A Full-Featured Pentium® PCI-Based Notebook Computer

The HP OmniBook 5000 computer takes advantage of new technologies such as mobile Pentium, PCI, plug and play, lithium-ion batteries, and hot docking to give users the same capabilities as their desktop computers.

by Timothy F. Myers

The HP OmniBook 5000 computer (Fig. 1) marks a change in the direction of notebook computers designed by Hewlett-Packard. Earlier OmniBook products focused on being ancillary tools to the conventional desktop PC. The designs were biased towards small size, long battery life (or more usually, a smaller battery), and the ability to run most major programs. They brought to the customer new features such as instant-on, battery charging while operating, expandability via the PCMCIA standard (now known as PC Card Standard, or more simply PC Card), and simplified use. As customers became acquainted with their mobile computers they demanded that their portables have the same functionality as their desktops. Thus began the emergence of color displays, larger hard drives, faster processors, and external flexible disk drives in the HP OmniBook family. When the Corvallis Division became the Mobile Computing Division with the charter to design, produce, and market a full range of mobile computers, we realized that we needed to fill a gap in HP's computer line: the full-featured notebook computer.

Fig. 1. *HP OmniBook 5000 computer.*

Full-featured notebook computers today are characterized as having the same capabilities as desktop computers, albeit with some time lag for the highest performing models. Over the past few years, the spread in processing performance and features between notebooks and desktops has narrowed. At the end of 1995, the gap was only about three to six months. Today's customers not only demand that their notebook have the same capabilities as their desktop but also expect more in features that make mobile computing easy. In addition to being a desktop replacement the notebook computer should provide the same flexibility in prepurchase configurations and future expandability.

To facilitate HP's entry into the full-featured notebook market we chose to partner with a foreign notebook design and manufacturing company to quickly modify and produce a product for this segment. While the HP OmniBook 4000 was a very solid and feature-rich notebook product, our customers quickly requested features that were unique to our original OmniBooks, especially instant-on. Instant-on is a feature that allows users to put the machine into a low-power state and later resume working exactly where they had suspended their work. The main difference between HP's instant-on and our competitors' suspend feature is that the amount of time that our products can remain in the suspended state is measured in weeks, compared with hours or a couple of days for competitors. With the advent of new technologies such as mobile

Pentium, PCI, plug and play, lithium ion batteries, and hot docking, we felt that we could design a product that would set HP apart from many competitors offering Pentium notebooks. The HP OmniBook 5000 shows that there are still abundant areas for contribution, even in a highly competitive market.

Because of the multiple choices before us in chipset selection and peripheral IC technologies, we needed to have some major goals to guide our design process. While earlier HP OmniBooks focused primarily on size, power, compatibility, and performance, in that order, our criteria were different. Our target market was to be mainly corporate users, so our first goal was compatibility: “If we can’t run it, they won’t buy it.” If our product makes it difficult to get some program or utility working, our customers will pick another product. The second major goal was performance. If our product is not near the top in benchmark performance, we will not appear to be technology leaders. The third goal was power management. If our product does not run very long on a battery charge it will not be very convenient. If we do not manage power wisely, the heat generated by the components could affect reliability, functionality, and customer satisfaction. Of course, there were other goals, such as convenience, quality, reliability, and functionality. However, the first three guided the decision process for the HP OmniBook 5000.

Architecture

The HP OmniBook 5000’s architecture is based on a layered bus concept. Fig. 2 is a block diagram of the computer. This approach allows the devices that need higher data bandwidths to reside on an appropriate layer to maximize performance, power, number of pins, and functionality. The widest-bandwidth bus is the Pentium’s 64-bit data bus. On this bus are the

