Developer Note

PowerBook G4 Computer

October 2001

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About This Developer Note

This developer note is a technical description of the PowerBook G4 computer. The note provides information about the computer's internal design, input-output features, and expansion capabilities.

> **Note:** This developer note has been updated to include information about the latest product features and configurations.

This developer note is intended to help hardware and software developers design products that are compatible with the Macintosh products described here. If you are not already familiar with Macintosh computers or if you would like additional technical information, you may wish to read the supplementary reference documents described in Appendix A.

Contents of This Note

The information in this note is arranged in four chapters and two appendixes.

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About This Developer Note

- Chapter 4, "Expansion Features" (page 67), describes the expansion features of interest to developers. It includes development guides for expansion-bay devices, the RAM expansion modules, and the PC Card slot.

- Appendix A contains links to supplemental reference documents.

- Appendix B (page 83) is a list of the abbreviations used in this developer note.

Introduction

This chapter outlines the features of the PowerBook G4 computer, with emphasis on the changes from the previous models.

New Features

The features that have changed are listed here along with references to the sections that describe them. For a quick summary of the changes, see Table 1-1.

■ **Processor:** The computer has a PowerPC G4 microprocessor running at a clock speed of 550 or 667 MHz. For more information, see "PowerPC G4 Microprocessor" on page 23.

■ **System bus:** The speed of the system bus in the 667 MHz model is 133 MHz.

■ **Cache location and speed:** The L2 cache is now located internal to the processor IC; the clock speed ratio is 1:1. See "Level-2 Cache" on page 24.

■ **Graphics IC and memory:** The ATI Mobility Radeon graphics controller contains 16 MB of DDR memory and operates on the AGP 4x bus. For more information, see "Video Display Subsystem" on page 26.

■ **Hard disk storage:** The computer comes with a built-in hard disk drive with a capacity of 20, 30, or 48 GB. For more information and developer guidelines for alternative hard drives, see "Hard Disk Drive" on page 41.

■ **CD-RW drive:** An optional slot-loading CD-RW drive can be ordered in place of the built-in DVD-ROM drive. For more information, see "CD-RW Drive" on page 47.

- **Ethernet:** The built in Ethernet port now supports 10Base-T, 100Base-T, and 1000Base-T operation. For more information, see "Ethernet Port" on page 36.

- **AirPort Card:** An AirPort Card wireless LAN module is standard on the 667-MHz model. For more information, see "AirPort Card Wireless LAN Module" on page 38.

Table 1-1   Feature changes

Feature	Previous model	Latest model
Processor	PowerPC G4	PowerPC G4
Processor clock speed	400 or 500 MHz	550 or 667 MHz
L2 cache size, location, and speed ratio	1 MB, Main logic board, 2:1	256 KB, Processor IC, 1:1
System bus speed	100 MHz	100 or 133 MHz
Graphics IC and bus	ATI RAGE Mobility 128, AGP 2x	ATI Mobility Radeon, AGP 4x
Display memory	8 MB of SDRAM	16 MB of DDR
Hard disk drive	10, 20, or 30 GB	20, 30, or 48 GB
Optical drive	DVD-ROM drive, slot-loading, built-in	DVD-ROM or optional CD-RW drive; slot-loading, built-in
Ethernet speed	10/100Base-T	10/100/1000Base-T
AirPort Card	Optional	Included on 667-MHz model, optional on 550-MHz model

Features

Here is a list of the features of the PowerBook G4 computer. Each feature is described in a later chapter, as indicated in the list.

- **Processor:** The computer has a PowerPC G4 microprocessor running at a clock speed of 550 or 667 MHz. For more information, see "PowerPC G4 Microprocessor" on page 23.

- **System bus:** The speed of the system bus is either 133 MHz (in the 667 MHz model) or 100 MHz (in the 550 MHz model).

- **Cache location and speed:** The L2 cache is now located internal to the processor IC; the clock speed ratio is 1:1. See "Level-2 Cache" on page 24.

- **RAM:** The computer has two standard SO-DIMM expansion slots for SDRAM modules. The computer comes with 128 or 256 MB of SDRAM installed. See "RAM Expansion Slots" on page 67.

- **ROM:** The computer has 1 MB of boot ROM used by Open Firmware at startup. For information about the ROM, see "Boot ROM" on page 25. For information about Open Firmware, see "Open Firmware" on page 78.

- **Hard disk storage:** The computer comes with a built-in hard disk drive with a capacity of 20, 30, or 48 GB. For more information and developer guidelines for alternative hard drives, see "Hard Disk Drive" on page 41.

- **Display:** 15.2-inch wide-screen TFT display (1152 x 768 pixels). See "Flat Panel Display" on page 58.

- **External monitor:** All configurations support an external video monitor, using the standard VGA video connector for a video monitor and an S-video connector for a PAL or NTSC video monitor. See "External Monitors" on page 59.

- **Graphics IC and memory:** The ATI Mobility Radeon graphics controller contains 16 MB of DDR memory and operates on the AGP 4x bus. For more information, see "Video Display Subsystem" on page 26.

- **Battery bay:** The computer has a single battery bay. The battery uses lithium ion cells and provides 55.3 watt-hours at 14.4 V (nominal).

- **DVD-ROM drive:** Standard configurations come with an internal slot-loading DVD-ROM drive. For more information, see "DVD-ROM Drive" on page 47.

- **CD-RW drive:** An optional slot-loading CD-RW drive can be ordered in place of the DVD-ROM drive. For more information, see "CD-RW Drive" on page 47.

- **CardBus slot:** The computer has a CardBus slot that accepts one Type I or Type II PC card or a CardBus Card. For more information, see "CardBus Slot" on page 73.

- **USB ports:** The computer has two USB 1.1 ports for an external keyboard, a mouse, and other USB devices, described in "USB Ports" on page 31.

- **FireWire port:** The computer has one IEEE-1394a high-speed serial FireWire port, which supports transfer rates of 100, 200, and 400 Mbps. For more information, see "FireWire Port" on page 33.

- **Target Disk Mode:** The PowerBook G4 computer can act like a FireWire storage device connected to another computer. See "Target Disk Mode" on page 35

- **Modem:** The computer has a built-in modem with 56 Kbps data rate and V.90 support. For more information, see "Internal Modem" on page 38.

- **Ethernet:** The computer has a built in Ethernet port with an RJ-45 connector for 10Base-T, 100Base-T, and 1000Base-T operation. For more information, see "Ethernet Port" on page 36.

- **Infrared link:** The computer has an IrDA infrared link capable of transferring data at up to 4 Mbits per second. For more information, see "Infrared Communication Link" on page 40.

- **AirPort Card:** An AirPort Card wireless LAN card is standard on the 667-MHz model and available as an option on the 550-MHz model. For more information, see "AirPort Card Wireless LAN Module" on page 38.

- **Sound:** The computer has a built-in microphone and stereo speakers as well as a stereo headphone jack. See "Sound System" on page 64

- **Keyboard:** The keyboard has an embedded numeric keypad and inverted-T arrow keys. Some of the function keys are used to control the display brightness and speaker volume; the other function keys are programmable by the user. See "Keyboard" on page 48.

- **Trackpad:** The integrated trackpad includes tap/double tap and drag features. For more information, see "Trackpad" on page 48.

- **Weight:** The computer weighs 2.4 kg (5.4 pounds).

■ **Size:** The computer is 341 mm (13.4 inches) wide, 241 mm (9.49 inches) deep, and 26.3 mm (1.04 inches) thick.

Appearance

Figure 1-1 is a front view of the PowerBook G4 computer. Figure 1-2 is a back view showing the I/O ports.

Figure 1-1   Front view of the computer

Sleep indicator light

Built-in speaker/ microphone

Function key

Trackpad

Display release button

Trackpad button

Slot-loading DVD-ROM drive or CD-RW drive

⏻ Power button

🔒 Security slot

Built-in speake

AirPort antenn window
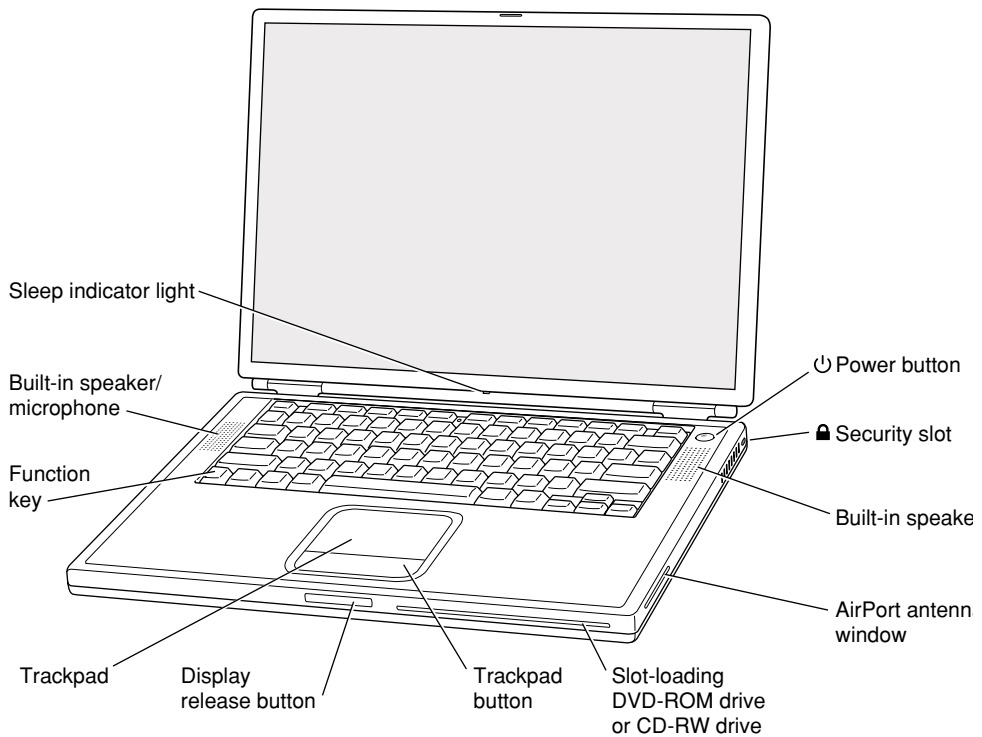
Figure 1-2   Back view showing I/O ports
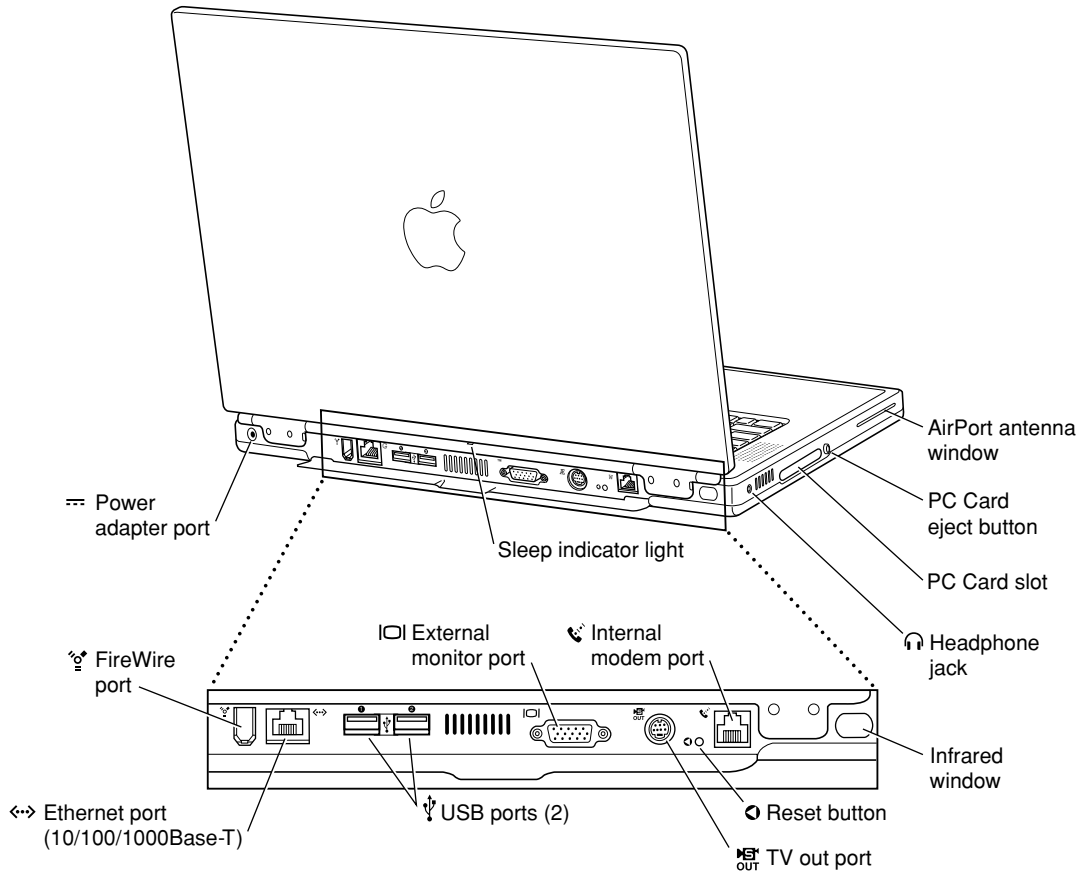
Peripheral Devices

In addition to the devices that are included with the computer, several peripheral devices are available separately:

- The PowerBook Intelligent Lithium Ion Battery is available separately as an additional or replacement battery.

