New Technical Notes
Macintosh

Developer Support

Sense Lines
Hardware

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Ever wonder how to set up an Apple video card or Macintosh built-in video to support various size monitors? Well, this Technical Note will tell you everything you need to know about what monitors are supported and how.

Changes since September 1992: Corrected the sense line pin descriptions in Figures 1, 2, and 3, plus the associated descriptions. In the previous release of the Technical Note, sense lines 2 and 0 were inverted. In each example, sense line 0 was marked as sense line 2 and vice versa. Modified Figure 3 to show only the relevant combinations of extended sense line combinations as presented in Table 3, “Extended Sense Line Descriptions for each Monitor.” Provided additional description on understanding the regular and extended sense line protocol notation. Added the Spring ’93 CPUs to Table 4, the list of what video hardware supports what monitors.

Sense Lines

The Sense Line Protocol was implemented when Apple recognized the need for a mechanism that would allow a display card to identify the monitor connected to it. For example, the built-in video display circuitry on the Macintosh Quadra and on the PowerBook 160, 165c, and others, can configure themselves according to the monitor that is connected at boot time. The identification scheme works fine, but there is one problem. Three sense lines limit the number of different monitors to seven plus the no-connect case. To overcome this limitation, newer display cards and built-in video use an extension to the sense line scheme that allows for 28 new codes.

The extension is based on the following idea: When the display circuitry senses a configuration that in the original scheme signals “no display connected” (in other words, when all three sense lines are not grounded), the card pulls down each sense line, one by one, and reads back what the other lines return. To return a unique code, the only requirement is that the sense lines be connected, in the cable or the monitor itself, by wires or diodes. The beauty of this idea is that existing monitors are detected correctly. Newer monitors, such as the Apple 16" Color Display, can have their own encoding, and the circuitry for detecting new monitors is relatively simple. Since there are no active components, adding the encoding to new or existing monitors involves only a few inexpensive diodes and a little wire.

The Original Scheme

In the original scheme of things, the display circuitry determines the type of monitor attached by reading three sense lines and comparing the signal value to ground. By convention, the sense lines were identified as 0, 1, and 2. Given the three lines and the two different states, on or off, there were a total of eight possible combinations. For a monitor to be recognized, a sense line on the monitor side was connected to ground to be read as a binary 0, or left unconnected to be read as a binary 1. The first seven monitors listed in Table 2 show the required sense line states for them to be recognized using the original sense line scheme.

It's important to note that monitors using the original sense line scheme need only have their sense lines read once to determine the monitor type. As new monitor types became available for the Macintosh, the Extended Sense Line Protocol was implemented.

Extended Sense Line Protocol

The Extended Sense Line Protocol is one of those oddities of software engineering that can at first defy logic. One wonders how late in the evening or how many cans of Mountain Dew were consumed before the protocol notation was defined. The extended sense line protocol sets the guidelines for defining a 6-bit binary number that defines how the monitor sense lines must respond in order to be recognized correctly.

With this unusual introduction, let's step back. Under the original scheme, sense lines were compared to ground to determine their state. To reiterate, with three pins, there are a total of eight possible combinations. Seven combinations of the sense line states were assigned to the early monitor types. The eighth sense line combination has become reserved for use to signal the extended sense line protocol. In this eighth configuration, none of the three sense lines are tied to monitor ground. When the display system software reads the state of the monitor sense lines and finds that none of the three lines are grounded, the extended sense line protocol is assumed. For the extended sense line protocol, the sense lines get tied to each other within the monitor using a combination of straight wire and/or diode connections.

Under the extended sense line protocol, each sense line is asserted and the other two sense lines are read. Instead of being compared to ground, each line is compared to the asserted line. If a sense line is the same state as the asserted sense line, the state equates to a binary 0, otherwise, it is binary 1.

The diagram in Figure 1 shows an example of the Extended Sense Line Protocol notation. There are three pairs of binary numbers. Each pair of binary digits represents the relative state of two sense line pins to the third sense line pin, which is held low. Each bit is sense line specific. The idea is that software tells the video card/hardware to hold one line low and read the result of the other two lines.

