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DESCRIPTION CN105449987A

10 Power supply unit

[0001]

14 Technical Field

[0002]

18 The present invention relates to a power supply device, and more particularly to an internal structure of the power supply device.

[0003]

23 Background technique

[0004]

27 As human beings' requirements for smart life increase, society's demand for data processing is growing.

28 The global energy consumption for data processing reaches hundreds of billions or even trillions of degrees per year on average; and a large data center can occupy tens of thousands of square meters.

30 Therefore, high efficiency and high power density are key indicators for the healthy development of this industry.

[0005]

35 The key unit of a data center is the server, whose motherboard is usually composed of data processing chips such as CPU, chipsets, memory, their power supply and necessary peripheral components.

37 As the processing power per unit volume of servers increases, the number and integration of these processing

chips also increase, resulting in an increase in space occupancy and power consumption.

³⁹ Therefore, the power supply that powers these chips (also called motherboard power supply because it is on the same motherboard as the data processing chip) is expected to have higher efficiency, higher power density and smaller size to support energy saving and floor space reduction for the entire server and even the entire data center.

[0006]

⁴⁷ In the server, the main board (Main Board PCB) is used for energy and signal transmission.

⁴⁸ The data processing chip and its power supply are placed on the main board. The casing height of a server is usually a standard value, which can be defined by the industrial standard U, such as 1U, 1.5U, 2U, etc. (1U = 1.75 inches = 44.45 mm). Taking a 1U server, which is about 40mm in height (the actual size of 1U varies due to differences in assembly labor, etc.), as an example, the motherboard is usually a PCB board with 6 to 50 layers, which is quite expensive. Under the limitation of a certain server casing height, while ensuring efficiency expectations, reducing the area occupied by the motherboard power supply, that is, the horizontal area of the motherboard power supply, can not only reduce the volume and increase the power density, but also reduce costs. In this article, the power per unit horizontal area of a power source is called "power pressure".

[0007]

⁵⁹ When using the same technical capability to design a power supply with a power of P_o , generally the larger the volume V of the power supply, the easier it is to achieve a higher efficiency, that is, the efficiency of the power supply is proportional to its volume V .

⁶² The volume V is equal to the height H multiplied by the horizontal area S . The power pressure P_p is P_o/S . Limit efficiency to a fixed target, that is, the efficiency remains unchanged. The relationship between power pressure P_p and height H can be obtained: that is, the larger the H is, the larger P_p can be. In other words, to improve P_p , we should consider solutions based on the utilization of height H . Of course, if the goal is to pursue efficiency, the height should be fully utilized according to the previous logic. Therefore, how to utilize height is the key to balancing power pressure P_p and efficiency.

[0008]

⁷¹ The thickness or height of the motherboard power supply can be 7mm or even thinner at best. Therefore, within a certain server height limit, such as 1U height, there can still be a space of more than 20mm above it.

⁷³ Its efficiency can be as high as 90% or even higher. Since its power consumption is only a fraction of that of a data processing chip (such as 0.1 times), it actually has the opportunity to handle thermal issues on its own without a cooling unit. In this way, the space on the motherboard power supply is not fully utilized.

[0009]

⁷⁹ Usually there are two specific methods for motherboard power supply.

⁸⁰ One is to use PCB as the carrier and assembled with discrete components. Through years of efforts in the

industry, this type of motherboard power supply has achieved good efficiency and power density. However, the assembly of discrete components requires necessary clearance and safety distance, which affects the further reduction of the horizontal area, and the irregular height also affects the subsequent heat treatment.

[0010]

88 Another approach to motherboard power supply is to use certain packaging technology to integrate the various power supply components into a very regular component.

90 Due to the use of packaging technology, its power density is significantly improved, the efficiency is not inferior, and the regular shape is conducive to subsequent heat treatment, which is a good solution. However, the packaging technology used in this approach mainly aims to reduce the height of the motherboard power supply to achieve a reduction in size and an increase in power density. However, blindly reducing the height will limit further reduction in its footprint. Therefore, this solution is only one of the better solutions for pursuing power density, but it still has great deficiencies in pursuing the power pressure of the data center motherboard power supply.

[0011]

100 Summary of the invention

[0012]

104 The present invention aims at the deficiencies of the prior art and proposes a new solution, which maximizes the balance between power pressure and efficiency and is suitable for applications with large restrictions on horizontal area, such as the power demand of data processing occasions such as data centers.

[0013]

110 One aspect of the present invention is to provide a power supply device, which includes a control unit and a power unit, which are stacked and adjacent to a load, the power unit includes at least one power semiconductor device, and the control unit includes at least one chip with control or driving capabilities; pins electrically connect the control unit and the power unit; the control unit is used to control the power unit so that the power unit supplies power to the adjacent load.

[0014]

118 In one embodiment, the control unit and the power unit are stacked and arranged on a main board, and the main board is also provided with the load.

[0015]

123 In one embodiment, the power supply device further includes: pads distributed on the side surfaces of the

power unit and the side surfaces of the control unit and electrically connected to the pins.

[0016]

129 In one embodiment, the pins include surface mount pins distributed on the outer surfaces of the power unit and the control unit and electrically connected to the pads.

[0017]

134 In one embodiment, the surface mount pins cover more than 30% of the outer surface area of the power unit.

[0018]

138 In one embodiment, the pins further include through-hole pins, which cooperate with surface mount pins to realize electrical connection between the power unit/control unit and the mainboard.

[0019]

143 In one embodiment, the pads are also distributed on a surface of the power unit that is perpendicular to the side surface where the pads are located.

[0020]

148 In one embodiment, the power unit includes a main power unit part and a secondary power unit part, the main power unit part has side distribution pads, and the secondary power unit part is stacked on the main power unit part.

[0021]

154 In one embodiment, the power unit and the load are located on the same side of the main board, and the control unit is located on the other side of the main board opposite to the power unit.

[0022]

159 In one embodiment, the power supply device further includes a power unit, two power units and a control unit are stacked on a mainboard, and the control unit controls the two power units through pins.

[0023]

164 In one embodiment, the two power units are respectively a power unit of a first-stage DC-DC converter and a power unit of a second-stage DC-DC converter; the control unit includes a control unit of the first-stage DC-DC converter and a control unit of the second-stage DC-DC converter.

[0024]

170 In one embodiment, the first-stage DC-DC converter is an isolated DC-DC converter; and the second-stage DC-DC converter is a non-isolated regulated DC-DC converter.

[0025]

175 In one embodiment, the non-isolated regulated DC-DC converter is closer to the mainboard than the isolated DC-DC converter.

[0026]

180 In one embodiment, one of the two power units includes a power unit of a first-stage DC-DC converter and a power unit of a second-stage DC-DC converter.

[0027]

185 In one embodiment, the first-stage DC-DC converter is an isolated DC-DC converter, and the second-stage DC-DC converter is a non-isolated regulated DC converter.

[0028]

190 In one embodiment, the isolated DC-DC converter includes: an isolated transformer, a plurality of primary switch tubes and a secondary switch tube; the non-isolated regulated DC converter is a load point step-down DC converter.

[0029]

196 In one embodiment, the isolation transformer, the secondary switch tube, the output capacitor for isolating the DC-DC converter, and the load point DC converter are arranged in the same power unit.

[0030]

201 In one embodiment, the primary switch tube is arranged in a control unit, and the control unit also includes a primary switch tube drive circuit, a control drive circuit of the load point DC converter and a control chip.

[0031]

206 In one embodiment, the primary switch tube is located near a side of the control unit.

[0032]

²⁰⁹ In one embodiment, thermally conductive insulating glue is filled between the power units and between the power units and the control unit.

[0033]

²¹⁵ In one embodiment, conductive welding material is filled between pins electrically connecting the power unit and the control unit and between pins electrically connecting the power unit and the power unit.

[0034]

²²⁰ In one embodiment, each power unit includes a planar transformer, and two planar transformers share a magnetic core.

[0035]

²²⁵ In one embodiment, the air gap of the magnetic core is disposed in the stacking gap between the power units.

[0036]

²²⁹ In one embodiment, the power unit includes a plurality of switching devices, a carrier board for carrying the switching devices, and an insulating sealing material for covering the switching devices; the switching devices are distributed near the pads.

[0037]

²³⁵ In one embodiment, the insulating sealing material is provided with a recess for mounting the pin.

[0038]

²³⁹ In one embodiment, the power unit further includes an inductor and a capacitor, and the inductor, the capacitor and the switch device are located on the carrier board near the side of the power unit.

[0039]

²⁴⁴ In one embodiment, the pads include a primary side group pads and a secondary side group pads, and the primary side group pads and the secondary side group pads are at least spaced apart by a safety distance.

[0040]

²⁴⁹ In one embodiment, the primary side group pads include a first signal pad and a first power pad, and a cross-sectional area of the first power pad is larger than a cross-sectional area of the first signal pad.

[0041]

²⁵⁴ In one embodiment, the secondary side group pads include a second signal pad and a second power pad, and a cross-sectional area of the second power pad is larger than a cross-sectional area of the second signal pad.

[0042]

²⁵⁹ In one embodiment, the number of the second power pads is greater than the number of the first power pads.

[0043]

²⁶³ In one embodiment, the first-stage DC-DC converter is a non-isolated regulated DC-DC converter; and the second-stage DC-DC converter is an isolated non-regulated DC-DC converter.

[0044]

²⁶⁸ In one embodiment, the first-stage DC-DC converter is a buck-boost circuit.

