TECHNOLOGY BRIEF

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CONTENTS

Intelligent Power Supply Technology

The role of power supplies in server and data storage products has become much more complex in recent years. Demand for more informative status and health information, more automation, and increased reliability of the power supplies has risen. To a great extent, the demand comes from system administrators who have to troubleshoot problems based on available status information. Compaq developed a solution called the Intelligent Power Supply that enables a host system to communicate more intelligently with the power supply, providing much more pertinent status information. This improved communication allows the system administrator to troubleshoot more effectively when problems arise and, in some cases, prevent problems or downtime from occurring at all. In addition, intelligent power supplies automatically perform several key functions that ensure the most efficient use of resources. Intelligent power supply technology is exclusive to Compaq products and another example of Compaq's leadership in innovation.

EXECUTIVE SUMMARY

This technology brief discusses in detail Compaq's intelligent power supplies, focusing on the roles of the I^2C (Inter-Integrated Circuit) serial bus and the embedded microcontroller. It also describes the different versions of Compaq's intelligent power supplies. Finally, it discusses the implementation of intelligent power supply technology in specific Compaq products.

This brief discusses a highly technical topic. It is intended for those interested in the technical details of the key features of the Compaq Intelligent Power Supply.

COMPAQ

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NOTICE

Intelligent Power Supply Technology

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INTRODUCTION

System administrators rely upon status monitors for accurate, timely, and pertinent data to troubleshoot problems effectively. In the past, status monitors provided no information regarding the health of a system's power supply. To address this situation, Compaq developed the Intelligent Power Supply with an embedded microcontroller and an I^2C bus. Via the I^2C bus, the microcontroller is able to communicate to the health drivers. These health drivers translate raw data from the microcontroller regarding the health and status of the power supply and send it to the status monitor. This status monitor can be Compaq Insight Manager or, in a Windows NT environment, Performance Monitor[1]. In the high-end server products, the information gathered by the status monitor is displayed through the Compaq Integrated Management Display, which is a LCD display on the front panel. Additionally, even without Compaq Insight Manager or Performance Monitor installed, the Compaq intelligent power supplies are capable of displaying some basic fault information through the LCD display.

In addition to providing power supply status information, the embedded microcontroller also performs several automated functions that aid system administrators in their tasks. These functions are discussed in detail later in the paper.

Compaq offers two versions of the intelligent power supply: a single rated 350W version and a dual rated 750/500W version. This paper describes both and their implementations in specific Compaq products.

CUSTOMER BENEFITS

Compaq's intelligent power supplies are designed to meet the demanding requirements of enterprise-level servers and options. These power supplies provide several customer benefits, including:

- Increased reliability due to self-test and load balancing
- Increased availability due to N+1 redundancy and hot-plug capability
- Longer life due to load balancing
- Greater and easier manageability due to enhanced remote and on-site status monitoring and addition of multi-color status LED
- Flexibility of configuration
- Flexibility of shut-down sequence

For more information regarding high availability in Compaq products, please see technology brief, *Eliminating Single Points of Failure and Enabling Rapid Recovery in Server Subsystems,* document #ECG043.0897.

I^2C SERIAL BUS

As mentioned above, Compaq intelligent power supplies have an *I^2C serial bus*. This is a two-wire, clock-and-data bus created by Philips Semiconductor as a way for integrated circuits within an appliance to communicate with each other. In Compaq intelligent power supplies, all communication between redundant power supplies and between power supplies and the host system passes through this bus. The I^2C bus controllers can arbitrate which device controls the

[1] *For information on the use of Performance Monitor with Windows NT platforms, please see the white paper "Compaq ProLiant 6000 Power Management Using Windows NT Performance Monitor," document #422A/0697ECG.*

bus at a given time. Use of the I^2C bus enables the microcontroller to send information regarding power supply temperature, fan speed, and AC line voltage to the health drivers.

EMBEDDED MICROCONTROLLER

The addition of the embedded microcontroller greatly increases the flexibility and manageability of power supplies. The microcontroller has control over several functions and states of the intelligent power supplies, including:

- Self-test
- On and standby
- Power down
- Fan speed
- Load balancing
- Hot plug sequencing
- Calibration
- Fault prevention

The following sections detail the microcontroller's role.

