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**METHOD AND APPARATUS FOR CONTROLLING THE VOLTAGE
SUPPLIED TO A SEMICONDUCTOR DEVICE**

FIELD OF THE INVENTION:

The present invention relates to the field of powering semiconductor devices, and more particularly, to methods and apparatus for controlling the voltage supplied to a semiconductor device.

BACKGROUND OF THE INVENTION:

Typically, semiconductor devices operate at a fixed power supply voltage, such as 5 volts. The fixed power supply voltage permits power supply manufacturers to develop a standard for powering devices. However, operating at a lower power supply voltage other than a fixed power supply voltage may result in improved performance for some semiconductor devices. For example, power supply voltages ranging from 2.5 volts to 3.6 volts are becoming more common for some semiconductor devices. Furthermore, different silicon processes are used to manufacture different semiconductor devices. Each process exhibits a different tradeoff between heat dissipation, performance of the semiconductor device, and other parameters. Therefore, it is desirable to maximize the performance of a semiconductor device by providing the optimal voltage for that device.

In addition to each semiconductor device having different requirements for power supply voltage, different systems have different performance requirements. For example, a computer system may employ any of one or more microprocessors. The operating voltage to the microprocessor represents a trade-off between speed and power dissipation. The operating voltage supplied to a microprocessor for a computer system that requires low power dissipation may be different than the voltage supplied to a microprocessor in a computer system that

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requires fast operation. Therefore, it is desirable to supply the voltage to a semiconductor device based on system requirements.

Although it is desirable to change the voltage supply to a semiconductor device based on device and system criteria, a standard power supply today cannot adapt to create the numerous voltage possibilities. Consequently, it is desirable to provide a flexible power supply system that delivers a specified voltage upon demand.

In electronic systems, upgrading a semiconductor device when new versions become available is desirable. For example, in a computer system, the ability to upgrade the microprocessor when a new version of the microprocessor becomes available is desirable. In order to accomplish this, the new microprocessor is typically pin to pin compatible with the existing microprocessor. The pin to pin compatibility permits the new microprocessor to be replaced into the existing socket of the microprocessor in the computer system. However, in some circumstances, in order to utilize the higher performance of an upgrade microprocessor, a different operating voltage is required. In addition, a lower voltage lessens the power dissipation. Therefore, it is desirable to supply a voltage to the microprocessor that varies depending upon the needs of the computer system.

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SUMMARY AND OBJECTS OF THE INVENTION

Therefore, it is an object of the present invention to provide a semiconductor device that is capable of specifying its own operating voltage.

It is a further object of the present invention to maximize the performance of a semiconductor device by providing the optimal voltage for that device.

It is another object of the present invention to supply the voltage to a semiconductor device based on process variations and system requirements.

It is another object of the present invention to provide the ability to upgrade a microprocessor in a computer system including selecting a new operating voltage based on system requirements.

These and other objects of the present invention are realized in an arrangement that includes a power supply, a power control regulator, and a voltage reference circuit contained within a semiconductor device. The power supply generates power for the semiconductor device at a supply voltage. The voltage reference circuit specifies an operating voltage to power the semiconductor device by generating a control value. The power control regulator is coupled to the power supply and the voltage reference circuit, and generates the operating voltage from the supply voltage in accordance with the control value.

The present invention has application for use in a computer system. The computer system contains at least one microprocessor that comprises a voltage reference circuit of the present invention. The computer system also includes a power supply that generates power for the computer system at a supply voltage, and a power control regulator. The voltage reference circuit within the microprocessor specifies an operating voltage to power the microprocessor by generating a control value. The power control regulator is coupled to the power supply and the voltage reference

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circuit, and generates the operating voltage for the microprocessor from the supply voltage in accordance with the control value.

Other objects, features and advantages of the present invention will be apparent from the accompanying drawings, and from the detailed description that follows below.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects, features, and advantages of the present invention will be apparent from the following detailed description of the preferred embodiment of the invention with references to the following drawings.

Figure 1 is a high level block diagram configured in accordance with the present invention.

Figure 2a illustrates an analog voltage reference circuit for generating a voltage reference in accordance with the teachings of the present invention.

Figure 2b illustrates one embodiment of the present invention when utilizing a digital voltage reference circuit.