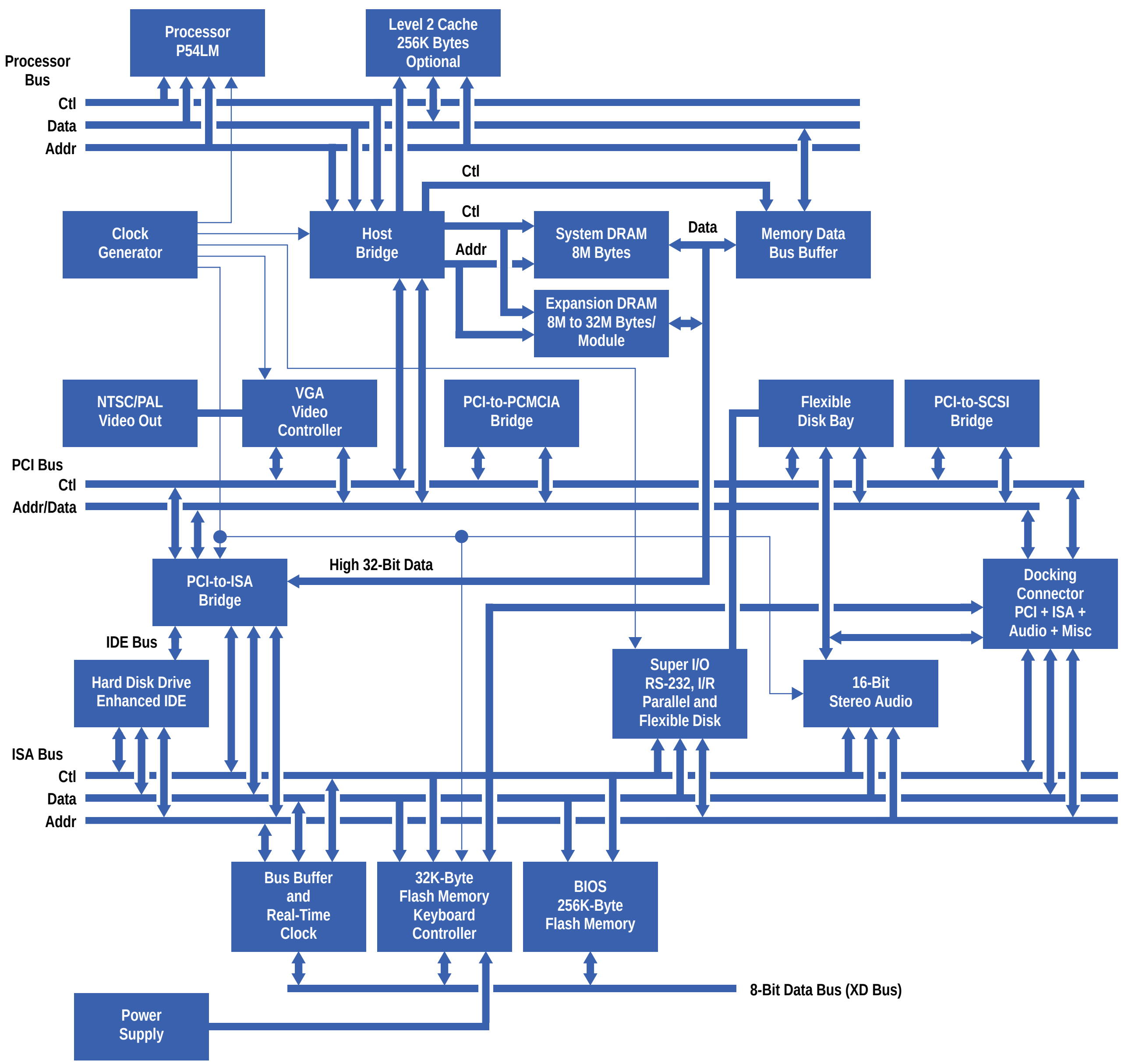


Fig. 2. *Block diagram of the HP OmniBook 5000 computer.*

system DRAM memory, the level-2 cache, the host bridge, and the Pentium CPU. The CPU bus can operate at 50, 60, or 66 MHz, depending on the CPU processing speed.