Self-Test Controls

Systems with traditional power supplies do not perform a power supply self-test. With intelligent power supply technology, upon start-up the microcontroller performs a self-test, which checks and verifies the power supply temperature sensors, RAM integrity, ROM revision, A/D (analog to digital) and D/A (digital to analog) accuracy, and non-volatile memory integrity. In the event of a failed self-test, the power supply will not enable and will indicate failure by flashing an amber status LED (this LED is discussed in more detail later in the paper). The inclusion of a self-test at system start-up greatly increases system reliability. A system administrator can now discover possible power supply problems before a system is runs and performs functions. This could prevent the power supply from failing during a critical function. For example, if the D/A accuracy were off (outside tolerances) the power supply status LED would indicate a failure.

On and Standby Controls

The embedded microcontroller can sense the status of the host system power switch. When the switch is closed (on position), pulling the on/standby port low, all of the power supplies in the system will enable or turn on the main DC outputs after a 10-second delay. When the switch is open (off position), pulling the port high, the contents of the operating status register (STBY_DELAY_REG) will determine subsequent events.

Under command from the I^2C bus, the microcontroller is also capable of remotely disabling the main DC outputs of the host system. This means that, rather than physically turning the power switch off, the microcontroller can disable the DC outputs. In order for the microcontroller to remotely disable power, the system power switch must be in the ON position. Additionally, the power switch will have to be toggled to return power to the system.

In addition, the microcontroller controls an output used to drive two status LEDs on the back of the power supply (Figure 1).

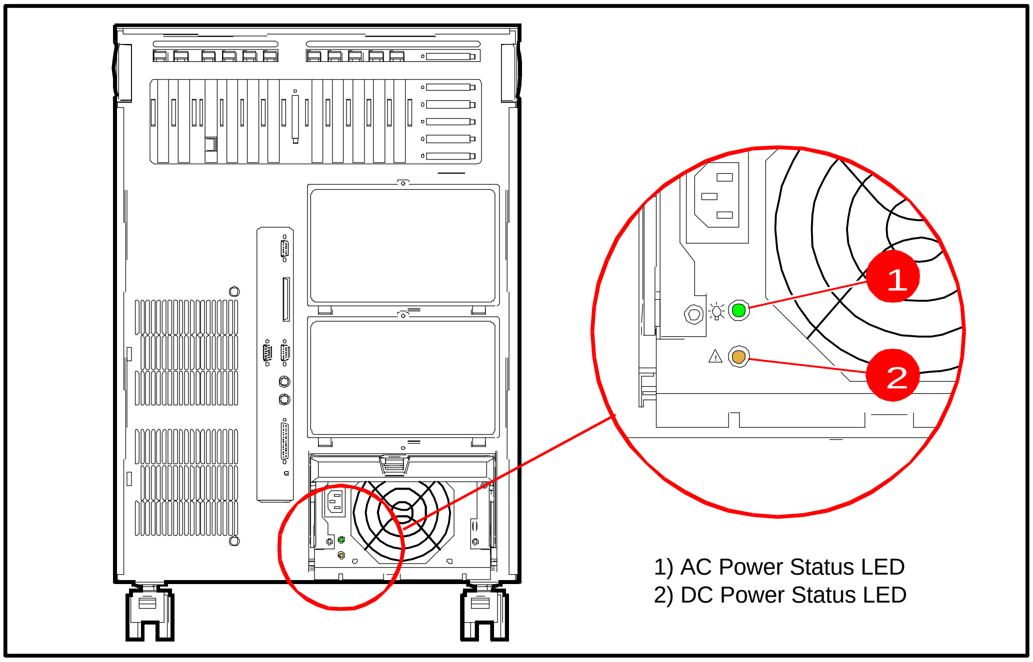

Figure 1: Back view of server with power supply detail showing two status LEDs.

The LED with the light bulb symbol next to it (LED 1) indicates AC power status. The LED with the symbol of an exclamation point inside a triangle next to it (LED 2) indicates DC power status. These symbols are consistent between the different versions of the intelligent power supply.

The DC power LED is a multi-color indicator. Unlike a rudimentary power indicator, the DC power LED provides the system administrator detailed status information that makes troubleshooting easier (Table 1). This LED is also the one that shows self-test status.

Table 1: Intelligent power supply LED indicators.

