
12-inch PowerBook G4 Developer Note

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Introduction to 12-inch PowerBook G4

Developer Note

This developer note gives a technical description of the new 12-inch PowerBook G4. The note provides information about the computer's internal design, input-output features, and expansion capabilities.

This developer note is intended to help hardware and software developers design products that are compatible with the Macintosh products described here. For additional technical information on Macintosh computers, refer to ["Supplemental Reference Documents"](#) (page 57).

Organization of This Document

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

- [Chapter 1, "Overview of the 12-inch PowerBook G4"](#) (page 11) introduces the 12-inch PowerBook G4 and describes its features.
- [Chapter 2, "Architecture"](#) (page 17) describes the internal logic of the 12-inch PowerBook G4, including the main ICs that appear in the block diagram.
- [Chapter 3, "Devices and Ports"](#) (page 25) describes the standard I/O ports and the built-in I/O devices.
- [Chapter 4, "RAM Expansion"](#) (page 51) describes the RAM expansion module.
- [Appendix A, "Supplemental Reference Documents"](#) (page 57) tells where to find more information about specific technologies used in the new 12-inch PowerBook G4.
- [Appendix B, "Conventions and Abbreviations"](#) (page 61) lists the standard units and abbreviations used in this developer note.

INTRODUCTION

Introduction to 12-inch PowerBook G4 Developer Note

Overview of the 12-inch PowerBook G4

This chapter lists the 12-inch PowerBook G4's features and provides references to detailed information within this developer note.

New Features

Here is a list of the new features of the 12-inch PowerBook G4. Each feature is described in a later chapter, as indicated in the list.

- **Processor speed:** The clock speed of the Power PC G4 microprocessor is 1.5 GHz. See [“Power PC G4 Microprocessor”](#) (page 19).
- **Hard disk storage:** The computer has a 5400 rpm hard disk drive with a storage capacity of 60 or 80 GB (build-to-order options of 80 or 100 GB). For more information and developer guidelines for alternative hard drives, see [“Hard Disk Drive”](#) (page 32).
- **System RAM:** The computer comes with 512 MB in RAM (256 MB on-board DDR SDRAM and 256 MB SO-DIMM in the expansion slot), expandable to a total of 1.25 GB. For more information, see [“System RAM”](#) (page 20).
- **Sudden Motion Sensor:** Helps protect the hard drive from sudden drops or falls by parking the hard drive when sudden changes in G force are detected. For more information, see [“Sudden Motion Sensor”](#) (page 23).
- **Scrolling trackpad:** The integrated trackpad includes tap/double-tap, drag, and scroll features. For more information, see [“Trackpad”](#) (page 38).

Feature Set

Here is a list of all of the features of the 12-inch PowerBook G4. Each feature is described in a later chapter, as indicated in the list.

- **Processor speed:** The clock speed of the Power PC G4 microprocessor is 1.5 GHz. See [“Power PC G4 Microprocessor”](#) (page 19).
- **System bus:** The speed of the system bus is 167 MHz.
- **System RAM:** The computer comes with 512 MB in RAM (256 MB on-board DDR SDRAM and 256 MB SO-DIMM in the expansion slot), expandable to a total of 1.25 GB. For more information, see [“System RAM”](#) (page 20).
- **Cache:** The microprocessor has a built-in L2 cache consisting of 512 KB of fast static RAM. The clock speed for the backside cache is the same as the clock speed of the microprocessor. See [“L2 Cache”](#) (page 19).

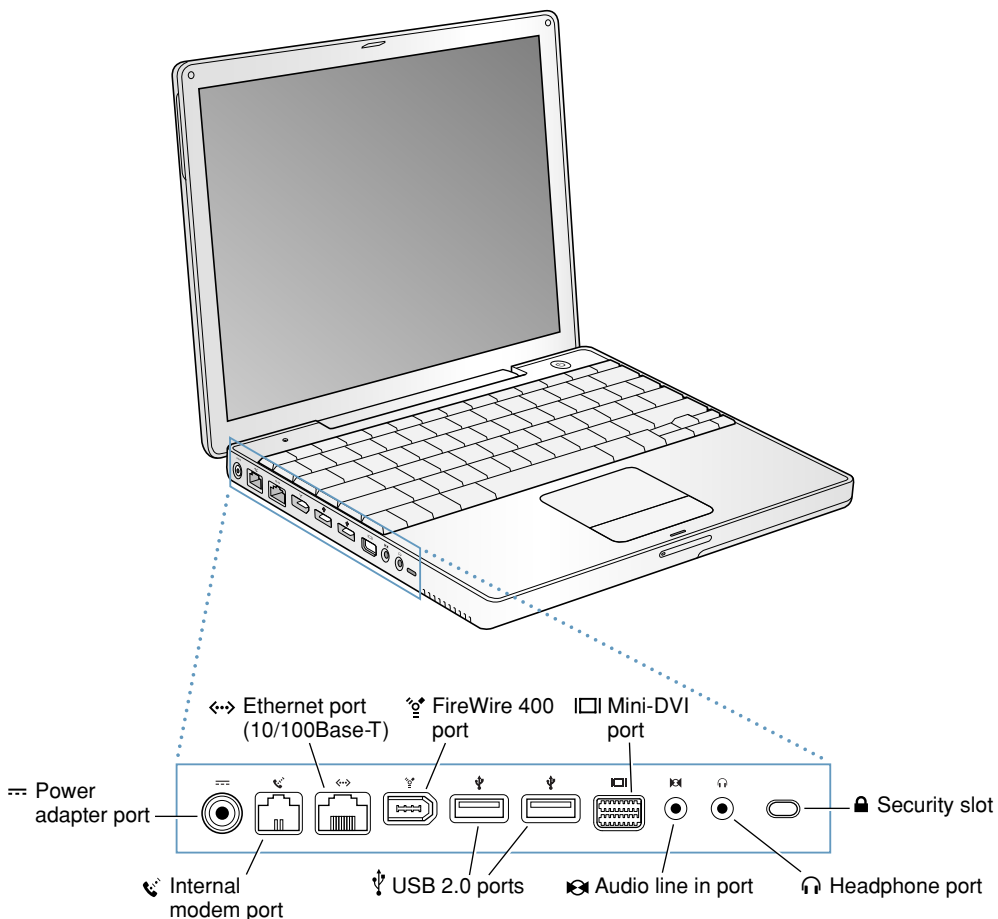
- **Hard disk storage:** The computer has a 5400 rpm hard disk drive with a storage capacity of 60 or 80 GB (build-to-order options of 80 or 100 GB). For more information and developer guidelines for alternative hard drives, see [“Hard Disk Drive”](#) (page 32).
- **Power Management:** This feature allows the user to step down the processor performance with dynamic frequency switching (DFS) to conserve battery life. For more information, see [“Power Management”](#) (page 15).
- **Combo drive:** Some configurations have a combination DVD-ROM/CD-RW drive. For more information, see [“Combo Drive”](#) (page 36).
- **SuperDrive:** Some configurations have a SuperDrive drive. For more information, see [“SuperDrive”](#) (page 37).
- **Graphics IC:** The display controller is an nVidia GeForce FX Go5200 with 64 MB of graphics DDR SDRAM. See [“Graphics IC”](#) (page 21).
- **External monitor port:** The 12-inch PowerBook G4 supports an external video monitor, using a mini-DVI connector for a video display. See [“External Display Port”](#) (page 44).
- **Microphone:** The computer has a built-in omnidirectional microphone. See [“Sound System”](#) (page 47).
- **Battery:** The computer has a single 50-watt-hour battery pack that uses six lithium ion cells pack to provide up to 5 hours of operation when maximum battery life options are specified in System Preferences.
- **Power adapter:** The computer comes with a 45 W power adapter with safety ground. The 12-inch PowerBook G4 is also compatible with Apple’s 65 W power adapter.
- **USB 2.0 ports:** The computer has two external USB 2.0 ports. See [“USB 2.0 Ports”](#) (page 25).
- **FireWire port:** The computer has an IEEE-1394a FireWire 400 Mbps serial port. See [“FireWire 400 Port”](#) (page 27).
- **Target disk mode:** The computer can act like a FireWire storage device connected to another computer. See [“Target Disk Mode”](#) (page 16).
- **Modem:** The computer has a built-in modem that supports 56 Kbps data rate with V.34, V.90, and V.92 support. See [“Internal Modem”](#) (page 29).
- **Ethernet:** The computer has a built in Ethernet port for 10Base-T and 100Base-T operation. See [“Ethernet Port”](#) (page 29).
- **AirPort Extreme:** A 54 Mbps AirPort Extreme wireless module is built into all models. See [“AirPort Extreme”](#) (page 30).
- **Bluetooth support:** Fully-integrated Bluetooth support enables short-range wireless connections between desktop and laptop computers and a host of other peripheral devices. For more information, see [“Bluetooth Technology”](#) (page 31).
- **Sound:** The computer has a built-in microphone, audio line-in port, and stereo speakers with midrange-enhancing third speaker; it provides stereo output signals on the audio minijack. See [“Sound System”](#) (page 47).
- **Keyboard:** The keyboard has function keys and arrow keys in an inverted-T configuration. Some of the function keys are used to control the brightness and sound and to toggle between dual and mirror modes. The keyboard also includes an embedded numeric keypad. See [“Keyboard”](#) (page 38).
- **Sudden Motion Sensor:** Helps protect the hard drive from sudden drops or falls by parking the hard drive when sudden changes in G force are detected.
- **Scrolling trackpad:** The integrated trackpad includes tap/double-tap, drag, and scroll features. For more information, see [“Trackpad”](#) (page 38).

- **Display:** The display is a 12.1 inch wide-screen TFT with 1024 by 768 pixels. See “Flat-Panel Display” (page 43).
- **Weight:** With the battery installed, the 12-inch PowerBook G4 weighs approximately 4.6 pounds. The exact weight depends on the configuration options.
- **Size:** The dimensions of the computer are 10.9” (27.7 cm) wide, 8.6” (21.9 cm) deep, and 1.18” (3.0 cm) thick.
- **Security slot:** The 12-inch PowerBook G4 has a slot for attaching a Kensington security cable.

Appearance

Figure 1-1 provides a view of the 12-inch PowerBook G4 and the input and output ports.

Figure 1-1 View of 12-inch PowerBook G4 ports



Peripheral Devices

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

- The battery is available separately as an additional or replacement battery.
- The 45 W power adapter, which comes with the computer, can recharge the internal battery in less than six hours while the computer is running or in three and a half hours while the computer is shut down or in sleep mode.
- A 65 W power adapter with safety ground is compatible with the 12-inch PowerBook G4 and is available separately.
- A power cable for use on airliners is also available. The airline power cable should have a sense resistor of 24.3K ohms connected between the power plug's shell and ground. See also “Power Control IC” (page 22).
- A mini-DVI to VGA adapter is included with the computer and is also available separately.
- A mini-DVI to DVI adapter is included with the computer and is also available separately.
- A mini-DVI to video adapter for composite and S-video support is available separately.
- Additional Apple DDR333 (PC2700) SO-DIMMs are available.