[0045]

²⁷² Another aspect of the present invention is to provide a power supply device, which includes: a control unit, a power unit and a pin.

²⁷⁴ The control unit and the power unit are stacked and arranged adjacent to a load having a data processing chip, the power unit contains at least one power semiconductor device, and the control unit contains at least one chip having control or driving capability; the pins electrically connect the control unit and the power unit; the control unit is used to control the power unit so that the power unit supplies power to the adjacent load.

[0046]

²⁸¹ In one embodiment, the control unit and the power unit are stacked and arranged on a main board, and the main board is also provided with the load of the data processing chip.

[0047]

²⁸⁶ In one embodiment, the power supply device further includes: pads distributed on the side surfaces of the power unit and the side surfaces of the control unit and electrically connected to the pins.

[0048]

²⁹¹ In one embodiment, the maximum operating voltage of the power input is higher than 20V, and the power unit includes: at least one transformer, the transformer includes at least one primary side and at least one

secondary side; at least one synchronous rectification combination and an output capacitor combination; high-frequency energy is transmitted from the primary side to the secondary side, and is rectified into direct current by the synchronous rectification combination and then transmitted to the output capacitor for integration.

[0049]

302 In one embodiment, the control unit is implemented by an embedded process and has a thickness less than 2 mm.

[0050]

307 In one embodiment, the power unit is a resonant circuit, and the operating frequency is higher than 1 MHz.

[0051]

311 In one embodiment, an input filter is further stacked above the control unit.

[0052]

315 In one embodiment, the power unit is a first-stage DC-DC converter; the control unit is a power unit of a second-stage DC-DC converter.

[0053]

320 In one embodiment, the first-stage DC-DC converter is a non-isolated regulated converter; and the second-stage DC-DC converter is a non-regulated isolated converter.

[0054]

325 In one embodiment, the first-stage DC-DC converter is an isolated converter; and the second-stage DC-DC converter is a non-isolated regulated converter.

[0055]

330 In one embodiment, the power supply device further includes at least a heat dissipation unit, which is placed above the pad or the pin combination, and the thermal resistance between the heat dissipation unit and the pad or the pin is less than 5 degrees Celsius/Watt.

[0056]

336 In one embodiment, there is an insulating material between the heat dissipation unit and the pad or the pin

assembly.

[0057]

³⁴² In summary, the technical solution of the present invention has obvious advantages and beneficial effects compared with the prior art.

³⁴⁴ The above technical solution can achieve considerable technological progress and has wide industrial application value.

³⁴⁶ Since the present invention adopts a stacked structure, the height of the power supply can be better utilized, and a smaller floor space is achieved under a certain volume; at the same time, there is enough volume to ensure high efficiency, achieving a balance between high power pressure and high efficiency.

³⁴⁹ It also provides support for realizing higher-performance data processing devices.

[0058]

³⁵³ The above description will be described in detail below with reference to implementation methods, and a further explanation will be provided for the technical solution of the present invention.

[0059]

³⁵⁸ BRIEF DESCRIPTION OF THE DRAWINGS

[0060]

³⁶² In order to make the above and other objects, features, advantages and embodiments of the present invention more clearly understood, the accompanying drawings are described as follows:

[0061]

³⁶⁷ FIG1 is a side view of a power supply device according to an embodiment of the present invention;

[0062]

³⁷¹ 2 to 16 are diagrams showing power supply architecture and stack content allocation according to an embodiment of the present invention;

[0063]

³⁷⁶ FIG. 17 to FIG. 19 are diagrams showing the contents that may be covered by the control unit and the power unit according to the embodiments of the present invention;

[0064]

³⁸⁰ 20 to 23 are stacking structure designs according to embodiments of the present invention;

[0065]

³⁸⁵ 24 to 34 are pin layouts shown according to embodiments of the present invention;

[0066]

³⁸⁹ 35 to 40 are heat dissipation processing structures according to embodiments of the present invention; and

[0067]

³⁹³ 41 to 43 are diagrams showing configurations of magnetic cores according to embodiments of the present invention.

[0068]

³⁹⁸ Detailed ways

[0069]

⁴⁰² In order to make the description of the present invention more detailed and complete, reference may be made to the attached drawings and various embodiments described below, in which the same numbers represent the same or similar components.

⁴⁰⁵ On the other hand, well-known components and steps are not described in the embodiments to avoid unnecessary limitations on the present invention.

[0070]

⁴¹⁰ In the embodiments and claims, the description of "coupled with" may generally refer to one component being indirectly connected to another component through other components, or one component being directly connected to another component without going through other components.

[0071]

⁴¹⁶ The technical aspect of the present invention is a power supply device, which can be applied to a server or widely used in various technical fields.

⁴¹⁸ It is worth mentioning that the power supply device of this technical aspect adopts a stacked structure, so the height of the power supply can be better utilized, achieving a smaller footprint at a certain volume.

[0072]

⁴²² FIG. 1 is a side view of a power supply device according to an embodiment of the present invention.

⁴²⁴ As shown in FIG. 1, the power application device (e.g., power supply device) includes a mainboard 110, a power unit 120, a control unit 130, and pins 140.

⁴²⁶ A load 150 is also disposed on the mainboard 110. The power unit 120 is located on the mainboard 110. The control unit 130 and the power unit 120 are stacked and disposed on the mainboard 110 adjacent to the load 150. The pins 140 electrically couple the mainboard 110, the control unit 130 and the power unit 120. In this embodiment, there are a plurality of pins 140 and they are respectively located on the sides of each of the power unit 120 and the control unit 130. The two power units 120 and the control unit 130 are stacked on the mainboard 110.

⁴³² The control unit 130 is used to control the power unit 120. Specifically, the control unit controls the two power units 120 through the pins 140 so that the power units 120 supply power to the adjacent loads 150.

⁴³⁴ The load 150 is a digital processing IC, such as a central processing unit (CPU), and a heat dissipation unit such as a heat sink 151 is provided on the CPU.

⁴³⁶ The power unit 120 includes at least one power semiconductor device (such as the switch tubes S21, S22, S23, S24 in FIG. 3 and the switch tubes S21, S22, S23, S24, S31, S32, S33 in FIG. 11), and the control unit 130 includes at least one chip with control or driving capability (such as the control circuit 310 in FIG. 3 and the control circuit 1100 and DSP in FIG. 11).

[0073]

⁴⁴³ In one embodiment, the power supply device is disposed on a mainboard 110. The mainboard 110 is also provided with a load 150 of a data processing chip (eg, CPU). The power supply device includes a power unit 120, a control unit 130, and pins 140.

⁴⁴⁶ The control unit 130 and the power unit 120 are stacked and arranged on the mainboard adjacent to the load 150. The pins electrically connect the mainboard 110, the control unit 130 and the power unit 120. The control unit 130 is used to control the power unit 120 so that the power unit 120 supplies power to the adjacent load 150.

[0074]

⁴⁵³ In general, the DC/DC power supply includes at least two units (ie modules): a control unit 130 and a power unit 120.

⁴⁵⁵ The two modules are stacked one above the other and are electrically connected to each other via conductors (i.e., pins 140) to transmit electrical signals.

⁴⁵⁷ The power unit 120 includes at least one active switch element. The power unit 120 receives input power and generates corresponding output power through the conduction and disconnection of the active switch element to provide it to the load 150, such as a data processing chip.

⁴⁶⁰ The control unit 130 module includes at least one control chip, which sends a control signal to the active switch element of the power unit 120 to control the on and off of the element.

⁴⁶² The unit disposed on the upper side has some pins fixed by the unit disposed on the lower side, and transmits electrical signals to the main board 110 (eg, PCB board).

[0075]

⁴⁶⁷ In this way, due to the stacked structure, the height of the power supply can be better utilized, achieving a smaller footprint at a certain volume; at the same time, there is enough volume to ensure high efficiency, achieving a balance between high power pressure and high efficiency.

⁴⁷⁰ It also provides support for realizing higher-performance data processing devices.

[0076]

⁴⁷⁴ Power architecture and stacking content distribution involved

[0077]

⁴⁷⁸ FIG. 2 is a schematic diagram of various types of power converters (i.e., motherboard power supply 200) that may be involved in a server motherboard.

⁴⁸⁰ The power converter input is usually direct current with a wide voltage range, including high voltage, such as 200-500V (taking 400V as an example), medium voltage, such as 18-72V (taking 48V as an example) and low voltage, such as 5-15V (taking 12V as an example).

⁴⁸³ Regardless of the input voltage, a corresponding DC/DC converter is required to convert it into a required output to provide it to the load 150, such as a data processing chip, such as a central processing unit (CPU) and memory.

⁴⁸⁶ The output voltage range is also very wide to meet different load requirements, for example, the output voltage can be as low as 0.8V or even lower, or as high as 12V or even higher.

⁴⁸⁸ When the load 150 is a CPU and a memory, the output voltage is usually between 0.8V and 2V.

⁴⁸⁹ Therefore, the power specifications involved mainly include the following:

[0078]

⁴⁹³ (1) Converter 210 converts 400V to 48V: the input is in a voltage range of 200-500V (400V is typical), and the output is a stable output or a fixed ratio with the input, with a typical value of about 48V, or a voltage range of 18V-72V.

⁴⁹⁶ Since the output voltage is relatively high, it is usually not directly connected to the data processing chip load. Another converter with different specifications needs to be cascaded behind it to adjust the voltage to a level that is suitable for the load.