Figure 2c illustrates another embodiment for implementing the digital voltage reference circuit in accordance with the teachings of the present invention.

Figure 3 illustrates a portion of a computer system configured in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION

Figure 1 is a high level block diagram configured in accordance with the present invention. A semiconductor device 100 is configured to specify the operating voltage for the device. In order to specify the operating voltage for the semiconductor device 100, the semiconductor device 100 includes a voltage reference circuit 140. The semiconductor device 100 receives power, indirectly, from a power supply 130. In order to vary the operating voltage for the semiconductor device 100, a power control regulator 120 couples the power from the power supply 130 to the semiconductor device 100.

The semiconductor device 100 is intended to represent a broad category of electronic devices. For example, the semiconductor device 100 may be a microprocessor. Moreover, the voltage reference circuit 140 may be associated with any electronic device without deviating from the spirit or scope of the invention. An application for the voltage reference circuit 140 operating in conjunction with a microprocessor is described more fully below.

In operation, the semiconductor device 100 receives an operating voltage at a V_{CC} terminal. The power supply 130 generates power for the semiconductor device 100 at a predetermined supply voltage. For example, the predetermined supply voltage may be set to a standard power supply voltage, such as 5 volts. The semiconductor device 100 and the power control regulator 120 operate in conjunction to form a control system. Specifically, the voltage reference circuit 140 generates a control value. The power control regulator 120 receives, as inputs, the control value and supply voltage, and generates, as an output, the operating voltage for the semiconductor device 100. At initial power-up, the operating voltage input to the V_{CC} terminal, prior to attaining a steady state condition from the control system, may be equal to any convenient value including zero.

The ability of the semiconductor device 100 to specify an operating voltage provides numerous system applications. For example, the present invention has application for use in electronic

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systems that provide upgrades for the semiconductor device 100. For example, a manufacturer may fabricate a semiconductor device that is pin for pin compatible with an earlier version of that semiconductor device. The compatible semiconductor device permits a user to upgrade a circuit by replacing the older semiconductor with the new semiconductor device. However, based on variations and improvements in process technologies, the upgraded semiconductor device may operate more efficiently at a different voltage. In this case, it is desirable to provide a different operating voltage to the upgraded semiconductor device without completely revamping the power supply system.

In one embodiment, the voltage reference circuit 140 is fabricated on the die of the semiconductor device 100. For the die embodiment, the voltage reference circuit 140 is an analog voltage reference circuit 205 (Figure 2a). The analog voltage reference circuit 205 generates a voltage reference signal, V_{ref} , representing the control value, to indicate the operating voltage for the semiconductor device 100. An interface to the power control regulator 120 from the voltage reference circuit 140 is described more fully below. The generation of a voltage reference signal from a circuit fabricated in a semiconductor die is well known in the art and will not be described further.

The analog voltage reference circuit 205 is fabricated on the semiconductor die, and therefore the control value is fixed at the time the semiconductor die is fabricated. However, it is desirable to select an operating voltage for the semiconductor device after the semiconductor die is packaged, assembled and tested. Through testing of the semiconductor device, an optimal operating voltage for the semiconductor device in a particular system application is specified. Furthermore, because process variations result in different optimal operating voltages, it may be desirable to select an operating voltage for a semiconductor device based on post assembly sorting. Any well known method of testing a semiconductor device to determine an optimal operating voltage for the semiconductor device in a particular system application may be used.

In other embodiments of the present invention, a digital voltage reference circuit 225 (**Figure 2b**) is configured after the semiconductor die is packaged, assembled and tested. As is explained more fully below, the digital voltage reference circuit 225 is configured from the bond out of the semiconductor die to the integrated circuit package, from various attributes of the integrated circuit package, or from a programmable circuit. The embodiments incorporating the digital reference voltage circuit 225 have several advantages over the embedded die embodiment. The embedded die embodiment must initially operate at the lowest supply voltage ever anticipated.

In one embodiment for the digital voltage reference circuit 225, a packaging solution is utilized to generate the control value. In a first packaging embodiment, "n" pins on the semiconductor device integrated circuit package are dedicated to generating the control value. Each pin of the "n" dedicated pins is tied to the supply voltage or to ground. A high logic level is generated by coupling a pin to the supply voltage, and a low logic level is generated by coupling a pin to ground. In this way, encoded data consisting of a binary code is generated for the control values.