It is imperative that external memory data be delivered to the CPU as fast as possible. The Pentium processor has 16K bytes (8K data, 8K code) of internal level-1 cache, and the CPU module can support 256K bytes of external level-2 cache. The level-2 cache is implemented using burst synchronous static RAM with fast access speeds so there are no wait states other than the address lead-off cycle. Because the Pentium CPU and level-2 cache consume quite a bit of power even in a nonclocked state, the power to these devices is turned off during suspend periods and the control signals from the host bridge are put into a high-impedance state (tristated). The host bridge provides the DRAM and level-2 control and also serves as a gateway to the PCI bus.

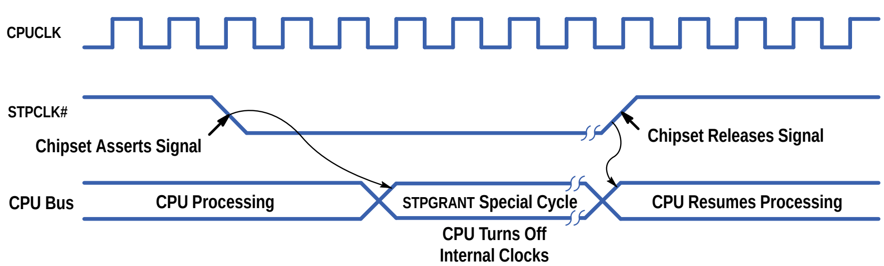
The system DRAM can be arranged into four logical banks in two physical slots. The user can select from 8M to 64M bytes of memory in granularity of 8, 16, 24, 32, 40, 48, and 64M bytes by combining 8M-byte, 16M-byte, and 32M-byte modules. The DRAM supports self-refreshing, so when the HP OmniBook 5000 is suspended, the DRAM retains its contents without clocks or signals from the host bridge. All DRAM memory is removable and accessible which makes it easier to replace and upgrade.

PCI-Based I/O Architecture

The HP OmniBook 5000 I/O bus architecture is designed around the Peripheral Components Interconnect (PCI) bus. The PCI bus in the HP OmniBook 5000 is designed to run at 33 MHz for all processor speeds. At 32 bits of data width, the theoretical bus transfer rate at burst speeds is 132 Mbytes per second. This overabundance of data transfer bandwidth allowed us to add many devices to the PCI bus to increase system performance. The video, SCSI, and 16-bit PC Card (formerly PCMCIA) controllers all reside on the PCI bus along with the CPU host bridge and the ISA (Industry Standard Architecture) bridge. The SCSI controller, the CPU host bridge, and the ISA bridge are capable of bus mastering, which allows them to assume control of the PCI bus.

The PCI-to-ISA bridge contains the power management unit that controls the CPU clocking and peripheral power states. The ISA bridge also contains the standard PC-compatible components such as the interrupt controller, the DMA controller, system timers, memory mappers, and the ISA bus interface. This IC translates the 32-bit PCI bus commands and data that are directed to the 16-bit ISA Bus.

The CPU clocks are managed by using a *clock throttling* scheme. This method was developed for the Pentium CPU since it has an internal fractional frequency multiplier to allow higher processor speeds while limiting the external bus speed. Because of this multiplier function, one cannot just slow down the CPU's frequency to reduce power consumption as was done in previous products. Instead, the power unit makes a request to the CPU for permission to stop the clock. The CPU responds by issuing a special bus cycle when it is finished with the current instruction and then stops its internal clock. When an external event such as an I/O or timer interrupt occurs, the power unit releases the request signal and the CPU restarts its internal clock and resumes operation. Fig. 3 shows the timing of the stop-clock function.



CPUCLK	CPU's external bus clock (50, 60, or 66 MHz, depending on model).
STPCLK#	Signal asserted by the chipset to alert the CPU to stop its internal clock.
CPU Bus	64-bit data bus of the Pentium CPU. A special cycle is asserted which states that the CPU acknowledges the STPCLK# signal.

Fig. 3. *Timing of the stop-clock function used for power conservation.*

The ISA bridge includes a 32-bit IDE controller, which allows faster disk accesses with newer operating systems. This IC redefines the ISA bus during idle cycles to handle the 16-bit IDE hard drive controller signals. Buffers provide isolation between the IDE and ISA buses and allow the hard disk to be powered off while the system continues to function.