System Software

The 12-inch PowerBook G4 comes with Mac OS X v. 10.3.7 installed. For more information about Mac OS X, see the reference listed in “Mac OS X” (page 58).

Here are a few items of interest about the system software on the 12-inch PowerBook G4.

Machine Identification

Current and recent Macintosh ROMs share the same BoxFlag. The intent is for applications to use properties in the Open Firmware device tree rather than checking BoxFlag to find out the features of the machine. On all these machines, a call to `gestaltMachineType` returns the value 406 (\$196).

Asset management software that reports the kind of machine it is run on can obtain the value of the property at `Devices:device-tree:model` in the name registry. The model string is the first program-usable string in the array of C strings in the `compatible` field. For the 12-inch PowerBook G4, the `model` property value is `PowerBook6,8`.

The string obtained from the `compatible` property cannot be displayed to the computer user. If available, 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.

Applications should not use either of these results to infer the presence of certain features; instead, applications should use Gestalt calls to test for the features they require.

Power Management

Apple's power management techniques for the 12-inch PowerBook G4 are described in the following paragraphs.

Power Saving States

The power management protocols on the 12-inch PowerBook G4 support two power-saving states: idle and sleep.

- **Idle:** The system is idling with the main processor in a low-power state. All clocks are running; the system can return to running code within a few nanoseconds. Cache coherency is maintained in this state. The CPU automatically transitions between run and idle, independent of the operating frequency. The operating frequency is based on the processor power management setting. For additional information, see [“Processor Power Management”](#) (page 15).
- **Sleep:** Most internal components are powered off and the state is saved; the DRAM state is preserved for quick recovery. The processor is powered off with its 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 state after a few hundred milliseconds 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 state.

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

When operating on the battery in sleep state, the computer consumes less than 1 watt of power, meeting the Energy Star power-saving standard. When operating on the power adapter in sleep state, the combined computer and adapter consume 3 to 4 watts of power.

Processor Power Management

To lower power consumption and heat generation, the 12-inch PowerBook G4 incorporates an automatic power management technique called dynamic frequency switching (DFS). DFS is designed to run at high processor speed and voltage when the demand on the processor is high, and to run at low processor speed and voltage when the demand on the processor is low. Switching between different processor speeds and voltages is achieved by a transition that operates seamlessly to the user and should not impact system or application performance.

The 12-inch PowerBook G4 allows the user to control DFS mode. The options for specifying either high, reduced, or automatic processor and bus speeds are located at System Preferences>Energy Saver>Show Details>Options>Processor Performance; then select Highest, Automatic, or Reduced. DFS is enabled with the automatic setting.

If the 12-inch PowerBook G4 detects a system temperature that is high, due to high ambient temperatures or other factors, it will automatically force the system to reduced speed mode regardless of the selected setting.

Note: The 12-inch PowerBook G4 meets all applicable safety standards, including UL 60950 and IEC 60950.

When DFS is enabled, the processor dynamically adjusts its speed based on the current needs of the system. The processor speed will switch between 1500 MHz and 750 MHz.

Note: The memory bus speed is not shifted, as it was in previous models.

Target Disk Mode

The user has the option at boot time to put the 12-inch PowerBook G4 into a mode of operation called target disk mode (TDM). When the 12-inch PowerBook G4 is in target disk mode and connected to another Macintosh computer by a FireWire cable, the 12-inch PowerBook G4 operates like a FireWire mass storage device with the SBP-2 (Serial Bus Protocol) standard. Target disk mode has two primary uses:

- data transfer between computers
- diagnosis and repair of a corrupted internal hard drive

The 12-inch PowerBook G4 can operate in target disk mode as long as the other computer has a FireWire port and either Mac OS X (any version) or Mac OS 9 with FireWire software version 2.3.3 or later.

To put the 12-inch PowerBook G4 into target disk mode, restart the computer and hold down the T key until the FireWire icon appears on the display. Then connect a FireWire cable from the 12-inch PowerBook G4 to the other computer. When the other computer completes the FireWire connection, a hard disk icon appears on its desktop.

If the 12-inch PowerBook G4 is turned off or the FireWire cable is disconnected while in target disk mode, an alert appears on the other computer. Disconnecting while the disk is in use can cause loss of data on the disk.

To take the 12-inch PowerBook G4 out of target disk mode, drag the hard disk icon on the other computer to the trash, then press the power button on the 12-inch PowerBook G4.

Architecture

This chapter describes the architecture of the 12-inch PowerBook G4.

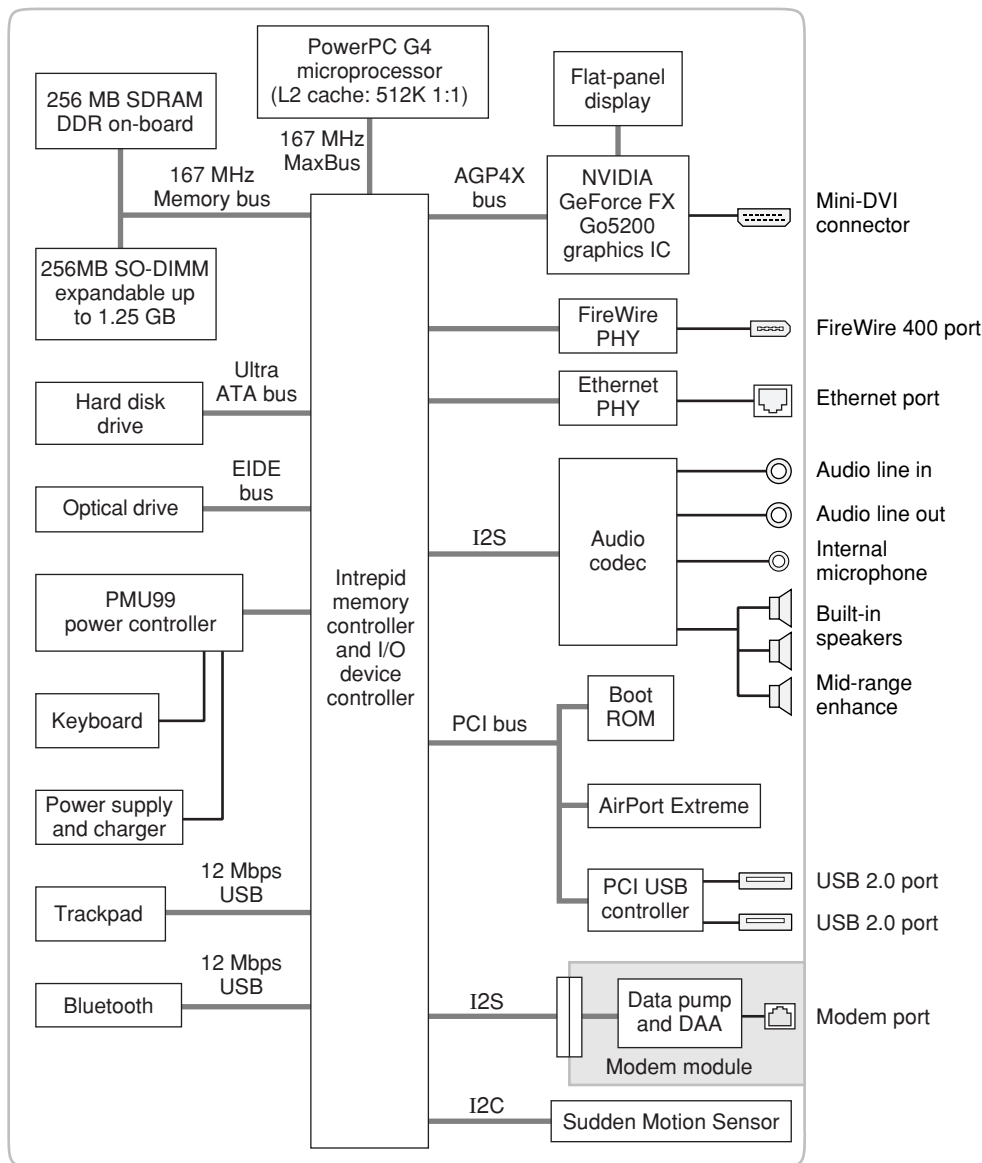
Block Diagram and Buses

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

Block Diagram

[Figure 2-1](#) (page 18) 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.

Figure 2-1 Block diagram



Main ICs and Buses

The architecture of the 12-inch PowerBook G4 is designed around the PowerPC G4 microprocessor and the custom Intrepid memory and I/O controller. The Intrepid IC occupies the center of the block diagram.

The microprocessor is connected to the Intrepid IC by a MaxBus with 64 data lines and a bus clock speed of 167 MHz. The Intrepid IC has other buses that connect with the Boot ROM, the main system RAM, the graphics IC, and the Ethernet and FireWire PHY ICs. Each of the components listed here is described in one of the following sections. The buses implemented by the Intrepid IC are summarized in Table 2-1, which is in the section “Intrepid Memory and I/O Device Controller” (page 19).

Microprocessor and Cache

The microprocessor communicates with the rest of the system by way of a 167 MHz, 64-bit MaxBus to the Intrepid IC. The backside cache is built into the microprocessor.

Power PC G4 Microprocessor

The microprocessor used in the 12-inch PowerBook G4 is a PowerPC G4. It has several features that contribute to superior performance, including:

- on-chip level 1 (L1) caches, 32 KB each for instruction cache and data cache
- an on-chip second level (L2) cache consisting of 512 KB with a clock speed ratio of 1:1
- a microprocessor core optimized for Mac OS applications
- 32-bit PowerPC implementation
- superscalar PowerPC core
- Velocity Engine (AltiVec technology): 128-bit-wide vector execution unit
- high bandwidth MaxBus with 36 address bits and 64 data bits

The G4 microprocessor in the 12-inch PowerBook G4 normally runs at a clock speed of 1.5 GHz. The power saving feature slows the CPU clock speed to save power when the computer is idle. See [“Power Management”](#) (page 15).

L2 Cache

The data storage for the L2 cache consists of 512 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.

Intrepid Memory and I/O Device Controller

The Intrepid memory and I/O device controller IC provides cost and performance benefits by combining many functions into a single IC. It also contains the PCI bus bridge, the Ethernet and FireWire interfaces, and the AGP port.