In a second packaging embodiment, all of the "n" dedicated pins are inherently grounded. In addition, a resistor pull-up circuit is provided external to the semiconductor device such that each of the "n" dedicated pins, when attached to the semiconductor device, are coupled to the supply voltage through a large resistance. In order to generate the encoded data for the control value, pins are selectively open-circuited thereby allowing the resistor to create the high logic level. For example, in order to open-circuit pins, traces are placed externally on the package, and the traces are selectively cut with a laser to generate the open-circuited pin condition. For the second packaging embodiment, the encoded data for the control value is specified such that if a pin inadvertently breaks, then the encoded data specifies a lower operating voltage. In this way, if a pin inadvertently breaks, the semiconductor device does not burn out due to delivery of a higher operating voltage.

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— In a third packaging embodiment, the control value is generated by varying the physical attributes of the semiconductor device integrated circuit package (e.g. holes or protrusions are made in the IC package).

In other embodiments for the digital voltage reference circuit 225, a programmable non-volatile circuit is utilized to generate the control value. For these embodiments, the control value is generated by a programmable circuit (not shown). For example, the programmable circuit may comprise an electrically erasable programmable read only memory (EEPROM), an electrically programmable read only memory (EPROM), a flash memory, a programmable logic device (PLD), or electrically configurable fuses. The programmable circuit may be fabricated directly on the semiconductor die. For example, the semiconductor die may include non-volatile cells programmed to generate the control value. In another embodiment, the programmable circuit is fabricated on a separate die than the semiconductor die. For example, the programmable circuit may be a serial boot PROM on a computer system. After the semiconductor die is packaged, assembled and tested, the programmable circuit is configured to generate a control value to represent the optimal operating voltage for the particular semiconductor device.

For the embodiments that generate encoded data for the control value, an encoding scheme is required. The number of "n" dedicated pins, bits or other attributes required varies based on the encoding scheme selected. In one embodiment, a simple binary code may be utilized. In order to generate a code for the control value, a highest operating voltage and a lowest operating voltage for the particular semiconductor device are selected. In addition, an acceptable step size between selectable operating voltages is determined. Based on these parameters, worst case mean error is calculated. The system level tolerances are based on selectability, drift and offset. For example, a linear range having a high operating voltage of 5.5 volts, a low operating voltage of 2 volts, and a tolerance of $\pm 5\%$ requires at least 4 bits to generate 16 selectable operating voltages (e.g.

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more than 4 bits are required to provide an error range for drift, selectability and offset). In a variety of systems, the use of three to five dedicated pins is sufficient. The coding scheme may also be nonlinear wherein each binary step does not represent an equally spaced analog operating voltage.

Figure 2a illustrates an analog voltage reference circuit for generating a voltage reference in accordance with the teachings of the present invention. The power control regulator 120 illustrated in **Figure 1** is implemented with a direct current to direct current (DC to DC) converter 200. In general, the DC to DC converter 200 receives a voltage reference, V_{ref} , and a supply voltage, V_{supply} , and generates a regulated operating voltage based on the voltage reference. As described above, for the die embodiment, the semiconductor device 100 generates a reference voltage signal (V_{ref}). The DC to DC converter 200 receives the reference voltage (V_{ref}) at a REF IN input. In addition, the DC to DC converter 200 receives a supply voltage, V_{supply} , from a power supply (not shown). In response to the input, the DC to DC converter 200 generates operating voltage, V_{op} , in accordance with the reference voltage, V_{ref} . The DC to DC converter 200 is intended to represent a broad category of voltage conversion devices and regulators which are well known in the art and will not be described further.

Figure 2b illustrates one embodiment of the present invention when utilizing a digital voltage reference circuit. The power control regulator 120 illustrated in **Figure 1** is implemented in this embodiment with a digital to analog converter 220 and a direct current to direct current (DC to DC) converter 200. As shown in **Figure 2b**, the digital voltage reference circuit 225 generates "n" bits of encoded data representing the control value. The circuit illustrated in **Figure 2b** also contains a digital to analog converter (DAC) 220 and the DC to DC converter 200. In operation, the DAC 220 receives the "n" bits of encoded data, and generates the reference voltage for input to the DC to DC converter 200. As described above, the DC to DC converter 200 receives the reference voltage, V_{ref} , and the supply voltage, V_{supply} ,

and generates a regulated operating voltage, V_{op} , for the V_{cc} voltage at the semiconductor device 100. In one embodiment, the DAC 220 is implemented with an R-2R ladder network. Alternatively, the DAC 220 may operate as any type of digital to analog converter.

