inductors.
- 13.** The circuit of claim 11, wherein: the first and the second pair of the inductors are configured to reduce output voltage ripple; and the output voltage ripple comprises one or more fluctuations in an output voltage of the circuit.
- 14.** The circuit of claim 11, wherein: in response to a load step up, the first and the second pair of the inductors are configured to reduce output voltage droop; and the output voltage droop comprises a reduction in an output voltage of the circuit based on a load change.
- 15.** The circuit of claim 11, wherein: the pair of inductors are configured to respond to a voltage droop of an output voltage based on inductance values of the pair of inductors.
- 16.** A circuit comprising: a voltage balancer; two or more stages, wherein: each stage of the two or more stages comprises: a two-phase isolated voltage regulator (IVR) comprising at least a pair inversely coupled dual inductors and a differential voltage input, and a respective Zener diode and capacitor combination coupled to the voltage balancer and the two-phase IVR, and a load coupled to the two-phase IVR; and wherein the two or more stages are coupled in series.
- 17.** The circuit of claim 16, wherein: a last stage of the two or more stages is coupled to one or more low dropout regulators (LDOs); and the one or more LDOs are configured to maintain an approximately constant output voltage.
- 18.** The circuit of claim 16, wherein: the differential voltage input of a first stage of the two or more stages comprises first and second nodes configured to receive respective first and second voltages; and the differential voltage input of a second stage of the two or more stages comprises the second node and a third node configured to receive the second voltage and a third voltage, respectively.
- 19.** The circuit of claim 16, further comprising: a printed circuit board (PCB) configured to house: the voltage balancer; and each of the respective Zener diode and capacitor combinations coupled to the voltage balancer, wherein the PCB is coupled to an integrated circuit comprising one or more processing units and a substrate package comprising each of the two-phase IVRs.
- 20.** The circuit of claim 16, further comprising: a first printed circuit board (PCB) configured to house: the voltage balancer; each of the respective Zener diode and capacitor combinations coupled to the voltage balancer; and each of two-phase IVRs a second PCB configured to house: an integrated circuit (IC) comprising one or more processing units.
-