In addition to the buses listed in Table 2-1, the Intrepid 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 Intrepid IC

Bus	Destinations	Width of data path	Bus clock speed
MaxBus	Microprocessor	64 bits	167 MHz
Memory	System RAM	64 bits	167 MHz

Bus	Destinations	Width of data path	Bus clock speed
AGP4X	Graphics IC	32 bits	66 MHz
Ultra ATA-100	Hard drive	16 bits	100 MBps
EIDE	Optical drive	16 bits	33 MHz

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

System RAM

The memory subsystem in the 12-inch PowerBook G4 consists of 256 MB of DDR333 (PC2700) SDRAM soldered on the main logic board and 256 MB DDR333 (PC2700) SO-DIMM in the expansion slot. RAM is expandable by 1 GB DDR SO-DIMM in the expansion slot for a total of 1.25 GB of system RAM.

The data bus to the RAM and SO-DIMM is 64 bits wide, and the memory interface is synchronized to the MaxBus interface at 167 MHz. See also [“RAM Expansion”](#) (page 51).

Boot ROM

The boot ROM includes the hardware-specific code and tables needed to start up the computer, to load an operating system, and to provide common hardware access services.

The boot ROM is connected to the PCI interface of the Intrepid IC. The boot ROM is a 1 M by 8 bit flash device and can be updated in the field.

Ethernet Controller

The Intrepid IC includes an Ethernet media access controller (MAC) that implements the link layer. As a separate channel connected directly to the Intrepid logic, it can operate at its full capacity without degrading the performance of other peripheral devices. The Intrepid IC provides DB-DMA support for the Ethernet interface.

The controller is connected to a PHY interface IC that is capable of operating in either 10-BaseT or 100-BaseT mode. The actual speed of the link is automatically negotiated by the PHY and the bridge or router to which it is connected. For information about the connector and the operation of the port, see [“Ethernet Port”](#) (page 29).

FireWire Controller

The Intrepid IC includes an IEEE 1394a FireWire 400 controller with a maximum data rate of 400 Mbps (50MBps). The Intrepid IC provides DMA (direct memory access) support for the FireWire interface. The FireWire 400 controller complies with the Open Host Controller Interface (OHCI) specification.

The controller IC implements the FireWire link layer. A physical layer IC, called a PHY, implements the electrical signalling protocol of the FireWire interface. The PHY is the interface to the external connector. For information about the connector and the operation of the port, see [“FireWire 400 Port”](#) (page 27).

Graphics IC

The graphics IC is an nVidia GeForce FX Go5200 with 64 MB of graphics DDR SDRAM. It provides video for both the internal flat panel display and an external video display. The signals to the external display can be either VGA, composite video, or S-video; for more information, see [“External Display Port”](#) (page 44).

The nVidia GeForce FX Go5200 graphics IC in the 12-inch PowerBook G4 supports a display size of 1024 by 768 pixels, with lesser resolutions scaled accordingly.

The nVidia GeForce FX Go5200 IC also has a 3D graphics engine for fast rendering of 3D objects.

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 more information, see [“Flat-Panel Display”](#) (page 43) and [“Extended Desktop Display and Mirror Mode”](#) (page 44).

Because the graphics IC uses the AGP bus, it can use part of main memory as additional graphics storage. The computer’s virtual memory system organizes main memory as randomly-distributed 4 KB pages, so DMA transactions for more than 4 KB of data would have to perform scatter-gather operations. To avoid this necessity for graphics storage, the AGP logic in the Intrepid IC uses a graphics address remapping table (GART) to translate a linear address space for AGP transactions into physical addresses in main memory.

EIDE Bus

The Intrepid IC provides an EIDE bus that is connected to the Combo or SuperDrive optical drive. The optical drive is connected as device 0 (master). Digital audio data from the CD or DVD drive is processed by the Sound Manager and then sent out through the Intrepid IC to the sound IC.

Ultra ATA-100 Bus

The Intrepid IC provides an Ultra ATA-100 channel that is connected to the internal hard disk drive. The Ultra ATA interface has a data transfer rate of ATA-100 and is ATA-6 compatible. The Intrepid IC provides DB-DMA (descriptor-based direct memory access) support for the Ultra ATA interface. The internal hard disk drive is connected as device 0 (master) in an ATA Device 0/1 configuration.

USB Interface

The Intrepid IC has three independent USB Open Host Controller Interface (OHCI) controllers. One each is used for the Bluetooth interface and trackpad and the third one is not used.

The external USB interface is via the PCI USB 2.0 controller; see [“PCI USB 2.0 Controller”](#) (page 23).

Modem Support

The internal modem is connected to an internal I2S port. The Intrepid IC provides DB-DMA support for the modem interface. The modem provides digital call progress signals to the sound circuitry.

The internal modem is a separate module that contains the datapump IC and the interface to the telephone line (DAA). The controller functions are performed by the main processor. See “[Internal Modem](#)” (page 29).

Sound Circuitry

The 12-inch PowerBook G4’s sound circuitry is connected to the Intrepid IC by a standard I2S bus. The Intrepid IC provides DB-DMA (descriptor-based direct memory access) support for the I2S port.

The sound circuitry includes a signal processing IC that handles the equalization and volume control functions and a codec IC that performs A-to-D and D-to-A conversion.

All audio is handled digitally inside the computer. The sound circuitry performs digital-to-analog conversion for the audio signals to the three internal speakers and the headphone mini-jack. The mid-range enhancer speaker is internal to the unit and is not visible. All audio signal conditioning is done in hardware and no user-level controls exist. The sound circuitry also provides parametric equalization for the internal speakers.

Modem progress audio is connected as a digital input to the sound circuitry so that it can be mixed into the sound output stream. The modem progress audio is processed as play-through only, not as a digital sound source.

Stereo signals from the audio input jack are routed to an analog line input buffer that drives the internal A/D converter. For information about sound system operation, see “[Sound System](#)” (page 47).

Power Control IC

The power manager IC in the 12-inch PowerBook G4 is a Mitsubishi M16C/62F microprocessor, also called the PMU99. It operates with its own RAM and ROM. The functions of the PMU99 include:

- controlling the sleep and power on and off sequences
- real time clock
- controlling power to the other ICs
- monitoring the battery charge level
- controlling battery charging
- supporting the interface to the built-in keyboard

The 12-inch PowerBook G4 can operate from a 15-volt power outlet on an airliner, however for safety reasons the computer will not allow battery charging. In order for the computer to detect the connection to airline power, the airline power cable should have a sense resistor of 24.3K ohms connected between the power plug's shell and ground.

The PMU99 also provides the hardware interface to the keyboard. Software in the PMU99 IC scans the keyboard, then sends the data to the system in packets like those from the ADB. To the system, the keyboard behaves as if they were ADB devices.

Sudden Motion Sensor

The Sudden Motion Sensor (SMS) helps to detect an accidental drop or fall by sensing a change in position and accelerated movement of the 12-inch PowerBook G4. In the event of a drop, the Mobile Motion Module instantly parks the hard drive heads to help lessen the risk of damage to the hard drive on impact. When the Mobile Motion Module senses that the PowerBook position is once again stable, it unlocks the hard drive heads and the system is up and running within seconds.

AirPort Extreme

The 54 Mbps AirPort Extreme shares the PCI bus with the boot ROM.

AirPort Extreme 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, which are built into the computer's case.

AirPort Extreme is compliant with the IEEE 802.11g standard. It transmits and receives data at up to 54 Mbps and complies with 802.11b-standard 11 Mbps systems, including all previous AirPort Card systems and base stations. For information about its operation, see ["AirPort Extreme"](#) (page 30).

Note: The 12-inch PowerBook G4 supports only the internal AirPort Extreme Card, not the original 802.11b internal AirPort Card.

PCI USB 2.0 Controller

The 12-inch PowerBook G4 CPU uses a PCI USB controller with one Enhanced Host Controller Interface (EHCI) function and two Open Host Controller Interface (OHCI) functions. The controller supports two external USB 2.0 ports.

The two external USB ports comply with the Universal Serial Bus Specification 2.0. The USB register set complies with the EHCI and OHCI specifications. For more information, see ["USB 2.0 Ports"](#) (page 25).

The two external USB 2.0 connectors support USB devices with data transfer rates of up to 480 Mbps. For more information about the connectors, see ["USB Connectors"](#) (page 25).

USB 2.0 devices connected to the 12-inch PowerBook G4 are required to support USB-suspend mode as defined in the USB specification. For additional reference information, see ["USB Interface"](#) (page 59).

The USB ports on the 12-inch PowerBook G4 comply with the Universal Serial Bus Specification 2.0. The USB controllers comply with the EHCI specification; the companion controllers comply with the OHCI specification. The internal USB 1.1 interface complies with the OHCI specification, see ["USB Interface"](#) (page 21).

Devices and Ports

This chapter describes both the built-in I/O devices and the ports for connecting external I/O devices in the 12-inch PowerBook G4. Each of the following sections describes an I/O port or device.

USB 2.0 Ports

The 12-inch PowerBook G4 has two external Universal Serial Bus (USB) 2.0 ports that can be used to connect additional I/O devices such as a USB mouse, printers, scanners, and storage devices.

For more information about USB on Macintosh computers, please refer to sources listed in “USB Interface” (page 59).

Note: Some self-powered USB devices inadvertently violate electrical specifications for self-powered USB devices. For details and ways to avoid this design issue, refer to <http://developer.apple.com/qa/hw/hw82.html>.

USB Connectors

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

Figure 3-1 USB Type A connector

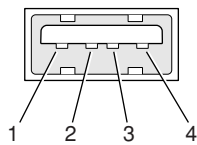


Table 3-1 Pin assignments on the USB port

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

The 12-inch PowerBook G4 provides power for the USB ports at 5 V and up to 500 mA each.

The external USB 2.0 ports support low-speed (1.5 Mbps), full-speed (12 Mbps), and high-speed (480 Mbps) data transfers. High-speed operation requires the use of shielded cables.

The Macintosh USB system software that comes with the 12-inch PowerBook G4 supports all four data transfer types defined in the USB specification.

USB Technology

The USB ports include power saving modes, support of USB mass-storage devices, and an EHCI controller.

Wake on Connect and Resume

The Intrepid IC contains special circuitry that allows the computer to wake from sleep mode on connect, disconnect, and resume events. Compatible USB devices should support the USB-suspend mode defined in the USB specification.

USB Class Drivers

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. For information about USB support on the Macintosh, see the references in “[USB Interface](#)” (page 59).

USB Controller

The 12-inch PowerBook G4 uses an Enhanced Host Controller Interface (EHCI) controller for USB communication. Some early USB devices (most notably keyboards) can't interoperate with an OHCI controller. Those devices are not supported by the Macintosh USB system software.

USB Device Programming

Mac OS X includes support for a variety of USB Class Compliant devices and provides access to vendor specific devices. Developers can use the built-in support or provide additional applications and drivers.

