METHOD AND APPARATUS FOR INTEGRATED CIRCUIT VOLTAGE REGULATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to the field of integrated circuits and more specifically to the regulation of the voltage from a power supply to integrated circuits in a computer system.

2. Related Art

Many electronic devices typically contain integrated circuits. The integrated circuits perform various electronic functions in many of these devices. The integrated circuits have the advantage of size, low power requirements, reliability, and performance over other electronic components. Many integrated circuits are designed with specific power requirements such that, once designed, the integrated circuits only function with the original electronic device they were designed for, or with a similar device with the same power supply mechanism. In most electronic devices, the integrated circuits are plugged (inserted) on printed circuit boards (also known as system boards) that provide the power necessary for an integrated circuit to function. As electronic devices such as computer systems continue to improve in performance, there is a need to design integrated circuits that are fast and operate at lower voltages. There is also a need to use these electronic devices on existing system boards which provide a single source of voltage without the need to redesign the system board.

Figure 1 illustrates an example of a prior art computer system with a system board 100 and a system power supply 130. Integrated circuit 110 is coupled to power sockets on the system board 100. Voltage planes 120 traverse the system board 100 to transfer power from the system power supply 130 to integrated circuit sockets 115 coupled to the system board 100. The integrated circuit sockets 115 allow specific voltages to be supplied to each integrated circuit 110. For example, in a personal computer system, many of the integrated circuits have 5 volts supplied to their power supply pins. Some integrated circuits 110 may also have 12 volts supplied to their power supply pins for specific purposes (e.g., serial port communications, etc.).

In each of these instances, the power supplied to each integrated circuit 110 is fixed to a predefined voltage, and therefore, there is not a production worthy

manner, nor easy way to change the voltage supply routing on the system board 100, to cater to integrated circuits 110 with differing power requirements without modifying the entire system board 100. Thus, if there is a need to change an integrated circuit 110 on the system board 100 in an existing computer system, (e.g., the need for a more advanced integrated circuit with the same functionality but different voltage requirements) the entire system board may have to be redesigned or re-manufactured to allow different components predefined to operate at a voltage different from that supplied on the system board to operate together on the same system board. For example, in a personal computer system upgrade, the PC is easily upgraded in performance by replacing the original processor, which may be operating at 5 volts, with a higher performance processor operating, for instance, at 3 volts. While the user of the computer system can typically change the processor without any problems, he is not in any position to modify the other components of the system to run at 3 volts nor change the 5 volts power supply to 3 volts.

Some prior art systems are implemented to allow the operation of integrated circuit components of differing voltage requirements on the same system board. Figure 2 illustrates a prior art solution to allow integrated circuits with different voltage requirements to operate on the same system board. Referring to Figure 2, the integrated circuit 110 is coupled to the system board 100. Power supply 130 is also coupled to the system board 100 via the power supply cables 135 to supply power to the system board 100 via the voltage planes 120. A voltage regulator 200 is coupled to the system board 100 to regulate voltage from the system power supply 130 to some other specified voltage in a localized area on the system board 100. That is, the voltage regulator 200 only regulates the voltage of sockets on the system board 100 directly connected to it. Capacitor 210 is also coupled to the system board 100 and the voltage regulator 200 to temporarily store power and make it available to the integrated circuit 105.

The voltage regulator 200 generates an output voltage to the integrated circuit 105 that is independent of an input voltage from the system board 100 via the power supply 130 when the input voltage falls within a specified range defined by the system designer. The integrated circuits 110 use voltage on the system board 100 and integrated circuit 105 uses voltage from the voltage regulator 200. For example, the voltage regulator 200 may receive an input voltage, such as 5 volts or 12 volts, from the system board 100 and generate an output voltage, such as 3 volts, to an integrated circuit requiring 3 volts. The regulation of voltage to specific

sockets on the system board allows prior art systems to use integrated circuit components of differing voltages on the system board 100.

There are a few problems with the prior art solution. One of these problems is that the extra hardware needed to implement such a solution is very expensive. Furthermore, the use of extra hardware requires more space on the system board 100 where space is at a premium. The addition of on-board capacitors 210 and regulators 200 also requires strict power routing in the system board 100 because the system board 100 has to be virtually segregated into different voltage areas to meet the voltage requirement of the different components. Also, the system board 100 has to be redesigned to allow the placement of capacitors 210 and regulators 200 in specific locations on the system board 100 to cater to the voltage requirements of the integrated circuits 110.

