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Technical Note HW26

Macintosh Quadra Built-In Video

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This is an in-depth article in three parts, describing the internal video on the Macintosh Quadra computers. The first part discusses a number of general Quadra video topics, the second part details how to wire the video connector sense pins to access all the Quadra's supported video modes, and the third describes the memory configurations necessary to support each of the video modes at specific pixel depths.

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Video Architecture

The Macintosh Quadra computers were designed with a flexible video hardware section in order to support a wide variety of displays. Since the purchaser of one of these CPUs is paying for a frame buffer on the motherboard (whether he or she wants it or not), and since the Quadras were designed to be high-performance machines, the frame buffer was designed both to be very flexible (to support most displays a user may want to use) and to be relatively high performance (to match the computer's capabilities).

Obviously every display made by every third-party monitor vendor can't be supported by the on-board video, but the Macintosh Quadra computers do support a much wider range of displays at a higher level of performance than any previous Macintosh. The Macintosh Quadra 700 and 900 support pixel depths ranging from 1 to 32 bits per pixel (bpp), Apple displays ranging from the 512 x 384 12-inch color monitor through the 1152 x 870 21-inch color monitor, pixel clocks ranging from 12 to 100 MHz, and a variety of industry standards such as VGA, SVGA, NTSC, and PAL. The Macintosh Quadra video port produces RS-343 RGB, and also provides horizontal, vertical, and composite sync outputs. Composite or S-video output is not provided, but can be accomplished by use of an external RGB-to-composite encoder. The Macintosh Quadra 700 and 900 also support Apple convolution for flicker-reduction on interlaced displays (that is, NTSC and PAL) at up to 8 bpp. The Macintosh Quadra computers automatically detect the type of display attached to the video connector via three "sense" pins on the video connector. Depending on the wiring of these three pins, software in ROM configures the video hardware for one of the supported display types. (A full description of sense pin wiring and supported display types is in the second part of this Technote.)

The Quadra 700 and 900 provide the highest built-in video performance of any Macintosh CPU to date. In a (very) simplified graphics model, we could say that performance depends on two main factors: processor horsepower and the bandwidth the processor has into frame buffer memory. These machines already have a fast processor--the 68040--that runs standard 32-Bit QuickDraw. To provide high bandwidth into frame buffer memory, dedicated video RAM (VRAM) was used for the frame buffer, and that VRAM was placed directly on the 68040 processor's local bus. This provides the 68040 the same access time into frame buffer memory that it has into main system RAM. (Transfer rates can exceed 40 MB per second.) In addition, memory options such as fast page mode are supported, which can improve graphics performance for operations such as scrolling and off-screen to on-screen pixmap transfers.

In a number of cases the design was optimized for high performance over low cost. A good example of this is 32 bpp operation on Apple's standard 13-inch RGB monitor at 640 x 480 resolution (and this also applies to VGA and NTSC), which is probably the most common color monitor in use on the Macintosh. The actual number of memory bytes needed to support 24 bpp is $640 \times 480 \times 3 = 921,600$. This would seem to fit within 1 MB of memory (as is the case with the Apple 8*24 video card), but the Quadra computers actually require 2 MB of VRAM for this mode. The 8*24 card supports 24 bpp at 640 x 480 by using a storage mode called "chunky planar" to fully utilize all its 1 MB of VRAM. However, this results in having to perform three separate memory accesses for each 24-bit pixel read from or written to the frame buffer. (This is done in hardware so software only performs a single read or write.) On a NuBus video card, this inefficiency is partially masked by the synchronization delays that occur at the processor-bus/NuBus interface. However, when frame buffer memory is placed directly on the processor bus, this approach results in a nearly threefold performance degradation. This was judged unacceptable for the Quadra machines. Each 24-bit pixel occupies one longword (4-bytes) in VRAM, so the Quadras actually provide 32 bpp for the 640 x 480 resolution. This pushes the memory requirement for this mode over the 1 MB boundary ($640 \times 480 \times 4 = 1,228,800$ bytes). Performance is improved still more by another frame buffer architectural feature. Frame buffer memory in the Quadra computers is organized into four "banks" of 512K per bank. As mentioned earlier, Quadra VRAM can operate in fast page mode. In addition, each bank of VRAM operates in fast page mode independently of the other three banks. This causes the number of in-page "hits" to increase, and thus improves the effective bandwidth into the frame buffer. Also, at 32 bpp, 640 x 480 resolution, each row is set to 4096 bytes, or 1024 32-bit pixels. Each successive row is assigned to a different VRAM bank (modulo 4, of course). This memory organization improves performance during certain commonly performed graphics operations such as vertical scrolling.