- The Apple Portable Power Adapter, which comes with the computer, is also available separately. The adapter can recharge the internal battery in less than five hours while the computer is running or less than three hours while the computer is shut down or in Sleep mode.

- The Apple Pro Keyboard, a full-featured USB keybooard, is available separately.

- The Apple Pro Mouse, an optical USB mouse, is available separately.

- The AirPort Card is available separately.

- The AirPort Base Station is available separately.

System Software

The PowerBook G4 computer comes with both Mac OS 9.2.1 and Mac OS X version 10.1 installed. Mac OS 9.2 is the default startup system. For the latest information, see the references listed in "Mac OS 9" on page 78 and "Mac OS X" on page 77.

Here are a few items of interest about the system software on the PowerBook G4 computer.

Open Firmware

System software on all current Macintosh models uses a design based on Open Firmware. With this approach, the ROM on the main logic board contains only the Open Firmware code needed to initialize the hardware and load an operating system. The rest of the system code is loaded into RAM from disk or from the network. For more information, see the references listed in "Open Firmware" on page 78.

Machine Identification

Instead of reading the box flag or the model string and then making assumptions about the computer's features, applications that need to find out the features of the machine should use the Name Registry and Gestalt calls (Mac OS 9) or IORegistry Explorer (Mac OS X) to test for the features they require.

Asset management software that reports the kind of machine it is run on can obtain the value of the property at `Devices:device-tree:compatible` in the Name Registry (in Mac OS 9) or in the device-tree node of the IODeviceTree plane of the IORegistry (in Mac OS X). The model string is the first program-useable string in the array of C strings in the `compatible` field. For the PowerBook G4 computer, the value of the model property is `PowerBook3,3`.

The string obtained from the `compatible` property cannot be displayed to the computer user. If it is available, you can use the result from calling `Gestalt ('mnam', &result)` where `result` is a string pointer. This call returns a Pascal style string that can be displayed to the user.

Power Saving Modes

The power management protocols on the PowerBook G4 computer support two power-saving modes: Idle and Sleep.

- Idle: The system is idling with the main processor stopped in Nap mode. All clocks are running; the system can return to running code within a few nanoseconds. Cache coherency is maintained in this level of idle.

- Sleep: The system is completely shut down, with only the DRAM state preserved for quick recovery. All processors are powered off with their state preserved in DRAM. All clocks in the system are suspended except for the 32.768 kHz timebase crystal on the PMU99 IC.

The computer automatically enters Idle mode after several seconds of inactivity. If the computer is attached to a network, it is able to respond to service requests and other events directed to the computer while it is in Idle mode.

While it is connected to an AC power supply, the computer can also respond to network activity when it is in Sleep mode. The user can enable this feature by selecting Wake-on-LAN in the Energy Saver control panel.

Introduction

In Sleep mode, the computer consumes less than 1 watt of power. That allows it to meet the Energy Star power-saving standard.

Important
Peripherals such as PCMCIA cards and USB devices that do not conform to the computer's power management protocols prevent the computer from switching to Sleep mode and so deny the user the benefits of this energy-saving mode. When such peripherals are attached to the computer, the operating system displays a dialog box to inform the user that the computer no longer meets the Energy Star requirements.

Introduction

Architecture

This chapter describes the architecture of the PowerBook G4 computer. It includes information about the major components on the main logic board: the microprocessor, the other main ICs, and the buses that connect them to each other and to the I/O interfaces.

Block Diagram and Buses

This section is an overview of the major ICs and buses on the computer's main logic board.

Block Diagram

Figure 2-1 is a simplified block diagram of the main logic board. The diagram shows the input and output connectors, the main ICs, and the buses that connect them together.

Architecture

Figure 2-1   Block diagram

PowerPC G4
microprocessor
L2 cache: 256K 1:1

Connector to
internal display

SO-DIMM
slots

Max bus

AGP bus — Mobility Radeon
graphics IC

S-video connector

VGA monitor
connector

memory bus

Uni-North
memory
controller
and PCI
bus bridge

Ethernet
PHY — Ethernet port

CardBus slot
connector

FireWire
PHY — FireWire port

CardBus
bridge

Boot
ROM

PCI bus

Connector
to internal
DVD-ROM
or CD-RW
drive

ATA bus

Ultra-ATA bus — Connector to
internal IDE
disk drive

Tumbler
audio — Headphone jack

Connector
to internal
antenna

KeyLargo
I/O device
and disk
controller

Internal
speaker
connector

RF
and
IF

DSP and
MAC

IrDA link

USB port

USB port

Wireless LAN module

PMU99
power
controller

USB

Data pump
and DAA — Telephone
connector

Modem module

Main ICs and Buses

The architecture of the PowerBook G4 computer is designed around the PowerPC G4 microprocessor and two custom ICs: the Uni-N memory controller and bus bridge, and the KeyLargo I/O device controller. Those three ICs occupy the center of the block diagram.

The PowerPC G4 microprocessor is connected to the Uni-N memory controller and bus bridge IC by a MaxBus bus. The bus clock speed is 133 MHz on the 667-MHz model and 100 MHz on the 550-MHz model. The Uni-N IC has other buses that connect with the KeyLargo IC, the main system RAM, and the graphics IC. The buses implemented by the Uni-N IC are summarized in Table 2-1, which is in the section "Memory Controller and Bus Bridge" (page 24).

The Uni-N IC is connected to the KeyLargo I/O controller IC by a 32-bit PCI bus with a bus clock speed of 33 MHz. That bus also connects to the Boot ROM and the CardBus controller. The KeyLargo IC has other buses that connect with the hard disk drive and the CD-ROM or DVD-ROM drive, the power controller IC, the sound IC, the internal modem module, and the wireless LAN module.

Each of the components listed here is described in one of the following sections.

Microprocessor and Cache

The microprocessor communicates with the rest of the system by way of a 64-bit MaxBus bus to the Uni-N IC. The microprocessor has a separate bus to its internal second-level cache.

PowerPC G4 Microprocessor

The PowerPC G4 microprocessor used in the Power Mac G4 computer has many powerful features, including a new pipelined system bus that is more efficient than the system bus on the PowerPC G3 microprocessors. The new bus design, called MaxBus, allows for much greater efficiency of bus utilization than was possible with the previous design.

Features of the PowerPC G4 include:

- 32-bit PowerPC implementation

- superscalar PowerPC core

- Velocity Engine (AltiVec technology): 128-bit-wide vector execution unit

- dual 32 KB instruction and data caches (the same as PowerPC G3)

- an on-chip level-2 (L2) cache consisting of 256 KB with a clock speed ratio of 1:1

- high bandwidth MaxBus (also compatible with 60x bus)

- fully symmetric multiprocessing capability

The PowerPC G4 microprocessor in the PowerBook G4 computer runs at a clock speed of 550 or 667 MHz.

Level-2 Cache

The data storage for the L2 cache consists of 256 KB of fast static RAM that is built into the microprocessor chip along with the cache controller. The built-in L2 cache runs at the same clock speed as the microprocessor.

Memory Controller and Bus Bridge

The Uni-N memory controller and bus bridge IC provides cost and performance benefits by combining several functions into a single IC. It contains the memory controller, the PCI bus bridge, the Ethernet and FireWire interfaces, and the AGP interface.

Each of the separate communication channels in the Uni-N IC can operate at its full capacity without degrading the performance of the other channels.

In addition to the four buses listed in Table 2-1, the Uni-N IC also has separate interfaces to the physical layer (PHY) ICs for Ethernet and FireWire, and an I2C interface that is used for configuring the memory subsystem.

Table 2-1   Buses supported by the Uni-N IC

Name of bus	Destinations	Width of data path	Bus clock speed
MaxBus bus	Microprocessor	64 bits	133 or 100 MHz
Memory bus	System RAM	64 bits	133 or 100 MHz
PCI bus	KeyLargo IC and Boot ROM	32 bits	33 MHz
AGP bus	Graphics IC	32 bits	66 MHz

The microprocessor and the I/O controller IC are described in their own sections. The following sections describe the other subsystems that are connected to the Uni-N IC.

System RAM

The memory subsystem in the PowerBook G4 computer supports two slots for 144-pin SO-DIMMs (small-outline dual inline memory modules). The data bus to the RAM and DIMM is 64 bits wide, and the memory interface is synchronized to the MaxBus bus interface at 133 or 100 MHz. See "RAM Expansion Slots" on page 67.

Boot ROM

The boot ROM is connected to the Uni-N IC by way of the high byte of the PCI bus plus three additional control signals: chip select, write enable, and output enable. The boot ROM is a 1 M by 8 bit device.

FireWire Controller

The Uni-N IC includes an IEEE 1394a FireWire controller with a maximum data rate of 400 Mbits (50MB) per second. The Uni-N IC provides DMA (direct memory access) support for the FireWire interface.

The controller in the Uni-N IC implements the FireWire link layer. A physical layer IC, called a PHY, implements the electrical signalling protocol of the FireWire interface and provides the electrical signals to the port. For more information, see "FireWire Connector" on page 33.

Ethernet Controller

The Uni-N IC includes an Ethernet media access controller (MAC) that implements the Link layer. The Uni-N IC provides DB-DMA support for the Ethernet interface.

The Ethernet controller in the Uni-N IC is connected to a PHY interface IC that provides the electrical signals to the port. The PHY is capable of operating in either 10Base-T, 100Base-TX, or 1000Base-T mode: The actual speed of the link is automatically negotiated by the PHY and the bridge or router to which it is connected, in compliance with IEEE 802.3u-1995. For more information, see "Ethernet Port" on page 36.

The PHY supports Auto-MDIX, which allows the use of straight-through cables in crossover situations (and conversely). For more information, see "Ethernet Port" on page 36.

Video Display Subsystem

The graphics controller IC is an ATI Mobility Radeon. Along with 16 MB of on-chip DDR memory, the graphics IC contains 2D and 3D acceleration engines, front-end and back-end scalers, a CRT controller, and an AGP 4X bus interface with bus master capability.

The features of the Mobility Radeon include

- support for 16 MB of DDR video memory

- 2D and 3D graphics acceleration

- video acceleration

- support for MPEG decoding

- support for video mirror mode

- support for dual-display mode

- S-video output for a TV monitor

The interface between the graphics IC and the rest of the system is an AGP 4x (accelerated graphics port, quadruple speed) bus on the Uni-N IC. To give the graphics IC fast access to system memory, the AGP bus has separate address and data lines and supports deeply pipelined read and write operations. The AGP bus has 32 data lines and a clock speed of 66 MHz.

The graphics IC uses a graphics address remapping table (GART) to translate AGP logical addresses into physical addresses. The graphics driver software can allocate memory in both the on-chip SDRAM and the main memory.

The graphics IC supports the built-in flat-panel display and an external monitor. The external monitor can either mirror the built-in display or show additional desktop space (dual-display mode). For information about the displays and supported resolutions, see "Flat Panel Display" on page 58 and "External Monitors" on page 59.

