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IBM Personal Computer Professional Graphics Controller Technical Reference

PROFESSIONAL GRAPHICS CONTROLLER

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Description

The IBM Personal Computer Professional Graphics Controller is an adapter that: (1) provides a high-function graphics capability and (2) acts as an IBM Color/Graphics Monitor Adapter, with the exception of the 160-by-100 color/graphics mode.

The operations of the Professional Graphics Controller are controlled by an 8088 Microprocessor. It carries out all communications through its data bus and address bus. The system-bus interface recognizes its own commands and passes only these commands to the controller. The interface allows the microprocessor to read or write to memory locations, using the IBM Professional Graphics Controller microprocessor's data and address busses.

The microprocessor controls and initializes several sections of the controller. It defines the requirements of the controller's hardware so the controller can imitate the actions of the IBM Color/Graphics Monitor Adapter. The microprocessor also regulates the emulator address control, which translates the system's I/O address information and stores the associated data in the graphics emulator memory for screen display. Finally, it initializes the video control generator, which generates timing pulses and the horizontal- and vertical-synchronization (sync) pulses.

During operation, the microprocessor intercepts commands sent to the emulator and interprets them. The microprocessor can also accept and interpret the high-function graphics commands, writing the results in the display memory for screen display. Both the emulator and high-function graphics functions have access to the look-up table (LUT) and output section.

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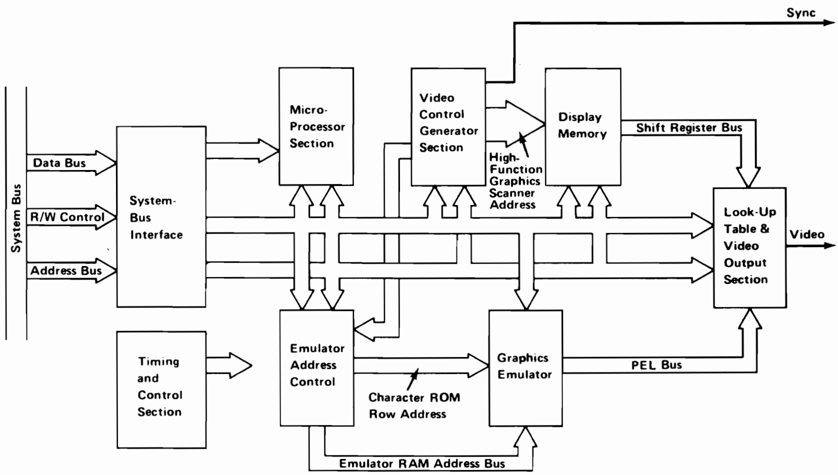
The following is a block diagram of the Professional Graphics Controller.



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Major Components

- System-Bus Interface
  - Bidirectional Buffer
  - Control Decode Logic
  - Address Decoder
- Microprocessor Section
  - 8088 Microprocessor
  - Clock Generator Control
  - Address Latch
  - Data Latch
  - Decoders
  - 2K by 8-bit RAM
  - 64K by 8-bit ROM
- Video Control Generator Section
  - Video Controller
  - Control Decoder
  - 16- by 8-bit State Length Memory
  - Synchronization Pulse Generator
  - State Multiplexer
  - Vertical and Horizontal State Counters
  - Vertical and Horizontal State Length Counters
  - Buffer
- Emulator Address Control
  - Controller
  - Cursor Generator
  - Parameter Registers
  - Character ROM Address Generator
  - Row Address Generator
  - Column Address Generator
  - Microprocessor Address Buffers
- Graphics Emulator
  - 16K by 16-bit Emulator RAM
  - Shift Registers
  - Character ROM
  - Attribute Latch
  - Emulator PEL Processing
  - Buffer

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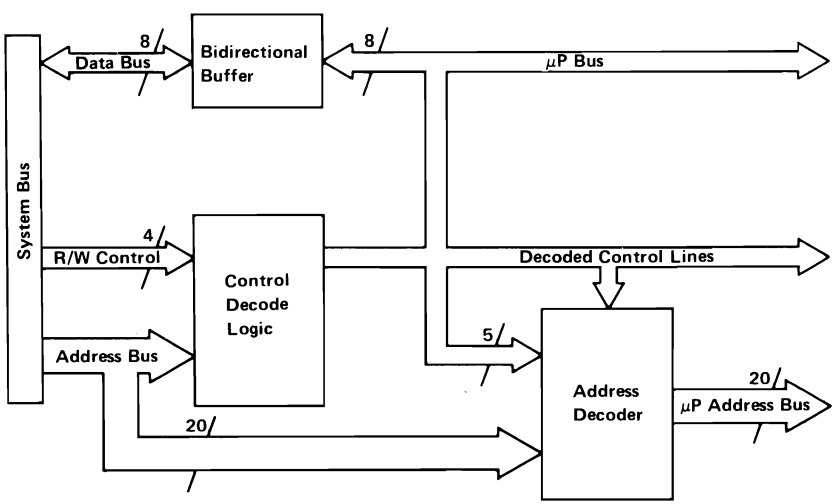
- Display Memory
  - High-Function Graphics Display Memory
    - Latch
    - Tri-State Bidirectional Driver
    - Tri-State Latch
    - 320K by 8-bit RAM
  - Display RAM Address Control
    - High-Function Graphics Scanner
    - ROM
    - Buffers
- Look-Up Table (LUT) and Video Output Section
  - Latches
  - Look-Up Table Memory
  - Buffer
  - Triple Digital-to-Analog Converter
- Timing and Control Section
  - 50-MHz Oscillator
  - High-Function Graphics Display Timing Generator
  - Control Decoder and Latches

System-Bus Interface

Following is a block diagram of the system-bus interface.



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The system-bus interface allows the system microprocessor to gain access to the display memory and emulated registers through the 'data,' 'address,' and 'control' lines. The system-bus interface can detect the attempt by the system microprocessor to execute a Memory Write command or an I/O Write command to either the emulator memory addresses or the communications memory for the high-function graphics mode.

When the interface logic detects an assigned address, a 'hold' signal is sent to the system microprocessor, which suspends the operation of the controller microprocessor until the proper time. Although the system microprocessor can gain access to the memory of the controller microprocessor (through a series of commands on the bus interface), it cannot directly access the display RAM, nor can it issue interrupts to the controller microprocessor. Likewise, the controller microprocessor cannot gain control of the system bus.

If the system microprocessor writes to a register of the emulated 6845 CRT Controller, the data is stored in the controller's local RAM.

The controller operates by mapping both the I/O addresses and the addressed memory into its own memory. It then reads these locations, interprets the data, and programs the hardware to imitate the IBM Color/Graphics Monitor Adapter. If high-function graphics commands are written to the communication area, the controller microprocessor interprets those commands and writes to the display memory for screen display.

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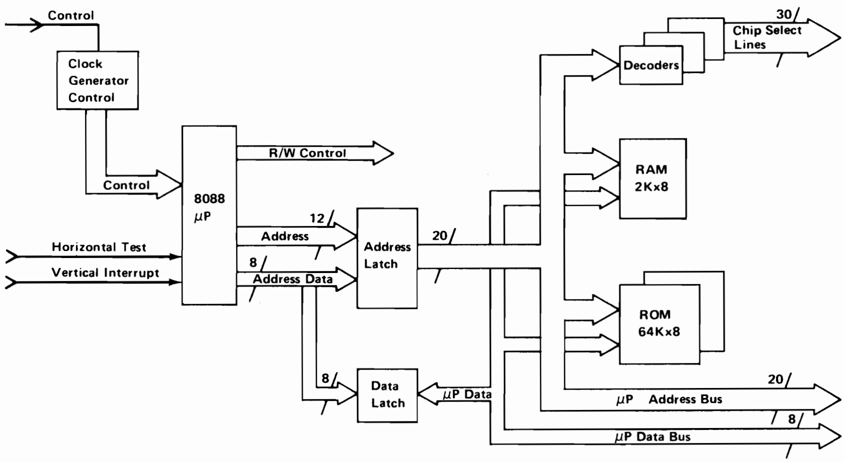
Microprocessor Section

Following is a block diagram of the microprocessor section



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The microprocessor section is a standard 8088 Microprocessor arrangement. A 'timing control' line's input leads into a clock generator control. The control signal emitted from the clock generator provides the clock frequency that drives the 8088 Microprocessor. Address and data latches store the signals sent over the address and data busses. Both the address and data lines use two 32K by 8-bit ROMs and a single 2K by 8-bit static RAM. The decoders control chip-select and latch registers.

A single, maskable interrupt occurs from the 'vertical interrupt' line. The test pin of the microprocessor samples the horizontal-synchronization pulse.