In any design there are a number of trade-offs to be made, and this is certainly true for the frame buffer in the Macintosh Quadra machines. While the video does operate at 32 bpp on displays up to 16 inches, it does not support 21-inch displays at this pixel depth since this would have significantly raised the cost of the motherboard. (Memory capacity and bus bandwidths would essentially have to double, and this would be expensive.) It does support NTSC and PAL timing, but does not provide a composite video output. While it is much faster than any non-accelerated video card, there are accelerated video cards that are faster (and much more expensive, too, by the way). A separate graphics processor was not added primarily for cost reasons. However, a graphics processor such as the 29000 RISC chip on the 8*24GC card can only speed up the graphics operations that it was designed to know about. If an application program bypasses QuickDraw (which is what most Macintosh graphics accelerators are designed to speed up), a graphics accelerator will not improve performance, and can actually cause performance degradation.

Overall, the Macintosh Quadra video provides a reasonable compromise of cost, performance, and features, which provides the video needed by the majority of Macintosh users at a reasonable price.

Supported Display Configurations

The Macintosh Quadra frame buffer determines what type of display is attached to the video connector by examining the state of three sense line pins. The following chart details how these three pins must be wired for each of the supported display types. For each supported display, the screen resolution (horizontal pixels x vertical pixels), dot clock frequency, and the vertical and horizontal scan rates are listed.

Basically, the Macintosh Quadra 700 and 900 support any display, whether from Apple or from another vendor, that meets one of the following specifications:

Standard Sense Codes:

Display	Sense pins 10 7 4			Hor x Vert Pixels	Dot Clock	Vert Refresh	Horiz
-----	-----			-----	-----	-----	-----
Apple 21S Color	0	0	0	1152 x 870	100	75	68.7
Apple Portrait	0	0	1	640 x 870	57.2832	75	68.9
12" Apple RGB	0	1	0	512 x 384	15.6672	60.15	24.48
Apple 2-Page Mono.	0	1	1	1152 x 870	100	75	68.7
NTSC	1	0	0	underscan-512x384	12.2727	59.94	15.7
	1	0	0	overscan- 640x480	12.2727	59.94	15.7
(To produce a color NTSC signal, an RGB-to-NTSC converter is required.)							
12" Apple Monochrome	1	1	0	640 x 480	30.24	66.7	35.0
13" Apple RGB	1	1	0	640 x 480	30.24	66.7	35.0
Extended sense codes will be examined if the following sense code is detected:							
	1	1	1				

Note 1 on above monitors: A sense pin value of 0 means that the pin should be grounded to the C&VSYNC.GND signal; a value of 1 means do not connect the pin.

Note 2 on above monitors: Sense pins 4, 7, and 10 are referred to as SENSE0, SENSE1, and SENSE2 in pinout tables for the video connectors.

Note 3: The terms *underscan* and *overscan* are used to describe the active video resolution for NTSC and PAL modes. *Underscan* means that the active video area appears in a rectangle centered on the screen with a black surrounding area. This ensures that the entire active video area always is displayed on all monitors. *Overscan* utilizes the entire possible video area for NTSC or PAL. However, most monitors or televisions will cause some of this video to be lost beyond the edges of the display, so the entire image will not be seen.

Extended Sense Codes:

Note for extended sense codes: A sense pin pair value of 0 means those pins should be tied together (as opposed to grounding the pins to pin 11); a value of 1 means do not connect the pins. Do *not* wire any of these pins to ground.