I/O Controller

The I/O controller IC in the PowerBook G4 computer is a custom IC called KeyLargo. It provides the interface and control signals for the following devices:

Note: In the device tree, the I/O controller is named "mac-io".

DMA Support

The KeyLargo IC provides DB-DMA (descriptor-based direct memory access) support for the following I/O channels:

- Ultra DMA ATA interface to the the internal hard drive

- modem slot interface to the built-in modem

■ I2S channel to the sound IC

The DB-DMA system provides a scatter-gather process based on memory resident data structures that describe the data transfers. The DMA engine is enhanced to allow bursting of data files for improved performance.

Interrupt Support

The KeyLargo IC has an interrupt controller (MPIC) that handles interrupts generated within the IC as well as external interrupts, such as those from the Ethernet and FireWire controllers.

USB Interface

The KeyLargo IC implements two independent USB controllers (root hubs), each of which is connected to one of the ports on the back panel of the computer. The use of two independent controllers allows both USB ports to support high data rate devices at the same time with no degradation of their performance. If a user connects a high-speed (12 Mbps) device to one port and another high-speed device to the other, both devices can operate at their full data rates.

The two external USB connectors support USB devices with data transfer rates of 1.5 Mbps or 12 Mbps. For more information about the connectors, see "USB Connectors" on page 31.

USB devices connected to the PowerBook G4 computer are required to support USB-suspend mode as defined in the USB specification. Information about the operation of USB-suspend mode on Macintosh computers is included in the Mac OS USB DDK API Reference. To obtain it, see the reference at "USB Interface" (page 80).

The USB ports on the PowerBook G4 computer comply with the Universal Serial Bus Specification 1.1 Final Draft Revision. The USB controllers comply with the Open Host Controller Interface (OHCI) specification.

Ultra ATA/66 Interface

The KeyLargo IC provides an Ultra ATA/66 channel that is connected to the internal hard disk drive. The KeyLargo IC provides DB-DMA (descriptor-based direct memory access) support for the Ultra DMA interface.

The internal hard disk drive is connected as device 0 (master) in an ATA Device 0/1 configuration.

EIDE Interface

The KeyLargo IC provides an EIDE interface (ATA bus) that supports the the DVD-ROM/CD-RW drive and the wireless LAN module. The DVD-ROM/CD-RW drive is an ATAPI drive and is connected as device 0 (master) in an ATA Device 0/1 configuration.

Modem Support

Unlike earlier Macintosh models which used serial-port modems, the internal modem is connected to an internal USB port. The KeyLargo IC provides DB-DMA support for the modem interface. The modem provides digital call progress signals to the Tumbler sound circuitry.

The internal modem is a separate module that contains the datapump IC and the interface to the telephone line (DAA). For more information about the modem, see "Internal Modem" on page 38.

Sound Circuitry

The sound circuitry, called Tumbler, is connected to the KeyLargo IC by a standard I2S bus. The KeyLargo IC provides DB-DMA (descriptor-based direct memory access) support for the I2S port.

Note: In the device tree, the sound circuitry is named "sound".

The Tumbler circuitry includes a signal processing IC that handles the equalization and volume control functions, a codec IC that performs A-to-D and D-to-A conversion, and a power amplifier that drives the headphone jack.

All audio is handled digitally inside the computer. The Tumbler circuitry performs digital-to-analog conversion for the audio signals to the internal speakers and the headphone jack.

For a description of the features of the sound system, see "Sound System" on page 64

Power Controller

The power management controller in the PowerBook G4 computer is a custom IC called the PMU99. It supports several power-saving modes of operation, including idle, doze, and sleep. For more information, see "Power Saving Modes" on page 18.

Note: In the device tree, the power controller is named "via-pmu".

Infrared Link Interface

The controller for the infrared link is part of the KeyLargo IC. The IR transceiver is connected to a serial port on the KeyLargo IC. For information about the operation of the infrared link, see "Infrared Communication Link" on page 40.

Wireless LAN Interface

The interface between the wireless LAN module and the KeyLargo IC is a subset of the PCMCIA interface.

The AirPort Card contains a media access controller (MAC), a digital signal processor (DSP), and a radio-frequency (RF) section. The card has a connector for the cable to the antennas.

Two antennas are built into the computer's case. To improve reception, a diversity module between the antennas and the connector measures the signal strength from both antennas and sends the stronger one to the card.

The design of the AirPort Card is based on the IEEE 802.11 standard. The card transmits and receives data at up to 11 Mbps and is compatible with older systems that operate at 1 or 2 Mbps. For information about its operation, see "AirPort Card Wireless LAN Module" on page 38.

CardBus Controller IC

The interface to the PC Card slot is connected to the PCI bus. The CardBus controller IC is a PCI1410A device made by Texas Instruments. It supports both 16-bit PC Cards and 32-bit CardBus Cards.

Devices and Ports

This chapter describes both the built-in I/O devices and the ports for connecting external I/O devices. Each of the following sections describes an I/O port or device.

USB Ports

The PowerBook G4 computer has two external USB 1.1 ports that can be used to connect additional I/O devices such as a USB mouse, printers, scanners, and low-speed storage devices.

The USB ports on the PowerBook G4 computer comply with the Universal Serial Bus Specification 1.1 Final Draft Revision. For more information about USB on the Macintosh computer, consult the references at "USB Interface" on page 80.

USB Connectors

The USB ports use USB Type A connectors, which have four pins each. Two of the pins are used for power and two for data. Figure 3-1 is an illustration of a Type A port and matching connector. Table 3-1 shows the pin assignments.

Figure 3-1   USB Type A port
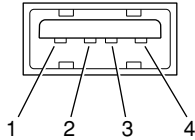
Table 3-1   Pin assignments on the USB port

Pin	Signal name	Description
1	VCC	+5 VDC
2	D–	Data –
3	D+	Data +
4	GND	Ground

The computer provides 5-volt power at 500 mA for each of the two ports.

The USB ports support both low-speed and high-speed data transfers, at up to
1.5 Mbits per second and 12 Mbits per second, respectively. High-speed operation
requires the use of shielded cables.

The PowerBook G4 computer comes with version 1.3 of the Macintosh USB system
software, which supports all four data transfer types defined in the USB
specification.

USB devices can provide a remote wakeup function for the computer. The USB root
hub in the computer is set to support remote wakeup whenever a device is attached
to the bus.

Booting from a USB Device

The PowerBook G4 computer can boot from a USB storage device that follows the
USB Mass Storage Class specification.

Class drivers are software components that are able to communicate with many USB devices of a particular kind. If the appropriate class driver is present, any number of compliant devices can be plugged in and start working immediately without the need to install additional software. The Mac OS for the PowerBook G4 computer includes USB Mass Storage Support 2.0, a class driver that supports devices that meet the USB Mass Storage Class specification.

FireWire Port

The PowerBook G4 computer has one external FireWire IEEE 1394a port. The FireWire port

- supports serial I/O at 100, 200, and 400 Mbps (megabits per second)

- provides up to 6 watts of power when the computer system is on

- supports booting the system from a mass storage device

- supports target disk mode

The FireWire hardware and software provided with the PowerBook G4 computer are capable of all asynchronous and isochronous transfers defined by IEEE standard 1394a.

FireWire Connector

The FireWire connector has six contacts, as shown in Figure 3-2. The connector pin assignments are shown in Table 3-2.

Figure 3-2 FireWire connector
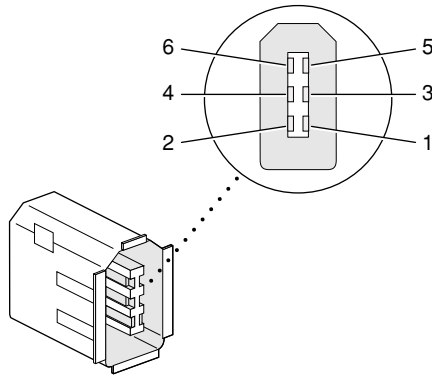
Table 3-2 Pin assignments on the FireWire connector

Pin	Signal name	Description
1	Power	Unregulated DC; 12-17 V no load
2	Ground	Ground return for power and inner cable shield
3	TPB-	Twisted-pair B, differential signals
4	TPB+	Twisted-pair B, differential signals
5	TPA-	Twisted-pair A, differential signals
6	TPA+	Twisted-pair A, differential signals
Shell	—	Outer cable shield

When the computer is on, the power pin provides a maximum voltage of 17 V (no load) and up to 6 W power. Maximum current is 0.5 A and is controlled by an auto-resetting fuse.

Pin 2 of the 6-pin FireWire connector is ground for both power and the inner cable shield. If a 4-pin connector is used on the other end of the FireWire cable, its shell should be connected to the wire from pin 2.

The signal pairs are crossed in the cable itself so that pins 5 and 6 at one end of the cable connect with pins 3 and 4 at the other end. When transmitting, pins 3 and 4 carry data and pins 5 and 6 carry clock; when receiving, the reverse is true.

FireWire Device Programming

Developers of FireWire peripherals are required to provide device drivers. A driver for DV (digital video) is included in QuickTime.

The PowerBook G4 computer can boot from a FireWire storage device that implements SBP-2 (Serial Bus Protocol) with the RBC (reduced block commands) command set. Detailed information is available only under non-disclosure agreement; contact Developer Technical Support at dts@apple.com.

For additional information about the FireWire interface and the Apple APIs for FireWire device control, refer to the resources listed at "FireWire Interface" on page 81.

Target Disk Mode

One option at boot time is to put the computer into a mode of operation called Target Disk mode. This mode is similar to SCSI Disk mode on a PowerBook computer equipped with a SCSI port, except it uses a FireWire connection instead of a special SCSI cable.

When the PowerBook G4 computer is in Target Disk mode and connected to another Macintosh computer by a FireWire cable, the PowerBook G4 computer operates like a FireWire mass storage device with the SBP-2 (Serial Bus Protocol) standard. Target Disk mode has two primary uses:

■ high-speed data transfer between computers

■ diagnosis and repair of a corrupted internal hard drive

The PowerBook G4 computer can operate in Target Disk Mode as long as the other computer has a FireWire port and is running either

■ Mac OS X (any version)

■ Mac OS 9 with FireWire software 2.3.3 or newer

To put the computer into Target Disk mode, the user holds down the T key while the computer is starting up. When Open Firmware detects the T key during the boot process, it transfers control to special Open Firmware code.

To take the computer out of Target Disk mode, the user presses the power button.

For more information about Target Disk mode, see the section "Target Mode" in Technote 1189, The Monster Disk Driver Technote. The technote is available on the Technote website at

http://developer.apple.com/technotes/

Ethernet Port

The PowerBook G4 computer has a built-in Ethernet port that supports 10Base-T, 100Base-T, and 1000Base-T transfer rates. In operation, the actual speed of the link is auto-negotiated between the computer's PHY device and the network bridge or router to which it is connected.

The connector for the Ethernet port is an RJ-45 connector on the back of the computer. Table 3-3 shows the signals and pin assignments for 10Base-T and 100Base-T operation. Table 3-4 shows the signals and pin assignments for 1000Base-T operation.

Table 3-3   Signals for 10Base-T and 100Base-T operation

Pin	Signal name	Signal definition
1	TXP	Transmit (positive lead)
2	TXN	Transmit (negative lead)
3	RXP	Receive (positive lead)
4	–	Not used
5	–	Not used

Table 3-3   Signals for 10Base-T and 100Base-T operation

Pin	Signal name	Signal definition
6	RXN	Receive (negative lead)
7	–	Not used
8	–	Not used

Table 3-4   Signals for 1000Base-T operation

Pin	Signal name	Signal definition
1	TRD+(0)	Transmit and receive data 0 (positive lead)
2	TRD–(0)	Transmit and receive data 0 (negative lead)
3	TRD+(1)	Transmit and receive data 1 (positive lead)
4	TRD+(2)	Transmit and receive data 2 (positive lead)
5	TRD–(2)	Transmit and receive data 2 (negative lead)
6	TRD–(1)	Transmit and receive data 1 (negative lead)
7	TRD+(3)	Transmit and receive data 3 (positive lead)
8	TRD–(3)	Transmit and receive data 3 (negative lead)

To interconnect two computers for 1000Base-T operation, you must use 4-pair cable (Category 5 or 6).