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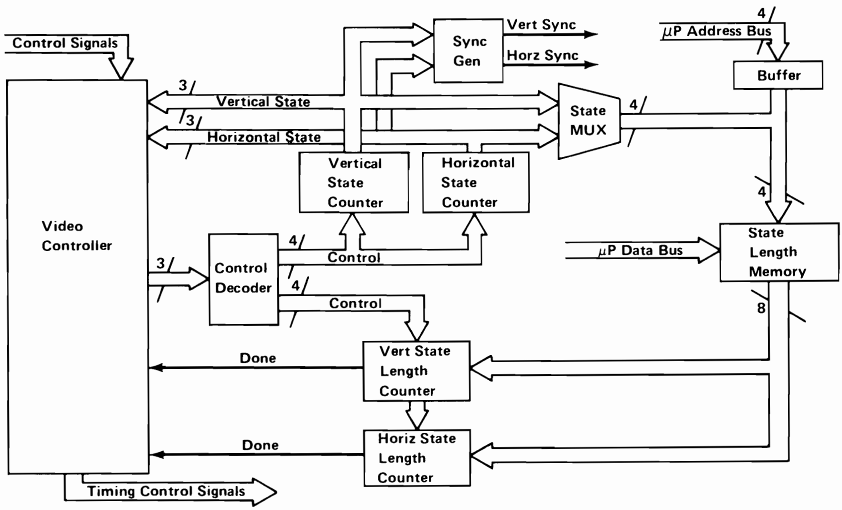
Video Control Generator Section

Following is a block diagram of the video control generator section.



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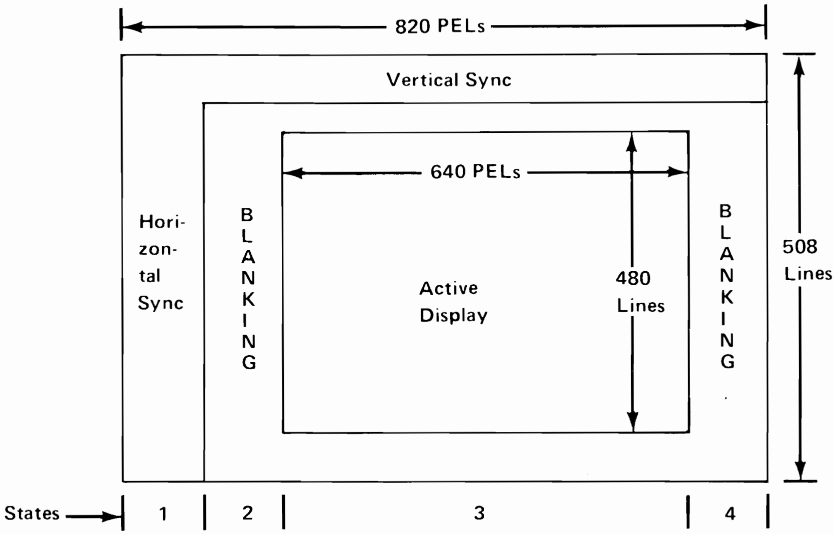
The video controller monitors and sequences the video control generator section. The main loop of the control generator controls the format of the display screen. A display screen is divided into four states, as shown in the following.



The state length memory is a part of the video control generator section. The contents of the state length memory provide the data to the state length counters, which then determine how long each state remains active. For each scan line, the state length memory loads this data, one at a time, into the horizontal state length counter. At the end of the count, the counter signals 'done' to the video controller, which then sets the control lines or particular stages of each state and sends the control information into the horizontal state counter. The video controller determines whether to start again at zero for some state, or to increment the state counter and begin on the next state. The horizontal state counter counts the number of states across the screen. From the state counter, the synchronization pulse generator determines the vertical- or horizontal-synchronization pulse and activates the appropriate line.

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This same loop occurs for vertical states. The video controller monitors the current vertical and horizontal states through the state counters and synchronization pulse generator.

The controller microprocessor can write directly to the state length memory to vary the size of each state on the screen. State lengths remain under program control.

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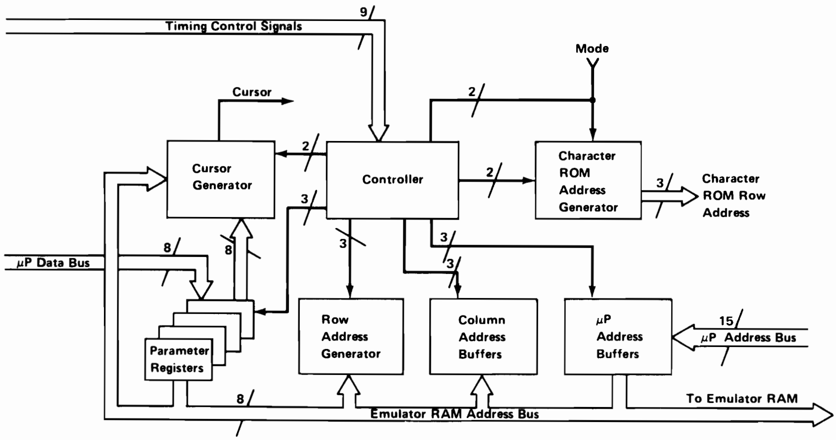
Emulator Address Control

Following is a block diagram of the emulator address control.



For the emulator mode, the address control consists of two generators—a row address generator and a column address generator. Both are driven by a controller and produce the addresses needed for the emulator RAM.

The controller microprocessor can access the address bus to program the address generators using an address buffer, and can program the four parameter registers. The cursor generator compares the addresses saved in the address generator with those saved in the parameter registers. If a match is found, the cursor generator activates the 'cursor' line.

The character ROM address generator produces a character ROM row address that defines which line to write using a font with 8 by 16 character cells.

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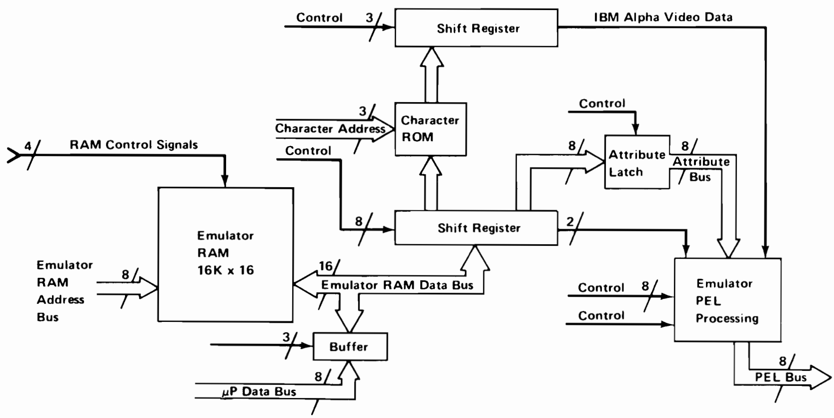
Graphics Emulator

Following is a block diagram of the graphics emulator.



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The emulator RAM address bus sends signals to the 16K by 16-bit emulator RAM. The 16-bit-wide RAM allows the character and its attributes to be read simultaneously. The RAM shifts this information into a register that also acts as a latch. During the alphanumeric mode, this information travels through an attribute latch and the character ROM. The character ROM checks the shift in the look-up table (LUT) before passing the information through another shift register.

The attributes determine the foreground and background colors of the character. The picture element (PEL) processor then shifts this information out onto the PEL bus.

During the 320-by-200 and 640-by-200 modes, the emulator RAM shifts out the information 16 bits at a time. The shift register then shifts out its signals two bits at a time into the PEL processor. The 640-by-200 mode uses these two bits alternately as either black or white values. The 320-by-200 mode uses the same two bits to determine the color placed on the screen.

The system microprocessor can read and write directly into the emulator RAM space using the CPU address bus.

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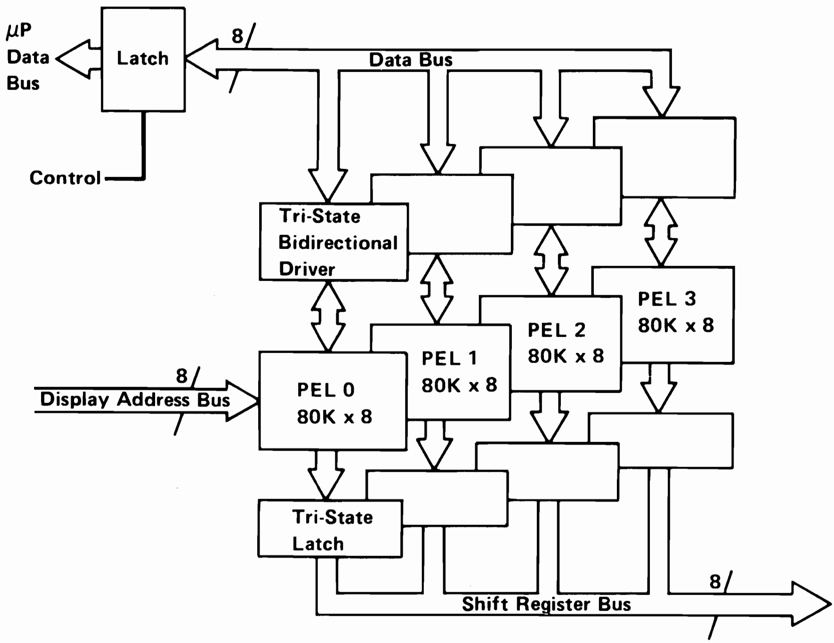
Display Memory

The display memory block consists of the high-function graphics display memory and the display RAM address control.

High-Function Graphics Display Memory

Following is a block diagram of the high-function graphics display memory



The high-function graphics display memory is logically arranged as an array of 640-by-480 PELs. Each PEL represents one byte of data. The Professional Graphics Controller provides a variety of PEL write modes to improve the transfer of data to display memory.

The high-function graphics display memory consists of five, 32-bit-wide banks (32 bits equal 4 PELs). The controller microprocessor can write through the latch into the PEL memory. All information is read from each memory and displayed each

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time the picture is scanned. This process begins when the tri-state drivers latch four PELs. Each tri-state driver is enabled individually as the beam crosses the screen. After the fourth PEL appears on the screen, four new PELs become latched.