Feature	Server Model	Drive Storage Model
Purpose	Designed specifically for use in high-end servers.	Designed specifically for use in drive storage options.
Description	Parallelable, hot pluggable, redundant capable	Parallelable, hot pluggable, redundant capable
Firmware	Identical	Identical
Power Rating	750/500W dual rated	350W single rated
Power Factor Corrected	Yes	Yes
Form Factor	5 x 8 x 11 inches	5.75 x 3.83 x 10 inches
Temperature Sensor Location	Positioned to monitor inlet air temperature.	Positioned to monitor the “hotspot,” or critical heatsink temperature.

Power Down Controls

In servers with traditional power supplies, power switches connect directly to the power lines. As a result, if the switch is accidentally turned off, power immediately disconnects from the system, which could disrupt functions and cause loss of critical information. In servers using Compaq intelligent power supplies, the power switch connects to the microcontroller, rather than directly to the power line. If a switch is accidentally turned off, the microcontroller ensures a proper shut down of the system. The power switch can be configured in one of three modes:

- **Secure Mode -** Power supply will not shut down if power switch is flipped.
- **Delay Mode -** Power supply will shut down after a 10-second delay. This allows time to reactivate the switch if it was mistakenly flipped.
- **Graceful Shut Down -** Power supply will shut down after all running applications have properly closed.

Therefore, if the power switch has been configured to “secure mode” and the host server’s power switch is accidentally flipped, the server will not shut down. In this situation, a user actually has to disconnect the power cord in order to shut down the server.

The power down control feature is only supported under Windows NT 4.0. Additionally, it is not implemented in the drive storage option that is equipped with an intelligent power supply, as it is unaware of the status of applications.

Note: In a Windows NT environment the utility used to control the power is called “Compaq Power Down Manager.” It is available on the Compaq NT SSD version 2.0 or later.

Fan Speed Controls

To ensure proper cooling of the host system and intelligent power supplies, the housings for both contain temperature sensors. These sensors, which are at locations unique to each application power supply, measure temperature over the range 20° to 100°C.

With the embedded microcontroller, the intelligent power supplies are capable of two levels of "smart cooling." First, when the power supply sensor indicates that the power supply inlet air temperature exceeds preset limits, the microcontroller adjusts the fan speed accordingly. Additionally, when the temperature drops below the trip point, the power supply will lower the fan speeds. The power supply firmware limits the actual adjustment range from 50% to 100% of the duty cycle. The trip point for low to high fan is programmed during calibration at the factory.

Second, when the host system sensors indicate that the temperature inside the host system box exceeds preset levels, the operating system (OS) drivers override the power supply and request that the microcontroller turn up the power supply fans to assist the host system fans. Although the OS is in charge here, the microcontroller still performs the action. The power supply fans will remain high until the OS tells them otherwise. Again, the trip point for low to high fan speed is programmed during calibration at the factory.

The microcontroller and OS maintain a two-way communication regarding temperature levels. When the microcontroller turns up the power supply fans in the first level of cooling, it tells the system OS, giving the OS the opportunity to turn the host system fans up also, and vice versa. This way, if any component in the system gets too hot, all the fans in the system can be turned up if required. Additionally, a "crowbar" temperature is built into the power supply hardware. The crowbar temperature is a safety feature that ensures the temperature does not exceed preset limits. When the temperature reaches the crowbar, the power supply will shut off. This feature is discussed later in the "Fault Tolerance" section of this paper.

The intelligent power supply fans further ensure proper cooling because, rather than being connected to the local power supply, they are connected to the power backplane. Therefore, if the power supply fails, the fan continues to cool the chamber.

Load Balancing Controls

With the embedded microcontroller, the intelligent power supplies provide automatic load sharing to within 10% of the average current of all supplies when more than one supply is installed. In a multiple power supply environment, a *power system master* is determined upon start-up of the host system. The first supply to talk to the others (usually the one at the lowest I^2C address) becomes the power system master. All other supplies are *power system slaves.*

To achieve load balancing, the power system master's microcontroller requests output current information from all power supplies. All supplies that respond with a value and an "OK" status for current sharing are taken into account to calculate average system current. The power system master's microcontroller then broadcasts the average current value. When the power system slaves' microcontrollers receive the current average information, they make their output current equal to the system average (to within 10%). The current is calculated once every second, so balancing is continuous. There are several benefits derived from this as the following paragraphs explain.