The Ethernet port on the PowerBook G4 computer supports Auto-MDIX: It switches between MDI (Medium Dependent Interface) and MDI-X operation automatically, so it can be connected to another device by either a straight-through cable or a cross-over cable.

The Ethernet interface in the PowerBook G4 computer conforms to the ISO/IEC 802.3 specification, where applicable, and complies with IEEE specifications 802.3i (10Base-T), 802.3u-1995 (100Base-T), and 802.3ab (1000Base-T).

Internal Modem

The PowerBook G4 computer comes with a built-in modem. The connector for the modem is an RJ-11 connector on the back of the computer.

The modem has the following features:

- modem bit rates up to 56 Kbps (supports K56flex and V.90 modem standards)
- Group 3 fax modem bit rates up to 14.4 Kbps

The modem is connected to an internal USB port and is a vendor-specific USB device. The modem driver controls the modem hardware and presents a virtual serial port to the operating system and applications. Applications that bypass the operating sysem's modem driver and communicate directly with the SCC will not work properly.

AirPort Card Wireless LAN Module

The PowerBook G4 computer supports the AirPort Card, an internal wireless LAN module. The AirPort Card is standard on the 667-MHz model.

The AirPort Card can be used for local printer sharing, file exchange, internet access, and e-mail access.

The AirPort Card transmits and receives data at up to 11 Mbps. It is also interoperable with some older wireless LANs, as specified in "Hardware Components" on page 39.

Wireless connection to the internet or a wired LAN requires a base station as the connection to the internet or a bridge between the wireless signals and a wired LAN. Software included with the AirPort Card enables a Macintosh computer that

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has an AirPort Card installed to act as a base station. The user also has the option of purchasing an AirPort Base Station that can be connected to the wired LAN or to a 56 Kbps hardware modem.

Data Security

Three features of the AirPort Card help to maintain the security of data transmissions:

■ The system uses direct-sequence spread-spectrum (DSSS) technology that uses a multi-bit spreading code that effectively scrambles the data for any receiver that lacks the corresponding code.

■ The system can use a table of authentic network client ID values to verify each client's identity before granting access to the network.

■ When communicating with a base station, the system encrypts the data using Wired Equivalent Privacy (WEP) with a 128-bit security key.

Hardware Components

The AirPort Card is a wireless LAN module based on the IEEE 802.11 standard and using direct-sequence spread-spectrum (DSSS) technology. It is interoperable with PC-compatible wireless LANs that conform to the 802.11 standard and use DSSS.

The AirPort Card contains a media access controller (MAC), a digital signal processor (DSP), and a radio-frequency (RF) section. The antennas are built into the computer's case.

The MAC provides the data communication protocols and the controls for the physical layer.

The DSP provides the core physical layer functionality and controls the RF section. The DSP communicates with the MAC for data exchange, physical layer control, and parameter settings.

The RF section provides modulation and transmission of outgoing signals and reception and demodulation of incoming signals. Its power output when transmitting is nominally 31 mW.

When transmitting data, the DSP converts the outgoing data stream into a DSSS signal and sends it to the RF section. When receiving data, the DSP accepts incoming DSSS data from the RF section and converts it to a normal data stream.

Two antennas are connected to the AirPort Card. One antenna is always used for transmitting. Either of the two antennas may be used for receiving. Using a diversity technique, the DSP selects the antenna that gives the best reception.

Software Components

Software that is provided with the AirPort Card includes

- AirPort Setup Assistant, a standalone assistant that takes users through the steps necessary to set up the AirPort Card, set up an AirPort Base Station, or set up a software base station.

- AirPort Application, an application that allows users to switch between wireless networks and to create and join peer-to-peer networks.

- AirPort Control Strip Module, which provides a signal strength indication and most of the functions of the AirPort Application.

- AirPort Admin, a utility for the advanced user. With it the user can edit the administrative and advanced settings for a hardware or software base station. It can also be used to determine the location for the base station that gives the best reception.

Infrared Communication Link

The PowerBook G4 computer has a directed infrared (IR) communication link connected internally to a serial port on the KeyLargo IC. When the computer is placed within range of another device with an IR interface, it can send and receive serial data. Other devices with an IR interface include PDAs, some digital cell phones, and some printers.

Operating range is 1 meter, and the devices must be positioned with their IR ports pointed toward each other within about 15 degrees.

The IR link in the PowerBook G4 computer supports the Infrared Data Association (IrDA) standard at up to 4.0 Mbps. The modulation method complies with the IrDA physical layer standard. For more information, see the reference at "Infrared Interface" on page 81.

Hard Disk Drive

The PowerBook G4 computer has an internal hard disk drive with a storage capacity of 20, 30, or 48 GB. The drive has fluid dynamic bearings for quieter operation.

The hard disk drive drive uses the extended IDE (integrated drive electronics) interface, which is also referred to as the ATA interface. The implementation of the ATA interface on this computer is a subset of the ATA/ATAPI-4 specification (ANSI NCITS 317-1998 AT Attachment - 4 with Packet Interface Extension). That specification is maintained by the National Committee on Information Technology Standards (NCITS) Technical Committee T13.

The software that supports the internal hard disk is the same as that in previous PowerBook models with internal IDE drives and includes DMA support. For the latest information about that software, see Technote #1098, ATA Device Software Guide Additions and Corrections. The web page for Technote #1098 includes a link to a downloadable copy of ATA Device Software Guide.

To obtain the reference documents listed here, see the reference links at "ATA Devices" on page 80.

Hard Disk Dimensions

Figure 3-3 shows the maximum dimensions of the hard disk and the location of the mounting holes. The hard disk is the same physical size as the ones in the recent PowerBook G3 Series computers: only 12.7 mm (0.5 inches) high.

The minimum clearance between any conductive components on the drive and the bottom of the mounting envelope is 0.5 mm.

Figure 3-3   Maximum dimensions of the internal hard disk

12.70 maximum
[0.500 maximum]

3.00
[0.118]

14.00 [0.551]

90.60
[3.567]

101.85 maximum
[4.01 maximum]

4.06
[0.160]

61.72
[2.430]

M3, 3.0 mm thread
depth minimum, 4X

69.85
[2.75]

M3, 2.5 mm thread
depth minimum, 4X
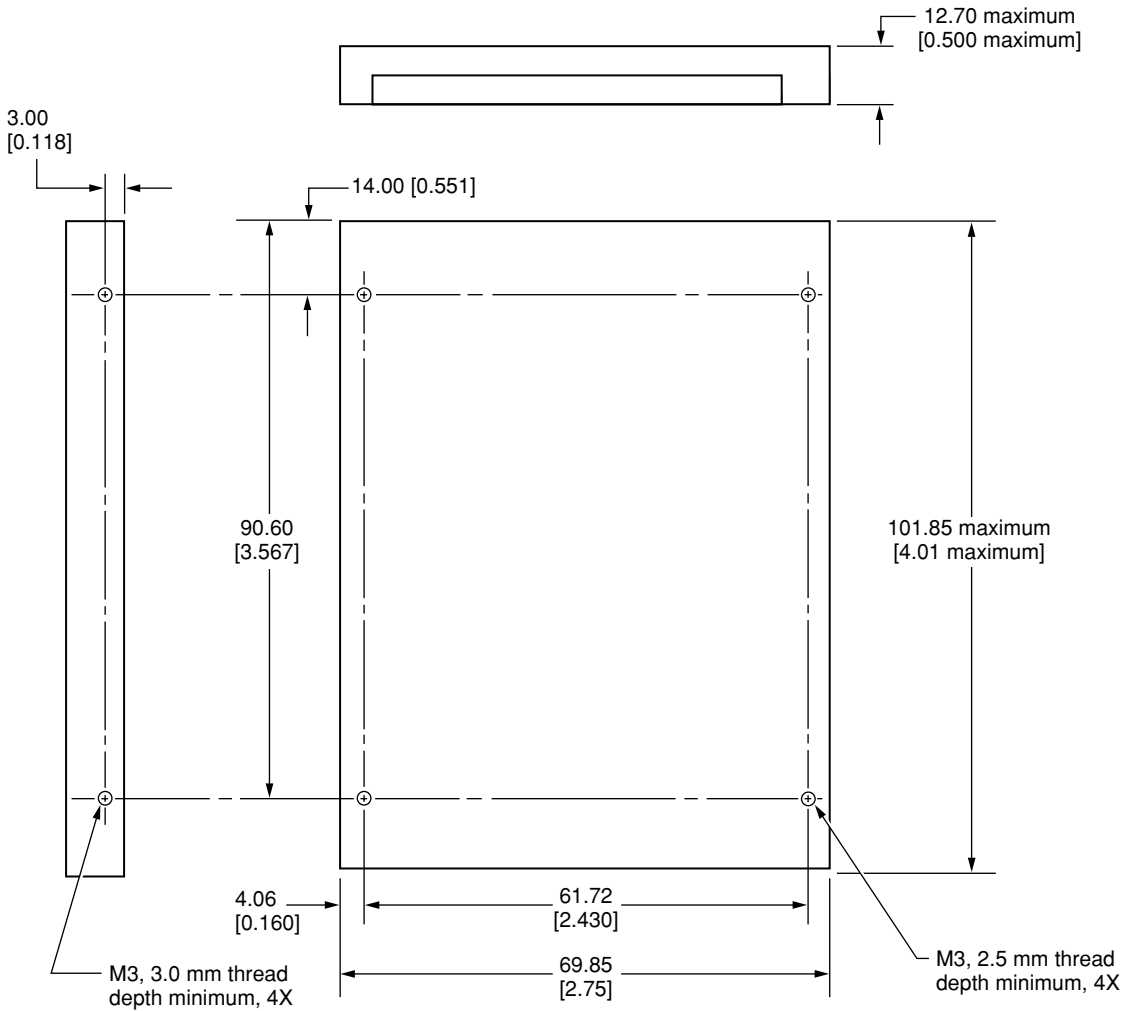
Note: Dimensions are in millimeters [inches].

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Hard Disk Connector

The internal hard disk has a 48-pin connector that carries both the ATA signals and the power for the drive. The connector has the dimensions of a 50-pin connector, but with one row of pins removed, as shown in Figure 3-4. The remaining pins are in two groups: pins 1–44, which carry the signals and power, and pins 46–48, which are reserved. Pin 20 has been removed, and pin 1 is located nearest the gap, rather than at the end of the connector.

Figure 3-4   Hard disk connector and location

© **Apple Computer, Inc. October 2001**
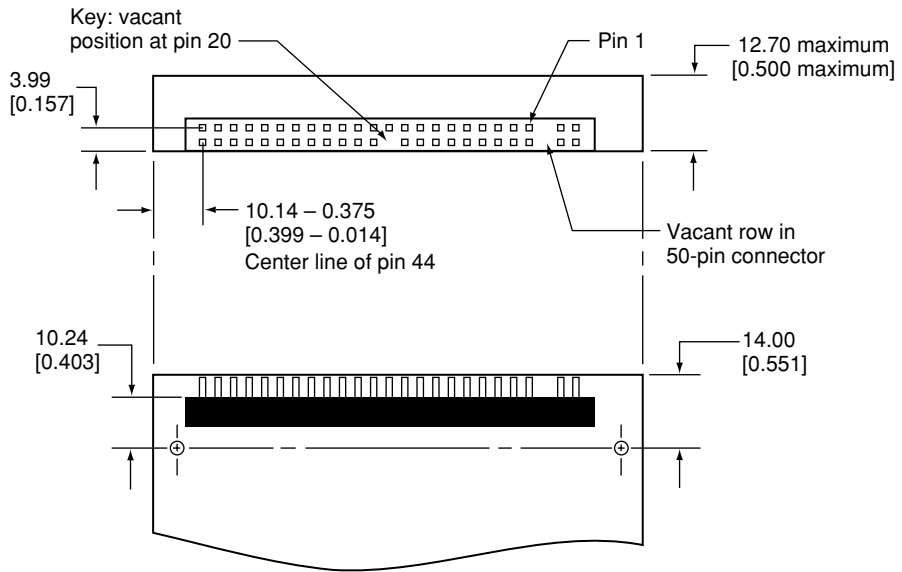
Signal Assignments

Table 3-5 shows the signal assignments on the 44-pin portion of the hard disk connector. A slash (/) at the beginning of a signal name indicates an active-low signal.