In the high-function graphics mode, the high-function graphics scanner generates addresses for a display access cycle on one of the five banks every 160 nanoseconds (ns). These cycles are staggered over an 800-ns period. Of the 32 bits of data latched from the memory, one PEL is released onto the shift register every 40 ns. The address selection generator, a field programmable logic sequencer (FPLS), interleaves microprocessor access cycles between display cycles, thus providing the possibility of access every 160 ns. This process achieves a display-memory access capacity of 32 bits every 80 ns.

During a microprocessor write operation, even in multi-PEL write modes, all data from the microprocessor is latched, so the microprocessor receives a 'ready' instantly. The FPLS cycles to the correct locations, or to all locations, depending on the mode, while the microprocessor prepares for the next access.

Another important aspect of the display memory is low power consumption. The staggered access technique reduces the RAM cycle time to as low as 400 ns, even with both the microprocessor and display at full capacity. When the display operates alone, the cycle time increases to 800 ns, minimizing RAM power consumption.

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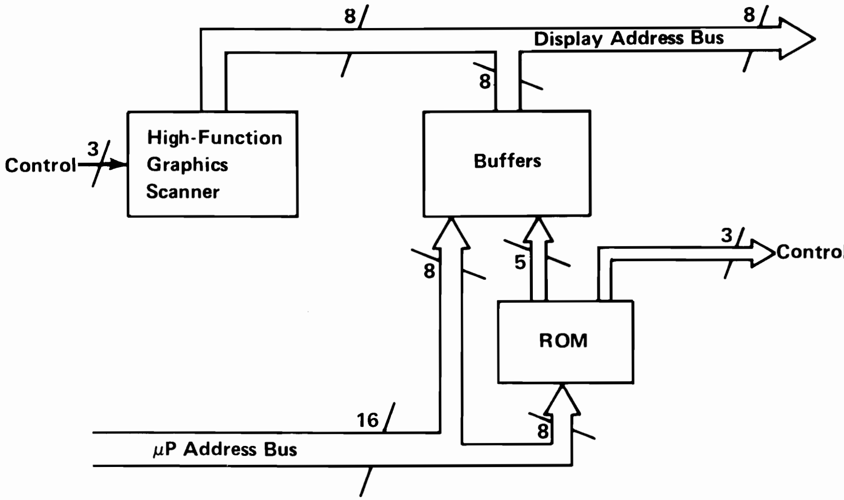
Display RAM Address Control

Following is a block diagram of the display RAM address control.



In the high-function graphics mode, the high-function graphics scanner operates as an address generator. The scanner output selects data from each of the five 32-bit-wide banks (for a total of 20 PELs written). The controller microprocessor expects memory to appear in a continuous manner; that is, 640 PELs across. The address-translator ROM is an address map of 640 adjacent memory locations. This provides the display format, thus leaving the controller microprocessor out of the conversion process.

Because this address system operates on 20-PEL boundaries, the memory for each line maps into an adjacent space of 640 locations for microprocessor access. Otherwise, if the microprocessor did the work, the very high writing speeds would be reduced.

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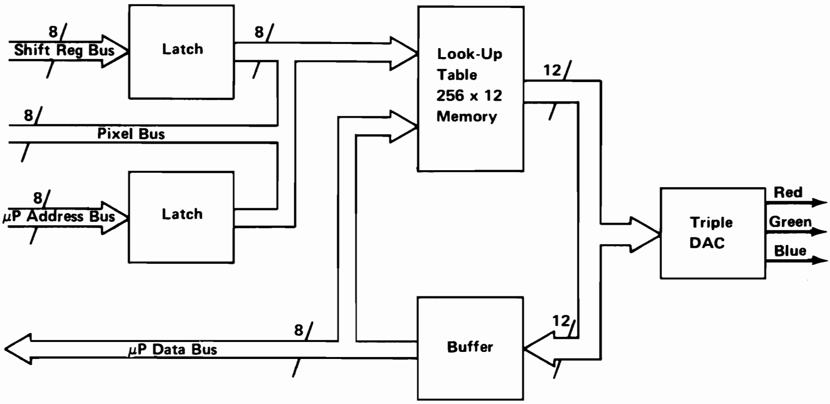
Look-Up Table and Video Output Section

Following is a block diagram of the look-up table and video output section.



Shift registers from the display memory latch onto the PEL bus leading from the emulator. Both the emulator and high-function graphics modes use the same PEL bus. The latches provide an address for data in the look-up table (LUT). The eight lines of the PEL bus provide up to 256 colors, while the 256- by 12-bit LUT in memory provides a selection from a palette of 4096 colors. The LUT generates the color sent as output. The 12 LUT output lines (4 bits each for red, green, and blue) are the inputs to a triple digital-to-analog converter (DAC), which converts the signal to red, green, and blue (RGB) intensities. The controller microprocessor can write to and read from the LUT.

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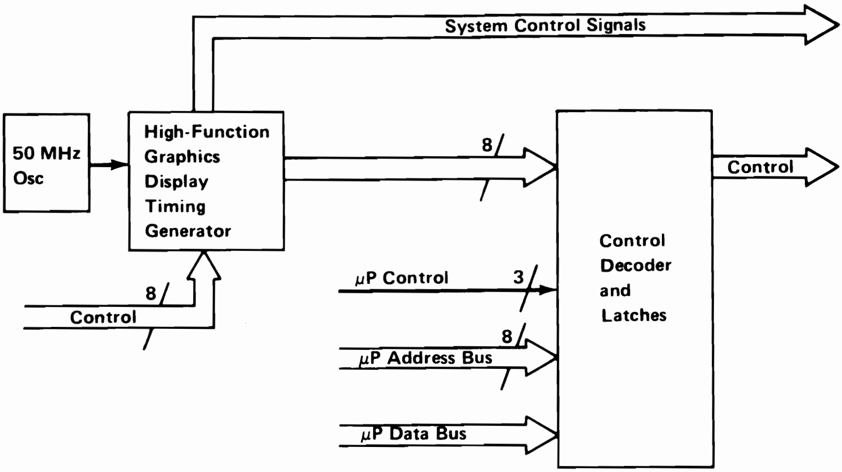
Timing and Control Section

Following is a block diagram of the timing and control section.



The high-function graphics-display timing generator, which is driven by a 50-MHz oscillator, sends control signals for memory and for the latch control from the display memory. It signals the controller microprocessor when it is ready to receive or send data from display memory. Except for system control signals, the signals from the timing generator are latched and decoded. The controller microprocessor maintains some control of the latches and decoder. The timing generator also generates clock signals to synchronize the board functions.

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Emulator Modes

To provide compatibility with the Color/Graphics Monitor Adapter protocols, the Professional Graphics Controller emulates the Color/Graphics Monitor Adapter in the alphanumeric and graphics modes.

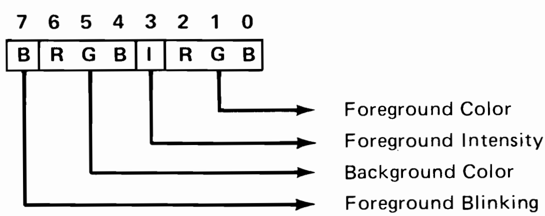
> **Note:** If a Color/Graphics Adapter is already present in the system unit, the emulator section of the Professional Graphics Controller is disabled with the enable/disable jumper.

Alphanumeric Mode

Every display-character position in the alphanumeric mode is defined by two bytes in the regen buffer, not the system memory. Both the Professional Graphics Controller and the Color/Graphics Monitor Adapter use the following 2-byte character or attribute format.

Display-Character Code Byte	Attribute Byte
7 6 5 4 3 2 1 0	7 6 5 4 3 2 1 0

The attribute byte definitions are:



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The following table provides a summary of available colors.

I	R	G	B	Color
0	0	0	0	Black
0	0	0	1	Blue
0	0	1	0	Green
0	0	1	1	Cyan
0	1	0	0	Red
0	1	0	1	Magenta
0	1	1	0	Brown
0	1	1	1	White
1	0	0	0	Gray
1	0	0	1	Light Blue
1	0	1	0	Light Green
1	0	1	1	Light Cyan
1	1	0	0	Light Red
1	1	0	1	Light Magenta
1	1	1	0	Yellow
1	1	1	1	White (High Intensity)

In the alphanumeric mode, the display mode can be operated in either a 40-by-25 mode or a 80-by-25 mode.

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40-by-25 Alphanumeric Mode

The 40-by-25 alphanumeric mode:

- Displays up to 25 rows of 40 characters each
- Has a ROM character generator that contains dot patterns for a maximum of 256 different characters
- Requires 2000 bytes of read/write memory (on the controller)
- Has a 16-high by 8-wide character box
- Has one character attribute for each character

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80-by-25 Alphanumeric Mode

The 80-by-25 alphanumeric mode:

- Supports the IBM Professional Graphics Display
- Displays up to 25 rows of 80 characters each
- Has a ROM character generator that contains dot patterns for a maximum of 256 different characters
- Requires 4000 bytes of read/write memory (on the controller)
- Has a 16-high by 8-wide character box
- Has one character attribute for each character

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Graphics Mode

The Professional Graphics Controller has two modes available with the graphics mode—the 320-by-200 color/graphics mode and 640-by-200 black-and-white graphics mode. Both are supported in ROM. The following table summarizes the two modes.