In Mac OS X, The USB Family (IOUSBFamily) handles device plug and unplug and supplies IOKit with a USB-specific matching method. The general services publish information about the bus and the devices in the IO Registry, so that IO Kit can match drivers to each connected USB device.

In the 12-inch PowerBook G4, Mac OS X provides the following USB class compliant drivers:

- Audio
- Bluetooth
- CDC (Communication Data Class)
 - modem (abstract control model only)
- HID (Human Interface Device)

- ❑ boot protocol
- ❑ report protocol
- HUB
- Mass storage
- MIDI
- Printer
- Still image/PTP (digital still cameras)

For information on writing USB drivers or applications, download the latest USB SDK from <http://developer.apple.com/sdk/>.

For information about USB support on the Macintosh, see the references in “USB Interface” (page 59).

FireWire 400 Port

The 12-inch PowerBook G4 has one external FireWire 400 IEEE 1394a port. The FireWire 400 port

- supports serial I/O at 100, 200, and 400 Mbps (megabits per second)
- provides up to 7 watts of peak power when the computer system is on or the power adapter is connected.
- supports booting the system from a mass storage device
- supports target disk mode (TDM)

The FireWire 400 hardware and software provided with the 12-inch PowerBook G4 are capable of all asynchronous and isochronous transfers defined by IEEE standard 1394a.

FireWire 400 Connector

The FireWire 400 connector has six contacts, as shown in [Figure 3-2](#) (page 27). The connector pin assignments are shown in Table 3-2.

Figure 3-2 FireWire 400 connector

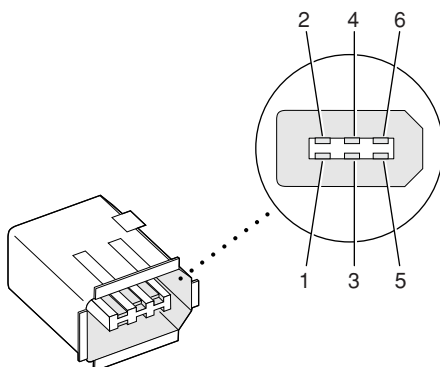


Table 3-2 Pin assignments on the FireWire 400 connector

Pin	Signal name	Description
1	Power	Unregulated DC; 9.0–12.6 V no load when operating with battery or power adapter
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

The FireWire power pin provides a maximum voltage of 12.6 V (no load) and up to 7 W peak power. Power is supplied to the FireWire port when

- the computer is awake or asleep with the power adapter connected
- the computer is awake on battery power with the power adapter not connected

Power is not supplied to the FireWire port when the computer is shutdown; or is asleep with the power adapter not connected.

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

Mac OS X includes general support for the FireWire bus and specific support for various kinds of FireWire devices and protocols. Developers can use the built-in support or provide additional applications and drivers for use with their products.

The general FireWire services will configure the FireWire bus, scan the bus for new devices, and allow multiple drivers and devices to share a single FireWire interface cooperatively. The general services also publish information about the bus and the devices in the IO Registry, so that IO Kit can match protocols and drivers to each connected FireWire device.

The specific device and protocol support in Mac OS X as provided with the 12-inch PowerBook G4 includes the following:

- General services for Serial Bus Protocol 2 (SBP-2) and support for most mass storage devices using SBP-2, such as hard disk drives, optical drives, flash card readers, Target Disk Mode (see “[Target Disk Mode](#)” (page 16), and the iPod. Mac OS X can boot from most of these devices.
- General services for the Audio Video Control (AV/C) protocol and support for most digital video (DV) cameras and decks using this protocol, including video capture through standard QuickTime APIs.
- A QuickTime device driver for IIDC/DCAM type cameras such as the iSight.

- A network device driver supporting IP (Internet Protocol) over FireWire according to IEEE RFC 2734.
- Additional services for user-space and kernel access to all FireWire resources.

For information on writing FireWire drivers or applications, download the latest FireWire SDK from <http://developer.apple.com/sdk/>

For additional references, refer to “FireWire 400 Interface” (page 59).

Ethernet Port

The 12-inch PowerBook G4 has a built-in 10/100 Mbps Ethernet port. The user can connect it to either a 10Base-T or a 100Base-T hub; the port will automatically sense which type of hub is connected.

The connector for the Ethernet port is a shielded RJ-45 connector near the left side of the computer. Table 3-3 shows the signals and pins on the connector.

Table 3-3 Signals on the Ethernet connector

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
6	RXN	Receive (negative lead)
7	–	Not used
8	–	Not used

When connecting two computers using Ethernet, a crossover cable is not required; circuits in the PHY detect the type of connection and switch the signal configuration as required.

The Ethernet interface in the 12-inch PowerBook G4 conforms to the ISO/IEC 802.3 specification, where applicable.

Internal Modem

The 12-inch PowerBook G4 comes with a built-in modem. The connector for the modem is an RJ-11 connector on the left side of the computer.

The modem has the following features:

- modem bit rates up to 56 Kbps (V.34, V.90, and V.92 support)
- fax modem bit rates up to 14.4 Kbps

The modem appears to the system as a serial port that responds to the typical AT commands. The modem provides digital sound output data to the Intrepid IC for monitoring the progress of the modem connection.

Note: Apple's implementation of V.92 does not support outgoing Modem On Hold. By default, PCM stream is turned off.

AirPort Extreme

The 12-inch PowerBook G4 comes with the 54 Mbps, 802.11g internal wireless LAN module AirPort Extreme Card built-in. By communicating wirelessly with a base station, AirPort Extreme can be used for internet access, email access, and file exchange. A base station provides the connection to the internet or the bridge between the wireless signals and a wired LAN or both. The AirPort Extreme Base Station has connectors for a wired LAN, a DSL or cable modem, or a standard telephone line using the optional 56K modem that is built-in on some models.

AirPort Extreme transmits and receives data at speeds up to 54 Mbps. AirPort Extreme is also compatible with other devices that conform to the IEEE 802.11b standard, including PC's. For more information about compatibility, see the reference at "[Wireless Networks](#)" (page 60).

Note: As is the case with the existing IEEE 802.11b standard, actual data throughput speeds will be lower than the indicated maximum connection speeds. Inherent in wireless LAN systems, bandwidth overhead is required for wireless routing, scrambling, security, error correction, and other processes.

Data Security

AirPort Extreme has several features designed to maintain the security of the user's data.

- In 802.11b mode, 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 an Access Control List of authentic network client ID values (wireless and MAC Addresses) to verify each client's identity before granting access to the network.
- When communicating with a base station, AirPort Extreme is capable of using 64-bit or 128-bit WEP encryption to encode data while it is in transit. Additional security features may be available via firmware upgrades as 802.11 enhancements are ratified by IEEE.
- The AirPort Extreme Base Station can be configured to use NAT (Network Address Translation), protecting data from would-be Internet hackers.
- The AirPort Extreme Base Station can authenticate users by their unique Ethernet IDs, preventing unauthorized machines from logging into the network. Network administrators can take advantage of RADIUS compatibility, used for authenticating users over a remote server. Smaller networks can offer the same security using a local look-up table located within the base station.

AirPort Extreme Hardware

AirPort Extreme is a wireless LAN module that complies with the IEEE 802.11g standard using both OFDM (orthogonal frequency-division multiplexing) and DSSS technologies. Using DSSS, AirPort Extreme is interoperable with PC-compatible wireless LANs that conform to the 802.11b standard at speeds of 11 Mbps, 5.5 Mbps, 2 Mbps, and 1 Mbps. Using OFDM, AirPort Extreme is compatible with all 802.11g standard speeds.

Two antennas are built into the computer's cover, one on either side of the flat-panel display, and are shared by AirPort Extreme and Bluetooth. One antenna is always used for transmitting. Either of the two antennas may be used for receiving. Using a diversity technique, the AirPort Extreme Card may select the antenna that gives the best reception.

AirPort Extreme Software

Software that is provided with the AirPort Extreme Card includes

- AirPort Setup Assistant, an easy-to-use program that guides through the steps necessary to set up AirPort Extreme or set up an AirPort Base Station.
- Users can switch between wireless networks and can create and join peer-to-peer networks. These functions are accessed via System Preferences or the AirPort status menu (which first must be activated in System Preferences).
- AirPort Admin Utility, a utility for advanced users and system administrators. With it the user can edit the administrative and advanced settings needed for some advanced configurations.

Bluetooth Technology

Bluetooth, which is standard on the 12-inch PowerBook G4, is an open specification that enables short-range wireless connections between desktop and laptop computers and a host of other peripheral devices. Bluetooth support is built into Mac OS X and compliant with Bluetooth specification 2.0 + EDR (enhanced data rate). It operates on a globally available 2.4 GHz frequency band (ISM band) for worldwide compatibility and has a maximum throughput of 3 Mbps.

The Bluetooth technology supports the following profiles:

- serial port (SPP) — provides a wireless serial connection to other Bluetooth devices
- dial-up networking (DUN) — enables a mobile phone to act as a modem
- object push (OPP) — enables the transfer of files between Bluetooth devices
- human interface device (HID) — enables the use of Bluetooth input devices (keyboards and mice)
- Bluetooth file transfer profile (FTP) — enables browsing of the file system of other Bluetooth devices which support Bluetooth FTP
- hardcopy cable replacement profiler (HCRP) — describes how to send rendered data over a Bluetooth link to a device, such as a printer. Although other profiles can be used for printing, the HCRP is specially designed to support hardcopy applications. Note: currently, to use this profile, Apple's Bluetooth Update Version 1.5 must be installed.

- headset profile (HSP) — enables the use of Bluetooth-enabled wireless headsets for applications such as iChat. This profile does not enable use of Apple Speech Recognition due to the fact that it is a low-precision audio channel. Note: currently, to use this profile, Apple's Bluetooth Update Version 1.5 as well as Firmware Update Version 1.1 must be installed.

Bluetooth shares the internal antennas with AirPort Extreme. For more information on Bluetooth technology, refer to ["Bluetooth"](#) (page 60).