Table 3-5   Pin assignments on the ATA hard disk connector

Pin number	Signal name	Pin number	Signal name
1	/RESET	2	GROUND
3	DD7	4	DD8
5	DD6	6	DD9
7	DD5	8	DD10
9	DD4	10	DD11
11	DD3	12	DD12
13	DD2	14	DD13
15	DD1	16	DD14
17	DD0	18	DD15
19	GROUND	20	KEY
21	DMARQ	22	GROUND
23	/DIOW	24	GROUND
25	/DIOR, /HDMARDY, HSTROBE	26	GROUND
27	IORDY, /DDMARDY, DSTROBE	28	CSEL
29	/DMACK	30	GROUND
31	INTRQ	32	/IOCS16
33	DA1	34	/PDIAG, /CBLID
35	DA0	36	DA2
37	/CS0	38	/CS1

Table 3-5   Pin assignments on the ATA hard disk connector (continued)

Pin number	Signal name	Pin number	Signal name
39	/DASP	40	GROUND
41	+5V LOGIC	42	+5V MOTOR
43	GROUND	44	Reserved

CSEL, /DASP, /IOCS16, and /PDIAG are not used; see Table 3-6.

ATA Signal Descriptions

Table 3-6 describes the signals on the ATA hard disk connector.

Table 3-6   Signals on the ATA hard disk connector

Signal name	Signal description
DA(0–2)	Device address; used by the computer to select one of the registers in the ATA drive. For more information, see the descriptions of the CS0 and CS1 signals.
DD(0–15)	Data bus; buffered from IOD(16–31) of the computer's I/O bus. DD(0–15) are used to transfer 16-bit data to and from the drive buffer. DD(8–15) are used to transfer data to and from the internal registers of the drive, with DD(0–7) driven high when writing.
/CBLID	The host checks this signal after Power On or hardware reset to detect whether an 80-conductor cable is present.
/CS0	Register select signal. It is asserted low to select the main task file registers. The task file registers indicate the command, the sector address, and the sector count.
/CS1	Register select signal. It is asserted low to select the additional control and status registers on the ATA drive.
CSEL	Cable select; not available on this computer (n.c.).
/DASP	Device active or slave present; not available on this computer (n.c.).

Table 3-6   Signals on the ATA hard disk connector (continued)

Signal name	Signal description
/DDMARDY	Drive ready to receive Ultra DMA data.
/DIOR	I/O data read strobe.
/DIOW	I/O data write strobe.
/DMACK	Used by the host to initiate a DMA transfer in response to DMARQ.
DSTROBE	Strobe for Ultra DMA data transfers to host.
/HDMARDY	Ultra DMA data ready.
HSTROBE	Strobe for Ultra DMA data transfers from host.
IORDY	I/O ready; when driven low by the drive, signals the CPU to insert wait states into the I/O read or write cycles.
/IOCS16	I/O channel select; not used on this computer.
DMARQ	Asserted by the device when it is ready to transfer data to or from the host.
INTRQ	Interrupt request. This active high signal is used to inform the computer that a data transfer is requested or that a command has terminated.
/PDIAG	Asserted by device 1 to indicate to device 0 that it has completed the power-on diagnostics; not available on this computer (n.c.).
/RESET	Hardware reset to the drive; an active low signal.
Key	This pin is the key for the connector.

The built-in ATA devices and ATA devices in the expansion bay are separately connected to the I/O bus through bidirectional bus buffers.

DVD-ROM Drive

The PowerBook G4 computer comes with a built-in DVD-ROM drive. The DVD-ROM drive uses slot loading. The drive is fully compatible with existing CD-ROM media; it supports CD-ROM at 24X speed maximum and DVD at 6x constant linear velocity (CLV). The DVD-ROM drive supports the following disc formats:

■ DVD-ROM (one- or two-layer, one- or two-sided)

■ Video DVD (one- or two-layer, one- or two-sided)

■ DVD-R (3.95 GB)

■ DVD-RAM (read only)

■ CD-ROM (Modes 1 and 2) and CD-ROM XA (Mode 2, Forms 1 and 2)

■ CD-Audio, Photo CD, CD-RW (read only), CD-R (read only), and CD-Extra

■ CD-I (Mode 2, Forms 1 and 2), CD-I Ready, and CD-I Bridge

■ Video CD

Digital audio signals from the DVD-ROM can be played through the sound outputs under the control of the Sound Manager.

The DVD-ROM drive is an ATAPI drive and is connected as device 0 (master) in an ATA Device 0/1 configuration.

CD-RW Drive

An internal CD-RW drive is available as an option. The drive has a slot for loading the disc. The drive is capable of writing CD-R media at 8x speed and CD-RW media at 8x speed. It can read CD-ROM media at 24x speed (CAV).

Digital audio signals from the CD-RW drive can be played through the sound outputs under the control of the Sound Manager.

Trackpad

The pointing device in the PowerBook G4 computer is a trackpad. The trackpad is a solid-state device that emulates a mouse by sensing the motions of the user's finger over its surface and translating those motions into ADB commands.

The user makes selections either by pressing the trackpad button (below the trackpad) or by tapping and double tapping on the pad itself. The trackpad responds to one or two taps on the pad itself as one or two clicks of the button. The user can tap and drag on the trackpad in much the same manner as clicking and dragging with the mouse. The tap and double tap functions are optional; the user activates or deactivates them by means of the Trackpad control panel.

Keyboard

The keyboard is a compact, low-profile design with a row of function keys and inverted-T cursor motion keys.

Removing the Keyboard

The keyboard is removable to allow access to the internal components and expansion connectors inside the computer. The keyboard is held in place by a locking screw and two latches.

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To unlock the keyboard, the user turns a slotted screw that is part of the Num Lock LED, which is between the F5 and F6 function keys. Turning the screw 180° locks or unlocks the keyboard.

> **Note:** The PowerBook G4 computer leaves the factory with keyboard locking screw in the unlocked position.

The two latches are between the ESC key and the F1 key and between the F11 and F12 keys. The user can release the latches by pulling them toward the front of the computer.

Changing the Operation of the Keyboard

Several of the keys on the keyboard have more than one mode of operation.

- Function keys F1–F6 can also control the display brightness, speaker volume, and the Num Lock function; function key F12 is also the media eject key.

- The function keys from F7 through F11 can be set by the user to open applications, documents, or AppleScripts.

- Certain control keys can be used as page-control keys.

- The keys on the right side of the keyboard can be used as a numeric keypad.

The next sections describe these groups of keys and the way their alternate modes of operation are selected by using the Fn key, the Num Lock key, and the Function Keys checkbox in the Keyboard control panel.

Keyboard Illustrations

Figure 3-5 shows the actual appearance of the keyboard. Figure 3-6 shows the alternate modes of operation of the function and control keys. Figure 3-7 shows the embedded numeric keypad.

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Figure 3-5   Keyboard layout

Figure 3-6 and Figure 3-7 include duplicate versions of some keys in order to show their alternate modes of operation. In some cases, the alternate key captions shown in the figures do not appear on the keyboard. For the actual appearance of the keyboard, refer to Figure 3-5.

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Figure 3-6   Alternate operations of function and control keys

fn key is down and checkbox is unchecked, or fn key is up and checkbox is checked.

fn key is up and checkbox is unchecked, or fn key is down and checkbox is checked.

fn key is up.

fn key is up.

fn key is down.

fn key is down.

Devices and Ports
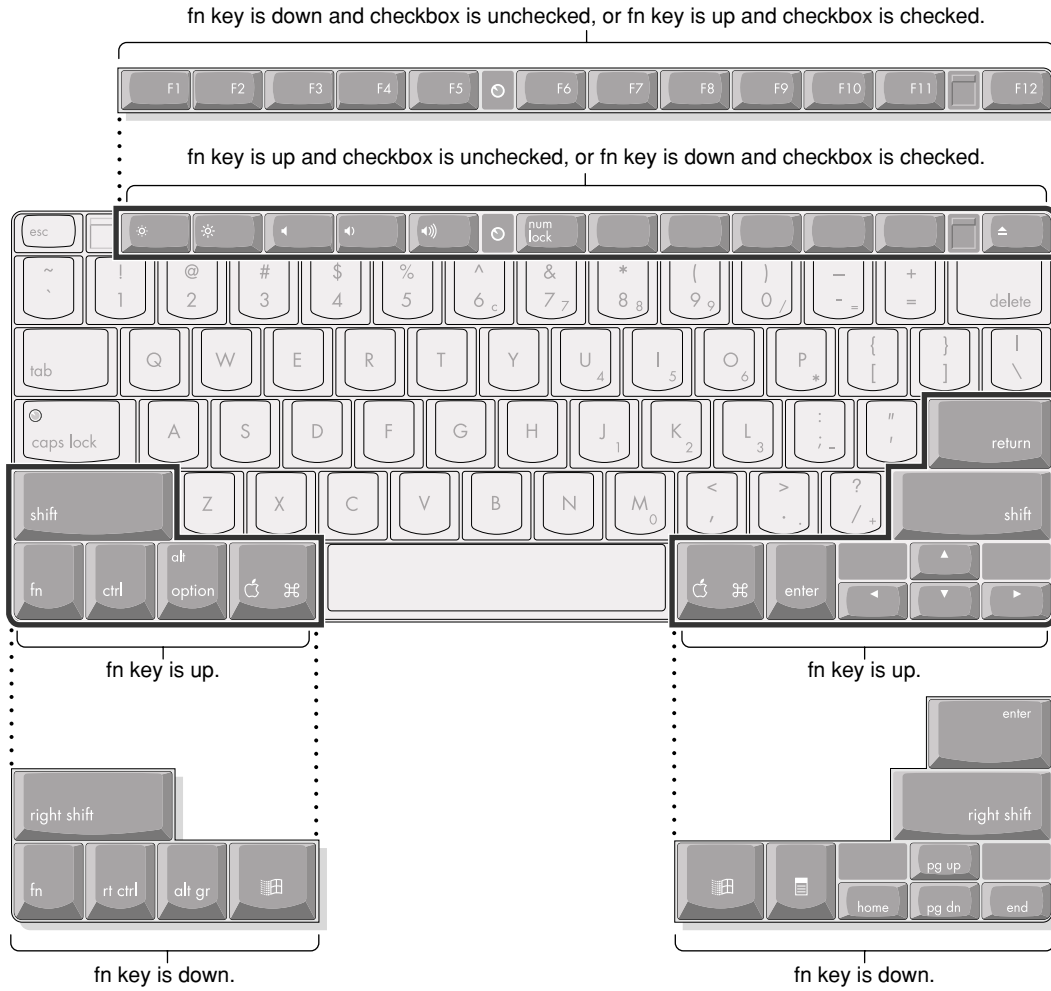
Figure 3-7   Embedded numeric keypad operation

num lock is off and fn key is down.

num lock is off and fn key is up.

num lock is on.