Modes	Number of Colors Available (Includes Background Color)
320 x 200	4 Colors Total 1 of 16 for Background and 1 of Green, Red, or Brown or 1 of Cyan, Magenta, or White
640 x 200	Black-and-white only

320-by-200 Color/Graphics Mode

The 320-by-200 color/graphics mode supports the Color Display. It has the following features:

- Contains a maximum of 200 rows of 320 picture elements (PELs), with each PEL being 2.4-high by 1-wide
- Preselects one of four colors for each PEL
- Requires 16,000 bytes of read/write memory (on the controller)
- Uses memory-mapped graphics

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- Formats four PELs for each byte as follows:

7 6	5 4	3 2	1 0
C1 C0	C1 C0	C1 C0	C1 C0
First	Second	Third	Fourth
Display	Display	Display	Display
PEL	PEL	PEL	PEL

- Organizes graphics storage in two banks of 8000 bytes, using the following format:

Memory Address (in hex)	**Function**
B9F3F	Even Scans (0,1,4,5,8,9. . .198) 8,000 bytes
B8000	Not Used
BA000	Odd Scans (2,3,6,7,10,11. . .199) 8,000 bytes
BBF3F	Not Used
BBFFF	

Address hex B8000 contains PEL information for the upper-left corner of the display.

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- Determines color selection by the following logic:

C1	C0	Function
0	0	Dot takes on the color of 1 of 16 preselected background colors
0	1	Selects first color of preselected Color Set 1 or Color Set 2
1	0	Selects second color of preslelcted Color Set 1 or Color Set 2
1	1	Selects third color of preselected Color Set 1 or Color Set 2

C1 and C0 select 4 to 16 preselected colors. This color selection (palette) is preloaded in an I/O port.

The two color sets are:

Color Set 1	Color Set 2
Color 1 is green	Color 1 is cyan
Color 2 is red	Color 2 is magenta
Color 3 is brown	Color 3 is white

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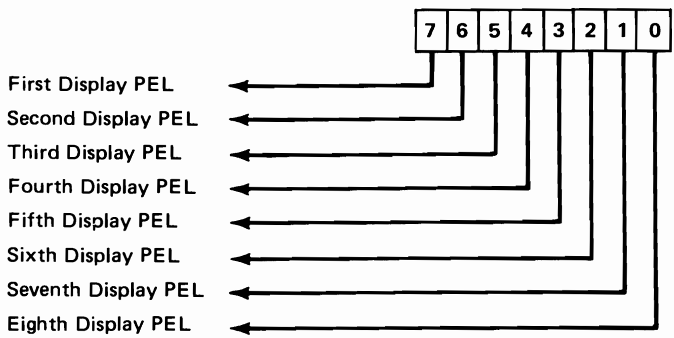
640-by-200 Black-and-White Graphics Mode

The 640-by-200 black-and-white graphics mode supports color monitors. This mode:

- Contains a maximum of 200 rows of 640 PELs, with each PEL being 1-high by 1-wide.
- Supports black-and-white mode only.
- Requires 16,000 bytes of read/write memory (on the controller).
- Uses the same addressing and mapping procedures as the 320-by-200 color/graphics mode, but the data format is different. In this mode, each bit in memory is mapped to a PEL on the screen.
- Formats eight PELs per byte as follows:



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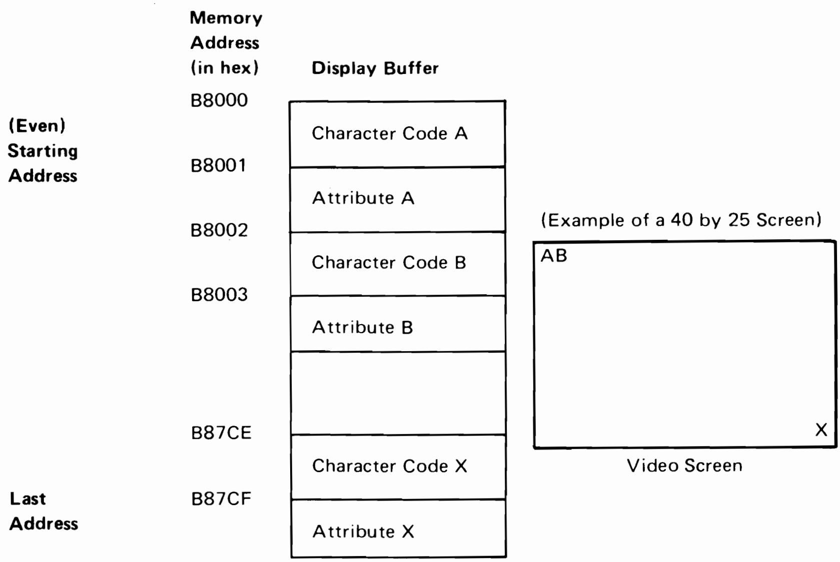
Description of Basic Operations

In the alphanumeric mode, the controller fetches character and attribute information from its display buffer. The starting address of the display buffer is programmable through the 8088 Microprocessor, but it must be an even address. The character codes and attributes are then displayed according to their relative positions in the buffer as shown in the following.



The processor and display control unit have equal access to the display buffer during all operating modes except the 640-by-200 alphanumeric mode. During this mode, the processor should have access to the display buffer during the vertical retrace time. If it does not, the display will be affected with random patterns as the processor is using the display buffer. In the alphanumeric mode, the characters are displayed from a prestored ROM character generator that contains the dot patterns of all the displayable characters.

In the graphics mode, the displayed dots and colors (up to 16K bytes) are also fetched from the display buffer.

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High-Function Graphics Mode

The Professional Graphics Controller provides high function graphics capability for the PC by processing simple command strings into bit-mapped images in the controller. The Professional Graphics Controller provides both alphanumeric and graphic capabilities.

Alphanumeric Operation

The alphanumeric operation:

- Contains a built-in character font with character enlargement capabilities.
- Uses a smoothing function for enlarged characters.
- Permits characters to be drawn in a foreground color with a transparent background; therefore, whatever is behind the character remains there.
- Contains programmable character fonts accessible through the high-function graphics command set.

  Note: The programmable character sets cannot be enlarged.

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Graphics Operation

The high-function graphics mode supports the Professional Graphics Display. It has the following features:

- Contains 480 rows of 640 PELs; the PELs are spaced the same distance vertically and horizontally providing the standard 4:3 screen aspect ratio.
- The color of each PEL is selected from a set of 256 colors, which are selected from a palette of 4096 colors.
- Requires 307,200 bytes of read/write memory (on the controller).

  Note: This memory is addressable only through the high-function graphics commands and does not occupy system address space.

- Uses memory-mapped graphics.
- Formats one PEL for each byte.
- Organizes a communications area consisting of a bank of 1000 bytes.

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- Color selection is determined by the following logic:

  The display RAM supplies an 8-bit byte that is used as an address to the LUT. This 8-bit address selects one of 256 12-bit words from the LUT. This data provides the color information for each PEL to be sent to the screen. The 12-bit word is divided into three groups of 4-bits: 4 red, 4 green, and 4 blue, as shown in the following table.

4 Bits	4 Bits	4 Bits
Red	Green	Blue
1 PEL		
1 Byte		

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Description of Basic Operations

The controller microprocessor interprets high-function graphics commands and translates them into data that is stored in the display memory. The display memory is then scanned 60 times each second. Each byte is then sent to the LUT. Whatever data is in memory is used as an address to the LUT data to determine what is sent to the screen.

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Programming Considerations

The Professional Graphics Controller provides the operation of two individual adapters: (1) the Color/Graphics Monitor Adapter and (2) the High-Function Graphics Adapter. The emulation operation and the high-function graphics operation may be individually programmed. High-function graphics commands determine which of the two operations appears on the screen.

Emulator Programming Considerations

The Professional Graphics Controller emulates the 6845 CRT Controller of the Color/Graphics Monitor Adapter.

Programming the 6845 CRT Controller

The CRT Controller has 19 accessible internal registers, which are used to define and control a raster-scan CRT display. One of these registers, the index register, is actually used as a pointer to the other 18 registers. It is a write-only register, and is loaded from the processor by executing an Out instruction to I/O address hex 3D4. The five least-significant bits of the I/O bus are loaded into the index register.

To load any of the other 18 registers, the index register is first loaded with the necessary pointer; then the data register is loaded with the information to be placed in the selected register. The data register is loaded from the processor by an Out instruction to I/O address hex 3D5.

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The following table defines the values that must be loaded into the 6845 CRT Controller registers to control the different modes of operation supported by the controller.

Address Register	Register Number	Register Type	Units	I/O	40 by 25 Alpha-numeric	80 by 25 Alpha-numeric	Graphic Modes
4	R4	Vertical Total	Character Row	Write Only	1F	1F	1F
5	R5	Vertical Total Adjust	Scan Line	Write Only	06	06	06
6	R6	Vertical Displayed	Character Row	Write Only	19	19	19
7	R7	Vertical Sync Position	Character Row	Write Only	1C	1C	1C
A	R10	Cursor Start	Scan Line	Write Only	06	06	06
B	R11	Cursor End	Scan Line	Write Only	07	07	07
C	R12	Start Address(H)	-	Write Only	00	00	00
D	R13	Start Address(L)	-	Write Only	00	00	00
E	R14	Cursor Address(H)	-	Read/ Write	XX	XX	XX
F	R15	Cursor Address(L)	-	Read/ Write	XX	XX	XX
Note: All register values are in hexadecimal							

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Programming the Mode Control and Status Registers

The following shows the I/O registers of the Professional Graphics Controller.