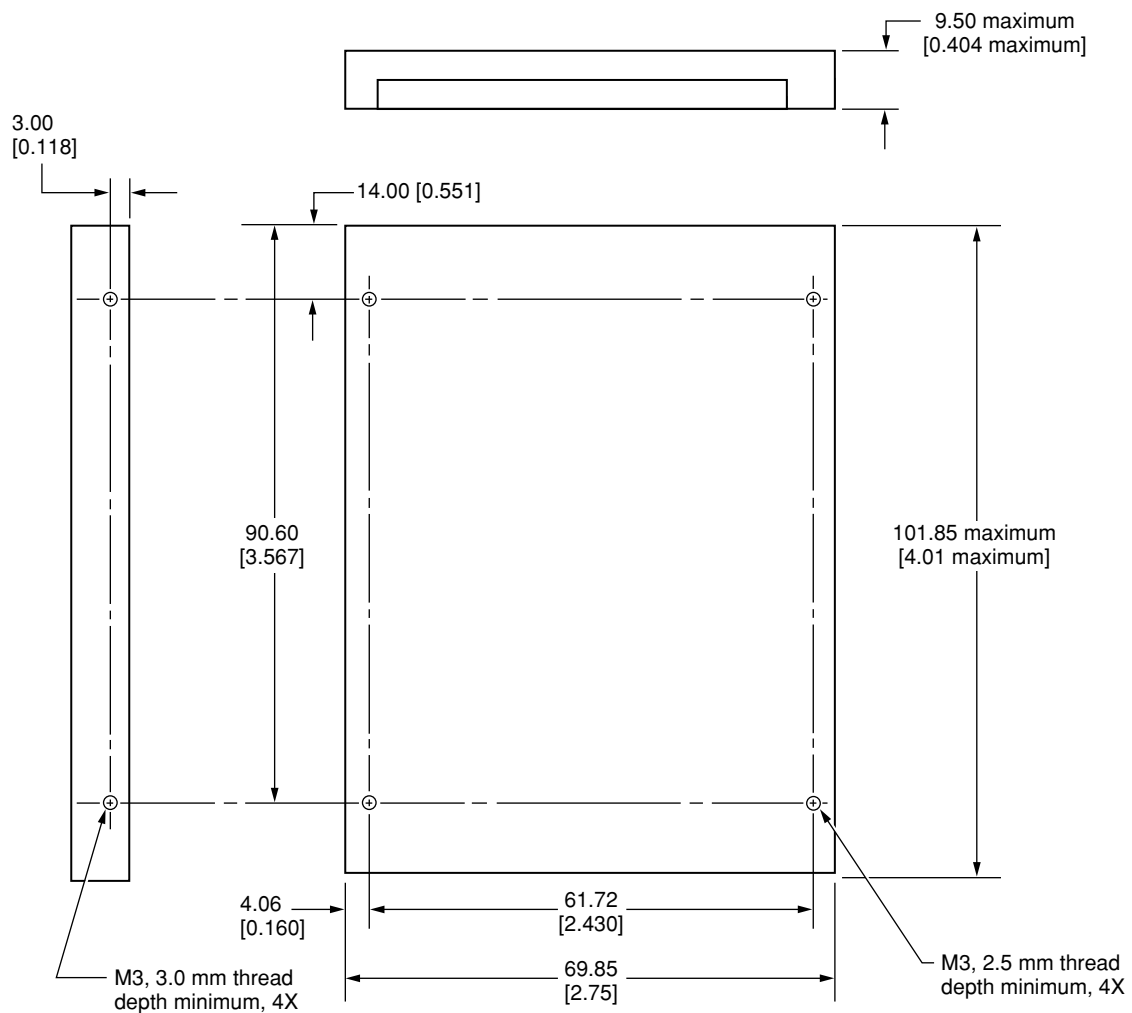
Hard Disk Drive

The storage capacity of the internal 5400 rpm hard disk drive is 60 or 80 GB, with a build-to-order option of 80 or 100 GB drive. The drive uses the Ultra ATA-100 (IDE, integrated drive electronics) interface and is ATA-6 compatible. Data Transfer Mode for the drive is ATA-100.

The software that supports the internal hard disk is similar to that in previous models with internal IDE drives and includes DMA support. For the information about that software, see the references in ["ATA Devices"](#) (page 59).

Hard Disk Dimensions

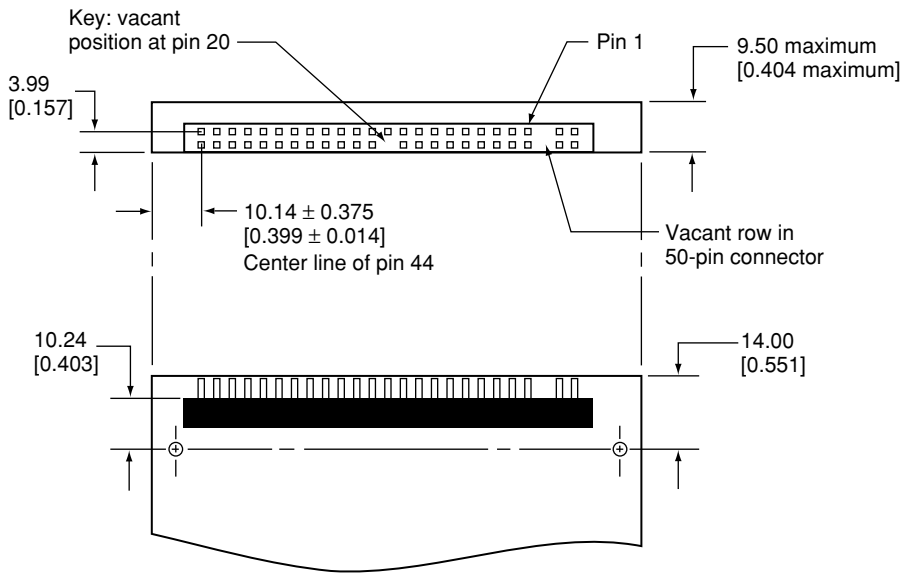
[Figure 3-3](#) (page 33) shows the maximum dimensions of the hard disk and the location of the mounting holes. The minimum clearance between any conductive components on the drive and the bottom of the mounting envelope is 0.5 mm.

Figure 3-3 Maximum dimensions of the internal hard disk

Note: Dimensions are in millimeters [inches].

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](#) (page 34). The remaining pins are in two groups: pins 1–44, which carry the signals and power, and pins 45–48, 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

Note: Dimensions are in millimeters [inches].

Signal Assignments

Table 3-4 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 3-4 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

Pin number	Signal name	Pin number	Signal name
23	/DIOW, /STOP	24	GROUND
25	/DIOR, /HDMARDY, HSTROBE	26	GROUND
27	IORDY, /DDMARDY, DSTROBE	28	CSEL
29	/DMACK	30	GROUND
31	INTRQ	32	obsolete
33	/DA1	34	/PDIAG, /CBLID
35	/DA0	36	/DA2
37	/CS0	38	/CS1
39	/DASP	40	GROUND
41	+5V LOGIC	42	+5V MOTOR
43	GROUND	44	Reserved
/IOCS16 is not used; see Table 3-5			

ATA Signal Descriptions

Table 3-5 describes the signals on the ATA hard disk connector.

Table 3-5 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.).

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 (pulled low by a 1 kilohm resistor).
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.
/STOP	Stop request; an active low signal.
Key	This pin is the key for the connector.

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

Combo Drive

Some configurations of the 12-inch PowerBook G4 have a slot-loading, Combo drive that can read DVD media and read and write CD media, as shown in Table 3-6.

Table 3-6 Types of media read and written by the Combo drive

Media type	Reading speed	Writing speed
DVD-ROM	8x (CAV)	–
CD-R	24x (CAV)	24x (ZCLV)
CD-RW	24x (CAV)	10x (CLV) 16x (ZCLV)

Media type	Reading speed	Writing speed
CD or CD-ROM	24x (CAV)	–

Important: The Combo drive supports only 12 cm disc media. It does not support 8 cm discs or noncircular media.

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

The Combo drive is an ATAPI drive and is device-selected as master in an ATA device configuration.

SuperDrive

Some configurations of the 12-inch PowerBook G4 have a slot-loading Apple SuperDrive drive.

The SuperDrive can read and write DVD media and CD media, as shown in [Table 3-7](#) (page 37) and provides DVD-Video playback.

Table 3-7 Media read and written by the SuperDrive

Media type	Reading speed (maximum)	Writing speed
DVD-R	6x (CAV)	8x (ZCLV)
DVD-RW	6x (CAV)	4x (CLV)
DVD+R	6x (CAV)	8x (ZCLV)
DVD+RW	6x (CAV)	4x (CLV)
DVD-ROM	8x (CAV, single layer) 6x (CAV, dual layer)	–
CD-R	24x (CAV)	24x (ZCLV)
CD-RW	24x (CAV)	10x (CLV)
CD-ROM	24x (CAV)	–

The SuperDrive writes to DVD-R 4.7 gigabyte General Use media. These discs are playable in most standard DVD players and computer DVD-ROM drives.

Digital audio signals from the SuperDrive can be played through the sound outputs under the control of the Sound Manager. The SuperDrive is an ATAPI drive.

Important: The SuperDrive supports only 12 cm disc media. It does not support 8 cm discs or noncircular media.

Trackpad

The pointing device in 12-inch PowerBook G4 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 digital signals.

The user makes selections either by pressing the trackpad button (below the trackpad) or by tapping and double tapping on the pad itself. When enabled via Systems Preferences, vertical and horizontal scrolling is available by dragging two fingers across the trackpad. 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 and scrolling function are optional and can be activated or deactivated by means of the mouse pane in System Preferences.

The trackpad on the 12-inch PowerBook G4 has palm-rejection capabilities that help prevent unintended trackpad input while typing is being performed. When the "Ignore accidental trackpad input" checkbox is selected on the keyboard and mouse pane of Systems Preferences, the system software attempts to filter out unintended contact with the trackpad. The trackpad will not respond when a mouse is present and the "Ignore accidental trackpad input" checkbox is selected on the mouse pane of Systems Preferences.

Note: If the trackpad is not responding to intended input, check to see if the "Ignore accidental trackpad input" checkbox is selected.

Keyboard

The keyboard is a compact, low-profile design with a row of function keys and cursor motion keys in an inverted-T configuration. A media eject key is located to the right of the function keys.

Access to internal components and expansion connectors is no longer via the keyboard; access is via the RAM expansion slot and is explained in "The RAM Expansion Slot" (page 51).

Keyboard Illustrations

[Figure 3-5](#) (page 39) shows a diagram of the keyboard. [Figure 3-6](#) (page 39) shows the alternate modes of operation of the function and control keys. [Figure 3-7](#) (page 40) shows the embedded numeric keypad.

Figure 3-5 Keyboard layout



Figure 3-6 (page 39) and Figure 3-7 (page 40) 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 a diagram of the keyboard, refer to Figure 3-5 (page 39).