[0079]

⁵⁰² (2) Another converter (not shown) converts 400 V to 12 V: the input is in a voltage range between 200 and 500 V (400 V is typical), and the output is a stable output or a fixed ratio with the input, with a typical value of around 12 V.

⁵⁰⁵ Since the output voltage is low, it can be connected to some data processing loads, such as hard disks.

506 However, when the load voltage is lower, for example, 0.5 to 5V, another specification DC/DC converter
needs to be cascaded behind it to adjust the voltage to a level suitable for the load.

[0080]

511 (3) Another converter (not shown) converts 400V to 0.5-5V: the input is a voltage range between 200-500V
(400V is typical), and the output is a stable voltage adjusted as needed, for example, between 0.5-5V.

513 Its output can be directly connected to data processing chips, such as CPU, memory, etc.

[0081]

517 The three types of converters in (1), (2) and (3) above have high voltage input and need to comply with high
voltage safety insulation requirements. Their insulation voltage can be as high as DC voltage 2000V or even
higher.

[0082]

523 (4) Converter 220 converts 48V to 12V: the input is in a voltage range of 18 to 72V (48V is typical), and the
output is a stable output or a fixed ratio with the input, with a typical value of about 12V, or in a voltage range
of 3V to 15V.

526 Converters of this specification can be directly connected to certain data processing loads, such as hard disks.

[0083]

530 (5) Converter 230 converts 48V to 0.5-5V: the input is a voltage range between 18 and 72V (48V is typical),
and the output is a stable voltage adjusted as needed, for example, between 0.5 and 5V.

532 And the output can be directly connected to data processing chips, such as CPU, memory, etc.

[0084]

536 (6) Converter 240 converts 12V to 0.5-5V: the input is a voltage range between 3V and 15V (12V is typical),
and the output is a stable voltage adjusted as needed, between 0.5 and 5V.

538 Its output can be directly connected to data processing chips, such as CPU, memory, etc.

539 Since it is a low voltage input, no isolation is required.

540 The output is directly connected to data processing chips, such as CPU, memory, etc.

[0085]

544 For the three types of converters (4), (5) and (6) above, since the input/output voltages are relatively low, the
withstand voltage requirements of the converters are relatively low, usually below a DC voltage of 2000V.

[0086]

548 When the converter output is 0.5-5V, since the output can be directly connected to a load 150, such as a data processing chip, the power converter is required to output low voltage and high current and have a high dynamic response capability. For example, when the load 150 is a CPU, a response capability of 1000A/ns is required. Therefore, the power converter needs to be placed close to the load.

553 Therefore these power supplies are called point-of-load power supplies (Point of the load).

554 Among them, the voltage regulation module (VRM) that supplies power to the CPU needs to be powered nearby.

[0087]

559 As the power converters with various input and output specifications mentioned above are all arranged on the mainboard, they are suitable for achieving both high power pressure and high efficiency in a stacking manner.

561 Of course, combinations of various converters are also suitable for stacking.

[0088]

565 As mentioned above, power supplies with 400V and 48V inputs usually have input and output safety withstand voltage requirements due to the large input and output voltage difference, and usually use transformers to isolate and transfer energy.

568 Of course, if necessary, for example, to achieve a wider input or output range, a low voltage input power supply such as a 12V input power supply can also use a transformer to transfer energy.

[0089]

573 The above-mentioned converters of various specifications can adopt various types of topologies to realize the conversion of electric energy, such as pulse width modulation (PWM) type forward circuit, full-bridge circuit, phase-shifted full-bridge circuit, half-bridge circuit, flyback circuit, etc.

576 In order to achieve high power density, a higher operating frequency is usually required, such as 500 kHz, 1 MHz, or even above 2 MHz.

578 In order to achieve high efficiency at such a high frequency, it is usually necessary to select a resonant type circuit, i.e. a pulse frequency modulation (PFM) type LLC series resonant converter (LLC-SRC), a parallel resonant converter (PRC), or the like.

[0090]

584 Figure 3 shows a half-bridge LLC circuit.

585 As shown in FIG3, the circuit includes a main circuit and a control circuit 310.

586 The main circuit includes: an input capacitor C1, a resonant capacitor C2, a resonant inductor L1, a transformer T1, primary-side switches S11, S12 and secondary-side switches S21, S22, S23, S24, wherein the input capacitor C1 is connected to the primary-side switches S11, S12, the primary-side switches S11, S12 are connected to a series circuit consisting of the resonant capacitor C2, the resonant inductor L1 and the

primary side of the transformer T1, the secondary side of the transformer T1 is connected to the secondary-side switches S21, S22, S23, S24, and the output capacitor C3 is connected to the secondary-side switches S21, S22, S23, S24.

⁵⁹⁴ The primary side switches S11 and S12 receive input power and convert the DC input signal into an AC signal, which is transmitted to the secondary side through the resonant inductor L1, the resonant capacitor C2 and the transformer T1, and through the secondary side synchronous rectification circuit (such as the secondary side switches S21, S22, S23, S24), an output voltage is generated on the output capacitor C3 and output power is provided to the load.

⁶⁰² It is particularly mentioned that, since the output is low voltage and high current, in order to reduce losses, it is usually necessary to connect low voltage and high current components (such as T1 secondary side, secondary side rectifier tube, output capacitor) in parallel to obtain low resistance.

⁶⁰⁵ For example, "a combination of rectifying combinations S21, S22 and a secondary side" and "another combination of rectifying combinations S23, S24 and another secondary side" are connected in parallel.

⁶⁰⁷ Since the output voltages are different, the structure of the secondary side of the transformer is not limited to the center-tapped rectifier structure shown in FIG3, and may also be other structures such as a full-bridge rectifier structure.

[0091]

⁶¹³ The control circuit 310 generates a control signal and provides it to the driver 320 for driving the primary side switches S11 and S12, and the driver 330 for driving the secondary side switches S21-S24 to control the opening and closing of each switch element in the main circuit, such as the switches S11, S12, S21-S24, etc.

⁶¹⁶ Of course, the control circuit 310 also includes other necessary components such as sampling, protection, and communication, which are not shown in the figure and will not be described here.

[0092]

⁶²¹ Since the power unit 120 operates at a high frequency and the output of the converter is low voltage and high current, the loop consisting of the secondary side of the transformer, the output synchronous rectification circuit and the output capacitor is usually as small as possible to meet the high frequency requirements.

⁶²⁴ Therefore, the transformer T1, the synchronous rectification circuit (ie, the secondary side switches S21, S22, etc.), and the output capacitor C3 must be placed in the same unit circuit (ie, the power unit 120).

[0093]

⁶²⁹ In one embodiment, the maximum operating voltage of the power input is higher than 20V, and the power unit 120 includes: at least one transformer T1, the transformer T1 includes at least one primary side and at least one secondary side; at least one synchronous rectification combination (such as: secondary side switches S21, S22) and an output capacitor combination (such as: output capacitor C3).

⁶³³ High-frequency energy is transferred from the primary side to the secondary side, rectified into DC by the synchronous rectification combination, and then transferred to the output capacitor for integration.

[0094]

- 639 On the other hand, there are usually many peripheral circuits around the control circuit 310, and the signals that need to be processed are usually very low, and they are also required to be placed nearby to improve the anti-interference ability.
- 642 Therefore, the control circuit 310 and its peripheral circuits need to be in the same unit circuit (i.e., the control unit 130).
- 644 In one embodiment, the control unit 130 is implemented by an embedded process and has a thickness less than 2 mm.
- 646 The power unit is a resonant circuit with an operating frequency higher than 1MHZ.
- 647 An input filter is further stacked above the control unit.

[0095]

- 651 As for the driving electrical appliances 320, 330, the primary side switch tubes S11-S12, the resonant capacitor C2, and the resonant inductor L1, they can be placed in the power unit 120 or the control unit 130 according to actual conditions.
- 654 The input capacitor C1 has the function of suppressing voltage spikes on the primary-side switching tubes S11-S12, so it is best to place it in the same unit close to the primary-side switching tubes S11 and S12.
- 656 L1/C2 etc. can be integrated with other components such as T1.
- 657 Even the magnetizing inductance of T1 can be connected in parallel with the primary side of the transformer by an independent inductor to help optimize the performance of T1.

[0096]

- 662 As shown in FIG1 , the entire power circuit is stacked by combining the control unit 130 and the power unit 120, which will effectively reduce the horizontal area of the power circuit 120 and reduce the area occupied by the mainboard 110 when it is finally placed on the mainboard 110.
- 665 As shown in FIG1 , the control unit 130 or the power unit 120 may be packaged using a packaging technology, such as molding using a plastic packaging material, to form a module.
- 667 Alternatively, both can be made using discrete components.
- 668 Regardless of the method, each unit can include a carrier board, such as a printed circuit board (PCB) or a ceramic circuit board (DBC), etc., to carry the components of the unit. Alternatively, the components within the unit can be directly stacked, such as directly stacking switching elements with inductors, capacitors and other components.
- 672 When the primary side switch tubes S11~S12, the resonant capacitor C2, and the resonant inductor L1 are integrated into the power unit, the circuit in the control unit will mainly process the control signal, so its height can become very small, such as 5mm, 3mm or even less than 1mm.

[0097]

- 678 In situations where the power is relatively high, multiple main circuits shown in Figure 3 can be connected in

parallel for input and output.