Display	Sense pins			Hor x Vert	Dot	Vert	Horiz
-----	4-10	10-7	7-4	Pixels	Clock	Refresh	Refrsh
-----	-----	-----	-----	-----	-----	-----	-----

16" Color, (i.e., E-Machines)	0	1	1	832 x 624	57.2832	75	49.7
----------------------------------	---	---	---	-----------	---------	----	------

PAL

PAL has two wiring options using the extended sense pin configuration. To produce a color PAL signal, an RGB-to-PAL converter is required.

PAL Option 1	0	0	0	underscan-640x480	14.75	50	15.625
				overscan-768x576	14.75	50	15.625

Note: This configuration does not presently doesn't support 24 bits per pixel.

PAL Option 2	1	1	0	underscan-640x480	14.75	50	15.625
				overscan-768x576	14.75	50	15.625

Note: This sense code also requires a diode between sense pins 10 and 7, with anode towards pin 7, cathode towards pin 10.

VGA	1	0	1	640 x 480	25.175	59.95	31.47
-----	---	---	---	-----------	--------	-------	-------

SVGA	1	0	1	800 x 600	36	56	35.16
------	---	---	---	-----------	----	----	-------

To enable SVGA, after configuring and connecting the monitor for VGA, open the Monitors control panel and select Options. Choose Super VGA from the dialog box and reboot your system.

No external monitor (video halted)							
	1	1	1				

Here are the Macintosh Quadra video connector pinouts:

Pin	Signal	Description
1	RED.GND	Red Video Ground
2	RED.VID	Red Video
3	CYSNC~	Composite Sync
4	MON.ID1	Monitor ID, Bit 1 (also known as SENSE0)
5	GRN.VID	Green Video
6	GRN.GND	Green Video Ground
7	MON.ID2	Monitor ID, Bit 2 (also known as SENSE1)
8	nc	(no connection)
9	BLU.VID	Blue Video
10	MON.ID3	Monitor ID, Bit 3 (also known as SENSE2)
11	C&VSYNC.GND	CSYNC & VSYNC Ground
12	VSYNC~	Vertical Sync
13	BLU.GND	Blue Video Ground
14	HSYNC.GND	HSYNC Ground
15	HSYNC~	Horizontal Sync
Shell	CHASSIS.GND	Chassis Ground

If your monitor is a VGA type, you can try the following cable pinouts:

Macintosh Quadra DB-15	VGA Connector
-----	-----
2 -----	Red Video ----- 1
1 -----	Red Ground ----- 6
9 -----	Blue Video ----- 3
13 -----	Blue Ground ----- 8
5 -----	Green Video ----- 2
6 -----	Green Ground ----- 7
15 -----	Hsync ----- 13
12 -----	Vsync ----- 14
14 -----	Sync Ground ----- 10
10 -----	
7 -----	Connect 7 and 10 so the sense pin ID will equal VGA

There are a few issues to keep in mind with VGA monitors:

- VGA monitors will vary depending on the vendor. Check with the vendor about Macintosh Quadra compatibility before buying, or better yet, actually try the monitor with a Quadra to see if it works and if the quality is acceptable.
- Vendors have different image quality specifications. There may be significant differences between Apple monitors and the wide range of VGA monitors. Do a side-by-side comparison of the monitors you are considering before buying.
- Many third party cable vendors have off-the-shelf cables that should work.

Most NTSC devices use an RCA-type phono-connector and the following diagram uses that as a reference point. A cable wired as follows may allow many different brands of NTSC monitors to work on a Macintosh Quadra. I would advise you to test the monitor on a Macintosh Quadra prior to purchase to see if it meets your expectations.

Adjust the phono-connector side to whatever type of connector is used (RCA, BNC, and so on). "Tip" is the pin in the center of the connector (the signal); the sleeve is the flange around the outer edges of the connector (the chassis ground).