Devices and Ports
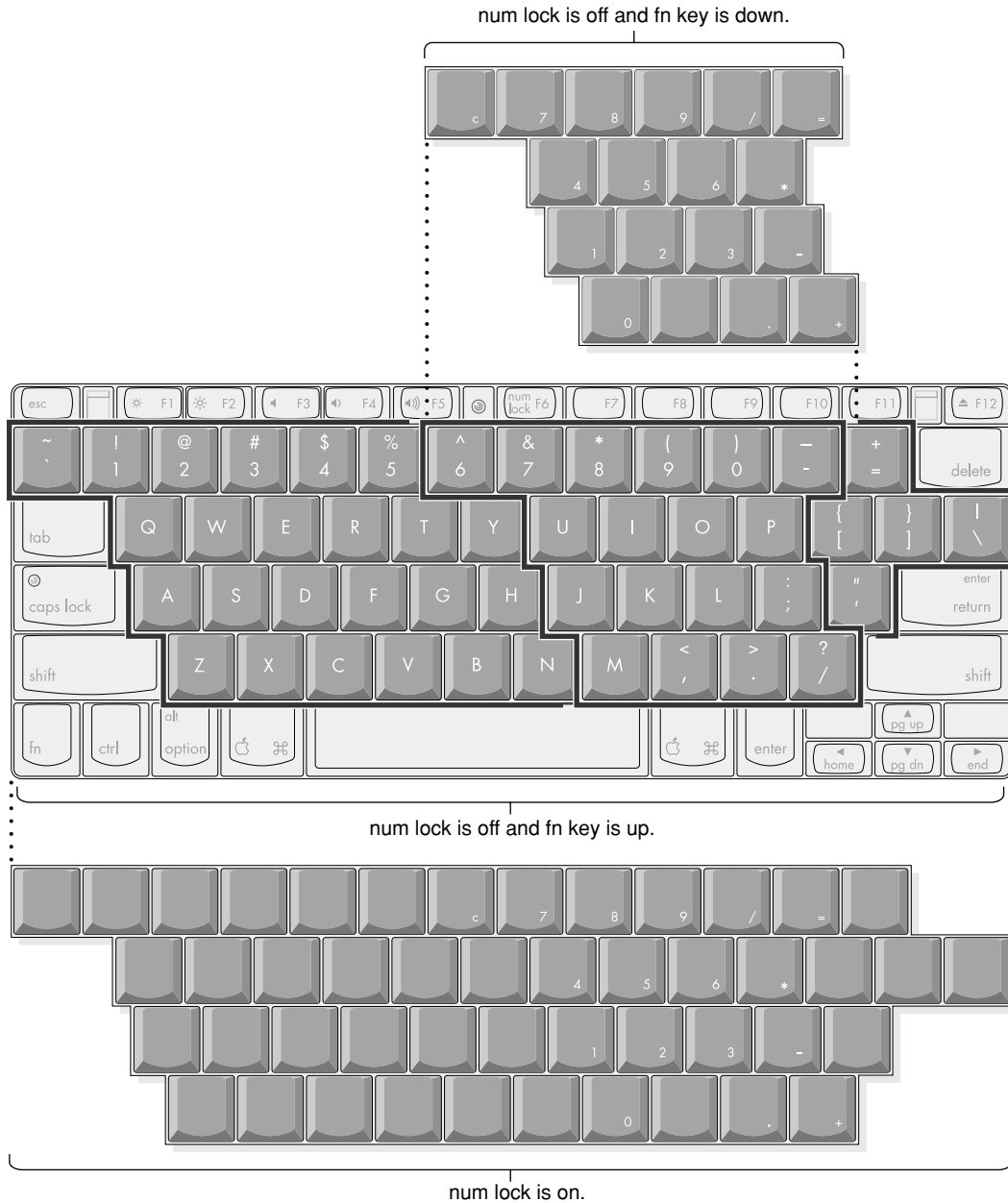
Using the Fn Key

Pressing the Fn key affects three sets of keys: the function keys F1–F12, the embedded numeric keypad, and certain modifier keys.

- It toggles the function keys between their control-button operation and their F1–F12 functions, as shown in Table 3-7 and Figure 3-6. The user selects the default modes of operation of those keys as described in the section "The Function-Keys Checkbox" (page 53).

- It selects the embedded numeric keypad on the right portion of the alphanumeric keys, as shown in Table 3-9 and Figure 3-7.

- It changes certain control keys, including the cursor control keys, to page control keys, as shown in Table 3-10 and Figure 3-7.

Using the Num Lock Key

Pressing the Num Lock key affects two sets of keys: the embedded keypad and the rest of the alphanumeric keys.

- It selects the embedded numeric keypad, as shown in Table 3-9 and Figure 3-7.

- It makes the rest of the alphanumeric keys functionless (NOPs), as shown in Figure 3-7.

The Function-Keys Checkbox

The Fn key lets the user switch the mode of operation of the function keys at any time. The user selects the default mode of the function keys by means of the Function-keys checkbox in the Keyboard Control Panel.

The Function-keys checkbox lets the user choose whether the function key operations are primary or secondary. "Function keys primary" means the function keys are normally in their F1–F12 mode of operation and pressing the Fn key selects their control-button mode. "Function keys secondary" means the function keys are normally in their control-button mode and pressing the Fn key selects their function-key mode.

In other words, pressing the Fn key reverses the mode of operation of the function keys from the default mode set by the checkbox. Table 3-7 summarizes the checkbox settings and the operation of the Fn key. The operations of the individual function keys are shown in Table 3-7 and Figure 3-6.

Table 3-7   Setting the default behavior of the function keys

Make Function Keys Primary checkbox	Operations of function keys	
	Fn key up	Fn key down
Checked	F1–F12 functions	Control buttons
Not checked	Control buttons	F1–F12 functions

Table 3-8   The function keys as control buttons

Key name	Control button
F1	Decrease display brightness
F2	Increase display brightness
F3	Mute the speaker
F4	Decrease speaker volume
F5	Increase speaker volume
F6	Num Lock
F7	User definable
F8	User definable
F9	User definable

Table 3-8   The function keys as control buttons (continued)

Key name	Control button
F10	User definable
F11	User definable
F12	Media eject

Operations of the Function Keys

Function keys F1–F6 are used as control buttons for the display and sound and F12 is used for media eject; function keys F7 through F11 are open for the user to define. The operations of the function keys are controlled by the Function keys checkbox and the Fn key. Table 3-8 is a list of the function keys and their operations as control buttons. The Keyboard Control Panel allows the user to assign operations to function keys F7 through F11. Operations that can be assigned include

- opening an application

- opening a document

- evoking an AppleScript

- logging on to a FileServer by way of an alias

The Embedded Keypad

A certain group of alphanumeric keys can also function as an embedded keypad. The user selects this mode by using the Fn key or the Num Lock key. Figure 3-7 shows the keys making up the embedded keypad and Table 3-9 lists them.

Table 3-9   Embedded keypad keys

Key name	Keypad function
6	Clear
7	7
8	8
9	9
0	/ (divide)
-	= (equals)
U	4
I	5
O	6
P	* (multiply)
J	1
K	2
L	3
;	– (subtract)
M	0
,	NOP
.	. (decimal)
/	+ (add)

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When the embedded keypad is made active by the Num Lock key, the other alphanumeric keys have no operation (NOP), as shown in Figure 3-7. The affected keys include certain special character keys: plus and equal sign, right and left brackets, vertical bar and backslash, and straight apostrophe.

Other Control Keys

The cursor control keys can also be used as page control keys. Other control keys can take on the functions of certain keys on a PC keyboard, for use with PC emulation software. The Fn key controls the modes of operation of this group of keys. Table 3-10 is a list of these keys and their alternate functions. These control keys are also show in Figure 3-7.

Table 3-10   Control keys that change

Key name	Alternate function
Shift	Right shift key
Control	Right control key
Option	Alt gr (right Alt key)
Command	Windows® key
Enter	Menu key (for contextual menus)
Left arrow	Home
Up arrow	Page up
Down arrow	Page down
Right arrow	End

Flat Panel Display

The PowerBook G4 computer has a built-in color flat panel display. It is a wide-screen display (1152 by 768 pixels) and is 15.2 inches across, measured diagonally.

The display is backlit by a cold cathode fluorescent lamp (CCFL). The display uses TFT (thin-film transistor) technology for high contrast and fast response.

In addition to its native resolution (1152 by 768) the display also supports several non-native resolutions, as shown in Table 3-11. The graphics controller IC includes a scaling function that expands displays with those smaller resolutions to fill the screen.

The display's native resolution, 1152 by 768, has an aspect ratio of 3:2. When selecting a picture resolution with an aspect ration of 4:3, the user can choose to have it displayed with square pixels and black margins on the sides, or with stretched pixels that fill the display from side to side. These options are shown in Table 3-11.

Table 3-11   Flat panel display resolutions

Picture resolution	Display area used	Black margins	Shape of pixels
640 by 480	1024 by 768	yes	square
640 by 480	1152 by 768	no	stretched
720 by 480	1152 by 768	no	square
800 by 600	1024 by 768	yes	square
800 by 600	1152 by 768	no	stretched
896 by 600	1152 by 768	no	square

Table 3-11   Flat panel display resolutions

Picture resolution	Display area used	Black margins	Shape of pixels
1024 by 768	1024 by 768	yes	square
1024 by 768	1152 by 768	no	stretched
1152 by 768	1152 by 768	no	square

When the internal display and an external monitor are both operating and mirror mode is selected, the scaling function is not available. Both displays show full-sized images only when the display resolution for the external monitor is set to the internal dispay's native resolution: 1152 by 768. Both displays can operate with other resolution settings, but in mirror mode, one of them will have a display that is smaller than the full screen and has a black border around it. With the resolution for the external monitor set to 640 by 480 or 800 by 600, the image on the internal display is smaller than its screen. For resolution settings larger than 1152 by 768, the image on the external monitor is smaller than its screen.

When the flat panel display and an external video monitor are operating at the same time, the system allocates 8 MB of video memory for each, enough to support the full 24-bit pixel depth at resolutions up to 1600 by 1200 pixels.

External Monitors

The computer has a built-in connector for an external monitor or projection device. The computer also has an S-video connector that supplies a video signal for an NTSC or PAL video monitor or VCR.

An external monitor or projection device connected to the computer can increase the amount of visible desktop space. This way of using an external monitor is called dual display to distinguish it from mirror mode, which shows the same information on both the external display and the built-in display.

Monitors and Picture Sizes

With the included adapter, the PowerBook G4 computer can be used with any
Apple monitor except those that have only an ADC or DVI connector. The computer
also supports VGA, SVGA, and XGA monitors. Table 3-12 lists the picture sizes and
frame rates supported.

Table 3-12   Picture sizes supported

Picture size pixels)	Frame rate	Pixel depth (flat panel inactive)	Pixel depth (flat panel active)
512 by 384	60 Hz	24 bpp	24 bpp
640 by 480	60 Hz	24 bpp	24 bpp
640 by 480	67 Hz	24 bpp	24 bpp
640 by 480	72 Hz	24 bpp	24 bpp
640 by 480	75 Hz	24 bpp	24 bpp
640 by 480	85 Hz	24 bpp	24 bpp
640 by 870	75 Hz	24 bpp	24 bpp
800 by 600	56 Hz	24 bpp	24 bpp
800 by 600	60 Hz	24 bpp	24 bpp
800 by 600	72 Hz	24 bpp	24 bpp
800 by 600	75 Hz	24 bpp	24 bpp
800 by 600	85 Hz	24 bpp	24 bpp
832 by 624	75 Hz	24 bpp	24 bpp
1024 by 768	60 Hz	24 bpp	24 bpp
1024 by 768	70 Hz	24 bpp	24 bpp
1024 by 768	72 Hz	24 bpp	24 bpp
1024 by 768	75 Hz	24 bpp	24 bpp
1024 by 768	85 Hz	24 bpp	24 bpp
1152 by 870	75 Hz	24 bpp	24 bpp

Table 3-12   Picture sizes supported (continued)

Picture size pixels)	Frame rate	Pixel depth (flat panel inactive)	Pixel depth (flat panel active)
1280 by 960	75 Hz	24 bpp	24 bpp
1280 by 1024	60 Hz	24 bpp	24 bpp
1280 by 1024	75 Hz	24 bpp	24 bpp
1600 by 1200	60 Hz	24 bpp	24 bpp
1600 by 1200	65 Hz	24 bpp	24 bpp
1600 by 1200	70 Hz	24 bpp	24 bpp
1600 by 1200	75 Hz	24 bpp	24 bpp
1792 by 1344	60 Hz	24 bpp	16 bpp
1856 by 1392	60 Hz	24 bpp	16 bpp
1920 by 1440	75 Hz	24 bpp	16 bpp

The graphics IC contains 16 MB of video memory and provides 24 bits per pixel on picture sizes up to 1920 by 1440 when the flat panel is inactive. When an external monitor and the flat panel display are operating at the same time, 8 MB of video memory is available for each. In that case, the maximum pixel depth available on the external monitor at picture sizes above 1600 by 1200 is less, as shown in Table 3-12.