Figure 2c illustrates another embodiment for implementing the digital voltage reference circuit in accordance with the teachings of the present invention. The power control regulator 120 illustrated in **Figure 1** is implemented in this embodiment with a direct current to direct current (DC to DC) converter 240. The semiconductor device 100 generates "n" bits of encoded data from the digital reference circuit 225 for input to a DC to DC converter 240. The DC to DC converter 240 is constructed to receive the "n" bits of encoded data from the semiconductor device 100. For the embodiment illustrated in **Figure 2c**, the DC to DC converter 240 generates, internal to the DC to DC converter 240, the operating voltage, V_{op} , based on the encoded data. Consequently, external translation of the encoded data to the operating voltage, V_{op} , is not required. The internal generation of the operating voltage, V_{op} , in the DC to DC converter 240 is preferred over the embodiment illustrated in **Figure 2b** due to the noise generated in the DAC 220.

Figure 3 illustrates a portion of a computer system configured in accordance with one embodiment of the present invention. The computer system illustrated in **Figure 3** contains a microprocessor 300 incorporating the reference voltage circuit 140 of the present invention. The computer system also contains a memory 310 coupled via a bus 315. In order to implement the power control system of the present invention, the computer system includes the power control regulator 120 and power supply 330.

In one embodiment, the power control regulator 120 is local to the microprocessor 300, thereby isolating fast switching current transients from other portions of the computer system components. In an alternative embodiment, the power control regulator 120 may be implemented within the power supply 330. Furthermore, the use of DC to DC converters provides improved static and dynamic voltage

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regulation that provides an important consideration with microprocessors whose current draw can vary dramatically.

The present invention permits upgrading microprocessors in the computer system with a replacement microprocessor that operates with a different supply voltage. This permits a manufacturer of microprocessors to introduce new upgraded microprocessors that operate at different supply voltages. Furthermore, the manufacturer of the microprocessor may maximize the performance of the process and products developed by utilizing the flexibility generated by the present invention. This dramatically enhances the upgrade microprocessor strategy by not requiring fabrication of upgrade microprocessors on the same process as the original microprocessor. Furthermore, if the performance of a particular microprocessor is enhanced by operating at a higher or lower voltage than the predecessor microprocessor, then the present invention permits changing of the operating voltage for the upgraded microprocessor. The present invention does not require the power supply industry to follow in lock step fashion as the voltage to the microprocessor changes. This enhances the availability and lowers the cost of commodity power supplies for the desktop computing and server markets.

Although the present invention has been described in terms of specific exemplary embodiments, it will be appreciated that various modifications and alterations might be made by those skilled in the art without departing from the spirit and scope of the invention as set forth in the following claims.

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CLAIMS

What is claimed is:

1. A method for controlling a voltage supplied to a semiconductor device, said method comprising the steps of:
specifying an operating voltage through said semiconductor device for operation of said semiconductor device by generating a control value;
receiving a supply voltage; and
generating said operating voltage from said supply voltage for said semiconductor device in accordance with said control value such that said semiconductor device operates correctly.
2. The method as set forth in claim 1, wherein the step of specifying an operating voltage by generating a control value comprises the step of generating an analog reference voltage signal.
3. The method as set forth in claim 1, wherein the step of specifying an operating voltage by generating a control value comprises the step of generating encoded data to specify said control value.
4. The method as set forth in claim 1, further comprising the steps of:
determining an optimal operating voltage for powering said semiconductor device; and
setting said control value to specify said optimal operating voltage.
5. The method as set forth in claim 3, wherein the step of generating encoded data comprises the steps of:
packaging said semiconductor device in an integrated circuit package;



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- providing at least one dedicated pin in said integrated circuit package;
encoding a high logic level when specified in said encoded data, by bonding a dedicated pin to a high logic indicating mechanism on said semiconductor device; and
encoding a low logic level when specified in said encoded data, by bonding a dedicated pin to a ground on said semiconductor device.