Another problem with the prior art solution is that computer systems in the prior art do not have an effective way of directing heat generated by the voltage regulators 200 away from the system power supply 130. The computer systems, therefore, become very hot during operation. To alleviate the heat problems, the system board 100 is designed so that the voltage regulator 200 and capacitors 210 are placed away from the system power supply 100. The redesigning of the system board 100 is very costly and still does not allow the flexibility of replacing the integrated circuits 110 with another integrating circuit having a different voltage requirement anywhere on the same system board. Therefore, it is desirable to provide a system where integrated circuits with different voltage requirements can be flexibly used on existing system boards without the need for redesigning or re-manufacturing.

The present invention provides a method and apparatus for regulating voltage requirements to individual integrated circuits on the same system board without requiring additional space or redesign of the system board. The present invention also provides a method and apparatus for precisely regulating and controlling voltage to meet the specific voltage requirements for each integrated circuit in a computer system.

The present invention integrates a voltage regulator and an integrated circuit in the same package to provide an on-package regulation of voltage for the integrated circuit. The integrated circuit package allows the flexibility of replacing integrated circuits anywhere on the system board with another having a different voltage requirement. The on-package regulation also allows the use of less

expensive power supplies and requires less stringent power routing requirements in the system board.

SUMMARY OF THE INVENTION

A method and apparatus for regulating voltage requirements in an integrated circuit package is described. The present invention includes an integrated circuit, a voltage regulator and capacitors coupled together into an integrated circuit package. The integrated circuit package also includes power planes which are coupled to the components, i.e., the voltage regulator and the integrated circuit, in the integrated circuit package to supply power to the components. The present invention also includes a power supply which supplies a predetermined voltage power to the integrated circuit.

The present invention provides a method of on-package voltage regulation that allows the integrated circuit package to operate at voltages which a system board in a computer system may not provide. The on-package voltage regulation also allows the present invention to precisely regulate voltage for each of the integrated circuits in a computer system.

The precise regulation and control of voltage to individual integrated circuits of the present invention is achieved by packaging each integrated circuit with a regulator and capacitors, such that the regulator is tuned to meet the voltage requirements of the integrated circuit. To alleviate the potential of wide voltage variations, the voltage regulator of the present invention is designed for tighter tolerance on the output voltage of the voltage regulator, i.e., the voltage variance is a +/- 1% of the voltage requirements of the integrated circuit. For example, an integrated circuit with a voltage requirement of 5 volts will be integrated with a regulator with an output voltage range of 4.95 - 5.05 volts. The voltage regulator of the present invention is also designed for tight voltage to provide voltage stability to the integrated circuit. Packaging the integrated circuit with a voltage regulator of the present invention also enables the computer system designer to place the integrated circuits anywhere on a system board.

BRIEF DESCRIPTION OF THE DRAWING

The present invention will be understood more fully from the detailed description given below and from the accompanying drawings of the preferred embodiment of the invention, which, however, should not be taken to limit the invention to specific embodiments, but are for explanation and understanding only.

Figure 1 is a block diagram illustrating a prior art system with a system board providing a predefined voltage to the integrated circuits coupled

Figure 2 is a block diagram illustrating a prior art system with on-board voltage regulators.

Figure 3 is a block diagram of an overview of one embodiment of the computer system of the present invention.

Figure 4 is a block diagram of a preferred embodiment of the present invention.

Figure 5 is a schematic diagram of one embodiment of the present invention.

Figure 6 is a block diagram of an implementation of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

A method and apparatus for regulating voltage requirements in an integrated circuit in a computer system is described. In the following description, numerous specific details such capacitance values, voltage regulator response times, etc., are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well known structures, circuits and interfaces have not been shown in detail in order not to unnecessarily obscure the present invention. Furthermore, the present invention is described with reference to its preferred embodiment, alternative embodiments which may be conceived by one of ordinary skill in the art are considered within the scope of the claims set forth.

The present invention addresses some of the obstacles of using high performance integrated circuits with existing methods of regulating voltage to the circuits. The present invention, unlike the prior art, integrates the high performance circuits with regulators in the same package keeping in mind the limited integrated circuit surface area and providing adequate capacitance while keeping the temperature of the package down. Addressing these obstacles enables the present invention to provide voltage regulation solutions to integrated circuits that are not as bulky and as expensive as in the prior art.

The packaging method of the present invention also enables the system designer to strategically place the integrated circuit package anywhere on the system board, e.g., away from the system power supply, etc. Such flexibility of placing the integrated circuit package helps in distributing heat generated by the integrated circuit package around the system, thereby solving the heat dissipation problem of the prior art.