680 In this way, the entire power supply device can be structurally configured such that one main circuit is used as one power unit, and multiple identical power units and control units are stacked, as shown in FIG1 .

683 The control unit 130 can be placed below and the two power units 120 can be stacked above, or the control unit can be placed between the two power units, or the control unit can be placed above the two power units.

685 Regardless of the method, the height is fully utilized to achieve power improvement without changing the floor space.

687 The control unit 130 may be one, for controlling the on and off of the switch elements in the two power units 120, or may be multiple, for example, two, for respectively controlling the on and off of the switch elements in the corresponding power units.

690 Of course, the control unit may also be integrated with one of the power units, so that at least one power unit 120 is stacked with a control unit 130, wherein the control unit integrates at least one main circuit.

692 As shown in Figure 4.

693 The power module includes a power unit 120 and a control unit 130 stacked up and down, and electrically connected to each other through pins 140.

695 The power unit 120 integrates a DC-to-DC converter, and the control unit 130 integrates another DC-to-DC converter and a control circuit, and the control circuit controls the two DC-to-DC converters.

[0098]

700 As previously mentioned, a power supply device receives an input and generates an output to provide energy to a load.

702 The power supply device can adopt a single-stage converter, such as the circuit shown in Figure 3, to achieve the voltage conversion requirement and even isolation.

704 Of course, multi-stage converters can also be used.

705 Due to the limitation of device characteristics, single-stage circuits are usually not suitable for wide-range input and output. Therefore, for loads with a wide voltage range, such as CPU, memory and other loads in server power applications, it is more appropriate to use a two-stage power supply, that is, one stage is responsible for isolation and the other is responsible for voltage regulation, each performing its own function to achieve the optimal state.

710 For example, see Figures 5 and 6.

[0099]

714 As shown in FIG. 5 , the input voltage V_{in} is in a wide voltage range, such as 38 to 60 V. The input voltage is isolated through a front-stage circuit such as an isolated non-regulated DC-DC converter, i.e., an isolated transformer module DCX (here, "non-regulated" means that the input and output of the circuit within the working range are in a fixed ratio, i.e., the output varies in proportion to the input, such as $V_{in}/V_o=n$, and $V_{in}/V_o=4$ is taken as an example in the figure), to achieve high-voltage isolation; and then the output is provided to the load through a rear-stage circuit such as a non-isolated regulated DC-DC converter.

720 For example, the subsequent circuit may be a point-of-load conversion unit POL, which can be used to achieve output voltage regulation and dynamic response requirements.

722 Since the subsequent circuit has the adjustment capability, the preceding circuit may not have the adjustment capability.
722 However, if necessary, the front stage may also have or partially have adjustment capability, that is, an isolated DC-DC converter.

[0100]

729 1 and 5, the two power units 120 are respectively the power unit of the first-stage DC-DC converter and the power unit of the second-stage DC-DC converter; the control unit 130 includes the control unit of the first-stage DC-DC converter and the control unit of the second-stage DC-DC converter.
732 Specifically, the first-stage DC-DC converter is an isolated DC-DC converter; the second-stage DC-DC converter is a non-isolated regulated DC-DC converter (as shown in FIG5), and the non-isolated regulated DC-DC converter is closer to the mainboard 110 than the isolated DC-DC converter.
735 Alternatively, the first-stage DC-DC converter is a non-isolated regulated DC-DC converter, and the second-stage DC-DC converter is an isolated non-regulated DC-DC converter.
737 For example, the first stage DC-DC converter is a buck-boost circuit.

[0101]

741 In one embodiment, the power unit 120 is a first-stage DC-DC converter; the control unit 130 is a power unit of a second-stage DC-DC converter.
743 For example, the first-stage DC-DC converter is a non-isolated regulated converter; the second-stage DC-DC converter is a non-regulated isolated converter; or, the first-stage DC-DC converter is an isolated converter; the second-stage DC-DC converter is a non-isolated regulated converter.

[0102]

749 Since the front stage is a non-adjustable isolation transformer module DCX, the circuit can be designed to operate at its optimal operating point, making the circuit relatively simple and highly efficient.
751 When the isolation transformer module DCX is a resonant circuit, the isolation transformer module DCX can operate near the resonant frequency; and when the DC transformer DCX is a PWM circuit, such as a full-bridge circuit, it can operate in a state with a maximum duty cycle.
754 The subsequent stage is an adjustment circuit, such as a point-of-load DC converter POL, which is usually implemented by a step-down conversion circuit (Buck circuit) (such as: point-of-load step-down DC converter) so that the output characteristics meet the requirements of the load. The circuit is simple and the output voltage range is very wide.
758 The combination of the two can easily achieve requirements such as wide input/output voltage range, high output voltage accuracy and dynamic response characteristics.
760 When the isolation transformer module DCX adopts a resonant circuit, such as an LLC-SRC circuit, it is easier to achieve high efficiency at high frequency of the power supply and have a high power density.
762 Of course, since the latter stage has an adjustment function, if DCX has a certain degree of output voltage adjustment capability for some reason, such as reducing the intermediate BUS voltage range to reduce the

withstand voltage amplitude of the intermediate BUS capacitor and related power devices, it will not affect the implementation and function of this embodiment.

[0103]

771 As shown in FIG. 6, the input voltage V_{in} is in a wide voltage range, such as 38V to 60V.

772 The input voltage V_{in} is converted into a required value, such as a constant voltage of 48V, by a front-stage circuit, such as a non-isolated regulated DC converter, i.e., a front-stage voltage regulator module (FrontRegulateModule) FRM, and can respond to dynamic changes in the load; and then an isolated non-regulated DC converter, i.e., an isolated transformer module DCX, is used in series thereafter to achieve voltage isolation and realize voltage reduction requirements.

777 In this architecture, the voltage regulation and dynamic response of the final output, i.e., the output of the subsequent circuit, are both achieved by the previous circuit.

779 Since the front-stage voltage regulation module FRM does not need to be isolated, it can be implemented using a variety of topologies such as buck, boost, or buck and boost circuits. In order to meet high-frequency requirements, soft switching technology can be added.

782 Therefore, the front-stage voltage regulator module FRM can also have a high power density, and the same is true for the isolation transformer module DCX.

[0104]

787 1 and 6, one of the two power units 120 includes a power unit of a first-stage DC-DC converter and a power unit of a second-stage DC-DC converter. The first-stage DC-DC converter is an isolated non-regulated DC-DC converter, and the second-stage DC-DC converter is a non-isolated regulated DC converter (as shown in FIG6).

[0105]

794 Under the above two power supply architectures, taking a motherboard power supply with an output power of 200W as an example, the isolation transformer module DCX and the load point DC converter POL (Figure 5 architecture) or the front-stage voltage regulator module FRM and the isolation transformer module DCX (Figure 6 architecture) can be realized in 1/16 brick (1.3in*0.9in, 33mm*22.9mm). Therefore, its power pressure is also 85.5W/inch² (actually, due to the installation gap between the two units, its power pressure is lower).

800 Because the height of both can be within 10mm or even 7mm.

801 If the method of the present invention is used, the two are stacked, as shown in FIG7, the control unit and the power unit are integrated into an isolation transformer module DCX and a load point DC converter POL, which are stacked on the mainboard 110; or, as shown in FIG8, the control unit and the power unit are integrated into a front-stage voltage regulation module FRM and an isolation transformer module DCX, which are stacked on the mainboard 110.

806 Thus, the power output can be instantly doubled to 171W/inch², greatly reducing the area occupied by the motherboard.

808 Even though stacking may require some additional height, such as for heat dissipation, the total height can be less than 25mm, which can fully meet the height requirements of the server (up to 30mm).

[0106]

813 In order to reduce the volume occupied by the internal interconnection pins, the power stages of the isolation transformer module DCX and the point-of-load DC converter POL can be built in the same power unit 120, and the control circuits of the two stages can be built in the same control unit 130.

816 This allows the power section to be centralized for better efficiency and smaller footprint.

817 The power unit part can also select one or more parallel connections according to actual power requirements. As shown in FIG9 , multiple power units 120 are connected in parallel and all include an isolation transformer module DCX and a power stage in a load point DC converter POL. The control unit 130 includes a control circuit in the isolation transformer module DCX and the load point DC converter POL.

[0107]

824 FIG. 11 is a schematic diagram of the circuit architecture in FIG. 5 .

825 The difference between it and FIG3 is that it adds a subsequent circuit, a circuit of a load point DC converter POL, on the basis of FIG3, such as the buck circuit in FIG11.

827 Because the output is low voltage and high current, the implementation of POL is often composed of multiple step-down circuits in parallel.

829 The specific number of parallel connections depends on the actual situation.

830 Figure 11 takes three parallel connections as an example.

831 The isolated non-regulated DC-to-DC converter includes: an isolation transformer T1, a plurality of primary switching tubes S11, S12 and a plurality of secondary switching tubes S21, S22, etc.; the non-isolated regulated DC converter is a point-of-load DC converter POL.