If a power supply fails in a redundant environment, the power system master's microcontroller senses this failure and redistributes the load across the remaining power supplies. If the power system master fails or is removed, a new master will be determined from among the remaining supplies.

Load balancing allows for a better transient response to load changes. For example, if an intelligent power supply carrying the entire load should fail, it would take more time for the remaining supplies to pick up the load because they would not have the momentum behind them. The automatic load sharing of the intelligent power supplies prevents this delay.

Another advantage of automatic load balancing is that it increases the *mean time between failure* (MTBF) for each power supply. The MTBF is the average time a component works without failure. Distributing the current load among all active power supplies reduces maximum internal operating temperatures. Therefore, load balancing provides greater reliability and ensures a longer life for the power supply.

Hot-Plug Sequencing Controls

Redundancy in power supplies has become increasingly critical for high availability. Compaq's intelligent power supplies provide redundancy and hot-plug capability. The embedded microcontroller in Compaq intelligent power supplies serves several functions with regard to redundancy and hot-plug swapping:

- *Controls the power up sequencing during hot-plug swapping* - Upon insertion, the microcontroller determines if the power supply has been installed into a running system. If it has, the microcontroller powers up the supply with all outputs margined low and brings them up to nominal settings in incremental steps. Once it reaches nominal settings, current sharing routines balance the output currents.
- *Determines inserts and removals* - The master microcontroller is cognizant of the insertion or removal of an intelligent power supply. In either event, the master microcontroller will redistribute current load across the active power supplies.
- *Enables health drivers to calculate redundancy "on the fly"* - The microcontroller for each power supply gathers raw data and tells the system health drivers whether the power supplies are active. The health drivers are able to calculate redundancy from the raw data provided by the power supplies' microcontrollers and display this information in the status monitor.
- *Informs health drivers of changes in load* - The microcontroller is capable of determining when the load on a power supply increases or decreases due to outside influences. For instance, if another hot-plug device in the host system (such as a drive or PCI controller) is added, the microcontroller recognizes that the load has increased and notifies the health drivers. The health drivers display this information in the status monitor.

Note: For more information on Compaq's PCI Hot Plug technology, please see the white papers, *PCI Hot Plug Technology*, document # 398A/1196 and *PCI Hot Plug Technology with Novell Architecture*, document # 131A/0397.

Calibration

Another function of the embedded microcontroller in Compaq's intelligent power supply is to work with a calibrated test station to determine and store calibration constants in internal, non-volatile memory. This memory is an on-board Erasable Programmable ROM (commonly referred to as EPROM) chip that is accessible via the I^2C bus. A calibration table contains the constants and a checksum. A back-up copy of the calibration table is made when the checksum command is executed. During the self-test, if the first table does not pass a checksum test, the second table will be tested. If the second table is good, the power supply will load the calibration constants from the second table. If the second test also fails, the self-test will fail and the DC power status LED will flash amber. At this point, the power supply should be returned to the factory for re-calibration. The capability of the microcontroller to perform a calibration self-test allows each power supply to perform at peak levels, despite variances in component tolerances.

Fault Prevention

The microcontroller in an intelligent power supply performs several fault preventative tasks. Several of these tasks are explained below:

- *Over current monitoring* – The microcontroller reports output current in excess of the surge limits for each channel. An output that exceeds the rated limit triggers a crowbar of all outputs. The microcontroller attempts to re-enable the outputs after a 10-second delay; however, if more than five over current events occur within a 2-minute span, the MODULE_FAIL signal is asserted and the power supply remains latched off until the power switch is toggled.
- *Over voltage monitoring* – The microcontroller monitors the output voltages. The limits for each channel are determined at calibration. If the sampled voltage channel is outside the limits, the MODULE_FAIL signal is asserted and the DC status LED will glow amber. An over voltage event that exceeds safe operating limits causes a "crowbar," and all outputs are disabled. The microcontroller attempts to re-enable the outputs after a 10-second delay; however, if more than five over voltage events occur within a 2-minute span, the MODULE_FAIL signal is asserted and the power supply remains latched off until the power switch is toggled.
- *Fan failure monitoring* – The microcontroller reports indications of a failed fan or locked fan rotor via the MODULE_FAIL signal. When this occurs, the power supply remains functional until hardware safety mechanisms disable the outputs due to overheating.
- *Power supply crowbar* – In the event of a power supply crowbar, the microcontroller resets the power supply by de-asserting ENABLE_LOW. The microcontroller does not allow main outputs to enable until after a 10-second delay. The microcontroller allows five re-start attempts no less than ten seconds apart. After five re-start attempts in a 2-minute window, the microcontroller asserts the MODULE_FAIL signal.
- *Crowbar status reporting* – When an over current or over voltage event occurs, the microcontroller stores the status of the fault lines to report the type of default.