Figure 3 is a block diagram of one embodiment of a computer system by the present invention. Referring to Figure 3, the computer system of the present invention generally comprises a bus 300 for communicating information, a processor 301 coupled to the bus 300 for processing instructions, a main memory 302 coupled to the bus 300 for storing instructions and data for the processor 301, the integrated circuits of the present invention, such as processor 301, the main memory 302, etc., which are coupled to a system board 303. The system board 303 also has voltage planes (not shown) which allow the distribution of voltage to the integrated circuits from the system power supply 304.

The computer system also includes a display device 310, such as a cathode ray tube, liquid crystal display, etc., coupled to the bus 300 for displaying information to the computer user, an alphanumeric input device 312 including alphanumeric and other keys is coupled to the bus 300 for communicating information and command selections to the processor 301 and a cursor control device 315 is coupled to the bus 300 for cursor movements. The system also includes a printer (not shown) for providing a visual representation to the user.

Certain implementations and uses of the present invention may not require nor include all the above components. For example, in certain implementations, a keyboard and cursor control device for inputting information to the system may not be required. In other implementations, it may not be required to provide a display device.

Figure 4 is a block diagram of an integrated circuit package 400 of the present invention. The integrated circuit package 400 comprises an integrated circuit 401, a voltage regulator 402 which is coupled to the integrated circuit 401, capacitors 403 which are also coupled to the integrated circuit 401 and the voltage regulator 402, and ground pins 404 (Vss pins) coupled to the integrated circuit 401 and to the voltage regulator 402. The coupling between ground pins 404, the integrated circuit 401 and voltage regulator 402 is well known in the art and has been omitted to avoid obscuring the present invention.

The integrated circuit 401 of the integrated circuit package 400 performs specific functions such as the processing of information, the storage of instructions and information, etc., in a computer system of the present invention. The voltage regulator 402 regulates and controls the voltage to the integrated circuit 401. Although the functions of the voltage regulator 402 are well known in the art, the voltage regulator 402 of the present invention unlike the prior art is designed for tighter tolerance voltage, i.e., +/- 1% on the output voltage of the voltage regulator and shorter loop response times. Although tight voltage tolerance is not required in many prior art regulators, the slow loop response times in many prior art regulators which can be in the order of microseconds can lead to wide variations in output voltages from the regulators such that voltage variations need to be controlled. Therefore, a tight voltage tolerance on the regulator helps maintain voltage stability. In one embodiment, the voltage regulator of the present invention with a tight tolerance voltage on its output voltage, coupled with the capacitors of the present invention, has low output voltage variations and loop response times of under a microsecond. The tight tolerance voltage on the output voltage of the voltage

regulator 402 allows a low voltage deviation to the integrated circuit 401 from the voltage supplied by the system board, thereby increasing the performance of the integrated circuit 401.

The capacitors 403 are miniaturized to fit in or on the integrated circuit package 400. The capacitors 403 are coupled to the integrated circuit 401 and the voltage regulator 402 to temporarily store charge and make it available to the voltage regulator 402. Because the voltage regulator 402 cannot always respond instantaneously to changes in the voltage requirements of the integrated circuit 401, the capacitors 403 store the supply voltage (voltage to the integrated circuit) which if unassisted will droop or rise at varying levels that might adversely affect the performance of the integrated circuit 401.

In order to solve the potential variations in the supply voltage, the present invention uses two different sets of capacitors. A first set of capacitors of very low inductance and low capacitance (e.g., 30nF) is built inside the integrated circuit package 400. The first set of capacitors responds to the instantaneous charge requirements (in the order of 10 nanoseconds) to the voltage regulator 402. This set of capacitors is placed close to the integrated circuit 401 creating a low impedance path which allows the instantaneous charge requirements from the integrated circuit 401 to be supplied. The storing of charge by the capacitors helps maintain stable output voltage variations from the voltage regulator 402 and reduce any voltage excursions that might occur.

The second set of capacitors of higher capacitance and slightly higher inductance (e.g., 10uF) is built on top of the integrated circuit package 400. The second set of capacitors responds to the low order of power requirements (e.g., from 10 ns - 1 us) to the integrated circuit 401.

The ground pins 404 are also coupled to the integrated circuit 401 to provide grounding and to enable the integrated circuit 401 to be is coupled to the system board 100. In the prior art, power supply and ground pins provide noise reduction and provide voltage stability to an integrated circuit when the power requirements of the integrated circuit suddenly change. The faster the clock rate of the integrated circuit, the larger the noise and therefore the need for more power supply and ground pins.