Function of Register	Hex Address	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0
Mode Control Register (DO)	3D8	1	1	1	1	0	1	1	0	0	0
Color Select Register (DO)	3D9	1	1	1	1	0	1	1	0	0	1
Status Register (D1)	3DA	1	1	1	1	0	1	1	0	1	0
6845 Index Register	3D4	1	1	1	1	0	1	0	1	0	0
6845 Data Register	3D5	1	1	1	1	0	1	0	1	0	1

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Color-Select Register

This is a 6-bit, output-only register (cannot be read). Its I/O address is hex 3D9, and it can be written to by using the 8088 Microprocessor's I/O Out command. Following is a description of the bits of the color-select register.

Bit 0	Selects B (blue) background color in 320 x 200 graphics mode Selects B (blue) foreground color in 640 x 200 graphics mode
Bit 1	Selects G (green) background color in 320 x 200 graphics mode Selects G (green) foreground color in 640 x 200 graphics mode
Bit 2	Selects R (red) background color in 320 x 200 graphics mode Selects R (red) foreground color in 640 x 200 graphics mode
Bit 3	Selects I (intensified) background color in 320 x 200 graphics mode Selects I (intensified) foreground color in 640 x 200 graphics mode
Bit 4	Selects alternate, intensified set of colors in graphics mode
Bit 5	Selects active color set in graphics mode
Bit 6	Not used
Bit 7	Not used

Bits 0, 1, 2, 3 Select the foreground color in the 640-by-200 color/graphics mode, and the background color (C0 or C1) in the 320 by 200 color/graphics mode.

Bit 4 When set, selects an alternate, intensified set of colors.

Bit 5 Used in the 320 by 200 color/graphics mode to select the active set of screen colors for the display.

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When bit 5 is set to 0, colors are determined as follows:

C1	C0	Colors Selected
0	0	Background (Defined by bits 0-3 of port hex 3D9)
0	1	Green
1	0	Red
1	1	Brown

When bit 5 is set to 1, colors are determined as follows:

C1	C0	Colors Selected
0	0	Background (Defined by bits 0-3 of port hex 3D9)
0	1	Cyan
1	0	Magenta
1	1	White

When bit 5 is set to 0 and bit 2 of the mode-select register is set to 1, colors are determined as follows:

C1	C0	Colors Selected
0	0	Background
0	1	Cyan
1	0	Red
1	1	White

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Mode-Select Register

This is a 6-bit, output-only register (cannot be read). Its I/O address is hex 3D8, and it can be written to using the 8088 Microprocessor's I/O Out command.

The following table is a description of the register's functions when the bit values are set to 1.

Bit 0	80 x 25 alphanumeric mode
Bit 1	Graphics select
Bit 2	Black/white select
Bit 3	Enable video signal
Bit 4	640 x 200 black/white mode
Bit 5	Change background intensity to blink bit
Bit 6	Not used
Bit 7	Not used

Bit 0 A 1 selects 80-by-25 alphanumeric mode.
A 0 selects 40-by-25 alphanumeric mode.

Bit 1 A 1 selects graphics mode.
A 0 selects alphanumeric mode.

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Bit 2 A 1 selects black-and-white mode.
A 0 selects color mode.

Bit 3 A 1 enables the video signal at certain times when modes are being changed. The video signal should be disabled when changing modes.

Bit 4 A 1 selects the 640-by-200 mode black-and-white graphics mode. One of 8 colors can be selected on direct-drive sets in this mode by using register hex 3D9.

Bit 5 When on (set to 1), this bit changes the character background intensity to the blinking attribute function for alphanumeric modes. When the high-order attribute bit is not selected, 16 background colors (or intensified colors) are available. For normal operation, this bit should be set to 1 to allow the blinking function.

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Mode-Select Register Summary

The following table shows the mode-select registers.

Bits

0	1	2	3	4	5	
0	0	1	1	0	1	40 x 25 Alphanumeric Black-and-White
0	0	0	1	0	1	40 x 25 Alphanumeric Color
1	0	1	1	0	1	80 x 25 Alphanumeric Black-and-White
1	0	0	1	0	1	80 x 25 Alphanumeric Color
0	1	1	1	0	z	320 x 200 Black-and-White Graphics
0	1	0	1	0	z	320 x 200 Color Graphics
0	1	1	1	1	z	640 x 200 Black-and-White Graphics

Enable Blink Attribute
640 x 200 Black-and-White
Enable Video Signal
Select Black-and-White Mode
Select 320 x 200 Graphics
80 x 25 Alphanumeric Select

z = Don't care condition

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Status Register

The status register is a 4-bit, read-only register. Its I/O address is hex 3DA, and it can be read using the 8088 Microprocessor's I/O In command. The following table is a description of the register functions.

Bit 0	Display Enable
Bit 1	Reserved
Bit 2	Reserved
Bit 3	Vertical Sync
Bit 4	Not Used
Bit 5	Not Used
Bit 6	Not Used
Bit 7	Not Used

Bit 0 When set to 1, indicates that access to the regen buffer memory can be made without interfering with the display.

Bit 3 When set to 1, indicates that the raster is in a vertical retrace mode. This is a good time to update the screen buffer.

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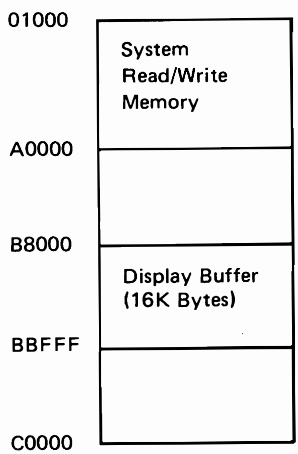
Sequence of Events for Changing Modes

1. Determine the mode of operation.
2. Reset the video enable bit in the mode-select register.
3. Program the CRT Controller to select the mode.
4. Program the mode- and color-select registers, including re-enabling video.

Memory Requirements

The memory used by this controller is provided entirely on-board. It consists of 16K bytes without parity. This memory is used as both a display buffer for alphanumeric data and as a bit map for graphics data. The regen buffer's address starts at hex B8000. The following table shows the memory requirements.

Read/Write Memory Address Space (in hex)



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High-Function Graphics Programming Considerations

The high-function graphics command set uses a wide range of two-dimensional and three-dimensional programs that include:

- Drawing primitives with points, vectors, and polygons in two and three dimensions
- Coordinate transformations with modeling (scaling, rotation, translation) and viewing transformations
- Drawing primitives with rectangles, circles, ellipses, arcs, and sectors in two dimensions
- Stored segments that define and execute command lists
- Color control functions
- Text generation

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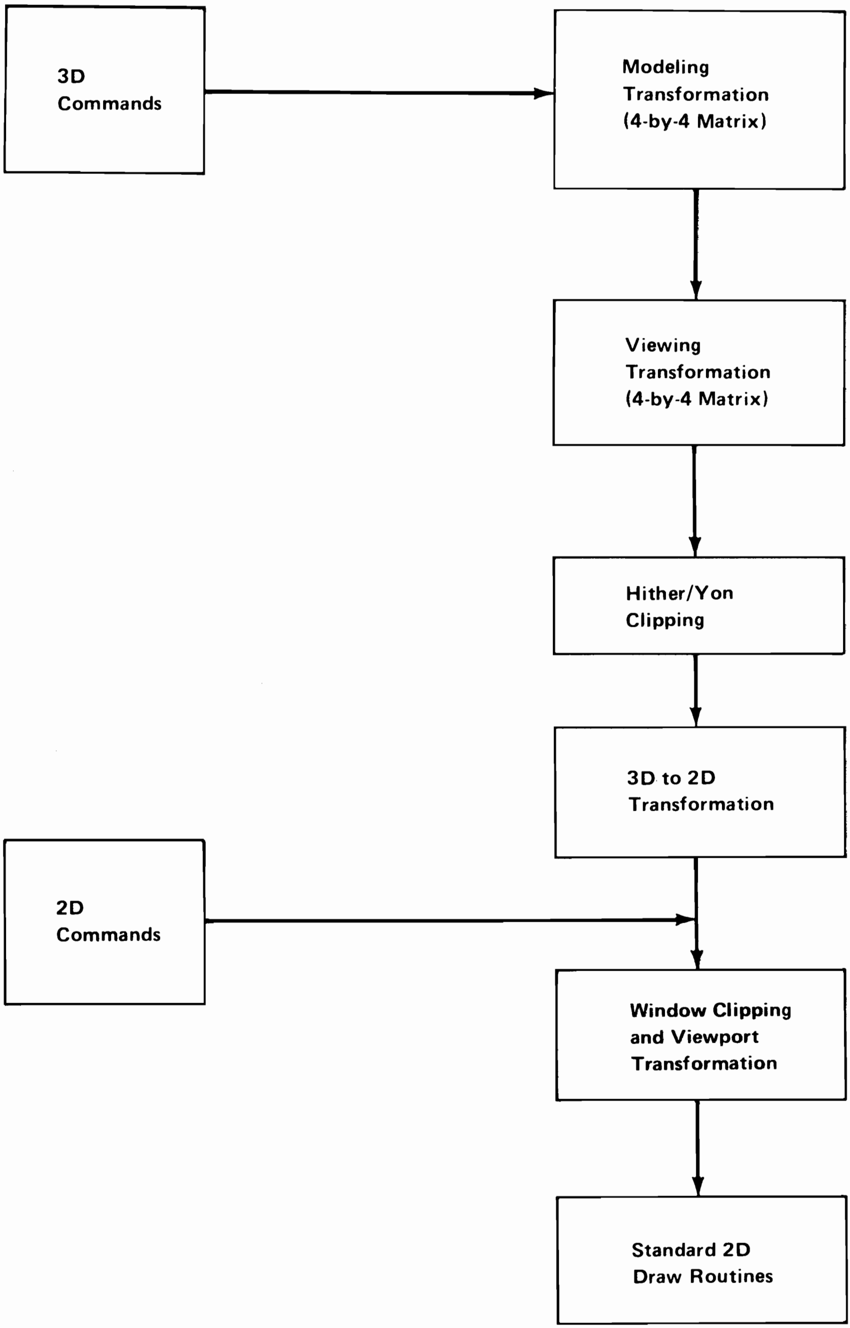
Following is a flowchart of the two- and three-dimensional commands.