Figure 3-6 Alternate operations of function and control keys

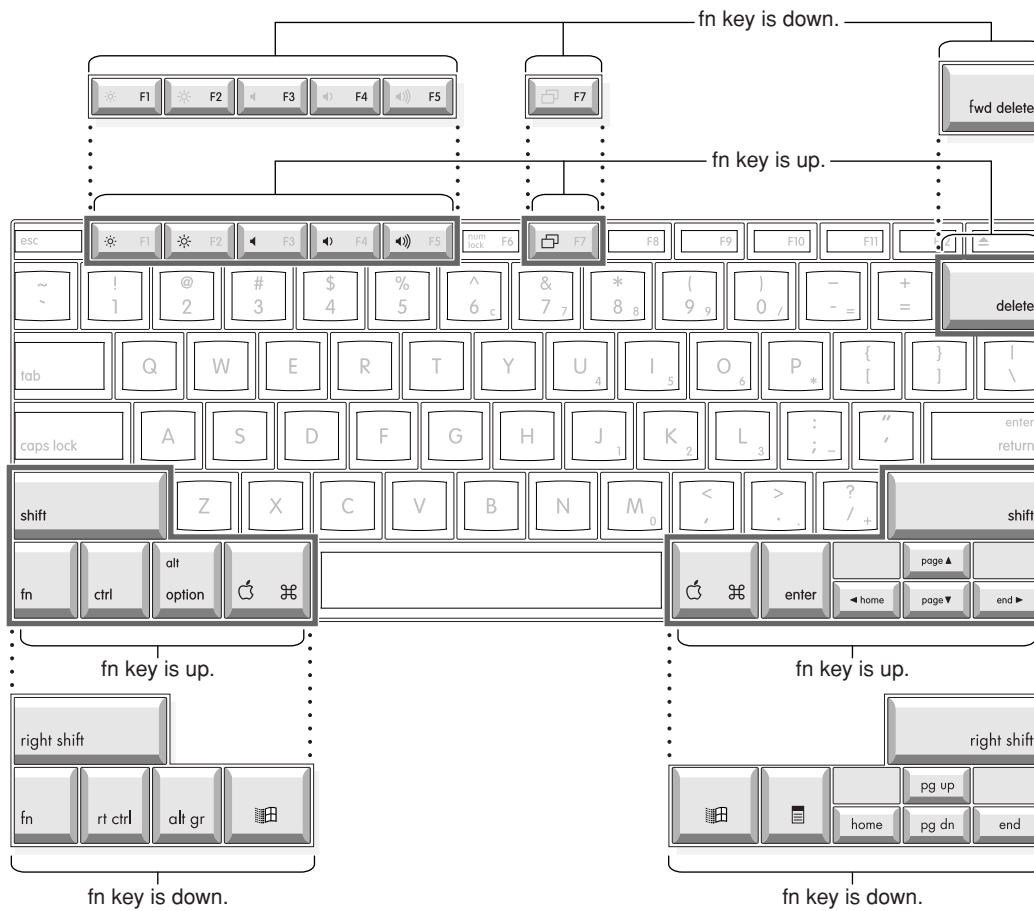
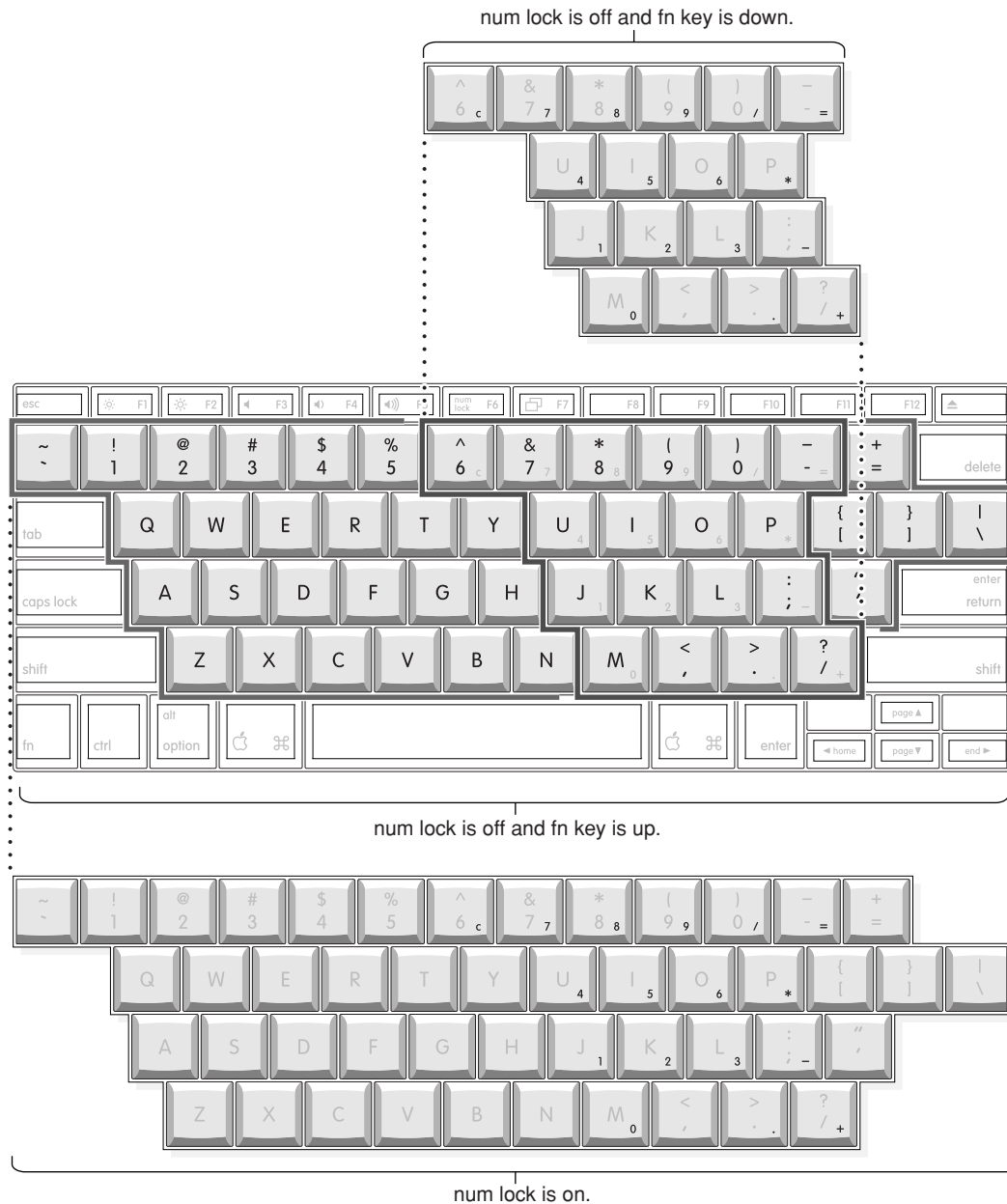


Figure 3-7 Embedded numeric keypad operation

Changing the Operation of the Keyboard

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

- Function keys F1–F7 can also control the functions listed in [Table 3-8](#) (page 41).
- 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.

Table 3-8 The default 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	Display mode toggle

[Table 3-8](#) (page 41) defines the default operation of the function keys. The "Use the F1-F12 keys for custom actions" checkbox in the Keyboard and Mouse pane in System Preferences allows you to toggle the default operation of these keys to custom actions. When this checkbox is enabled, the function keys operate as F1 through F12 keys that can be customized within individual software applications. Holding down the fn key while the checkbox is enabled, will go back to perform the default action that is listed in [Table 3-8](#) (page 41).

The next sections describe these groups of keys and the way their alternate modes of operation are selected by using the Fn key and the Num Lock key.

Using the Fn Key

Pressing the Fn key affects these keys: the function keys F1– F7, the embedded numeric keypad, certain modifier keys, and the delete key.

- It toggles the function keys between their control-button operation and their F1–F7 functions, as shown in [Table 3-8](#) and [Figure 3-6](#) (page 39).
- It selects the embedded numeric keypad on the right portion of the alphanumeric keys, as shown in [Table 3-9](#) and [Figure 3-7](#) (page 40).
- It changes certain control keys, including the cursor control keys, to page control keys, as shown in [Table 3-10](#) and [Figure 3-7](#) (page 40).
- Holding down Fn and the delete key executes a forward delete action.

Note: User-programmable function key assignments were supported in Mac OS 9. In Mac OS X, the user must provide a third-party utility to enable the feature.

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](#) (page 40).

- It makes the rest of the alphanumeric keys functionless (NOPs), as shown in [Figure 3-7](#) (page 40).

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](#) (page 40) 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)

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](#) (page 40). 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](#) (page 40).

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 12-inch PowerBook G4 has a built-in, color, flat-panel display. 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.

The display is 12.1 inches measured diagonally and displays 1024 x 768 pixels (XGA), showing up to millions of colors.

The graphics controller IC is an nVidia GeForce FX Go5200 with 64 MB of video DDR SDRAM on the chip. It supports 3D acceleration and display depths up to 24 bits per pixel. When more graphics storage is needed, the graphics IC can also use part of main memory. For more information, see [“Graphics IC”](#) (page 21).

The graphics IC includes a scaling function that expands smaller-sized images to fill the screen. By means of the scaling function, the computer can show full-screen images at 1024 by 768, 800 by 600, or 640 by 480 pixels.

Extended Desktop Display and Mirror Mode

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 extended desktop display to distinguish it from mirror mode, which shows the same information on both the external display and the built-in display. The F7 function key toggles between extended desktop and mirror mode.

The scaling function is available when the internal display and an external monitor are both operating and the mirror mode is selected. However, the external monitor could have black borders during mirroring, depending on the supported timings between the two displays and on the monitor's selection algorithm. Both displays show full-sized images only when the display resolution for the external monitor is set to the internal display's native resolution: 1024 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 1024 by 768, the image on the external monitor is smaller than its screen.

External Display Port

The 12-inch PowerBook G4 has a mini-DVI port that supports DVI, VGA, and TV signals by means of adapters. The mini-DVI to video adapter connects an external video monitor or projector and must be purchased separately. A mini-DVI to VGA adapter and a mini-DVI to DVI adapter are included with the 12-inch PowerBook G4.

Note: When a dongle is used to attach a display, connect the dongle to the display *before* plugging the dongle into the computer.

The computer detects the type of adapter connected to it and programs the graphics IC to provide the appropriate type of video signals, as shown in [Table 3-12](#) (page 45). [Table 3-11](#) (page 44) provides a list of supported resolutions for analog monitors.