6. The method as set forth in claim 3, wherein the step of generating encoded data comprises the steps of:
packaging said semiconductor device in an integrated circuit package;
providing at least one dedicated pin in said integrated circuit package;
bonding each dedicated pin to ground to generate a first logic level;
open circuiting a dedicated pin in said integrated circuit package to encode a second logic level in accordance with said encoded data;
coupling each dedicated pin to a pull-up resistor; and
coupling each pull-up resistor to a voltage representing said second logic level.

7. The method as set forth in claim 3, wherein the step of generating encoded data comprises the steps of:
packaging said semiconductor device in an integrated circuit package; and
altering the physical attributes of said integrated circuit package to generate said encoded data.

8. The method as set forth in claim 3, wherein the step of generating encoded data comprises the step of programming a programmable device to generate said encoded data.



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9. The method as set forth in claim 8, wherein the step of programming a programmable device to generate said encoded data comprises the step of programming a non-volatile memory.

10. An apparatus for controlling a voltage supplied to a semiconductor device, said apparatus comprising:
a power supply for generating power for said semiconductor device comprising at least one supply voltage;
a voltage reference circuit coupled to said semiconductor device for specifying an operating voltage to power said semiconductor device by generating a control value; and
a power control regulator coupled to said power supply and said voltage reference circuit for generating said operating voltage from said supply voltage in accordance with said control value.

11. The apparatus as set forth in claim 10, wherein said voltage reference circuit is enclosed within said semiconductor device.

12. The apparatus as set forth in claim 10, wherein said voltage reference circuit comprises an analog voltage reference circuit for generating a reference voltage signal to specify said control value.

13. The apparatus as set forth in claim 10, wherein said power control regulator comprises a direct current (DC) regulator.

14. The apparatus as set forth in claim 10, wherein said voltage reference circuit comprises a digital voltage reference circuit for generating encoded data to specify said control value.

15. The apparatus as set forth in claim 14, wherein said digital voltage reference circuit comprises a programmable device for generating said encoded data.



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16. The apparatus as set forth in claim 15, wherein said programmable device comprises a non-volatile memory.

17. The apparatus as set forth in claim 14, wherein said power control regulator comprises:

- a digital to analog converter (DAC) coupled to said digital voltage reference circuit; and
- a direct current (DC) regulator coupled to said DAC.

18. The apparatus as set forth in claim 14, wherein said power control regulator comprises a direct current (DC) to direct current (DC) converter, said DC to DC converter being configured to convert said encoded data to generate said operating voltage from said supply voltage

19. The apparatus as set forth in claim 14, wherein said digital voltage reference circuit comprises:

- an integrated circuit package enclosing said semiconductor device; and
- at least one dedicated pin coupled to said integrated circuit package, a dedicated pin being bonded to a first logic state indicating mechanism on said semiconductor device to encode said first logic level when specified by said encoded data, and a dedicated pin being bonded to ground on said semiconductor device to encode a second logic state when specified by said encoded data.

20. The apparatus as set forth in claim 14, wherein said digital voltage reference circuit comprises:

- an integrated circuit package enclosing said semiconductor device; and
- at least one dedicated pin coupled to said integrated circuit package and being bonded to ground, and being pulled



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up to a supply voltage via a pull-up resistor, said at least one dedicated pin being open circuited from said integrated circuit package to encode a high logic level when specified by said encoded digital data.

21. The apparatus as set forth in claim 10, wherein said semiconductor device comprises a microprocessor.

22. The apparatus as set forth in claim 10, wherein said power control regulator is contained within said power supply .

23. A microprocessor comprising:
a semiconductor die including microprocessor circuitry; and
a voltage reference circuit coupled to said semiconductor die for specifying an operating voltage to power said microprocessor by generating a control value.

24. The microprocessor as set forth in claim 23, further comprising a system, said system comprising:
a power supply for generating power for said microprocessor, said power supply being configured to generate at least one supply voltage; and
a power control regulator coupled to said power supply and said voltage reference circuit for generating said operating voltage for said microprocessor from said supply voltage in accordance with said control value.

25. The system as set forth in claim 24, wherein said power control regulator is contained within said power supply.

26. The system as set forth in claim 24, wherein said power control regulator comprises a localized direct current (DC) to direct current (DC) regulator.