In the present invention, since the power supply source is not connected directly to the integrated circuit 401 but to the voltage regulator 402, the power supply pins (not shown) do not participate in any noise reduction in the integrated circuit package 400. To reduce the noise level of the present invention, the number

of ground pins 404 used may be increased to provide the necessary noise immunity. Therefore, the actual number of ground pins used or required may vary. The on-package voltage regulator 402 and capacitors 403 also provide local power supply voltage stability to the integrated circuit package 400.

Figure 5 is a schematic diagram of the integrated circuit package 400 of the present invention. Referring to Figure 5, unlike the prior art where the supply voltage to the integrated circuit 401 comes through the power supply pins via one or more iso-voltic (same voltage) planes on the system board and distributed from the planes to the integrated circuit 401, the present invention uses multiple voltage planes defined to contain different voltages.

An input voltage plane 500 contains the input voltage from the system power supply 130 and an output voltage plane from the voltage regulator 402 contains a regulated output voltage. The input voltage plane 500 is coupled to the input of the voltage regulator 401 to supply unregulated power or regulate different voltage from the system power supply 130 to the integrated circuit package 400. The voltage regulator 402 after receiving an input voltage powers up a set of iso-voltic output voltage plane 501 to the integrated circuit 401. The output voltage plane 501 is coupled the output of the voltage regulator 402 and to the integrated circuit 401 to supply regulated output voltage to the integrated circuit 401. For example, if the input voltage supplied by the system power supply is 5 volts, the voltage regulator 402 receives the 5 volts input voltage, translates it into 3 volts for instance, and sends the 3 volts to the integrated circuit via the iso-voltic plane. The translation is based on the voltage requirements of the integrated circuit 401 and the definition of the iso-voltic planes in the integrated circuit package 400.

The capacitors 403 are coupled to the voltage plane 501 to store charge to the integrated circuit 401. In a preferred embodiment of the present invention, two set of capacitors are used to store charge and assist in maintaining stability in the supply voltage as mentioned in Figure 4 above. In addition to using two different sets of capacitors, the present invention also uses ceramic capacitors on the order of under 10 micro farads which have better temperature characteristics that allow the capacitor to operate over a wide range of voltages. The capacitors 403 and the voltage regulator 401 are both coupled to the ground pin 404 on the integrated circuit package 400 via ground line 502 which provide grounding to the integrated circuit package 400.

Figure 6 illustrates one embodiment of a system board level implementation of the present invention. Referring to Figure 6, system board 100 is shown having

a plurality of voltage planes traversing the system board 100. Voltage planes 120 are coupled to the power supply pins of the integrated circuit package 400 to supply power to the individual integrated circuits on the system board 100. The integrated circuit package 400 is coupled to existing integrated circuit sockets 115 on the system board 100. Power supply 130 is also shown coupled to the system board 100 via power supply cables to a supply predetermined voltage of power, e.g. 5 volts, to the system board 100.

Although the integrated circuit package 400 may operate at voltage ranges different than that supplied by the system board 100, the integrated circuit package 400 is still able to use the existing integrated circuit sockets 115 on the system board 100. This is accomplished by the voltage regulator 402 in the integrated circuit package 400 translating the voltage supplied on the system board 100 into a voltage adequate for the integrated circuit 401. In this manner, the integrated circuit package 400 unlike the prior art can be coupled to power sockets anywhere on the system board.

The flexibility of placing the integrated circuit package 400 anywhere on the system board 100 helps in distributing heat generated by the integrated circuit package 400 around the computer system. This helps alleviate any heat dissipation problem in the computer system.

Although the present invention has been described herein with reference to a specific preferred embodiment, many modifications and variations therein will readily occur to those skilled in the art. Accordingly, all such variations and modifications are included within the intended scope of the present invention as defined by the following claims.

Thus a method and apparatus for regulating voltage in an integrated circuit has been described.

CLAIMS

What is claimed is:

1. A computer system comprising:

a) system board means for coupling integrated circuits;

b) power supply means for providing power to said integrated circuits, said power supply means coupled to said system board; and

c) integrated circuit package means coupled to said system board including:

integrated circuit means for performing specific functions in said computer system; and

voltage regulator means for regulating voltage from said power supply to said integrated circuit means, said voltage regulator means coupled to said integrated circuit means.

2. The computer system of claim 1 wherein said integrated circuit package means includes capacitor means for storing power to said voltage regulator means, said capacitor means coupled to said voltage regulator means and said integrated circuit means.