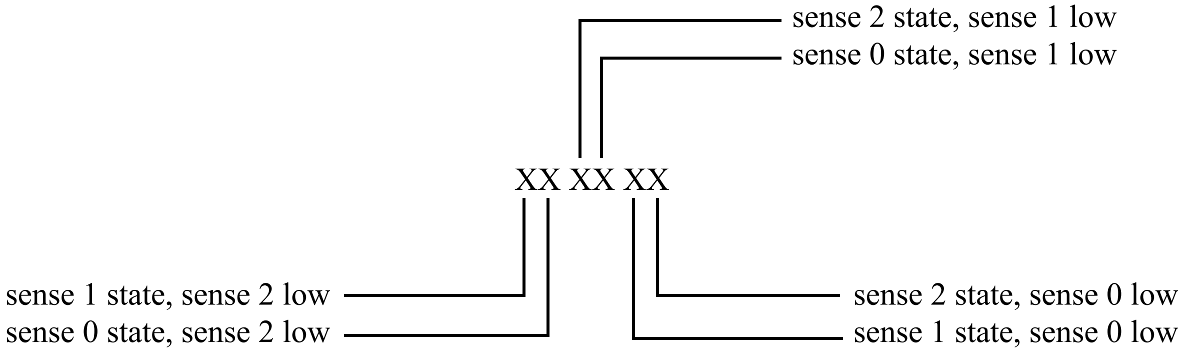
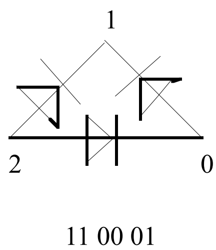


Figure 1—Extended Sense Line Decode Method

To make "sense" of the protocol notation, we now present a diagram showing some theoretical interconnection between the sense lines. Given the extended sense line notation of 11 00 01, Figure 2 shows how the monitor cable sense lines would be interconnected for the system to detect a specific extended monitor type. In the Extended Sense Line Protocol, the first pair of binary digits represent the sense state of pins 1 and 0 when sense line 2 is held low. The diagram maintains the same sense of order, showing sense line 2 on the left side and sense line 0 on the right.

To read the chart in Figure 2: The three points of the triangle correspond to the three sense lines. The diodes and wires show the required connection. The 6-bit binary number below each diagram (see Figure 3 for all the current valid diagrams) corresponds to the result that will be read when polled. It is read: when 2 is pulled low, 1 and 0 return the first two digits; when 1 is pulled low, 2 and 0 return the second two bits; when 0 is pulled low, 2 and 1 return the last two bits.



The circuitry shown here produces the following code:

SENSE 2 low	SENSE 1 1	SENSE 0 1
SENSE 1 low	SENSE 2 0	SENSE 0 0
SENSE 0 low	SENSE 2 0	SENSE 1 1

Figure 2—Extended Sense Line Decode Sample

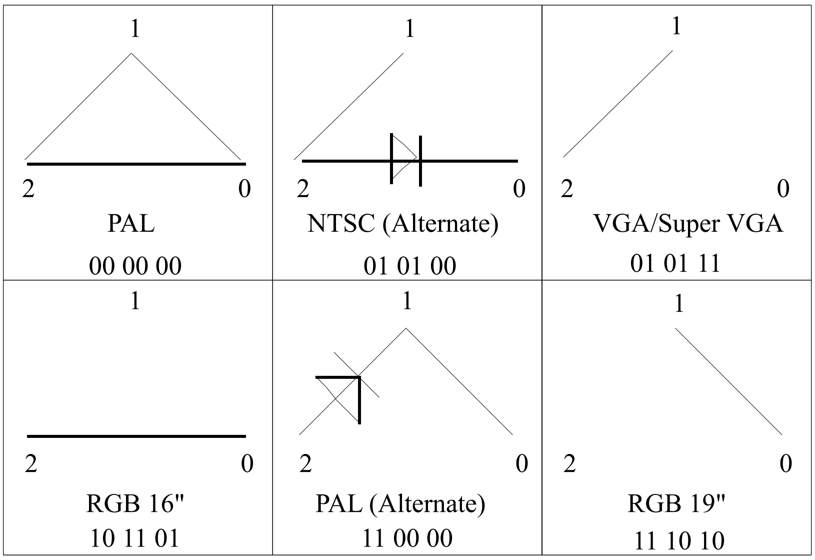


Figure 3—Extended Sense Line Decode Table

Figure 3 shows the sense line interconnections required for the existing monitors that require extended sense line coding. This Technical Note will be updated as new monitors sense codes are defined.