Table 3-11 Resolutions supported for analog monitors

Resolution	Refresh rates (Hz)
640x480	60, 75, 85, 100
800x600	60, 72, 75, 85, 100, 120
832x624	120
1024x768	60, 70, 75, 85, 100
1152x870	60, 75, 85, 100
1280x870	60, 75, 85, 100
1280x1024	60, 75, 85, 100

Resolution	Refresh rates (Hz)
1600x1024	60, 76, 85
1600x1200	60, 65, 70, 75, 85
1792x1344	60, 75
1856x1392	60, 75
1920x1080	60, 72, 75, 80, 85
1920x1200	76, 85
1920x1440	60, 75
2048x1280	75
2048x1536	60, 75

Table 3-12 Display adapters

Adapter type	Video signals	Connector type(s)
DVI	TMDS	DVI-D
VGA	RGB	VGA 15-pin miniature D-type
Video	Composite and S-video TV signals	RCA and S-video

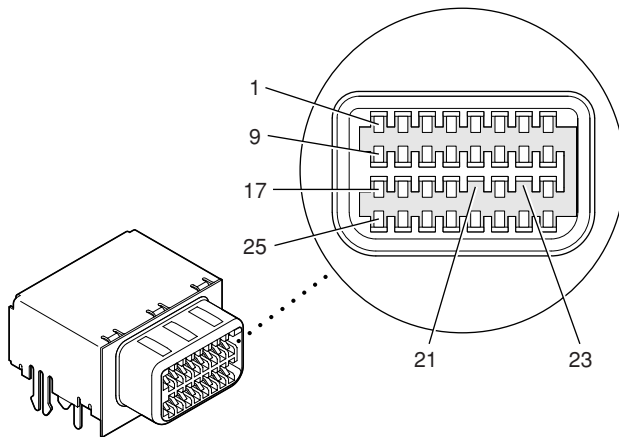
In mirror mode and extended desktop mode, the 12-inch PowerBook G4 supports up to 1024x768 pixels on the built-in display and up to 2048x1536 on an external display, both showing millions of colors. The settings for the resolutions are selectable in System Preferences.

Composite video and S-video signals can be displayed on either an NTSC display or a PAL display. When a display is connected by way of the video adapter, the computer detects the type of adapter and enables the composite and S-video outputs. The settings for the resolutions and standards (NTSC or PAL) are then selectable in System Preferences.

In mirror mode, the video output mirrors the flat panel display: internal and external video share the same buffer, and the hardware sends the image to both displays.

Mini-DVI Connector

The connector pins are identified in [Figure 3-8](#) (page 46).

Figure 3-8 Mini-DVI display connector

The 12-inch PowerBook G4 detects the type of display adapter that is plugged in and programs the graphics IC to route the appropriate video signals to the connector.

The signal assignments on the mini-DVI connector are shown in [Table 3-13](#) (page 46). The cable detect function on pin 25 is implemented by connecting pin 25 to +5V in the adapters. The computer detects which adapter is present by reading its EDID (Extended Display Identification Data) via DDC. The EDID for video is in the adapter; the EDID for VGA and DVI are in the display.

Table 3-13 Mini-DVI pin assignments

Pin	Signal name	Pin	Signal name
1	Dat2_P	17	+5V
2	Dat2_N	18	DDC_DAT
3	Dat1_P	19	spare
4	Dat1_N	20	BLUE
5	Dat0_P	21	not installed
6	Dat0_N	22	GREEN
7	CLK_P	23	not installed
8	CLK_N	24	RED
9	DGND	25	Detect
10	DGND	26	DDC_CLK
11	DGND	27	spare
12	DGND	28	DGND
13	DGND	29	HSYNC

Pin	Signal name	Pin	Signal name
14	DGND	30	DGND
15	DGND	31	VSYNC
16	DGND	32	DGND

Older Monitors Not Supported

The computer supports current video monitors and is compatible with older monitors that use DDC for monitor identification. The detection scheme on some older monitors are not supported and will use a default configuration, including the following Apple monitors:

- Multiple Scan 17
- Multiple Scan 20
- AudioVision 14
- Apple Hi-Res RGB
- Apple 16" Color
- Apple Hi-Res Monochrome
- Macintosh 12" RGB

Sound System

The 16-bit stereo audio circuitry provides sound input through the built-in microphone, the audio line in, the USB port, and sound output through built-in stereo speakers and the midrange-enhancer speaker and the audio minijack.

All audio is handled digitally inside the computer, including audio data from the optical drive and devices connected to the USB and FireWire 400 ports. Sound data is converted to analog form only for output to the internal speakers and the audio line out.

The sound circuitry handles audio data as 44.1 kHz 16-bit samples. If audio data sampled at a lower rate on another computer is played as output, the Sound Manager transparently upsamples the data to 44.1 kHz prior to sending the audio data to the sound circuitry.

Audio Line Out

The audio line out is located on the left side of the computer. The jack accepts a standard stereo mini-plug.

The stereo audio signals at the jack are configured to drive a pair of low-impedance stereo headphones. External powered speakers may also be connected to the audio line out.

The audio signals on the audio line-out have the following electrical characteristics:

- output impedance: 16 ohms each channel
- minimum recommended load impedance: 32 ohms each channel
- maximum level: 1.5 V rms (4.4 V P-P)

Audio Line In

The 12-inch PowerBook G4 has a stereo audio line in jack located on the left side of the computer next to the line out.

The audio inputs are designed to accept high-level audio signals: 2 Vrms or +8 dbu, which is the standard output level from CD and DVD players. The output level of some consumer audio devices is lower, often 0.1 Vrms or –10 dbu. Sound recordings made on the 12-inch PowerBook G4 with such low-level devices have more noise than those made with high-level devices. The user may obtain better results by connecting an amplifier between the low-level device and the computer's audio input jack.

The audio input jack is a 3.5 mm miniature phone jack with the signals connected as follows:

Tip	Left-channel audio
Ring	Right-channel audio
Sleeve	Audio ground

The sound line in has the following electrical characteristics:

- maximum input signal amplitude 2 Vrms (5.65 Vpp), +8 dbu peak
- input impedance at least 47 kilohms
- channel separation greater than 60 dB
- recommended source impedance 2 kilohms or less
- ground noise rejection greater than 40 dB
- frequency response 5 Hz to 20 kHz, +0.0, –0.5 dB
- distortion below –80 dB
- signal to noise ratio (SNR) greater than 90 dB (unweighted)

Internal Microphone

The computer has a built-in microphone located on the top left part of the case next to the escape key.

Internal Speakers

The 12-inch PowerBook G4 has a pair of stereo speakers located on the back of the cpu case and an internal midrange-enhancing speaker. The sound system provides parametric equalization for the speakers. The computer turns off the sound signal to the speakers when headphones are connected to the audio minijack.

Sound effects and output from other audio sources can be specified in the System Preferences Sound panel. An output device is displayed on the Sound panel when the computer detects that it is plugged in. The system default setting is the internal audio controller. Once the default is changed to a different device, it will remain the default as long as the device is plugged in.

Note: Unlike Mac OS 9, Mac OS X does not automatically switch to USB audio when the device is attached.

RAM Expansion

This chapter tells how to gain access to the RAM expansion slot in the 12-inch PowerBook G4 and then describes the RAM expansion module.

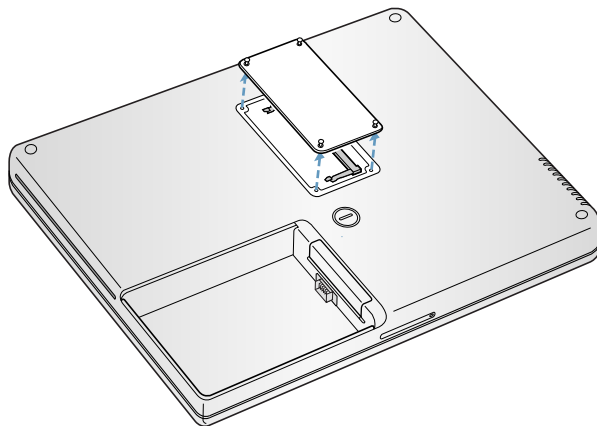
The RAM Expansion Slot

The 12-inch PowerBook G4 has one RAM expansion slot. To get access to the RAM expansion slot, the user must open up the computer by performing the following operations.

Important: The user should be reminded to observe the usual precautions to avoid damage to the electronic components due to static electricity.

1. Shut down the computer.
2. Unplug the AC adapter from the computer.
3. Remove the battery from the computer.
4. Place the computer upside down on a soft cloth.
5. Using a Phillips head screwdriver, remove the four screws that secure the memory door, and lift off the door. See [Figure 4-1](#) (page 51).

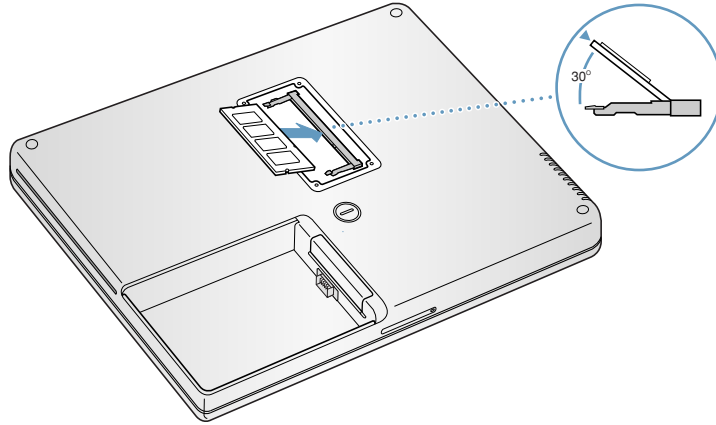
Figure 4-1 Remove RAM door



6. If a memory card is installed, release it by spreading apart the tabs in the expansion slot from the notches in the card. Allow the card to pop up slightly, and pull it off of the slot.

7. Insert the replacement memory card into the slot at a 30 degree angle, as shown in [Figure 4-2](#) (page 52).

Figure 4-2 Insert RAM



8. Press down on the sides of the card to lock in place.
9. Reinstall the memory door and reassemble the computer.

If AC and battery power are removed for longer than ten minutes, the computer's clock may need to be reset in System Preferences when the computer is turned back on.

The RAM Expansion Module

The RAM expansion slot accommodates a standard DDR333 (PC2700) SO-DIMM (small outline, dual inline memory module) that uses DDR SDRAM devices.

Important: A RAM expansion SO-DIMM for the 12-inch PowerBook G4 must use DDR SDRAM devices. If the user installs an SO-DIMM that uses single data rate (SDR), SGRAM, or non-DDR SDRAM devices, the computer will beep twice when the user attempts to restart the computer.

An SO-DIMM for the 12-inch PowerBook G4 can contain either 128, 256, 512 MB, or 1 GB of memory. Maximum total RAM capacity using devices currently available is 1.256 GB and is limited by the space available for the SO-DIMM.

Note: The 12-inch PowerBook G4 comes standard with 256 MB RAM in the expansion slot; this RAM must be removed before adding additional RAM.

Mechanical Design of the RAM SO-DIMM

The mechanical characteristics of the RAM expansion module are given in the JEDEC specification JESD95 for the 200-pin 8-byte DRAM SO-DIMM. To find out how to obtain the specification, see [“RAM Expansion Modules”](#) (page 59).