Monitor Connector

The connector is a standard DB-9/15 connector for use with a VGA, SVGA, or XGA monitor. Figure 3-8 shows the pin configurations and Table 3-13 lists the signal pin assignments.
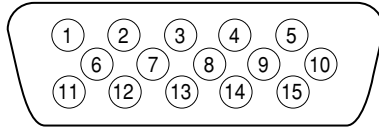
Figure 3-8   Signal pins on the monitor connector

Table 3-13   Signals on the monitor connector

Pin	Signal name	Description
1	RED	Red video signal
2	GREEN	Green video signal
3	BLUE	Blue video signal
4	MONID(0)	Monitor ID signal 0
5	GND	DDC return
6, 7, 8	AGND_VID	Analog video ground
9	+5V_IO	5 V power
10	GND	HSYNC and VSYNC ground
11	VGA_ID	VGA ID signal
12	MONID(2)	Monitor ID signal 2
13	HSYNC	Horizontal synchronization signal
14	VSYNC	Vertical synchronization signal
15	MONID(1)	Monitor ID signal 1

External Video Port

The PowerBook G4 computer has a video port that provides S-video output to a PAL or NTSC video monitor or VCR. The video output connector is a 7-pin S-video connector. Figure 3-9 shows the arrangement of the pins and Table 3-14 shows the pin assignments on the S-video connector.

Figure 3-9   S-video connector
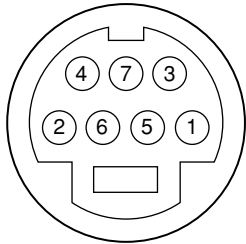
Table 3-14   Pin assignments for the S-video output connector

Pin number	S-video output connector
1	Analog GND
2	Analog GND
3	Video Y (luminance)
4	Video C (chroma)
5	composite video
6	Unused
7	Unused

An adapter (included) can be plugged into the S-video connector and accepts an RCA plug for connecting a composite video monitor.

The PowerBook G4 computer provides video output at picture sizes and frame rates compatible with the NTSC and PAL standards; the picture sizes are listed in Table 3-15. Those picture resolutions produce underscanned displays on standard monitors.

Table 3-15   Picture sizes for S-video output

Picture size	Pixel depth
512 by 384	24 bpp
640 by 480	24 bpp
720 by 480 (NTSC only)	24 bpp
720 by 576 (PAL only)	24 bpp
800 by 600	24 bpp
832 by 624	24 bpp
1024 by 768	24 bpp

Sound System

The sound system for the PowerBook G4 computer supports stereo sound output and input, available simultaneously. The sound circuitry handles audio data as 16-bit samples at a 48 kHz sample rate.

The sound circuitry and system software can create sounds digitally and either play the sounds through the built-in speakers or send the sound signals out through the sound output jack or one of the USB ports.

Devices and Ports

The PowerBook G4 computer can record sound data from either the built-in microphone, an audio CD, a USB audio device, or a CardBus card. For each sound input source, sound playthrough can be enabled or disabled. Sound data from digital sources is converted to analog form for output to the speakers and the sound output jack.

Sound Inputs

The sound system accepts inputs from four possible sources:

- the built-in microphone
- a CD or DVD in the DVD drive
- a digital audio device connected to a USB or FireWire port
- sound signals from the communication (modem) slot

The microphone preamp has a dedicated analog input channel in the Tumbler ciruitry; the other inputs send digital data. The analog input can be set for play-through or recording. The digital inputs can be selected or mixed by the Tumbler sound circuitry.

The computer also accepts digital sound data from the DVD drive or from devices connected to the USB or FireWire ports. Sound data from those sources can be sent to the sound system to be converted to analog form for output to the speakers and the output jack.

Note: The PowerBook G4 computer does not have a sound input jack. The USB port can be used for sound input from a USB microphone.

Built-in Microphone

The sound signal from the built-in microphone goes through a dedicated preamplifier that raises its nominal 30-mV level to a nominal 150 mV (peak-to-peak) signal to the sound circuitry. That signal level assures good quality digitizing without driving the analog input into clipping.

Modem Activity Sound Signals

Modem activity sound signals from the communications slot are sent to the Tumbler sound circuitry as 8-bit digital data.

Devices and Ports

Sound Outputs

The sound system sends sound output signals to the built-in speakers and the external sound output jack.

Headphone Jack

The headphone jack is located on the left side of the computer. The headphone jack provides enough current to drive a pair of low-impedance headphones. It can also be used as a line-level output.

The headphone jack has the following electrical characteristics:

- impedance suitable for driving standard 32-ohm headphones

- output level 2.0 V peak-to-peak (0.7 V RMS)

- signal-to-noise (SNR) 90 dB unweighted (typical)

- total harmonic distortion (THD) 0.03% or less

Internal Speakers

The computer has two 20mm speakers, one on either side of the keyboard. The computer turns off the sound signals to the speakers when an external device is connected to the sound output jack and during power cycling.

Digitizing Sound

The sound circuitry digitizes and records sound as 48-kHz 16-bit samples. If a sound sampled at a lower rate on another computer is played as output, the Sound Manager transparently upsamples the sound to 48 kHz prior to outputting the audio to the sound circuitry.

When recording sound from a microphone, applications that may be affected by feedback should disable sound playthrough by calling the Sound Manager APIs.

Expansion Features

This chapter describes the expansion features of the PowerBook G4 computer: the RAM expansion slots and the CardBus slot.

RAM Expansion Slots

The computer has two RAM expansion slots that accommodate standard SO (small outline) DIMMs using SDRAM devices. One of the slots is normally occupied by a factory-installed SO-DIMM. The other slot is available for a user-installed SO-DIMM.

Note: Some configurations come with factory-installed SO-DIMMs in both slots.

RAM expansion SO-DIMMs for both models must be PC133 compliant. PC133 SO-DIMMs in the 550-MHz model operate at the speed of PC100 modules.

The SO-DIMMs must use SDRAM devices. If the user installs an SO-DIMM that uses EDO devices, the boot process will fail when the user attempts to restart the computer and the computer will not operate.

The address logic for the RAM slots supports up to 1 GB total RAM. Using the highest-density devices currently available, an SO-DIMM can contain up to 512 MB of RAM, so the two RAM expansion slots can accomodate up to 1 GB total RAM.

Getting Access to the Slots

The RAM expansion slots are stacked in a dual socket on the main logic board. The user can get access to the slots by removing the keyboard, as shown in Figure 4-1.

The keyboard is held in place by a locking screw and two latches.

The keyboard locking screw is a slotted screw that is part of the Num Lock LED, which is located between the F5 and F6 function keys. The locking screw can be turned through 360°; turning it 180° switches between the locked and unlocked positions. The computer is shipped with the locking screw in the unlocked position.

The two latches are between the ESC key and the F1 key and between the F11 and F12 keys. You release the latches by pulling them toward the front of the computer.

Pulling only on the latches (not on the keys), and without disconnecting the keyboard's membrane cable, you can lift the keyboard up and turn it face down onto the front part of the case.

Figure 4-1   Interior view showing RAM expansion slots

Upper memory slot

Lower memory slot (filled)

Keyboard flipped over
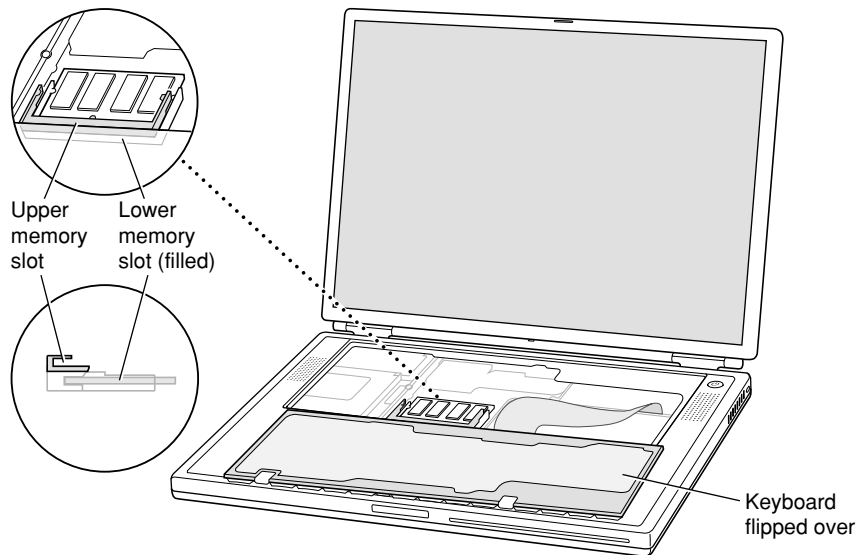
Mechanical Design of RAM SO-DIMMs

The RAM expansion modules used in the PowerBook G4 computer are standard 144-pin 8-byte DRAM SO-DIMMs, as defined in the JEDEC specifications.

The mechanical characteristics of the RAM expansion SO-DIMM are given in the JEDEC specification for the 144-pin 8-byte DRAM SO-DIMM. The specification number is JEDEC MO-190-C. To obtain a copy of the specification, see the references listed at "RAM Expansion Modules" on page 79.

The specification defines SO-DIMMs with nominal heights of 1.0, 1.25, 1.5, and 2.0 inches. The PowerBook G4 computer can accommodate SO-DIMMS with heights of 1.5 inches or less.

Important
The PowerBook G4 computer will not accept a 2-inch SO-DIMM.

The JEDEC specification defines the maximum depth or thickness of an SO-DIMM as 3.8 mm. That specification is also a maximum: Modules that exceed the specified thickness can cause reliability problems.

Electrical Design of RAM SO-DIMMs

SO-DIMMs for the 667-MHz model are required to be PC133 compliant. For information about the PC133 and PC100 specifications, see the references at "RAM Expansion Modules" on page 79.

Important
PC100 DIMMs will not work in the 667-MHz model.

The electrical characteristics of the RAM SO-DIMM are given in section 4.5.6 of the JEDEC Standard 21-C, release 7. To obtain a copy of the specification, see the references listed at "RAM Expansion Modules" on page 79.

The JEDEC and Intel specifications define several attributes of the DIMM, including storage capacity and configuration, connector pin assignments, and electrical loading. The specifications support SO-DIMMs with either one or two banks of memory.

Expansion Features

Important
The memory controller on the PowerBook G4 computer uses
a separate CKE signals for each bank, as called out in the
JEDEC specification. SO-DIMMs that have all the CKE pins
connected together will not operate properly.

The JEDEC specification for the SO-DIMM defines a Serial Presence Detect (SPD)
feature that contains the attributes of the module. SO-DIMMs for use in PowerBook
computers are required to have the SPD feature. Information about the required
values to be stored in the presence detect EEPROM is in section 4.1.2.5 and Figure
4.5.6–C (144 Pin SDRAM SO–DIMM, PD INFORMATION) of the JEDEC standard
21-C specification, release 7.

Important
For a DIMM to be recognized by the startup software, the
Serial Presence Detect (SPD) feature must be programmed
properly to indicate the timing modes supported by the
DIMM.

Capacitance of the data lines must be kept to a minimum. Individual DRAM devices
should have a pin capacitance of not more than 5 pF on each data pin.

SDRAM Devices

The SDRAM devices used in the RAM expansion modules must be self-refresh type
devices for operation from a 3.3-V power supply. The speed of the SDRAM devices
must be 100 MHz or higher for the 550-MHz model and 133 MHz or higher for the
667-MHz model.

The devices are programmed to operate with a CAS latency of 3. At that CAS
latency, the access time from the clock transition must be 5.4 ns or less. The burst
length must be at least 4 and the minimum clock delay for back-to-back random
column access cycles must be a latency of 1 clock cycle.

When the computer is in Sleep mode, the RAM modules are in self-refresh mode
and the maximum power-supply current available for each RAM module is 8 mA
(see the section "RAM SO-DIMM Electrical Limits" (page 72)). Developers should
specify SDRAM devices with low power specifications so as to stay within that
limit.

Configuration of RAM SO-DIMMs

Table 4-1 shows information about the different sizes of SDRAM devices used in the memory modules. The first two columns show the memory size and configuration of the SO-DIMMs. The next two columns show the number and configuration of the SDRAM devices making up the memory modules.