Video Controller. The HP OmniBook 5000 video controller features LCD panel (DSTN or TFT) and external video interfaces with VGA or SVGA options. In addition, the video system provides NTSC/PAL video output (the video used in VCRs or camcorders) to allow presentations to be displayed on a standard TV monitor or recorded on a VCR for playback at a later date.

The video controller resides on the PCI bus so that data from the CPU is quickly written to the video memory. The video memory provides a 1M-byte video space for up to 64 million colors in 640 × 480 VGA mode. It also has a 0.5M-byte frame buffer to increase the performance of the dual-scan (DSTN) LCD. The memory on the video controller operates at 3.3V to conserve power and reduce heat. The video DRAM's self-refresh mode preserves the video screen data while the HP OmniBook 5000 is suspended and clocks to the video controller are stopped.

The video circuits automatically detect when a user connects either SVGA or NTSC/PAL video cable to the HP OmniBook 5000. The BIOS will detect the appropriate monitor type and enable the proper video settings based on the selections made in the system setup utility. This feature makes it easier for the user to set up presentations quickly.

16-Bit PC Card Controller. The PC Card controller resides on the PCI bus to allow for several features. By making this controller a PCI device, we are able to map it to a different I/O address should there be a conflict with a legacy ISA card in the docking station (described later). This design makes it possible to support new PC Card standards (e.g., Cardbus, based on 32-bit PCI) in the docking station by remapping or disabling the internal controller. We are also able to increase the system performance by having PC Card accesses bypass the bus translations that would be necessary with separate PCI, ISA, and PC Card buses as in the classical implementation. Performance is also increased because devices that support DMA (e.g., the sound card) do not slow down CPU-to-PC Card transfers (i.e., networks). The HP OmniBook 5000 design has two slots for either two type II cards or one type III (double-height) card. The interface software allows the cards to be shut off completely during suspend mode and to be restored when operation resumes. Device drivers are designed to support advanced power management calls (described later) to prevent disk corruption during suspend mode.

SCSI Controller. The SCSI controller option on the HP OmniBook 5000 is provided to give the user a simple way of connecting to external devices such as CD-ROM, external hard disks, backup tape drives, and scanners. This versatile interface provides a high data transfer rate (up to 10 Mbytes per second). The SCSI interface can be disabled when not in use to conserve power. A SCSI BIOS is provided so no drivers are required to operate a SCSI hard disk if it is connected when the system boots. This SCSI BIOS supports the SCAM protocol, which allows the user to set the SCSI IDs for SCAM-equipped devices from the HP OmniBook 5000 keyboard to simplify setup.

Special device drivers were written to support advanced power management calls to prevent read/write operations to the disk from being interrupted when the user tries to go into the suspend mode. This feature helps prevent corrupt disk images resulting from mobile use, which was not taken into account when the SCSI standard was developed.

Keyboard Controller

The keyboard controller in the HP OmniBook 5000 provides the personality of the notebook. It performs many of the notebook-related tasks so that the Pentium CPU can remain focused on compatibility and performance. Some of the tasks performed by the keyboard controller are:

- Keyboard scanning
- Support for three PS/2 ports (internal trackball, external mouse, external keyboard)
- Status panel control
- Battery charging and low-voltage monitoring
- Battery capacity gauge communication and tutoring
- Temperature sensing and thermal feedback control
- Interface to EEPROM for passwords, PC Tattoo, serial number, and other system tunable parameters
- Docking station control
- Power on/off control.

Because of the complexity of the tasks it has to perform, the keyboard controller is flash-memory-based so that it can be reprogrammed in the field along with the system BIOS and the EEPROM that contains user and system tunable parameters for battery charging, voltage detection, and so on. A special technique was implemented to perform the in-circuit programming of the flash memory in the keyboard controller. First, a bootstrap program is downloaded to the keyboard controller RAM space and executed. This program takes over the keyboard controller and handles the communication with the Pentium. The Pentium downloads the flash update program into the keyboard controller's RAM. The flash memory inside the keyboard controller is erased and then the new keyboard controller BIOS is transferred to the keyboard controller and programmed into the flash memory. Upon a hard reset, the keyboard controller begins functioning with the new BIOS.