The specification defines SO-DIMMs with nominal heights of 1.0, 1.25, 1.5, or 2.0 inches. The 12-inch PowerBook G4 can accommodate standard SO-DIMMs with a height of 1.0 or 1.25 inches.

The JEDEC specification defines the maximum depth or thickness of an SO-DIMM as 4 mm. That specification is also a maximum: Modules that exceed the specified thickness can cause reliability problems.

Electrical Design of the RAM SO-DIMM

The electrical characteristics of the RAM SO-DIMM are given in section 4.5.6 of the JEDEC Standard 21-C, release 7 (JESD-21C). To find out how to obtain the specification, see [“RAM Expansion Modules”](#) (page 59).

The specification defines several attributes of the DIMM, including storage capacity and configuration, connector pin assignments, and electrical loading. The specification supports SO-DIMMs with either one or two banks of memory.

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 the 12-inch PowerBook G4 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 (200-pin DDR SDRAM SO-DIMM, PD INFORMATION) of the JEDEC standard 21-C specification, release 7.

DDR SDRAM Devices

The DDR SDRAM devices used in the RAM expansion modules must be self-refresh type devices for operation from a 2.5 V power supply. The speed of the DDR SDRAM devices must be DDR333 or greater.

The devices are programmed to operate with a CAS latency of 2.5. At this CAS latency, the access time from the read command cycle to when data is available for reading on the bus should be 15 ns (2.5 clock cycles). 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. The devices must support the use of CKE power management.

Configuration of RAM SO-DIMMs

Table 4-1 shows information about the different sizes of SO-DIMMs used in the 12-inch PowerBook G4. The first three columns show the memory size, configuration, and number of banks in the SO-DIMMs. The other three columns show the number, density, and configuration of the DDR SDRAM devices making up the memory modules.

Table 4-1 Sizes of RAM expansion DIMMs and devices

Size of SO-DIMM	Configuration of SO-DIMM	Number of banks	Number of devices	Device density	Device configuration
128 MB	16 M x 64	1	8	128 Mbit	16 M x 8
128 MB	16 M x 64	2	8	128 Mbit	8 M x 16
256 MB	16 M x 64	2	16	128 Mbit	16 M x 8
256 MB	16 M x 64	2	8	256 Mbit	16 M x 16
256 MB	32 M x 64	1	8	256 Mbit	32 M x 8
256 MB	32 M x 64	2	8	256 Mbit	16 M x 16
512 MB	64 M x 64	2	16	256 Mbit	32 M x 8
512 MB	64 M x 64	2	8	512 Mbit	32 M x 16 64 M x 8
1GB	128 M x 64	2	16	512 Mbit	32 M x 16 64 M x 8

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 DDR SDRAM devices. Table 4-2 lists the types of devices that can be used in the 12-inch PowerBook G4 by size, configuration, and sizes of row, column, and bank addresses.

Important: The 12-inch PowerBook G4 supports only the types of DDR SDRAM devices specified in Table 4-2. Other types of DRAM devices should not be used with this computer.

Table 4-2 Types of DDR SDRAM devices

Device size	Device configuration (bytes x bits x banks)	Row address bits	Column address bits
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
512 Mbits	8 M x 16x 4	13	10
512 Mbits	16 M x 8x 4	13	11

RAM SO-DIMM Electrical Limits

Each RAM SO-DIMM must not exceed the following maximum current limits on the 2.5 V supply:

Active: 1.2 A (maximum of 8 devices per bank, 150 mA per device)

Sleep: 6 mA/128 MB

The Intrepid memory controller does not support 4-bit-wide SDRAM devices in any RAM expansion module.

Supplemental Reference Documents

This section contains additional information about the technologies mentioned in this developer note by providing references to helpful websites.

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

<http://developer.apple.com/documentation/Hardware/hardware2.html>

Apple Technical Notes

Apple Technical Notes answer many specific questions about the operation of Macintosh computers and the Mac OS. The technical notes are available on the 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.

General information on OpenGL is available on the World Wide Web at

<http://www.opengl.org>

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.freescale.com/webapp/sps/site/prod_summary.jsp?code=MPC7447A&nodeId=018rH3bTdG8653

Mac OS X

Mac OS X version 10.3.7 is installed by default on the 12-inch PowerBook G4. For access to Apple's developer documentation for Mac OS X, see the Apple Developer Connection (ADC) website at

<http://developer.apple.com/documentation/MacOSX/index.html>

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.

Velocity Engine

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 available on the Apple website, at

<http://developer.apple.com/hardwaredrivers/ve/index.html>

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. Obtain a copy of the AltiVec PEM from the following Freescale site on the World Wide Web by logging in and searching for ALTIVECPEM/D.

<http://www.freescale.com/>

Open Firmware

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

TN1061: Open Firmware, Part I, available on the technical note web site at

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

TN1062: Open Firmware, Part II, available on the technical note web site at

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

TN1044: Open Firmware, Part III, available on the technical note web site at

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

TN2001: Running Files from a Hard Drive in Open Firmware, at

<http://developer.apple.com/technotes/tn/tn2001.html>

Another technical note tells how to debug open firmware code. Please refer to *TN2004: Debugging Open Firmware Using Telnet*, available on the technical note web site at

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

RAM Expansion Modules

The mechanical characteristics of the RAM DDR SO-DIMM are given in JEDEC specification number JESD95. The specification can be found by using the search string JESD95 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 JESD-21C on the Electronics Industry Association's website at

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

ATA Devices

ATA (AT Attachment), also referred to as integrated drive electronics (IDE), is a standard interface used with storage devices such as hard disk drives. For more information on ATA, refer to the following Apple website at

<http://developer.apple.com/documentation/Hardware/DeviceManagers/ata/ata.html>

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, refer to Apple Computer's *Accessing Hardware from Applications* at

<http://developer.apple.com/documentation/Hardware/DeviceManagers/usb/usb.html>

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

<http://www.usb.org/developers/docs>

FireWire 400 Interface

For additional information about the FireWire 400 IEEE 1394a interface and the Apple APIs for FireWire software, refer to the resources available on the Apple FireWire web site at:

<http://developer.apple.com/firewire/index.html>

Supplemental Reference Documents

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

<http://shop.ieee.org/store/>

Useful information is also available at the 1394 Trade Association's web site:

<http://www.1394ta.org/>

Wireless Networks

More information about Wi-Fi and wireless networks using the IEEE 802.11 standard is available on the web site of the WiFi Alliance, at

<http://www.wi-fi.org>

Bluetooth

For more information regarding Bluetooth technology, refer to the following locations on the World Wide Web.

Bluetooth specification:

<http://www.bluetooth.org/spec/>

Bluetooth SIG:

<http://www.bluetooth.org>

Bluetooth developer tools on the Apple web site at:

<http://developer.apple.com/hardware/drivers/bluetooth/>

Conventions and Abbreviations

This developer note uses the following typographical conventions and abbreviations.

Typographical Conventions

Note: A note like this contains information that is of interest but is not essential for an understanding of the text.

Important: A note like this contains important information that you should read before proceeding.

Abbreviations

When unusual abbreviations appear in this developer note, the corresponding terms are also spelled out. Standard units of measure and other widely used abbreviations are not spelled out.

Here are the standard units of measure used in developer notes:

A	amperes	MB	megabytes
dB	decibels	Mbps	megabits per second
GB	gigabytes	Mbit	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		

Other abbreviations used in developer notes include these:

10Base-T	an Ethernet standard for data transmission at 10 Mbits per second
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100Base-T	an Ethernet standard for data transmission at 100 Mbps per second
ADB	Apple Desktop Bus
ADC	Apple Display Connector
AGP	accelerated graphics port
AIM	ATA Interface Module
AP	access point, for a wireless LAN
API	application programming interface
ASIC	application-specific integrated circuit
ATA	AT attachment
ATAPI	AT Attachment Packet Interface
CAS	column address strobe, a memory control signal
CAV	constant angular velocity
CD	compact disc
CD-ROM	compact disc read-only memory
CKE	clock enabled
CLV	constant linear velocity
CPU	central processing unit
DAA	data access adapter (a telephone line interface)
DAC	digital-to-analog converter
DDC	display data channel
DDR	double data rate, a type of SDRAM where data is clocked on rising and falling clock edges
DFS	dynamic frequency switching
DIMM	Dual Inline Memory Module
DMA	direct memory access
DPS	dynamic power step
DSP	digital signal processor
DSSS	direct-sequence spread-spectrum
EDID	Extended Display Identification Data

EDO	extended data out
EDR	enhanced data rate
EHCI	Enhanced Host Controller Interface —USB 2.0 protocol
EIDE	enhanced integrated device electronics
G4	Generation 4, the fourth generation of PowerPC microprocessors
GND	ground
HFS	hierarchical file system
HCRP	hardcopy cable replacement profiler
HID	human interface device, a class of USB devices
I2C	inter IC control bus (same as IIC)
I2S	inter IC sound bus (same as IIS)
IC	integrated circuit
IDE	integrated device electronics
IIC	inter IC control bus (same as I2C)
IIS	inter IC sound bus (same as I2S)
I/O	input and output
ISM	industrial, scientific, and medicine
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
LAN	local area network
LED	light emitting diode
MAC	media access controller
Mac OS	Macintosh Operating System
modem	modulator-demodulator, a data communications interface for use with analog telephone lines
NMI	nonmaskable interrupt
NOP	no operation

NTSC	National Television System Committee; the standard system used for broadcast TV in North America and Japan
NV-RAM	nonvolatile random-access memory
OFDM	orthogonal frequency-division multiplexing
OHCI	Open Host Controller Interface —USB 1.1 protocol
OS	operating system
PAL	Phase Alternate Lines; the standard for broadcast TV in most of Europe, Africa, South America, and southern Asia
PCAV	partial constant angular velocity (CLV at small radius, CAV at large radius)
PCI	Peripheral Component Interconnect
PHY	physical layer
PLL	phase-locked loop
POST	power-on self test
RADIUS	Remote Authentication Dial-In User Service
RAM	random-access memory
RF	radio frequency
rms	root mean square
ROM	read-only memory
SCC	Serial Communications Controller
SCSI	Small Computer System Interface
SDRAM	synchronous dynamic RAM
SMS	Sudden Motion Sensor
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
TMDS	transition minimized differential signalling
TDM	target disk mode
VCC	positive supply voltage (voltage for collectors)

APPENDIX B

Conventions and Abbreviations

VESA	Video Electronics Standards Association
VGA	video graphics adapter
VPN	virtual private network
WEP	Wired Equivalent Privacy
Wi-Fi	Logo used by the Wireless Ethernet Compatibility Alliance for certification of interoperability of 802.11 products
WLAN	wireless LAN
ZCLV	zone constant linear velocity