Card Connector		RCA-Type Phono-Connector	
-----		-----	
4	MON.ID1 (sense0) --		
7	MON.ID2 (sense1) --		
11	C&VSYNC.GND -----		
5	GRN.VID ----->	Tip (signal)	
Shell	CHASSIS.GND ----->	Sleeve (ground)	

By grounding pin 4 and pin 7 to pin 11, the Macintosh Quadra computers are told that an NTSC monitor is attached. The actual black-and-white video signal is on pin 5 and connects to the center (Tip) of the phono-plug. The shell of the card connector connects to the sleeve of the phono-plug.

To acquire a color NTSC signal from a Quadra (or any Apple Macintosh display card), an RGB-to-NTSC converter is required, such as those available from RasterOps, Truevision, and Computer Friends. Sorry, but I do not have the cable requirements for any of these devices.

VRAM Configurations

The Quadra frame buffer supports a variety of pixel depths, from 1 to 32 bits per pixel. The supported pixel depths (1, 2, 4, 8, or 32 bpp) depend on the display resolution and the amount of VRAM in the Quadra. The fully expanded capability of both Quadra machines is the same, that is, both the 900 and 700 can be expanded to 2 MB of VRAM. However, note that 512K of VRAM is the minimum configuration for the Quadra 700 whereas it is 1 MB of VRAM for the Quadra 900 (this is the amount of VRAM soldered on the motherboard). The Quadra 700 has six VRAM expansion slots, while the 900 has only four. Also note that only 0.5 MB, 1 MB, and 2 MB configurations are supported (that is, 1.5 MB is not supported).

The Quadra 700 and 900 can be expanded using 256K (that is, 128K x 16) 100 nS VRAM SIMMs. These are the same as the VRAM SIMM shipped in the base configuration of the Macintosh LC, or the VRAM SIMMs used to expand an Apple 4*8 video card to an 8*24 card. Note that the 512K VRAM SIMMs used to upgrade the Macintosh LC will *not* work in a Quadra. (The 256K SIMMs removed from an LC when performing a VRAM upgrade will work, however. All those old 256K VRAM SIMMs laying around from upgraded Macintosh LCs can be used to upgrade Macintosh Quadra 700s and 900s!) The DRAM SIMMs used to upgrade an 8*24GC video card will also not work.

The following chart lists the Macintosh Quadra 700 and 900 built-in video's maximum pixel depth supported depending upon the VRAM configuration:

Display size	512K VRAM	1 MB VRAM	2 MB VRAM
	-----	-----	-----
12-inch landscape 384 x 512 (such as 12" RGB)	8 bpp	32 bpp	32 bpp
12-inch Monochrome 640 x 480	8 bpp	8 bpp	8 bpp
13-inch RGB & VGA 640 x 480	8 bpp	8 bpp	32 bpp
SVGA 800 x 600	8 bpp	8 bpp	32 bpp
15-inch Portrait (b/w) 640 x 870	4 bpp	8 bpp	8 bpp
16" Color, 832 x 624	8 bpp	8 bpp	32 bpp
2-Page Display (b/w) 1152 x 870	4 bpp	8 bpp	8 bpp
21" Color 1152 x 870	4 bpp	8 bpp	8 bpp
PAL without convolution			
underscan-640x480	8 bpp	8 bpp	32 bpp*
overscan-768x576	8 bpp	8 bpp	32 bpp*
PAL with convolution			
underscan-640x480	n.a.	8 bpp	8 bpp
overscan-768x576	n.a.	8 bpp	8 bpp
NTSC without convolution			
underscan-512x384	8 bpp	8 bpp	32 bpp
overscan- 640x480	8 bpp	8 bpp	32 bpp
NTSC with convolution			
underscan-512x384	n.a	8 bpp	8 bpp
overscan- 640x480	n.s	8 bpp	8 bpp

*Note that there are two ways to cable a PAL monitor to a Macintosh Quadra; only by using the proper extended sense code are you able to achieve 32 bits per pixel. For details, refer to the previous section on Quadra video sense pinouts.

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