The keyboard controller has eight 10-bit analog-to-digital converter (ADC) channels, which are used to monitor the battery temperature for each of the two battery slots, the CPU temperature, the ambient temperature, both battery slot voltages, and a 2.5V reference. The voltages read by the ADC channels are digitally filtered by the keyboard controller before being used by the system BIOS.

The keyboard controller also handles talking to various I/O ports such as three PS/2 channels, two Benchmarq smart battery channels, and an I^2C interface. Events that have higher priorities are serviced first by the keyboard controller. If the keyboard controller is servicing a lower-priority task and a higher-priority event occurs, it is processed first and the lower-priority task is rescheduled. The highest-priority tasks are docking and low-battery detection, then keyboard and mouse-related tasks, followed by housekeeping chores of battery charging, battery capacity monitoring (see below), and status panel updating.

Smart Batteries with Tutor Assist

ICs in the HP OmniBook 5000 battery packs allow the battery packs to retain their charge state and status information. If the battery is removed from the HP OmniBook 5000 and used or charged in another device, the capacity of the battery is reread from the pack when it is reinserted. These “smart” batteries can measure their temperature and current flow and perform compensated updates of the battery capacity gauge so that, over time, the gauge contents do reflect the state of the battery.

Although there is quite a bit of intelligence designed into the battery capacity gauge circuits, there are events and boundary conditions that result in the gauge’s not representing the capacity of the battery accurately. One example is the first time the battery pack is assembled. The capacity gauge requires that the battery pack be discharged and then charged back to a full state to calibrate and initialize the battery capacity reference. So that the user does not have to perform this function, the HP OmniBook 5000 will calibrate the pack under certain conditions when it knows the battery’s charged state. At those times, the HP OmniBook 5000 will compare the pack’s battery capacity reading and if it disagrees with the HP OmniBook 5000’s own gauge by a fixed factor, the pack’s gauge will be updated. This tutoring approach provides a closed-loop system to help correct for any inaccuracies caused by component tolerances, bad assumptions by the smart battery, current crest factor corrections, and charging inefficiencies. With this approach, the user does not have to be involved in the recalibration of the battery pack. The philosophy is that, even with machines, two heads are better than one.

Power Supply and Battery Charging

The power supply generates 3.3V, 5.0V, and 12.0V. It can charge either a NiMHy battery using a constant current source or a Li-Ion Battery using a constant current/constant voltage source. The ac adapter is the same as that used by the HP OmniBook 600 Series. It provides an output of 12V at 3.3A maximum current or a total power of about 40 watts. Half of the adapter wattage is used to operate the product and half is used to charge the batteries in the system. The battery voltages for both the NiMHy and Li-Ion packs can each be higher or lower than the +12V adapter voltage, depending on the charge state of the cells. A flyback configuration is used in the adapter since it can be designed to support this voltage span (see subarticle “***Flyback Charger Circuit***”). The power to the batteries during charging is limited by both current and voltage sensing. An important convenience goal of the HP OmniBook 5000 was to charge and operate at the same time. This feature allows the user to operate the HP OmniBook 5000 during the day and still have full battery power for ready use after disconnecting the computer from the ac adapter.

The 3.3V and 5.0V regulators use a synchronous switching topology that allows the power supply to maintain a high level of efficiency. The +12V output is derived using a transformer tap on the 3.3V inductor to generate about 14V, which is then linearly regulated back to +12V. This technique generates a very clean and stable +12V to program the system flash memory, the keyboard controller flash memory, and any PC Card memory cards. Sometimes the +12V is used for analog circuits on PC Cards, so we felt it necessary to provide a filtered signal.

One challenging design parameter of the power supply is that it must deliver about 15W during maximum operation and also maintain regulation while supplying less than 100 mW to the system in suspend mode.