It is important to clarify the NTSC (Alternate) and the PAL (Alternate) diagrams for those who might wonder whether a diode is missing. For NTSC (Alternate), the binary extended notation is 01 01 00. One might at first feel that for the last pair of binary digits, 00, to make sense, there must be diode between sense line 0 and 1. In fact since sense line 1 is wired to sense line 2, asserting sense line 0 means that sense lines 2 **and** 1 will be read at the same state. Similar logic applies to the PAL (Alternate) diagram. This saves the implementation of another diode. For the PAL diagram, any one of the three sense line interconnections could be removed and the same extended sense line logic would be maintained.

Video Connector

Table 1 Signal Assignments for the External Video Connector

Pin	Signal Name	Signal Description
1	RED.GND	Red Ground
2	RED.VID	Red Video Signal
3	/CSYNC	Composite Sync Signal
4	SENSE2	Monitor Sense Line 2
5	GRN.VID	Green Video Signal
6	GRN.GND	Green Ground
7	SENSE1	Monitor Sense Line 1
8	n.c.	Not Connected
9	BLU.VID	Blue Video Signal
10	SENSE0	Monitor Sense Line 0
11	C&VSYNC.GND	Ground for CSYNC & VSYNC
12	/VSYNC	Vertical Sync Signal
13	BLU.GND	Blue Ground
14	HSYNC.GND	HSYNC Ground
15	/HSYNC	Horizontal Sync Signal

Sense Line to Monitors

Table 2 Sense Line Descriptions for Each Monitor

Signal	Sense 0	Sense 1	Sense 2	Frequency (MHz)
RGB 21"	0	0	0	100
NTSC	0	0	1	12.2727 MHz
RGB 12"	0	1	0	15.6672
B&W 12" & RGB 13"		0	1	1 30.24
B&W 15"	1	0	0	57.2834
RGB 15"	1	0	1	57.2834
B&W 21"	1	1	0	100
RGB 16"*	1	1	1	57.2834
RGB 19"*	1	1	1	80
VGA*	1	1	1	25.175
Super VGA*	1	1	1	35.16
NTSC w/convolution*	1	1	1	12.2727
PAL*	1	1	1	14.75
PAL w/convolution*	1	1	1	14.75

* These monitors require extended sense line support.

Note: The binary values in this table indicate the relative state of the sense pin measured against monitor ground, pin 11, from Table 1 above.

Table 3 Extended Sense Line Descriptions for Each Monitor

SIGNAL	1-0(2 low)	2-0(1 low)	2-1(0 low)
PAL	00	00	00
NTSC (Alternate)	01	01	00
VGA/Super VGA	01	01	11
RGB 16"	10	11	01
PAL (Alternate)	11	00	00
RGB 19"	11	10	10

Note: 1-0(2 low) indicates that the software is driving monitor sense line 2 and reading back monitor sense lines 1 and 0. For example, if you have a PowerBook 160, 165c, 180, or 180c, you can make the CPU recognize that there is an Apple 16" RGB external monitor attached by noticing that the sense line code in Table 3 for such a monitor is 10 11 01. From Figure 3, this sense code equates to sense line 2 being connected to sense line 0. Using Table 1, this means that by tying pin 4 to pin 10, the PowerBook will think that the larger monitor is attached. It’s important to recognize that pins 4 and 10 in this example must not be tied to ground, otherwise, a 12" RGB monitor would be detected.