COMPARISON OF INTELLIGENT POWER SUPPLY MODELS

Compaq has developed two versions of the intelligent power supply. Although they have many similarities, one is designed for use in high-end servers and the other is designed for use in drive storage options. Table 2 compares the two models of the intelligent power supply.

Table 2: Comparison of Compaq's intelligent power supplies.

Feature	Server Model	Drive Storage Model
Purpose	Designed specifically for use in high-end servers.	Designed specifically for use in drive storage options.
Description	Parallelable, hot pluggable, redundant capable	Parallelable, hot pluggable, redundant capable
Firmware	Identical	Identical
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Power Factor Corrected	Yes	Yes
Form Factor	5 x 8 x 11 inches	5.75 x 3.83 x 10 inches
Temperature Sensor Location	Positioned to monitor inlet air temperature.	Positioned to monitor the "hotspot," or critical heatsink temperature.

The intelligent power supply was introduced into the Compaq product line with the ProLiant 6000, 6500, and 7000 high-end servers. The ProLiant 6000 and 7000 support a maximum of three power supplies. One power supply is standard and the other two provide redundancy or (in a heavily loaded system) additional power. Therefore, if the power load requires two supplies and two are installed, both supplies perform load balancing. However, if the power load only requires two supplies and three are installed, the third provides load balancing and hot-swap redundancy.

The ProLiant 6500 supports a maximum of two power supplies. One power supply is standard and the other provides redundancy.

The first implementation of the intelligent power supply in a Compaq drive storage option was with the ProLiant Storage System (models F1 and F2). In this device, one power supply provides full load 350W non-redundant. Two power supplies provide full load 350W redundant.

Power Factor Correction

Both versions of Compaq's intelligent power supply have an important feature that is inherent to their power processing hardware: *power factor correction.*

Voltage and current have polarity (amplitude) and frequency (wavelength), represented in the form of a sinusoidal wave. These voltage and current waves do not necessarily have the same phase relationship (Figure 2a). Therefore, power (voltage X current, measured in watts) is not maximized. Power can be maximized when the voltage and current waves are synchronized, or are in phase (Figure 2b). This is called power factor correction. Compaq's intelligent power supplies have built in power factor correction to ensure that maximum power is available.

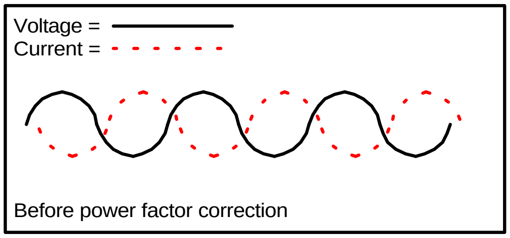

Figure 2a: Voltage and current unsynchronized

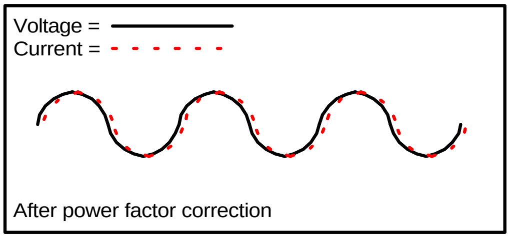

Figure 2b: Voltage and current synchronized

CONCLUSION

Compaq is the first in the industry to incorporate this technology into PC level products. Compaq used general-purpose microcontrollers to perform a wide variety of tasks from relatively simple ones to complex ones such as load balancing and hot plug sequencing.

Intelligent power supply technology delivers a great deal more flexibility, system reliability, and automation than previous power supplies. The additional information available from the status monitor and the two-color LED allows system administrators to check status more quickly and troubleshoot problems more effectively. This technology, exclusive to Compaq products, is indicative of the innovation and leadership that Compaq brings to all its products.