Docking Strategy

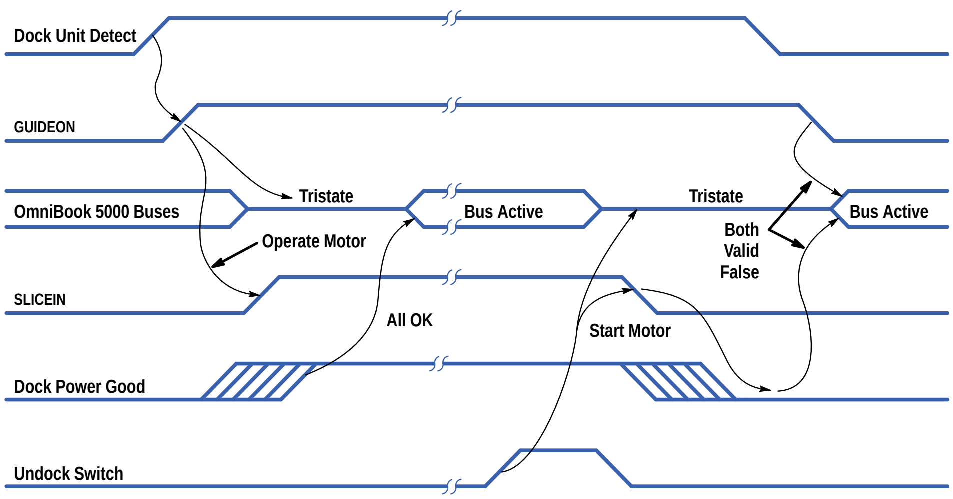
The HP OmniBook 5000 docking station (Fig. 4) provides the docked computer with one PCI slot and 2 ISA slots, giving the user access to the same options as desktop users. The docking station provides one-handed, power-assisted docking (VCR style). The I/O ports on the HP OmniBook 5000 are replicated on the docking station so that the user does not have to remake a lot of cable connections. Some ports, such as the sound system (line in, line out, and microphone), MIDI, and SVGA out ports, are passed straight through the docking station. Other interfaces such as the SCSI, RS-232, parallel, and game ports are replicated by using the same ICs as the HP OmniBook 5000’s internal chips, which are disabled. By using the plug and play features of the BIOS, the docked HP OmniBook 5000 can have either the same configuration as the portable HP OmniBook 5000 or a different configuration.

Control of the docking sequence is handled by the keyboard controller using some control signals and the I^2C bus. The I^2C bus is used to read and write additional signals and to save and restore configuration information for the docking station. Fig. 5 shows the timing of the docking sequence.

The user initiates the docking event by placing the HP OmniBook 5000 on the docking station’s receiving tray and providing a gentle shove. When the docking station’s detection switch is activated, the motor engages and captures the HP OmniBook 5000 and draws it onto the connector. When the docking connector guide pins begin to mate into the HP OmniBook 5000 the keyboard controller is notified by a nonmaskable interrupt and it notifies the chipset that a hot-dock event is about to take place. The chipset then halts the Pentium processor and tristates the buses. When the two connectors mate, the keyboard controller is notified by a signal on the connector. The keyboard controller verifies that the docking station has a valid power good signal, and if it does, the keyboard controller signals the chipset to release the Pentium and begin driving the PCI and ISA buses. The BIOS first disables the internal I/O chips and configures the I/O chips on the docking station before allowing the user to resume work. Depending on the operating system on the HP OmniBook 5000, a reboot of the operating system may be necessary to load device drivers for SCSI peripherals or other cards that may be plugged into the slots.

Fig. 4. *HP OmniBook 5000 computer in docking station.*

The undock sequence begins when the user either presses the undock key on the docking station or initializes an undock sequence via the operating system (Windows® 95). When the keyboard controller receives the undock event it signals the chipset to halt the Pentium once again and releases control of the buses. It then signals the docking station via the I^2C bus to begin the undock sequence for the motor. The motor starts and begins to eject the HP OmniBook 5000 from the docking station. The keyboard controller detects that undocking has occurred by monitoring the docking detect signal. It then tells the chipset to release the Pentium and drive the buses again. The BIOS then reconfigures the I/O devices back to the mobile configuration. Again, depending on the operating system and selection of peripherals, it may be necessary to perform a reboot.