What Video Hardware Supports What Monitors

Table 4 Monitor Versus Video Hardware Versus Supported Depth

4•8:

Monitor	Max. Bit Depth
NTSC	8
NTSC w/convolution	8
RGB 13"	8
B&W 15"	4
B&W 21"	4
B&W 12"	8
PAL**	8
PAL w/convolution**	8
RGB 16"**	4
RGB 21"**	4

** These monitors are supported on this card if the card has a new ROM (see your dealer).

8•24:

Monitor	Max. Bit Depth
NTSC****	1-8 w/conv; millions w/o conv
RGB 13"	Millions
B&W 15"	8
B&W 21"	8
B&W 12"	Millions
PAL****	1-8 w/conv; millions w/o conv
RGB 16"**	8
RGB 21"**	8

**These monitors are supported on this card if the card has a new ROM (see your dealer).

**** In the Monitors control panel, the display circuitry implements convolution automatically for bit depths 1–8, and nonconvolution for the millions bit depth

8•24GC:

Monitor	Max. Bit Depth
NTSC****	1-8 w/conv; millions w/o conv
RGB 13"	Millions
B&W 15"	8
B&W 21"	8
B&W 12"	Millions
PAL****	1-8 w/conv; Millions w/o conv
RGB 16"**	8
RGB 21"**	8

** These monitors are supported on this card if the card has a new ROM (see your dealer).

**** In the Monitors control panel, the display circuitry implements convolution automatically for bit depths 1–8, and nonconvolution for the millions bit depth

Macintosh LC/LC II

Monitor	Max. Bit Depth
VGA	8
RGB 13"	8
RGB 12"	Thousands
B&W 12"	8

Macintosh IIvx/IIvi

Monitor	Max. Bit Depth

VGA	8
RGB 13"	8
RGB 12"***	Thousands
B&W 12"	8

*** For the 12" RGB monitor, the built-in video does not support 1 bit/pixel mode.

Macintosh IIci/IIsi

Monitor	Max. Bit Depth
RGB 13"	8
RGB 12"	8
B&W 15"	4
B&W 12"	8
RGB 15"	4

Macintosh LC III

Monitor	Max. Bit Depth
VGA	Thousands
RGB 13"	Thousands
RGB 12"	Thousands
B&W 12"*****	Thousands
B&W 15"	8
RGB 16"	8

***** Thousands mode is available because the built-in video circuitry cannot distinguish between the 12" black-and-white and the 13" RGB monitors. The 12" black-and white display is capable of 256 gray levels; however, when the Thousands mode is selected, there are only 32 gray levels available due to the way 16 bits-per-pixel support is implemented.

PowerBook 160/165c/180/180c

Monitor	Max. Bit Depth
VGA/Super VGA	8
RGB 13"	8
RGB 12"	8
B&W 12"	8
B&W 15"	4
RGB 16"	8

Macintosh Quadra 700/900

Monitor	Max. Bit Depth
NTSC	Millions
NTSC w/convolution	8
VGA	Millions
Super VGA	Millions
PAL	Millions
PAL w/convolution	8
RGB 13"	Millions
RGB 12"	Millions

B&W 15"	8
RGB 16"	Millions
RGB 21"	8
B&W 21"	8
B&W 12"	Millions

Macintosh Quadra 950

Monitor	Max. Bit Depth
NTSC	Millions
NTSC w/Convolution	8
VGA	Millions
Super VGA	Millions
PAL	Millions
PAL w/Convolution	8
RGB 13"	Millions
RGB 12"	Millions
B&W 15"	8
RGB 16"	Millions
RGB 21"	Thousands
B&W 21"	8
B&W 12"	Millions
RGB 19"	8

Macintosh Centris 610/650
Macintosh Quadra 800

Monitor	Max. Bit Depth
NTSC	Thousands
VGA	Thousands
Super VGA	Thousands
PAL	Thousands
RGB 13"	Thousands
RGB 12"	Thousands
B&W 15"	8
RGB 16"	Thousands
RGB 21"	8
B&W 21"	8
B&W 12"	Thousands
RGB 19"	8

Further Reference:

- *Guide to the Macintosh Family Hardware*, second edition, Displays
- *develop* Issue 3, “Macintosh Display Card 8•24GC: The Naked Truth”
- Developer Notes (for each CPU)
- M.HW.ColorMonitors