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Objects may be defined in three dimensions using the three-dimensional drawing commands. A modeling matrix allows the object to be moved (translated), changed in size (scaled), and rotated. A viewing matrix allows the object to be viewed from different directions and distances.

Two clipping planes are defined at right angles to the line-of-sight. Any part of an object beyond the *yon* clipping plane and any part of an object in front of the *hither* clipping plane are not seen.

Three-dimensional objects are projected onto a two-dimensional *viewplane*, which is the plane of the monitor's screen. Two-dimensional objects are defined directly on the viewplane. Coordinates on the viewplane are referred to as *virtual* coordinates. A *window* defines that area of the viewplane that is visible. Any part of an object outside the defined window is not seen. A *viewport* specifies a rectangular area on the monitor's screen that completely contains the defined window.

Coordinate Space

Two-dimensional commands operate on a virtual coordinate space whose x and y boundaries range from -32768.00000 bits to +32767.99999 bits, with 16 bits of precision to the right of the decimal point. The display screen, however, is 640 PELs wide by 480 high. Therefore, commands are available to specify how coordinates are converted from virtual values to screen values. In addition, portions of the physical screen may be declared "off limits" to drawing. This is accomplished through the command VWPORT, which defines a rectangular clipping viewport.

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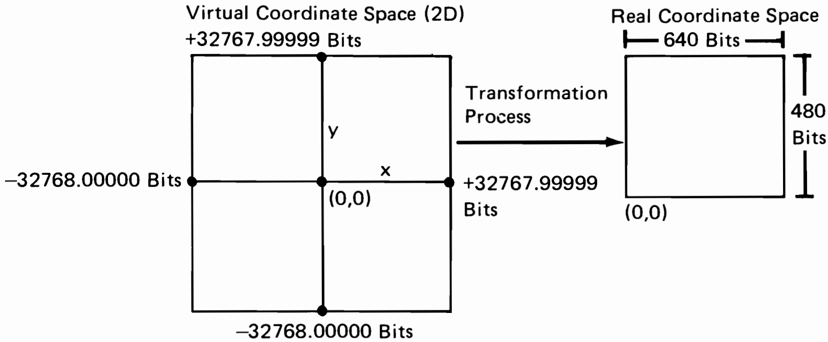
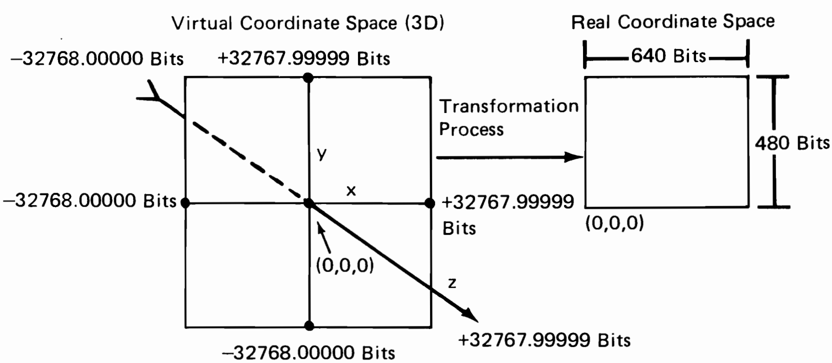
The following figure shows the relationship of two-dimensional virtual coordinate space to real coordinate space.



Three-dimensional drawing commands operate in a virtual coordinate space whose x and y boundaries range from -32768.00000 bits to +32767.99999 bits, but a z coordinate is added, which may have any value in the same range as x and y. All three-dimensional drawing may be divided into a series of points and lines; these points and lines are what are mapped onto the two-dimensional plane for actual writing to the display.

The following figure shows the relationship of three-dimensional virtual coordinate space to real coordinate space.



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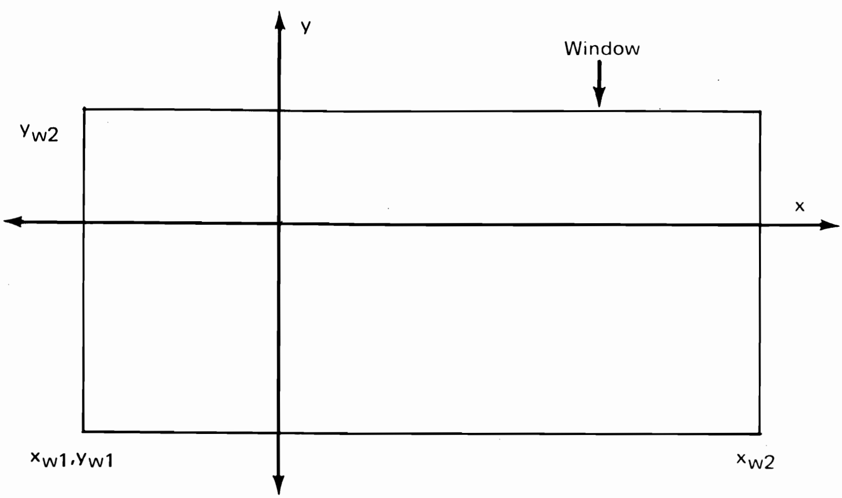
Coordinate Transformations

The high-function graphics mode refers to four coordinate systems when converting three-dimensional virtual coordinates to a screen image. The two-dimensional commands MOVE and DRAW undergo a single transformation.

Two-Dimensional Transformation

The lowest level of transformation occurs following the two-dimensional command MOVE or DRAW. These commands use parameters given in two-dimensional virtual coordinates. The high-function graphics mode converts these points to screen coordinates. To understand this conversion, keep in mind that the window in two-dimensional virtual space maps onto the viewport of the screen.

The WINDOW command defines an area (window) in two-dimensional virtual space to be mapped into a defined viewport with x and y virtual coordinate values, as follows:



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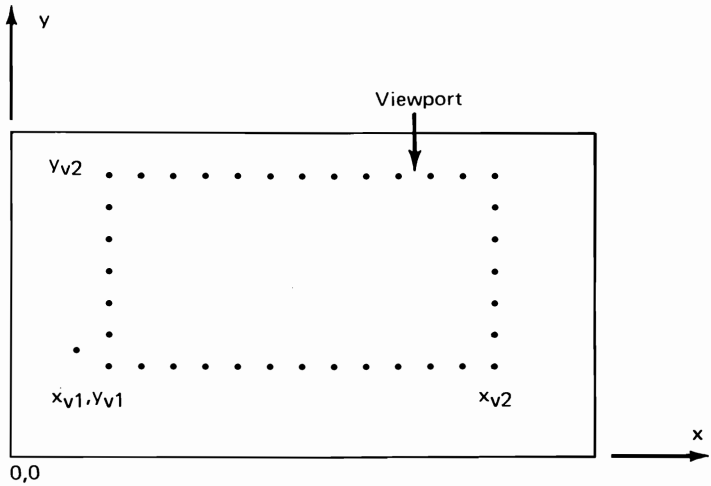
The x and y values may range from -32768.00000 to +32767.99999. The VWPORT command defines an area (viewport) within the display screen with x and y screen coordinate values, as shown in the following.



The x values range from 0 to 639, and the y values from 0 to 479. The two-dimensional command uses virtual coordinates; that is, X2dvir and Y2dvir. The high-function graphics mode converts these to screen coordinates, Xscrn and Yscrn, using the following equations.

$$Xscrn = (X2dvir - Xw1) \times \frac{(Xv2 - Xv1)}{(Xw2 - Xw1)} + Xv1$$

$$Yscrn = (Y2dvir - Yw1) \times \frac{(Yv2 - Yv1)}{(Yw2 - Yw1)} + Yv1$$

The X2dvir, Y2dvir are two-dimensional virtual coordinates. The variables Xw1, Xw2, Yw1, and Yw2 are window coordinates, and Xv1, Xv2, Yv1, and Yv2 are viewport coordinates.