Dock Unit Detect	Sensor that detects that the OmniBook 5000 is present and ready for docking. Starts the dock motor for VCR-style docking. Moves the OmniBook 5000 into the dock connector.
GUIDON	Sensor that detects that connectors are about to mate. Alerts the keyboard controller to begin the docking sequence to tristate the system buses.
OmniBook 5000 Buses	PCI and ISA buses are tristated to prevent data corruption during docking and undocking sequences.
SLICEIN	Signal that the connectors have mated.
Dock Power Good	Signal read by the keyboard controller to verify that a good docking event has occurred and the system can resume. If the dock power good signal is not detected, the system is powered off.
Undock Switch	Button or software event to initiate the undock sequence.

Fig. 5. *Docking sequence timing diagram.*

CPU Thermal Management

The Pentium CPU has a maximum thermal envelope of about 7.5W. This power is dissipated as heat in the CPU. The HP OmniBook 5000 combines many techniques to remove the heat from the CPU to ensure both functionality and reliability of the product. The tape carrier package (TCP) version of the Pentium is used to allow the case temperature of the CPU to be higher than is allowed in the standard ceramic package. The TCP package is essentially a metal plate attached to the backside of the CPU die. The pads on the circuit side of the CPU connect to thin-film conductors on a piece of cellulose (which looks similar to 35-mm film) rather than using traditional bonding wires. The top side of the die and film are then covered with an epoxy coating to protect the bond connections and to seal the die from contaminants. The net effect of this package is that the thermal heat resistance from the CPU to the outside mounting pad of the package is minimal. This feature allows us to operate the case temperature at 95°C versus 75°C for the PGA package.

The TCP package has very little thermal mass, so we need to move the heat energy away from the package and out into the product. Aluminum cast heat sinks are attached to two sides of the CPU package, both to the package epoxy and to the backside of the package through the use of many via holes under the die. This approach moves the heat energy away from the CPU to a larger mass for further disposal out of the product.

To get the heat out of the product the cast heat sink is attached to an extruded aluminum heat sink, which attaches to the back aluminum I/O panel. This heat sink has the ridges found in typical heat sinks so that the heat can convect out of vents in the top case.

To remove additional heat from the cast CPU heat sink, a heat pipe technology is used (see Fig. 6). A heat pipe is basically a small Carnot engine that transfers heat from one end of the pipe to the other via a temperature differential, using a wicking action to recycle the fluid. The fluid in the pipe is just water that has been depressurized to allow it to boil at a lower temperature. When the CPU heat sink is heated to the boiling point of the water in the heat pipe, the water changes state from liquid to gas. This phase change extracts a large amount of thermal energy from the heat sink. As the water boils, the wick inside the heat pipe brings cooler water to the CPU end and the gas moves down the heat pipe to the condensing end. When the gas in the heat pipe cools below the boiling point, the energy taken from the CPU is released into the condenser. The condenser consists of a thin aluminum stamped sheet. This sheet is attached to the back of the metal plate of the keyboard and the heat is spread out over the keyboard surface area.