834 The circuit of each load point DC converter POL includes switch tubes S31, S32 and S33 and filter inductors L21, L22 and L23 connected to the switch circuit, thereby forming a step-down circuit accordingly. The output of the circuit of each load point DC converter POL is connected in parallel to both ends of the capacitor C4 to generate output power to provide to the load. The control chip 1100 is used to generate a control signal to control the on and off of a switch element in the point-of-load DC converter POL. To achieve high efficiency, the power unit 120 at least includes an isolation transformer T1 of an isolation transformer module DCX, synchronous rectifier switches S21-S24, an output capacitor C3, and switches S31-S33 in a point-of-load DC converter POL. In other words, the isolation transformer T1, the secondary switch tubes S21, S22, S23, S24, the output capacitor C3 for isolating the DC-DC converter, and the load point DC converter POL are arranged in the same power unit 120. Of course, FIG. 11 also includes filter inductors L21 to L23 and output capacitor C4. The control unit 130 at least includes a control chip 1100 and its peripheral circuits, such as the signal processor DSP and the peripheral circuits of the controller (not shown in the figure). The primary switch tubes S11 and S12 are arranged in the control unit 130. The control unit 130 also includes a primary switch tube driving circuit, a control driving circuit of the load point DC converter and a control chip 1100.

[0108]

⁸⁵³ The architecture of the front-stage voltage regulator module FRM and the isolation transformer module DCX can also be implemented in this way to achieve both higher efficiency and higher power pressure. As shown in Figure 10, multiple power units 120 are connected in parallel and all include the power stages in the front-stage voltage regulator module FRM and the isolation transformer module DCX, and the control unit 130 includes the control circuits in the front-stage voltage regulator module FRM and the isolation transformer module DCX.

[0109]

⁸⁶² Of course, the above-mentioned isolation transformer module DCX can also be an adjustable converter or a semi-regulated converter.

⁸⁶⁴ The change of its function does not affect the contribution of the present invention to the improvement of its efficiency and power pressure.

[0110]

⁸⁶⁹ In the above embodiments, the power supply adopts a direct current to direct current (DC/DC) converter.

⁸⁷⁰ These examples can be applied in architectures where DC power is input directly to the server motherboard, for example.

⁸⁷² Of course, with the development of technology, there will also be an alternating current power supply AC directly input to the server motherboard 1200. As shown in FIG. 12, an alternating current power source AC (e.g., 220V_{in}) is directly connected to a server mainboard 1200, and the input power is transmitted to a corresponding load through a mainboard power supply 1210 composed of power modules 1201 to 1205 connected in cascade or parallel at various levels. Compared with the mainboard power supply with DC input, this structure also has a pre-stage cascaded electromagnetic interference filter (EMI filter) 1221, a power factor correction (PFC) circuit 1222, and an auxiliary power module (Aux. Power Module) 1223, etc. Under this architecture, the stacking technology described above can also be used.

[0111]

⁸⁸³ As shown in FIG13, it is a schematic diagram of a cascaded power factor correction circuit 1320 after an electromagnetic interference filter 1310.

⁸⁸⁵ As shown in the figure, the electromagnetic interference filter 1310 receives an AC input, such as V_{AC}=220V, and then provides an output signal to the subsequent PFC circuit for power factor correction. The power factor correction circuit 1320 can actually adopt various types of topologies, such as boost, buck, double boost, and totem pole structure as shown in the figure, etc. Taking the totem pole power factor correction circuit shown in the figure as an example, the main circuit of the power factor correction circuit 1320 includes a high-frequency capacitor C, a power factor correction inductor L and a power switching device, namely, a first bridge arm composed of active switching elements S1 and S2 connected in series and a second bridge arm composed of passive switching elements D1 and D2 connected in series. The first and second bridge

arms are connected in parallel with the high-frequency capacitor C, and the power switch device and the high-frequency capacitor C are electrically coupled to the power factor correction inductor L; the midpoints of the two bridge arms are respectively connected to the output of the electromagnetic interference filter 1310 or connected to the output of the filter through the input inductor. The corresponding power factor correction drive and control circuit 1330 is used to control the power switching device. Specifically, the power factor correction drive and control circuit 1330 includes an output sampling voltage divider circuit (Voltage divider) 1331 for sampling the output VDC of the power factor correction main circuit, input sampling voltage divider circuits 1332, 1333, and 1334 for sampling the input voltages VAC-P and VAC-N, and sampling circuits such as the input current IL. The output signal VDC of the output voltage sampling voltage divider circuit 1335 is compared with the corresponding reference signal VDC-ref, and then a signal is output through the voltage loop controller 1335 to be operated with VAC to obtain the reference signal IL-ref of the input current IL. After the input current IL is compared with IL-ref after operation, it passes through the current loop controller 1336 to obtain the corresponding control signals PWM-S1 and PWM-S2 for controlling the switches S1 and S2.

[0112]

⁹¹⁸ FIG. 14 is a schematic diagram showing a stacked structure of a power factor correction circuit.

⁹¹⁹ The first bridge arm, the second bridge arm, the output capacitor and the corresponding drive, the control unit, etc. in the main circuit of the power factor correction circuit can be integrated into the control unit, and the power factor correction inductor L can be placed in the power unit 120, and then the power unit 120 is placed on the control unit 130 for stacking. In this way, the electrical distribution parameters can be optimized in the control unit 130 to obtain better characteristics, leaving more volume for the inductor, which is also conducive to improving the efficiency to a higher level. Of course, the main circuit can also be integrated into the power unit 120, and the drive and control circuit 1330 can be integrated into the control unit 130.

[0113]

⁹³⁰ As shown in FIG15, a power unit, an electromagnetic interference filter unit, can be stacked on the basis of FIG14.

⁹³² Because electromagnetic interference filtering mainly serves the power factor correction circuit, stacking it close to the power factor correction circuit is more conducive to optimizing the design and achieving higher characteristics. Likewise, the auxiliary power supply can be stacked in a similar manner to the power factor correction circuit. That is, the control, drive, primary-side power devices and high-frequency capacitors are integrated into the control unit, while the transformer, output rectifier and output capacitors are integrated into the power unit. The stacking shown in the above figures can obtain the advantages of the present invention in terms of both power density and power pressure. Of course, the stacking order can be adjusted according to actual needs.

[0114]

⁹⁴³ On the other hand, the present invention is also applicable to DC/AC applications, that is, inverter applications.

⁹⁴³ FIG16 shows that the power unit 120 includes an inverter circuit. A DC input V_{in} generates an AC signal after passing through a first bridge arm composed of active switch elements S1 and S2 connected in series and a second bridge arm composed of active switch elements S3 and S4 connected in series. The signal generates an output voltage V_o on the output capacitor C_o after passing through a filter circuit (including a filter inductor L and an output capacitor C_o). The specific control and drive circuits are not shown in this figure. Such an inverter may also adopt a stacked structure similar to the power factor correction circuit described above. That is, the control unit integrates the first and second bridge arms of the main circuit, the input capacitor C_{in} and the control drive circuit, while the power unit integrates the output filter inductor L and the output capacitor C_o . Of course, all components of the main circuit, namely the output capacitor C_{in} , S1-S4, the filter inductor L and the output capacitor C_o , can also be integrated into the power unit 120, and the control unit can integrate the control drive circuit and the like.

[0115]

⁹⁵⁹ What the control unit can cover

[0116]

⁹⁶³ The main purpose of the control unit is signal processing, and most of its components are relatively small in height. Therefore, in order to improve the overall space utilization, the components contained in the unit can be evaluated based on their thinness.

[0117]

⁹⁶⁹ As mentioned above, the controller responsible for sending signals to the drive circuit or switching device (in some specific applications, the drive circuit can also be regarded as a part of the controller) and its peripheral necessary resistors, capacitors and other components must be included in the control unit.

⁹⁷² However, as the integration of control chips increases, there may still be a certain amount of surplus space after all these components are placed.

⁹⁷⁴ Therefore, more components can be added to the control unit.

⁹⁷⁵ Taking FIG. 3 as an example, if all power devices are placed in the power unit 120, the arrangement diagram is shown in FIG. 17. The left side of Figure 17 is a diagram showing the positions of components of the power unit 120, and the right side is a diagram showing the positions of components of the control unit 130. The square boxes in FIG. 17 represent carriers 1710 and 1720 on which components are placed. The components placed on the carriers 1710 and 1720, wherein the symbols in the left figure correspond to the corresponding components in FIG. 3. As shown in FIG. 17, if the power unit 120 and the control unit 130 have the same area, that is, the carrier boards 1710 and 1720 of the two units have the same area, the utilization rate of the control unit 130 is obviously low. To improve the utilization rate of each unit area, some components can be moved from the power unit to the control unit 130. As shown in FIG18, the primary switch tubes S11 and S12 are located near the side of the control unit, that is, placed on the carrier 1720 of the control unit 130. The

selection criteria for the components to be moved should not only be thin, but also have no effect on the electrical characteristics or even have a better effect.

[0118]

- 1000 The primary-side switch tubes S11 and S12 on the high-voltage input side are semiconductors, so their thickness can be comparable to or even thinner than the control chip, and they can be placed in the control unit.
- 1003 Taking the primary side switch tubes S11 and S12 as MOSFETs as an example, if they are placed in the power unit, as shown in FIG3 , there will be more than 4 pins (the gate and source of each switch) connected to each other between the power unit 120 and the control unit 130; if they are placed in the control unit 130, the connection between the control unit 130 and the power unit only requires 2 pins, such as the connection point of the primary side switch tubes S11 and S12 in FIG11 and the source of the switch tube S12. Moreover, since the high voltage input side is not particularly sensitive to the distributed parameters of the circuit, moving it to the control unit 130 will have a completely acceptable impact on the electrical characteristics. Of course, if the primary-side switches S11 and S12 are moved, the input capacitor C1 and its driving circuit must also be moved to the control unit 130. Such close placement can not only reduce the voltage spike of the primary-side switches S11 and S12, but also reduce unnecessary pins in the power unit.