Table 4-1   Sizes of RAM expansion modules and devices

SO-DIMM		SDRAM Devices		
Size	Configuration	Number	Configuration	Banks
64 MB	8 M x 64	8	8 M x 8	1
64 MB	8 M x 64	8	4 M x 16	2
64 MB	8 M x 64	4	8 M x 16	1
128 MB	16 M x 64	8	16 M x 8	1
128 MB	16 M x 64	8	8 M x 16	2
256 MB	32 M x 64	16	16 M x 8	2
256 MB	32 M x 64	8	32 M x 8	1
256 MB	32 M x 64	8	16 M x 16	2
512 MB	64 M x 64	16	32 M x 8	2

Note: The PowerBook G4 computer does not use memory interleaving, so installing two SO-DIMMs of the same size does not result in any performance gain.

Address Multiplexing

Signals A[0] – A[12] and BA[0] – BA[1] on each RAM SO-DIMM make up a 15-bit multiplexed address bus that can support several different types of SDRAM devices. Table 4-2 lists the types of devices that can be used in the PowerBook G4 computer by size, configuration, and sizes of row, column, and bank addresses.

Important
The PowerBook G4 computer supports only the types of
SDRAM devices specified in Table 4-2. Other types of
devices should not be used with this computer.

Table 4-2   Types of DRAM devices

Device size	Device configuration	Row address bits	Column address bits
64 Mbits	2 M x 8 x 4	12	9
64 Mbits	1 M x 16 x 4	12	8
64 Mbits	512 K x 32 x 4	11	8
128 Mbits	4 M x 8 x 4	12	10
128 Mbits	2 M x 16 x 4	12	9
128 Mbits	1 M x 32 x 4	12	8
256 Mbits	8 M x 8 x 4	13	10
256 Mbits	4 M x 16 x 4	13	9

RAM SO-DIMM Electrical Limits

Each RAM SO-DIMM must not exceed the following maximum current limits on
the +3.3 V supply:

Active: 1.2 A (8 devices at 150 mA each)

Sleep: 12 mA

Important
The restriction on sleep current is required not only to
maximize the battery life but to meet the limitations of the
backup battery during sleep swapping of the main battery.
Developers of RAM expansion modules that exceed the limit
on sleep current must include a warning to the user that
battery sleep swapping may not work with those modules
installed.

The maximum current specified for active operation generally rules out the use of 4-bit-wide SDRAM devices in a RAM expansion module. Such a module would have 16 such devices, and the 1.2 A maximum current would allow only about 75 mA per device. To stay within the current limits, RAM expansion modules should use only 8-bit or 16-bit SDRAM devices.

CardBus Slot

The CardBus slot accepts one Type I or Type II card. The slot supports both 16-bit PC Cards and 32-bit CardBus Cards. The card can be removed and replaced while the computer is operating.

Note: The CardBus slot does not provide 12-V power.

For information about the CardBus and the PC Card Manager, refer to the CardBus DDK and the PC Card Manager SDK. To obtain the DDK and the SDK, see the reference at "PC Card Manager" on page 79.

Important
As noted in the user manual, the AirPort Card does not work in the CardBus slot.

Expansion Features

Supplemental Reference Documents

For more information about the technologies mentioned in this developer note, you may wish to consult some of the following references.

For information about older models of Macintosh computers, refer to the developer notes archive at

http://developer.apple.com/techpubs/hardware/hardware2.html.

You should also have copies of the relevant books describing the system software for Macintosh computers available in technical bookstores and on the World Wide Web at

http://developer.apple.com/techpubs/macos8/mac8.html

Apple Technotes

Apple Technotes answer many specific questions about the operation of Macintosh computers and the Mac OS. The technotes are available on the Technote website at

http://developer.apple.com/technotes/

3D Graphics

Developers of 3D graphics for games should know about OpenGL for Macintosh®, a new version of SGI's application programming interface (API) and software library for 3D graphics.

Information is available on the World Wide Web at

http://www.apple.com/opengl

Developer support and documentation is available at

http://developer.apple.com/opengl/

PowerPC G4 Microprocessor

Information about the PowerPC G4 microprocessor is available on the World Wide Web at

http://www.mot.com/SPS/RISC/smartnetworks/arch/powerpc/index.htm

Velocity Engine (AltiVec)

Velocity Engine is Apple's name for the AltiVec vector processor in the PowerPC G4 microprocessor. Apple provides support for developers who are starting to use the Velocity Engine in their applications. Documentation, development tools, and sample code are now available on the World Wide Web, at

http://developer.apple.com/hardware/ve/index.html

Supplemental Reference Documents

AltiVec Technology Programming Environments Manual (AltiVec PEM) is a reference guide for programmers. It contains a description for each instruction and information to help in understanding how the instruction works. You can obtain a copy of the AltiVec PEM through the Motorola AltiVec site on the World Wide Web, at

http://www.mot.com/SPS/RISC/smartnetworks/arch/powerpc/features/altivec/avindex.htm

Mac OS X

For access to Apple's developer documentation for Mac OS X, see the website at

http://developer.apple.com/techpubs/macosx/macosx.html

Two introductory books are available: *Mac OS X: An Overview for Developers*, and *Inside Mac OS X: System Overview*. Both are available on the Mac OS X website at

http://developer.apple.com/macosx/gettingstarted/

O'Reilly & Associates publishes a series of books about Mac OS X development. The books in this series have been technically reviewed by Apple engineers and are recommended by the Apple Developer Connection. The first Mac OS X titles, *Learning Carbon* and *Learning Cocoa*, are avilable now. In addition to the book series, the O'Reilly Network provides news and articles for Macintosh Developers on the World Wide Web at

http://www.oreillynet.com/mac

Mac OS 9

For a description of Mac OS 9.2, developers should refer to the technote for Mac OS 9.2. Other technotes contain information about the New World software architecture and the API changes for Power Manager 2.0. The technotes are available on the Technote website at

http://developer.apple.com/technotes/

Developers should also have copies of the relevant books describing the system software for Macintosh computers available in technical bookstores and on the World Wide Web at

http://developer.apple.com/techpubs/macos8/mac8.html

Open Firmware

Three Technotes provide an introduction to Open Firmware on the Macintosh platform. They are:

TN 1061: *Open Firmware, Part I*, available on the Technote website at

http://developer.apple.com/technotes/tn/tn1061.html

TN 1062: *Open Firmware, Part II*, available on the Technote website at

http://developer.apple.com/technotes/tn/tn1062.html

TN 1044: *Open Firmware, Part III*, available on the Technote website at

http://developer.apple.com/technotes/tn/tn1044.html

Another Technote tells how to debug open firmware code. Please refer to
TN 2004: *Debugging Open Firmware Using Telnet*, available on the Technote web site
at

http://developer.apple.com/technotes/tn/tn2004.html

RAM Expansion Modules

The mechanical characteristics of the RAM SO-DIMM are given in JEDEC
specification number JEDEC MO190-C. The specification can be found by using the
search string MO190-C on the Electronics Industry Association's website at

http://www.jedec.org/DOWNLOAD/default.cfm

The electrical characteristics of the RAM SO-DIMM are given in JEDEC Standard
21-C. The specification can be found by using the search string JESD21-C on the
Electronics Industry Association's website at

http://www.jedec.org/DOWNLOAD/default.cfm

The RAM DIMMs are required to be PC133 or PC100 compliant. Information about
the PC133 and PC100 specifications is available from Intel's website at

http://developer.intel.com/technology/memory/pcsdram/

PC Card Manager

For information about the CardBus and the PC Card Manager, refer to the CardBus
DDK and the PC Card Manager SDK. The DDK and SDK are available on the Apple
Developer World web page at

http://developer.apple.com/sdk/index.html

ATA Devices

For information about the system software for ATA devices such as the IDE drive, see Technote #1098, *ATA Device Software Guide Additions and Corrections*, available on the world wide web at

http://developer.apple.com/technotes/tn/tn1098.html

The web page for Technote #1098 includes a link to a downloadable copy of *ATA Device Software Guide*.

Information about the ATA standards is available at the Technical Committee T13 AT Attachment website, at

http://www.t13.org/

USB Interface

For more information about USB on Macintosh computers, you should refer to Apple Computer's *Mac OS USB DDK API Reference*. Information is also available on the World Wide Web, at

http://developer.apple.com/techpubs/hardware/DeviceManagers/usb/usb.html

USB game controllers are supported by the InputSprocket component of the Apple Games Sprockets software architecture. InputSprocket software and information about the InputSprocket APIs can be found at

http://developer.apple.com/games/

For full specifications of the Universal Serial Bus, you should refer to the USB Implementation Forum on the World Wide Web, at:

http://www.usb.org/developers/home.php3

FireWire Interface

For additional information about the FireWire IEEE 1394 interface and the Apple APIs for FireWire software, refer to the resources available on the Apple FireWire website at

http://developer.apple.com/hardware/FireWire/index.html

or send electronic mail to

firewire@apple.com

The IEEE 1394 standard is available from the IEEE. Ordering information can be found on the World Wide Web at

http://standards.ieee.org/catalog/bus.html

You may also find useful information at the 1394 Trade Association's website:

http://www.1394ta.org/

Infrared Interface

You can obtain more information about the IrDA physical layer standard at the Infrared Data Association (IrDA) website

http://www.irda.org/

Supplemental Reference Documents

Abbreviations

Abbreviations and Standard Units

Standard units of measure used in this note include:

A	amperes	MB	megabytes
dB	decibels	Mbps	megabits per second
GB	gigabytes	Mbits	megabits
Hz	hertz	MHz	megahertz
KB	kilobytes	mm	millimeters
kg	kilograms	ns	nanoseconds
kHz	kilohertz	V	volts
mA	milliamperes	VDC	volts direct current
mAh	milliampere-hours		

Abbreviations

Other abbreviations used in this note include:

10Base-T	an Ethernet standard for data transmission at rates up to 10 Mbits per second
100Base-T	an Ethernet standard for data transmission at rates up to 100 Mbits per second
1000Base-T	an Ethernet standard for data transmission at rates up to 1000 Mbits per second
AGP	accelerated graphics port
AIM	ATA Interface Module
ANSI	American National Standards Institute
API	application programming interface
ASIC	application-specific integrated circuit
ATA	AT attachment
CAS	column address strobe, a memory control signal
CD	compact disc
CD-ROM	compact disc read-only memory
CPU	central processing unit
CRT	cathode ray tube, a video display device
DAA	data access adapter (a telephone line interface)
DAC	digital-to-analog converter
DIMM	Dual Inline Memory Module
DB-DMA	descriptor-based direct memory access
DDK	device developer's kit
DDR	double data rate, a type of SDRAM
DMA	direct memory access
EDO	extended data out
EIDE	enhanced integrated device electronics
G3	Generation 3, the third generation of PowerPC microprocessors, including the PPC 740 and PPC 750

Abbreviations

G4	Generation 4, the fourth generation of PowerPC microprocessors, incorporating Altivec technology
GND	ground
HFS	hierarchical file system
HID	human interface device, a class of USB devices
IC	integrated circuit
IDE	integrated device electronics
IEC	International Electrotechnical Commission
I/O	input and output
IR	infrared
IrDA	Infrared Data Association
ISO	International Organization for Standardization
JEDEC	Joint Electron Device Engineering Council
L1	level 1 or first level, a type of CPU cache
L2	level 2 or second level, a type of CPU cache
LED	light emitting diode
Mac OS	Macintosh Operating System
MDI	Medium Dependent Interface
MDI-X	Medium Dependent Interface with Cross-Over
modem	modulator-demodulator, a data communications interface for use with analog telephone lines
NMI	nonmaskable interrupt
NOP	no operation
NVRAM	nonvolatile random-access memory
OHCI	Open Host Controller Interface
OS	operating system
PCI	Peripheral Component Interconnect, an industry-standard expansion bus
PLL	phase-locked loop

Abbreviations

RAM	random-access memory
RCA	Radio Corporation of America
rms	root mean square
ROM	read-only memory
SBP	Serial Bus Protocol
SCSI	Small Computer System Interface
SDK	software developer's kit
SDRAM	synchronous dynamic RAM
SMB	System Management Bus (for Smart Battery)
SNR	signal to noise ratio
SO-DIMM	small outline dual inline memory module
SPD	Serial Presence Detect, a feature of the SO DIMM
USB	Universal Serial Bus, an industry-standard expansion bus
VCC	positive supply voltage (voltage for collectors)
VIA	versatile interface adapter

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