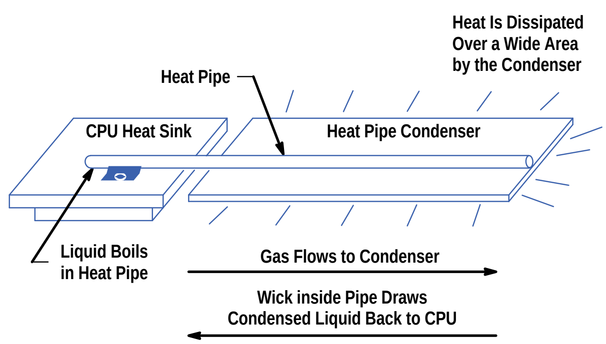


Fig. 6. *Heat pipe principle.*

To prevent the CPU from generating excess heat during typical operation, the chipset provides different methods of controlling the CPU activity with the use of *advanced power management* (APM). Software APM is the most effective. It consists of having a running program shut the CPU clock down when there are periods of inactivity in the program. Of course, this method requires the software to be APM compliant. If the user is operating software that is not APM compliant, the HP OmniBook 5000 can be set to use hardware APM as a default. Hardware APM is implemented by monitoring the interrupts and major I/O function accesses. When the program is performing any I/O activity or the I/O devices generate an interrupt, a timer is reset that keeps the CPU active from one half second to eight seconds, depending on the setting. If another event occurs before the timer times out, the timer will be set back to the full count. If the program is just executing out of the CPU memory and the timer expires, then the CPU clock is throttled back to 1/4 speed. This reduction lowers the power used by the CPU by about 75%. Access to an I/O event will again set the timer to the full count and enable the CPU to run at full speed again.

To prevent the CPU from reaching the critical case temperature, active thermal feedback is employed. This technique measures the temperature of the CPU module and the ambient air inside the unit. The temperature limits for each are monitored by the keyboard controller. If either limit is exceeded, the CPU speed is reduced by clock throttling. When the CPU and ambient temperatures cool below their restart thresholds, the keyboard controller will again allow the CPU to work at full speed. For the thermistor on the CPU module, the feedback is fairly rapid because of the mechanical heat removal methods, and the CPU tends to run at an average clock speed at which thermal equilibrium is reached for the given operating conditions. In the case of the ambient air sensor (used to protect other ICs in the notebook from overheating) the effect of slowing down the CPU is not very rapid because of the large thermal resistance between the sensor and the CPU module. If this sensor trips the thermal feedback, the unit will run at a slower speed (1/2 clock rate) until the air temperature returns to a cooler level. This rate was chosen so that the user can still operate the machine even if it takes several minutes for the ambient air to cool.

Summary

The technologies developed for the HP OmniBook 5000 computer are designed to achieve the notebook features required for the future. The PCI bus will allow higher speed and functionality in video and communications than is possible today. The heat transfer and modular assembly technologies will permit incorporation of new faster processors as they become available. The Li-Ion batteries will continue to provide more energy for a given weight, thereby making possible lighter products or longer battery life. The instant-on feature allows the user the freedom to work whenever it is convenient, thus helping the customer adapt to a more mobile lifestyle. The PCI and ISA hot-docking technology allows the user to have full desktop functionality and performance when purchasing a notebook computer.

Acknowledgments

The design of the HP OmniBook 5000 posed many challenges related to the new technologies of PCI, Pentium, plug-and-play, and hot docking. Many of the product's most significant features would not have been possible without the efforts of many people both within and outside of Hewlett-Packard. Kevin Quan and Justin Maynard of Systemsoft dedicated themselves to the design and implementation of the system and keyboard BIOSs. Without the tireless efforts of Shen Wang, Donald Chen, and Gwo-Huang at Twinhead, the transition from a product concept to a producible notebook would have been much more difficult. Many HP team members devoted their time and energy to make the OmniBook 5000 the finest product possible. Dan Rudolph was instrumental on the video, SCSI, PCMCIA, and sound designs. Andy Van Brocklin worked ceaselessly on getting the product qualified for EMI submittal. Tracy Lang's enthusiasm and diligence on the mechanical design ensured a solid-fitting product. The HP software team headed by Eric Evett along with Stan Blascow, Dan Pinson, and Everett Kaiser defined how the OmniBook 5000 would function for the customer and ensured that the completed product was as close to the original specification as possible. Of course, there were many others that contributed to the product's development that cannot be named here. Special recognition should be given to Terry Bradley and Bill Wickes, who as project and section managers, respectively, were able to coordinate and lead a team of creative people spanning the world while focusing individual team member efforts with patience, diligence, and continual motivation.

- Go To Next Article
- Go To Sidebar
- Go Table of Contents
- Go To HP Journal Home Page