[0119]

- 1016 FIG. 18 is a schematic diagram showing some switch components arranged in the control unit 130 .
- 1017 The control unit 130 includes an input capacitor C1, a resonant capacitor C2 and primary side switches S11 and S12; the power unit 120 includes a plurality of switch devices, a carrier board 1710 carrying the switch devices (such as S11 and S12), and an insulating sealing material 3430 (shown in FIG. 34) covering the switch devices; the switch devices are distributed near the pads 3440 (shown in FIG. 34). The power unit 120 includes a transformer T1, a resonant inductor L1, an output capacitor C3, and secondary side switches S21, S22, S23, and S24. It can be seen that the utilization rate of the right control unit 130 is significantly improved, and the inductor (i.e., the resonant inductor L1), the capacitor (i.e., the output capacitor C3) and the switching device (i.e., the secondary side switch tubes S21, S22, S23, S24) are located on the carrier 1710 near the side of the power unit. The left power unit 120 can provide more space for magnetic components, which is of great significance to the improvement of efficiency. Therefore, high efficiency and high power pressure can be better balanced. It is worth noting that since the switches S11 and S12 are not in the power unit 120, the input of the power unit 120 comes from the control unit 130 and is a high-frequency AC power signal modulated by the switches S11 and S12, such as 500KHZ or even above 3MHZ, and the amplitude can be below 12V or even above 400V.

[0120]

- 1034 If in some applications, the positions of the secondary side switches S21, S22, S23, S24 are not sensitive to electrical characteristics, the secondary side switches S21, S22, S23, S24, the driver 330, the output capacitor C3, the OringMOS, etc. can also be arranged in the control unit 130, so that the space can be more fully

utilized.

[0121]

1044 In the stacking structure shown in FIG10 , if the control unit 130 is disposed at the bottom and the control unit 130 is located between the power unit 120 and the mainboard 110, the pins from the output end of the power unit 120 to the mainboard become longer, which may affect the responsiveness to load changes, especially when the load is a data processing chip such as a CPU.

1048 At this time, the output capacitor C3 of part of the main circuit can be set in the control unit 130 (or the corresponding POL output capacitor C4 in Figure 11), and the control unit 130 includes the output capacitor C3, thereby reducing the influence of the pin length, as shown in Figure 19.

1051 Of course, this requires that the output capacitor C3 is partially well connected to the pin 140 during design.

[0122]

1055 In the above-mentioned embodiments, the control unit 130 includes a carrier board, such as a printed circuit board or a lead frame.

1057 Of course, the entire control unit can also be implemented using embedded technology. The control unit 130 may also be a method in which components within the unit are stacked on each other and electrically connected using conductors on the surface of the components. It is implemented using embedded technology, that is, some electrical components, such as control ICs, resistors, capacitors and even power semiconductors, are buried in the carrier board. This allows the control unit to be very thin and small, and enables relatively fine internal and unit surface wiring. Embedded technology can easily realize the interconnection between the upper and lower surfaces without position restriction, that is, the corresponding pins can be directly realized without the need to output the pins from the side as shown in Figure 34. Taking a circuit containing a transformer and a synchronous rectifier, such as a bridge resonant circuit, as an example, the control unit can be implemented using Embedded technology and then stacked with a power module containing a transformer and a synchronous rectifier. It has the following characteristics: the power unit contains at least one transformer (Core and Winding), an output synchronous rectifier, some output capacitors, and an SRMOS control signal (which can be generated by the power module itself or provided by the control unit) to achieve high power level efficiency; the power unit still uses side output Pins, which at least include the positive and negative poles of the output and the two poles of the modulated input side high-frequency pulse. The control unit is at least embedded with a control logic IC, which is responsible for sampling, control signal and drive signal generation, protection, and necessary communication with the outside of the power supply. It contains at least one pair of high-voltage side power elements and generates input-side high-frequency pulses transmitted to the power unit. The pins of the control unit can be arranged sideways or penetrate the upper and lower surfaces at any position as required, or they can be connected from the inside to the surface and arranged on one surface as required. After being embedded, the control unit can be very thin, such as about 1mm, and the pins are mainly SMD to enhance the connection strength of the pins. Thanks to Embedded technology, it is easy to achieve wiring capabilities similar to those of PCBs, and to realize richer interconnections on the surface, which can support more content-rich stacking combinations. For example, some necessary components

that are difficult to embed in the control unit, such as the input electromagnetic interference filter, that is, the input capacitor, can be placed on the surface of the control unit together with the power unit. Because it can achieve a very small volume, it is more suitable for high-frequency working environments, such as working frequencies above 1MHZ. Therefore, the conversion circuit is preferably a resonant circuit. The thickness of the control unit implemented by Embedded is also preferably less than 2mm.

[0123]

1115 The control unit 130 may be a collection of control circuits as described in the previous examples, may be a control circuit including components of some power circuits, or even a drive circuit, or may be a power converter with complete functions as shown in FIG. 7 .

1118 In this way, the structure in which the control unit and the power unit are stacked and connected to each other through pins or even to the main board through pins becomes a structure in which two or more power units are stacked on each other. It is just that at least one of the power units contains components of the control unit. This structure is usually suitable for system architectures such as multi-stage power unit parallel or cascade.

[0124]

1126 What can be covered by the power unit

[0125]

1130 Generally speaking, the power unit can be a complete and independently working DC/DC or AC/DC power converter, such as; an isolation transformer module DCX, a load point DC converter POL, a front-stage voltage regulation module FRM, a regulated bus converter (Regulated Bus Converter, RBC), a power factor correction circuit, an auxiliary power module, etc., that is, a power converter including a power stage circuit and a control circuit, or it can be only their power stage circuit, or even only a part of the power stage circuit as in the previous embodiment, such as the part that needs to be placed closest to each other, such as the three key components of the transformer T1, the output rectifier element (such as the secondary side switches S21, S22, S23, S24) and the output capacitor C3 in Figure 18.

1138 The power unit can have isolation capability like the isolation transformer module DCX and RBC, that is, it contains at least one transformer, or it can be like the load point DC converter POL, the front stage voltage regulator module FRM, and the power factor correction circuit without isolation, that is, it contains at least one inductor.

[0126]

1145 The transformer and inductor on the power unit can be integrated or separate.

[0127]

1149 The input of the power unit can be direct current, industrial frequency alternating current, or high frequency alternating current as shown in Figure 18.

[0128]

1154 The output of the power unit can be in various voltage ranges from 0.1 to 12V, above 12V to 400V.

1155 The load can be other power converters, hard disks, memories, graphics processing chips, CPUs, communication ASICs, and other data processing chips.

[0129]

1160 In addition, the power unit, like the control unit, can include a carrier board, such as a printed circuit board or a wire rack, and the electrical connection between the power unit devices is achieved through the traces on the carrier board. The components in the power unit can be placed on the carrier board; it can also be implemented using embedded technology, that is, some electrical components, such as resistors, capacitors, etc., are buried in the carrier board.

1165 In addition, the power unit may also be formed by stacking components within the unit and making electrical connections using conductors on the surface of the components.

[0130]

1170 When the entire circuit includes two or more power units, the completely identical power units can be connected in parallel as shown in Figure 19 to achieve higher power and higher current conversion, or connected in series to achieve higher power and higher voltage conversion; different power units can also be connected in series as shown in Figure 8 to achieve a larger working range; or different power units can be used to share one input and provide multiple outputs to achieve a power conversion function; or different power units can be used to provide one output and accept multiple inputs to achieve a power conversion function.

[0131]

1180 In summary, the application scope of the present invention is very wide and can help the server achieve higher performance.

1182 Of course, the power converter implementation method of the present invention may also be applicable to other application occasions.

[0132]

1187 Stacked structure design

[0133]

1191 One aspect of the present invention is to decompose a power converter into at least two units, namely, at least one control unit 130 and a power unit 120, in a server, and then stack them to make full use of the space height, thereby realizing a high-efficiency and high-power pressure power converter to achieve a higher performance server.

1191 There are several forms of power converter stacking.

[0134]

1199 1.

1200 As shown in FIG. 19 , the units 120 , 130 have a similar area and are stacked up and down to form a power converter, which is then disposed on the mainboard 110 .

[0135]

1205 2.

1206 As shown in FIG. 20 , the control unit and the power unit with a larger area are used as the first unit 2010 and the power unit with a smaller area are used as the second unit 2020. The first unit 2010 is located between the second unit 2020 and the main board 110. The areas of the units 2010 and 2020 are different. The smaller unit is stacked on the larger unit to form a power converter, which is then set on the main board 110.

1210 As shown in FIG. 21 , the control unit and the power unit are integrated into an isolation transformer module DCX and a front-stage voltage regulator module FRM. This is one of the implementation methods of the above-mentioned front-stage voltage regulator module FRM + isolation transformer module DCX architecture. However, in order to obtain higher efficiency, the inductor L of the front-stage voltage regulator module FRM is externalized.

1215 After the front-stage voltage regulator module FRM and its external inductor L are arranged above the isolation transformer module DCX, a power converter is formed and then arranged on the main board 110.

[0136]

1220 3.