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Three-Dimensional Transformation

Three-dimensional transformations involve converting three-dimensional points to two dimensions. This process uses the following matrix operation for the conversion; that is three-dimensional world coordinates to three-dimensional viewing coordinates:

```
[Xview, Yview, Zview, 1 ] =
[Xvirtual, Yvirtual, Zvirtual, 1] x [M] x [VRP] x [V]
```

[M] represents the modeling matrix, [VRP] represents the view reference point matrix, and [V] denotes the viewing matrix. The three-dimensional viewing coordinates can be read back using the command FLAGRD 24. The last value of the viewing matrix remains 1 only if the last columns of all matrixes entered in this formula have the following form.

$$\begin{vmatrix} X & X & X & 0 \\ X & X & X & 0 \\ X & X & X & 0 \\ X & X & X & 1 \end{vmatrix}$$

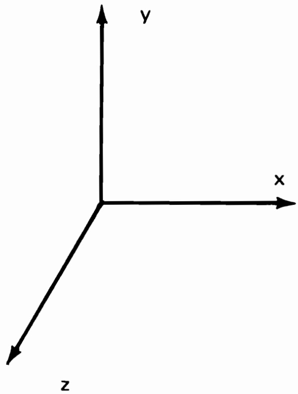
Otherwise, the result will have the form:

```
[Xview, Yview, Zview, Q]
```

To reduce this result to the form required, simply divide the X, Y, and Z values by the value Q. This operation gives a 1 as the final column value of the matrix, and proper values for the other three parameters.

The Modeling Matrix

The modeling matrix, [M], rotates, translates, and scales the coordinate values of an object defined in three-dimensional virtual coordinates. Rotation about any axis uses the right-hand rule. To understand this principle, refer to the coordinate space depicted below (the positive z direction comes out of the page).



To rotate in a positive direction around the y axis, the positive z axis rotates toward the positive x axis. To rotate in a positive direction around the x axis, the positive y axis rotates toward the positive z axis. To rotate in a positive direction around the z axis, the positive x axis rotates toward the positive y axis.

Keep in mind that the order of rotation changes the viewing faces of the object. That is, an object rotated along the x axis, then the y axis, gives a different perspective than if the same object is rotated first along the y axis, then the x axis.

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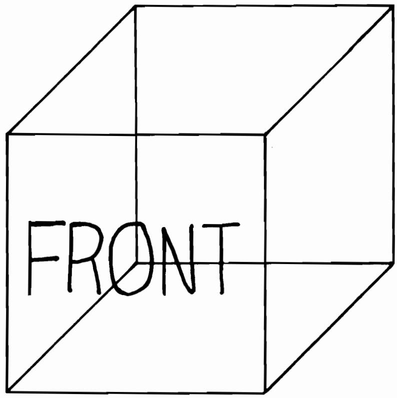
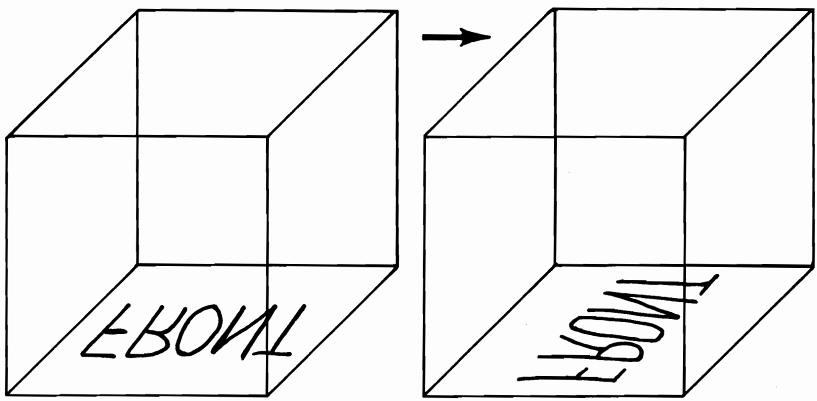
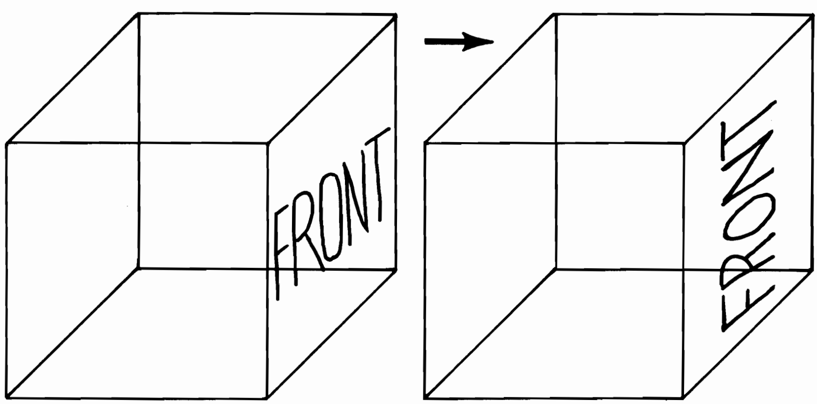
The following illustration depicts various viewing perspectives.



Original



MDROTX 90 ... then ... MDROTY 90



MDROTY 90 ... then ... MDROTX 90

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Rotation involves the matrix operation,

```
[M(new)] = [M(old)] x [M(rst)]
```

[M(rst)] represents the rotation, scaling, or translation matrix. For rotation, this matrix differs with each axis chosen as the axis of rotation. For each direction of rotation, the algorithm refers to the appropriate matrix as follows:

$$R_x(\theta) = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

$$R_y(\theta) \begin{vmatrix} \cos\theta & 0 & -\sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

$$R_z(\theta) = \begin{vmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

The scaling operation uses the following matrix.

$$S = \begin{vmatrix} x_s & 0 & 0 & 0 \\ 0 & y_s & 0 & 0 \\ 0 & 0 & z_s & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

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The translation operation uses the following matrix.

$$T = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ x_t & y_t & z_t & 1 \end{vmatrix}$$

Viewer Reference-Point Matrix

The viewer reference-point matrix, [VRP], translates the point viewed by the user to the center of the currently defined window. Because the window coordinates map onto the viewport coordinates, this matrix also places the user-viewed point at the center of the viewport.

The viewing matrix, [V], affects the degree of rotation of the object by moving the eye about the object, while keeping the object stationary. Like the modeling matrix, the viewing matrix uses the right-hand rule for rotation of the eye about the viewing reference point.

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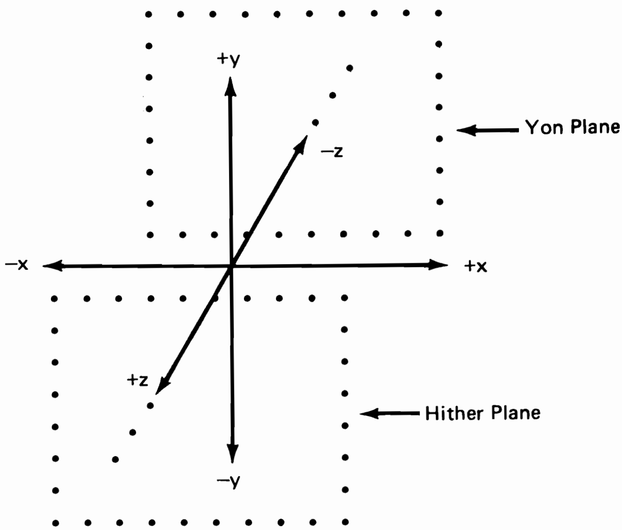
Three-Dimensional Hither and Yon Clipping

Besides two-dimensional viewport clipping, the high-function graphics mode also clips in the third dimension. The hither and yon clipping designate two x-y planes along the z axis beyond which no drawing takes place.



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Three-Dimensional Viewing to Two-Dimensional Virtual Projection

Using the DISTAN command, the user specifies the distance from the eye to the viewplane. The command PROJCT provides a viewing angle with a value ranging from 1 to 179 degrees. The high-function graphics mode projects the viewing coordinate into a two-dimensional coordinate value using the following formulas.

$$X2dvir = \frac{DISTAN}{DISTAN - Z} \times Xview \times \frac{WINDOW\ DIAGONAL}{2 \times DISTAN \times \tan\left(\frac{PROJCT}{2}\right)}$$

$$Y2dvir = \frac{DISTAN}{DISTAN - Z} \times Yview \times \frac{WINDOW\ DIAGONAL}{2 \times DISTAN \times \tan\left(\frac{PROJCT}{2}\right)}$$

Placing the object closer magnifies the X and Y values. Increasing the viewing angle increases the amount of picture visible in the viewing field.

If the PROJCT angle is 0, the projection is orthographic parallel (non-oblique), The high-function graphics mode projects the viewing coordinate into a two-dimensional coordinate value using the following formulas:

$$X2dvir = Xview$$

$$Y2dvir = Yview$$

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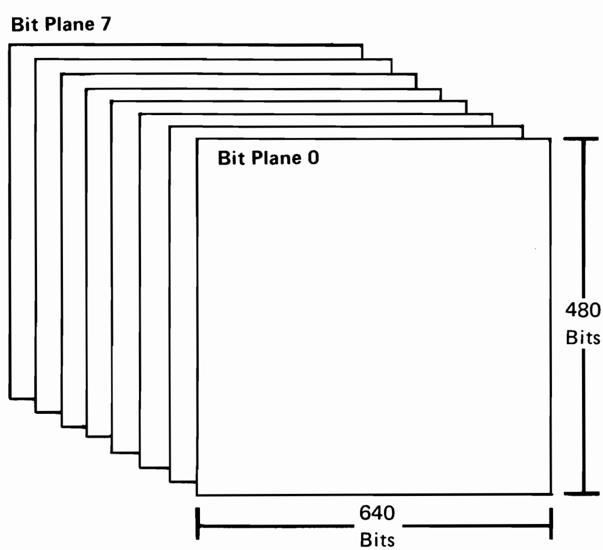
Video Generation

A total of 256 colors may be displayed on the screen at one time. A total of 4096 possible color selections is available to the LUTs. The video generation process begins when the video scanner reads the value of the PEL about to be displayed. The PEL value consists of eight bits and is used as an address to the LUT. The PEL value selects one of 256 12-bit entries in the table. The three 4-bit output values from the LUT represent the red, green, and blue intensities required to compose the target PEL. Because the table outputs are 4 bits each for the three colors, the 256 simultaneous colors may be chosen from a 4096-color palette. The LUTINT command sets the entire look-up table from one of several predefined LUT selections. The LUT command loads individual LUT entries, and LUTRD reads them back.