3. The computer system of claim 1 wherein said integrated circuit package means further includes power plane means for supplying unregulated power from said power supply means to said voltage regulator means, and regulated power from said voltage regulator means to said integrated circuit means, said power planes means coupled to said voltage regulator means and said integrated circuit means.

4. The computer system of claim 3 wherein said power planes includes power plane means includes a first single input plane coupled to an input of said voltage regulator means to supply voltage from said power supply means and a second set of iso-voltic (same voltage) planes coupled to an output of said voltage regulator and an input of said integrated circuit to supply regulated power from said voltage regulator to said integrated circuit.

5. The computer system of claim 1 wherein said integrated circuit package means operates at voltages different from that supplied on said system board.

6. The computer system of claim 1 wherein said voltage regulator means operates at a tight voltage level such that voltage variations to said integrated circuit is reduced.

7. The computer system of claim 1 wherein the loop response time of said voltage regulator means is reduced, such that voltage variations from said voltage regulator means is reduced.

8. A computer system comprising:

a) system board means for coupling integrated circuits;

b) power supply means for providing power to said integrated circuits, said power supply means coupled to said system board; and

c) integrated circuit package means coupled to said system board including:

integrated circuit means for performing specific functions in said computer system;

voltage regulator means for regulating supply voltage from said power supply means to said integrated circuit means, said voltage regulator means coupled to said integrated circuit means;

capacitor means for storing voltage charges to said voltage regulator means, said capacitor means coupled to said voltage regulator means and said integrated circuit means; and

power plane means for supplying unregulated power from said power supply means to said voltage regulator means, and regulated power from said voltage regulator means to said integrated circuit means, said power planes means coupled to said voltage regulator means and said integrated circuit means.

9. The computer system of claim 8 wherein said capacitor means includes a first and second set of capacitors coupled to said integrated circuit package means to assist in reducing voltage droop in said integrated circuit package.

10. The computer system of claim 9 wherein said first set of capacitors couple to said voltage regulator to respond to high instantaneous power

requirements to said voltage regulator means while maintaining a low inductance and capacitance.

11. The computer system of claim 9 wherein said second set of capacitors couple to said integrated circuit means to respond to low charges while maintaining a low inductance and high capacitance.

12. The computer system of claim 8 wherein said voltage regulator precisely regulates voltage means requirements of said integrated circuit means such that power deviations to said integrated circuit means is reduced.

13. The computer system of claim 8 wherein said voltage regulator means further specifically tunes said integrated circuit means to increase the performance and the voltage of said integrated circuit means.

14. An integrated circuit package comprising:

integrated circuit for performing specific functions;

voltage regulator for regulating voltage requirements to said integrated circuit, said voltage regulator coupled to said integrated circuit;

a plurality of capacitors for storing instantaneous voltage charge to said integrated circuit, said capacitors coupled to said voltage regulator and said integrated circuit; and

a plurality of power planes for supplying unregulated power and regulated power to said voltage regulator and said integrated circuit respectively, said power planes coupled to said voltage regulator, said integrated circuit and said capacitors.

15. The integrated circuit package of claim 14 wherein said voltage regulator further controls the voltage requirements of said integrated circuit at a minimized loop response time such that the total voltage variance of said integrated circuit is reduced.

16. The integrated circuit package of claim 14 wherein said capacitors includes a first set of capacitors closely coupled to said voltage regulator to create a low impedance to allow high instantaneous voltage requirements to be supplied to said integrated circuit while maintaining a low inductance and capacitance.

17. The integrated circuit package in claim 14 wherein said capacitors further include a second set of capacitors coupled to said voltage regulator to respond to low power requirements of said integrated circuit while maintaining a low inductance and high capacitance.

18. A method for regulating voltage on an integrated circuit package comprising the steps of:

supplying unregulated power from a power supply to an input of an on-package voltage regulator on the integrated circuit;

receiving unregulated power from said power supply by said on-package voltage regulator via an input voltage plane coupled to said integrated circuit package;

converting said unregulated power to regulated power suitable for an integrated circuit coupled to said integrated circuit package; and

powering up a set of iso-voltic planes to supply regulated power from said on-package voltage regulator to said integrated circuit.

19. The method of claim 18 including the step of creating a low impedance path to allow instantaneous power requirements to be supplied to said integrated circuit.

20. The method of claim 18 further including the steps of tuning said voltage regulator to precisely regulate power to said integrated circuit to minimize total voltage variance to said integrated circuit.

21. The method of claim 18 further including the step of reducing noise and maintaining voltage stability to said integrated circuit package by increasing the number of ground pins on said integrated circuit package.