1221 As shown in Figure 22, the control unit and the power unit with a larger area are used as the first unit 2010 and the smaller area is used as the second unit 2020. The second unit 2020 is located between the first unit 2010 and the main board 110. The areas of the units 2010 and 2020 are different. The smaller one is placed on the lower surface of the larger one to form a power converter, which is then set on the main board 110.

[0137]

1228 4.

1229 As shown in FIG. 23 , the power unit 120 and the load are located on the same surface of the mainboard 110, and the control unit 130 is located on the other surface of the mainboard 110 opposite to the power unit 120. The power unit 120 and the control unit 130 are respectively located on two opposite surfaces of the mainboard 110, that is, each unit 120 and 130 are respectively placed on the upper and lower surfaces of the

mainboard 110, and the control unit 130 is electrically connected to the pin 140 through the conductive through hole 2310 in the mainboard 110. The overlapping portion of the projected area between the units accounts for at least 1/3 of the projected area of the unit.

1237 Obviously, for the purpose of heat dissipation and thickness limitation, it is preferred that the control unit 130 is disposed on the lower surface of the mainboard and the power unit 120 is disposed on the upper surface of the mainboard 110.

[0138]

1246 Obviously, the above-mentioned various implementation methods can effectively utilize the height, take into account the high efficiency and high power pressure of power conversion, and realize a higher performance power module, especially in the application of server power supply.

[0139]

1252 Pad layout and implementation

[0140]

1256 A power converter has many pins.

1257 These involve the pins that connect the converter to the system, such as the converter power input and output pins, the communication pins with the system, and the internal interconnection pins, i.e. the pins that connect the power unit and the control unit.

1260 Since the pins are defined in other ways in this application, the lead pins of the components on the carrier board are called pads here.

1262 Figure 24, based on the amount of current, they are usually divided into two categories: power pads and signal pads.

1264 The power pad refers to the pad through which the converter power current flows, which is usually used to make electrical connections between components in the power circuit. Due to the large current flowing through it, the pad is usually relatively thick, that is, the cross-sectional area of the pad is relatively large.

1267 The signal pad is a pad for transmitting signals in the converter. For example, the control circuit in the control unit usually transmits control signals to the drive circuit through the signal pad to control the on and off of the power components. Usually the current flowing through the control pad is small and the pad is thin, so there is no need for a too large cross-sectional area. Its size is determined by the process capability.

[0141]

1274 When the power converter is an isolated circuit (isolation is usually achieved by a transformer in the power circuit), its input and output have isolation safety voltage requirements.

1276 Therefore, the pads can be divided into primary side group pads (i.e. pads located on the primary side of the transformer) and secondary side group pads (i.e. pads located on the secondary side of the transformer) according to their positions. The two groups of pads need to be spaced a certain distance apart to meet

safety regulations. For example, when the converter input is 400V, since insulation of more than 2000V is required, the distance between any pad in each group and any pad in the other group must be at least 4-8mm; and when the input is 36-72V, the safety insulation voltage that usually needs to be met is 1500V, then the distance is 1-4mm. As for the primary side group, since the input is relatively high voltage and the current is small, the cross-sectional area of the pad is relatively small. The secondary side group has a relatively large pad cross-sectional area due to its low voltage and large current. For example, when converting 48V to 1V, the current difference is 48 times. If the same current density is used to define the pad volume, the difference will be 48 times. Obviously, the secondary side group needs more space for placement.

[0142]

1294 Pads can be placed around the power unit, as shown in Figures 24 and 25.

1295 24, the primary side pad group 2410 and the secondary side pad group 2420 each occupy two sides of the power unit, and the two sides are parallel to each other. The primary side pad group 2410 includes a first signal pad 2411 and a first power pad 2412, and the cross-sectional area of the first power pad 2412 is larger than the cross-sectional area of the first signal pad 2411. The secondary side pad group 2420 includes a second signal pad 2421 and a second power pad 2422, and the cross-sectional area of the second power pad 2422 is larger than the cross-sectional area of the second signal pad 2421. The number of the second power pads 2422 is greater than the number of the first power pads 2412. The method of Figure 24 is suitable for occasions with lower output current. FIG25 is suitable for applications with large current output. The primary side group pads 2410 are distributed on one side of the unit, and the secondary side group pads 2420 are distributed on the remaining three sides of the unit and are separated from the primary side group pads 2410 by a safety distance d . When the current is relatively large and multiple pads are required for the same electrical polarity, that is, when the pads are reused, the positive and negative poles can usually be staggered, for example: V_{o+} , V_{o-} , to achieve the lowest possible pad inductance, so that when the application is similar to the CPU load, there will be better dynamic response and reduce the amount of capacitance used on the motherboard.

[0143]

1313 In the present application, the pins are electrically connected to the pads.

1314 Figure 26 shows the front view after the pins are connected to the pads and the units are interconnected. The pins shown in Figure 26 are surface mount pins. The L-shaped surface mount pin 2610 electrically connects the units 120 and 130 to form a surface mount pin power converter, which is set on the mainboard 110. By using I-type pins instead, a power converter with I-type direct-insertion pins 2710 as shown in Figure 27 can be realized. Figure 28 shows the power converter assembly process. After the units 120 and 130 are stacked, the pins 2710 are respectively soldered to the pads of the units 120 and 130 to form a corresponding power converter.

[0144]

1324 Figure 29 shows another approach.

1324 That is, each unit 120, 130 first has its own pins, all of which are surface mount pins, and the upper and lower surfaces of the same pin have surface mount pads (SMDPad) 2910. Both ends of each pin 140 have surface mount pads 2910 extending to the upper and lower surfaces of the corresponding units 120, 130, so as to ensure firm welding and reduce conductive losses of the pads. In this way, the units can be assembled together through the SMD welding process to form a power converter with surface mount pins. FIG30 shows that the bottom unit (eg, control unit 130) has direct-insertion pins 3010 as surface-mount pins on the surface of the unit and direct-insertion pins at the bottom, thus forming a direct-insertion pin power converter. Specifically, at least one pin 140 among the plurality of pins 140, 140' is disposed on the side of the unit (e.g., control unit 130) closest to the mainboard 110 among the control unit 130 and the power unit 120, one end of at least one pin 140 has a straight-in pin 3010 inserted into the mainboard 110, and the other end of at least one pin 140 has a surface-mount gasket 2910 extending to the upper surface of the unit closest to the mainboard 110; both ends of each of the remaining pins 140' among the plurality of pins 140, 140' have surface-mount gaskets 2910 extending to the upper and lower surfaces of the corresponding ones of the remaining units (e.g., power unit 120) among the power unit 120 and the control unit 130. In short, the pin 140' is a surface mount pin, and the direct insertion pin 3010 cooperates with the surface mount pin to realize the electrical connection between the power unit 120/control unit 130 and the mainboard 110, and is convenient for installation. In one embodiment, the power unit 120 includes a main power unit portion (e.g., a lower power unit 120) and a secondary power unit portion (e.g., an upper power unit 120), the side distribution pads 3340 of the main power unit portion (shown in Figure 34), and the secondary power unit portion is stacked on the main power unit portion. Figure 31 shows the assembly process. First, the units 120, 120 are assembled with their respective pins 140, and then the units 120, 120 are assembled together.

[0145]

1349 FIG32 shows that the control unit and the power unit are integrated into a first unit 2010, a second unit 2020 and an external inductor L. The first unit 2010 is located between the second unit 2020 and the main board 110. One end of the pin 140 has a straight pin 3010 inserted into the main board 110. The other end of the pin 140 has a surface mount pad 2910 extending to the upper surface of the first unit 2010. The lower surface of the first unit 2010 is provided with a surface mount pin 3210 to connect to the main board 110. Certain wiring is performed on the upper surface of the lower unit (i.e., the first unit 2010) to achieve mutual electrical connection between multiple units stacked on its upper surface.

1356 More surface mount pins 3210 can also be provided on the lower surface of the lower unit, so that pins can be provided on both the side and the lower surface at the same time to make better use of the space, especially in situations where the area is very small, such as less than 1/32 brick, so that there is enough space to arrange the pins. FIG33 shows that both ends of the pin 140 have surface mount gaskets 2910 extending to the upper and lower surfaces of the first unit 2010, and the lower surface of the first unit is provided with surface mount pins 3210 to connect to the mainboard 110. The power converter reuses direct-insert pins and surface-mount pins to meet the needs of some occasions where the power pads need to be in direct-insert form.

[0146]

1366 As mentioned above, when the surface mount pins are implemented, it is necessary to ensure the flatness of each pin 140 to facilitate assembly and customer use.

1366 Therefore, taking FIG. 31 as an example, before assembling the pins, if the surfaces of the units 120 and 130 are regular, it will be more conducive to assembling the pins. Then, before assembling the pin 140, each unit 120, 130 can be wrapped by a packaging process such as molding or embedding to form a regular surface, such as the plane shown in Figure 31, or the recess 3410 shown in Figure 34. Since the insulating sealing material 3430 is provided with a recess 3410 for installing the pin 140, it is more conducive to the precise use of space, and then the surface mount pin can be installed thereon. Specifically, either the control unit or the power unit has a carrier 3420 and an insulating sealant 3430, the insulating sealant 3430 is formed on two opposite surfaces of the carrier 3420, the side of the carrier 3420 has a solder pad 3440, and the solder 3450 on the solder pad 3440 is soldered to the pin 140. The edges of the upper and lower surfaces of the insulating sealing material 3430 have recesses 3410, and both ends of the pin 140 have surface mount gaskets 2910 extending to the recesses 3410 on the upper and lower surfaces. The recesses 3410 have glue 3460 adhered to the surface mount gaskets 2910.

[0147]

1383 The unit shown in Figure 34 may be the above-mentioned power unit and/or control unit, the pads 3440 are distributed on the side of the power unit and the side of the control unit, and the pins 140 are electrically connected to the pads 3440.

1386 Pin 140 is a surface mount pin, which is distributed on the outer surface of the power unit and the control unit and is electrically connected to pad 3440. The solder pads 3440' are also distributed on the surface perpendicular to the side of the power unit and the solder pads 3440. Although the solder pads 3440' in Figure 34 are only distributed on the lower surface, this does not limit the present invention. In one embodiment, the solder pads are distributed on the side of the power unit 120 and the upper and lower surfaces of the control unit 130, and the pins 140 are electrically connected to the solder pads 3440.

[0148]

1395 Surface mount pins can be installed on various surfaces of the unit, but in order to obtain better heat dissipation and make the overall size of the module smaller, the above examples show that the pads are located on the side of the carrier board in each unit, and the surface mount pins are welded to electrically connect the lead pins of the device in the unit and the control signal lead pins.

1399 However, in some special cases, as shown in FIG33 , the pads of the first unit 2010 can also be made on the surface where the second unit 2020 and the inductor L are stacked, and a typical connection between the first unit 2010 and the second unit 2020 and the inductor L is achieved through pins. For the contact surface other than the solder joints between the pins and the pads, glue and other processes can be used to bond the surface of the surface-mount pins to the surface of each unit to enhance the mechanical strength and improve reliability.

[0149]

[0150]

1412 After the units are stacked into modules, the heat dissipation path changes compared to the original independent placement design.

[0151]

1417 As shown in FIG. 35, after stacking, sufficient gaps can be left between the upper and lower units as needed to be used as air ducts. In other words, there is a gap between any two adjacent units in the control unit 130 and the power unit 120 to serve as an air duct 3510.

1420 The distance between the upper and lower units, that is, the thickness of the air duct, should be between 1 and 5 mm. If it is less, the heat dissipation effect will be poor, and if it is more, it will take up more space and increase the size of the module.

1423 This allows the individual surfaces of each unit to be used as much as possible for heat exchange.

1424 To achieve effective heat dissipation, the wind speed in the air duct should be above 0.5 m/s.

[0152]

1428 In many applications, it may be difficult to provide sufficient wind speed for the wind duct 3510 in Figure 35.

1429 Therefore, it is still desirable to transfer heat to each surface of the overall stack. In order to better achieve thermal uniformity, thermally conductive insulating glue can be filled in the gaps between units. As shown in Figure 36, the gaps between any two adjacent units of the control unit 130 and the power unit 120 are filled with thermally conductive insulating glue 3610, and the power units 120 and the power units 120 and the control unit 130 are filled with thermally conductive insulating glue 3610. In order to effectively achieve thermal conductivity, the thermal conductivity of the thermally conductive insulating adhesive should be greater than 1W/m.k. You can also fill the part that needs to be interconnected with a metal plate, such as a copper plate, to get better results. The filled area should be more than 30% of the surface. Of course, the thermally conductive insulating adhesive and the metal plate can be filled together.

[0153]

1441 As shown in FIG. 37, a transverse heat-conducting carrier plate 3730 (such as a PCB) is provided in the power unit 120. Both ends of the pin 140 have a pin extension layer 3710 extending to the upper and lower surfaces of the corresponding ones of the power unit 120 and the control unit 130. At least one of the upper and lower surfaces is occupied by more than 30% of the area of the pin extension layer 3710. A conductive welding material 3720 is provided below the pin extension layer 3710 located on the lower surface of each unit. In other words, the pins electrically connected between the power unit 120 and the control unit 130 and the pins electrically connected between the power units 120 and the power units 120 are filled with the conductive welding material 3720. The conductive welding material 3720 is only welded where interconnection is required, and the electrical connection between the units can be achieved through this

welding method.

1459 The thermal conductivity of solder is usually high enough. Therefore, the surface area of each surface mount pin can be increased, allowing more metal filling between cell gaps for thermal uniformity. To achieve effective heat dissipation, the area of the pins should account for more than 30% of the surface. For example, the surface mount pins cover more than 30% of the surface area of the power unit, thereby effectively dissipating the heat for the high-heat power unit.

[0154]

1468 Furthermore, it is obvious that the more uniform the heat distribution among the units, the more effective the heat dissipation means.

1470 In reality, the hot spots of each unit cannot achieve ideal uniform distribution, so better heat diffusion capabilities are needed. The electrical signal transmission carrier in each unit usually contains a good conductor of heat and electricity, such as copper or silver. If the metal content of the carrier board is as high as possible during design, it will be beneficial to the diffusion of heat, especially lateral diffusion. Therefore, in the present invention, the metal content of the carrier plate in the unit where heat is relatively concentrated should be above 10%. Similarly, as shown in Figure 22-5, if the metal content of the customer's electrical signal carrier is also above 10%, it will help to diffuse the heat transferred to it by the power converter to a larger area, achieving better heat dissipation.

[0155]

1481 Of course, a high lateral thermal conductivity carrier is more conducive to lateral heat diffusion.

1482 For each unit, especially the units with large losses and obvious heat generation, such as power units, if the covering/wrapping material can be a high thermal conductivity insulating glue, it will be beneficial to the vertical heat diffusion. For example, use covering/cladding materials with a thermal conductivity of more than 1W/m.k. This can be achieved by adding ceramic particles to the coating material. Such as plastic packaging materials with added ceramic particles.

[0156]

1490 As shown in FIG38 , better heat exchange capability can be achieved by placing each pin 140 on the side and top surfaces to expand the occupied area.

1492 The coverage area of the unit should have at least one side that accounts for more than 30% of the surface of the unit, preferably more than 50%. In addition, in order to have better diffusion capability, the average thickness of the pins should be above 0.2 mm, preferably above 0.3 mm.

[0157]

1498 39 and 40 show how the cooling unit is installed.

1499 As shown in Figure 39, the electrically insulating heat dissipation unit 3910 is set on the power unit 120, the power unit 120 is set on the control unit 130, and the control unit 130 is set on the mainboard 110; or, as

shown in Figure 40, the electrically insulating heat dissipation unit 4010 is set on the sides of the power unit 120 and the control unit 130. It can be installed on the upper surface of the assembled module or on the side. To avoid affecting the electrical performance, the heat dissipation unit may be made of an electrically insulating material, such as ceramic. Or when it is a conductive material, such as aluminum, copper, or graphite, there needs to be a thermally conductive and electrically insulating material between the pins, such as a ceramic sheet. The heat sinks are installed on the pads or pin combinations. To ensure the heat dissipation effect, the thermal resistance between the heat sink and the pad or pin combination should be less than 5 degrees Celsius/Watt. There is insulating material between the heat sink and the pad or pin combination.

[0158]

1515 Other optimized embodiments

[0159]

1519 In the above embodiments, it has been mentioned that a higher power can be achieved by stacking multiple power units.

1521 These power units typically each use magnetic components with similar operating conditions, such as transformers or inductors.

1523 As shown in FIG41, there are multiple power units 120 stacked on the control unit 130. Each power unit 120 is provided with a magnetic core 4110 and a winding 4120 thereof. In other words, each magnetic element has a similar winding and a similar magnetic core. In reality, the magnetic flux in the two lateral columns at the stacked contact point has the same magnitude but opposite directions. Therefore, the method of Figure 42 can be used, that is, each power unit 120 includes a planar transformer, and the two planar transformers share a magnetic core 4210. In this way, the transverse columns at the stacked contact parts can be removed, which not only significantly reduces the height, but also reduces the core loss, thereby achieving a double harvest of efficiency and power density.

[0160]

1534 A further optimization is shown in Figure 43.

1535 Since the magnetic component usually has an air gap 4320, the magnetic flux leaking from the air gap 4320 usually causes inductive heating of nearby conductors and generates losses. By sharing the magnetic core 4310 during stacking, and setting the air gap 4320 of the magnetic core 4310 in the stacking gap 4330 between the power units 120, the air gap can be kept away from the conductor as much as possible to reduce the loss.

[0161]

1543 In the above embodiments, the power unit and the control unit are stacked up and down to form a power module.

1545 In fact, after the power module is flipped 90 degrees, the power unit and the control unit are stacked left and right, and the electrical connections between each other and between each other and the main board are made through pins. This structure can also be well applied. Therefore, the power unit and the control unit of the present invention can not only be stacked up and down but also be stacked left and right in the horizontal direction.

[0162]

1553 In summary, the Quasi-Cascade device, drive optimization, application optimization and packaging optimization disclosed in the present invention can be used to improve the power density or efficiency of the power converter, and can obtain better electrical performance, high frequency performance and higher reliability compared with the prior art.

1557 It can fully exploit the characteristics of the device and is easy to use after adopting the packaging solution, which is very helpful in improving the power density or efficiency of the converter. The specific driving, application and packaging implementation methods provided by the present invention are also very feasible and effective. The present invention is very suitable for improving the overall performance and cost performance of a power converter.

[0163]

1565 Although the present invention has been disclosed as above in the form of an implementation method, it is not intended to limit the present invention. Anyone familiar with this technology can make various changes and modifications without departing from the spirit and scope of the present invention. Therefore, the scope of protection of the present invention shall be based on the scope defined by the attached claims.