Each bit of each PEL resides in one of eight bit planes in the display memory. The bit planes are masked for reading and writing. These bit planes are shown in the following.



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Current Point

The *current point* is the x-y-z coordinate point at which the last command finished. Many high-function graphics commands use a current point in carrying out their functions. Two current points are maintained; one is used by two-dimensional commands, the other by three-dimensional commands. For example, the two-dimensional command CIRCLE draws a circle centered on the two-dimensional current point; the three-dimensional command DRAW3 draws a vector that starts at the three-dimensional current point. The current points are moved whenever move and draw commands are executed. When referred to in the command descriptions, the applicable current point will be identified, unless it is clear from the context of the command.

The command CONVRT will change a three-dimensional current point to a two-dimensional virtual coordinate. This conversion allows the user to overdraw a three-dimensional drawing with two-dimensional commands, such as text.

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Current Color

The *current color* is the last color a COLOR command defines for general drawing. Drawing is possible in two modes—the complement drawing mode and the replace drawing mode. In the complement drawing mode, the PEL bit value in display RAM is complemented from its current value. In the replace drawing mode, the PEL bit value in display RAM is changed to a specified value. The value comes from the current color, which is set by using the COLOR command.

> **Note:** In both cases, the actual value written into a PEL may be affected by a mask.

Display Control

Display control commands set or reset flags or define commonly used parameters. All these commands affect the way that later commands draw to the screen.

Drawing Modes

The high-function graphics mode provides several drawing modes. It has its own language. The Professional Graphics Controller also imitates two current graphics modes resident in the existing PC graphics systems. The Professional Graphics Controller will accept and execute all commands sent to either mode. To view the current status of commands sent to a particular mode, use the DISPLA command, indicating the appropriate mode as the parameter. This command simply switches between the high-function graphics screen and the emulator screen. All previous drawing sent to either screen remains intact during these switches, because Draw commands are independent of the viewing status; that is, high-function graphics commands affect the high-function graphics screen even while the emulator screen is displayed.

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Primitive Fills and Drawing Patterns

The command PRMFIL sets an on/off flag to fill the commands that draw defined geometric shapes and create an enclosed area. Each command description will note the effects of any flags.

The user can change the drawing pattern by using Pattern commands. The command LINPAT governs any vector or other command drawing a geometric shape (with PRMFIL off). The parameter, a 16-bit number, acts as a mask during drawing. Each bit sets an on/off pattern for a corresponding PEL on the screen. This pattern repeats every 16 PELs. A 1 in any bit position draws a PEL, while a 0 changes nothing. The value 65535 produces a solid line.

Similarly, the command AREAPT establishes a drawing pattern for an area using a 16-bit by 16-bit format. This command repeats in blocks of 16-by-16 PELs, duplicating the pattern in both a horizontal and vertical direction. To define a pattern, enter sixteen 16-bit words, visualizing their orientation on a grid. For example:

Word Order	Pattern	Bit Number
F	`XXXX  XXXX  XXXX`	62415
E	` XXXX  XXXX  XXX`	31207
D	`  XXXX  XXXX  XX`	15603
C	`X  XXXX  XXXX  X`	40569
B	`XX  XXXX  XXXX  `	53057
A	`XXX  XXXX  XXXX `	59294
9	`XXXX  XXXX  XXXX`	62415
8	` XXXX  XXXX  XXX`	31207
7	`  XXXX  XXXX  XX`	15603
6	`X  XXXX  XXXX  X`	40569
5	`XX  XXXX  XXXX  `	53057
4	`XXX  XXXX  XXXX `	59294
3	`XXXX  XXXX  XXXX`	62415
2	` XXXX  XXXX  XXX`	31207
1	`  XXXX  XXXX  XX`	15603
0	`X  XXXX  XXXX  X`	40569
	`FEDCBA9876543210`	

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Each word, then, would equal the decimal equivalent of the 16-bit number. For this example, use 40569 for word 0, 15603 for word 1, and so on. In hexadecimal mode, these same words should read 9E79 for word 0, 3CF3 for word 1, and so on.

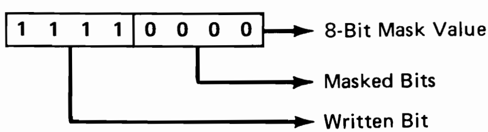
Masks

Masks act as an overlay to either reveal or overwrite the bits of a PEL. In reference to bit planes, the mask can effectively separate planes and protect certain ones. Masks affect only read and write operations but do not affect the displayed PELs.

Bit Planes

The number of bits used to define the colors of a graphics system also defines the number of bit planes. Masks control the CPU reads and writes. By using LUT entries, the user can designate which bits will actually draw to the screen. This capability effectively produces backgrounds. For example, if a mask hides the first four bits of all color values, the system draws colors using only the last four bits. Colors defined using the first four bits can be protected by suitably setting the LUTs. Switching among more than one LUT can produce animation.

The following mask writes only PELs whose color-values (indexes) are given as x0H, where x can equal 0 to F.



Color values such as 19H and B4H will write as 1xH and BxH respectively, where x leaves any previous draw untouched.

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Area Pattern Mask

The command FILMSK affects the two Area Fill commands. The 8-bit value of FILMSK is ANDed with the value of MASK and with each PEL value read in an Area Fill command. The high-function graphics mode then compares the ANDed value to the boundary color.

Clipping

The high-function graphics mode describes a clipping window and a set of clipping planes. Both the VWPORT and WINDOW command define a clipping border, for the screen and two-dimensional virtual space, respectively. The clipping window can change to include more or less of the image in two-dimensional virtual space. The viewport clipping window defines the area on the screen that is to contain the image. Redefining the coordinates of the viewport allows several clipped images to appear on the screen simultaneously.

In three-dimension, the high-function graphics mode adds hither and yon clipping capabilities. The previously defined clipping window projects forward and backward to define a clipping space. The high-function graphics mode calculates all intersecting clipping planes.

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Viewing

Viewing involves selecting a viewing distance with the command DISTAN and a viewing angle with the command PROJCT.

WAIT

The command WAIT causes the system to pause for a specified number of frame scan cycles. An imbedded Wait command will hold the drawn image on the screen for a specified amount of time before continuing with the program. The Wait command bases its timing on frame time, which equals 1/60 of a second. Use this value to calculate the actual wait period. For example, specifying 300 frame times would give a wait period of 5 seconds.

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Drawing Primitives

The term *drawing primitives* defines a group of commands that draw defined geometric shapes. The user specifies size and position with the parameters associated with each command.

Two-Dimensional and Three-Dimensional Command Format

Two-dimensional commands use no numbers within the 6-letter command. All three-dimensional commands end in the numeral 3. Coordinates for two-dimensional commands require one variable each for the x and y values; the three-dimensional commands require three coordinate values (one each for the x, y, and z direction). Not all two-dimensional Draw commands have a three-dimensional counterpart.

Move Commands

The Move commands change the current point in either the two-dimensional or three-dimensional coordinate space, one current point for each space. The commands MOVE and MOVE3 specify a change using absolute coordinate values. These commands use the virtual coordinate systems. MOVER and MOVER3 change the current point by a relative amount, adding the parameter values to the current point to produce a new coordinate value as the current point.

Point

The Point command changes the PEL at the current point to the current color.

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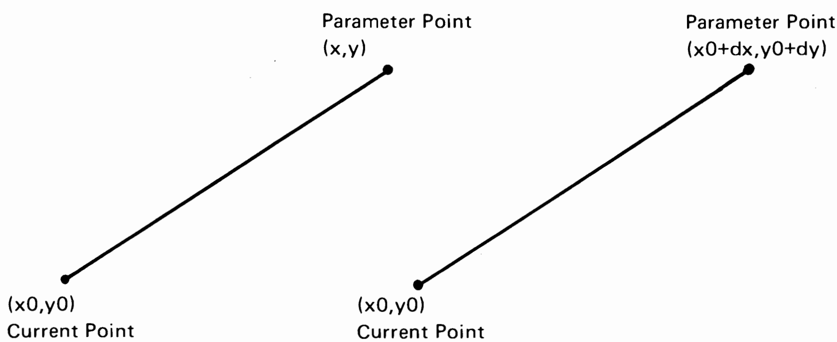
Vectors

Draw commands produce vectors (directed line segments) between two specified points. The current-point value supplies the first coordinate. The high-function graphics mode then draws a vector ending at the absolute coordinate values given in a DRAW or DRAW3 command or at the relative distance specified by the parameters of a DRAWR or a DRAWR3 commands. After a vector command, the current point shifts to the location of the last PEL drawn. The following examples show vectors.



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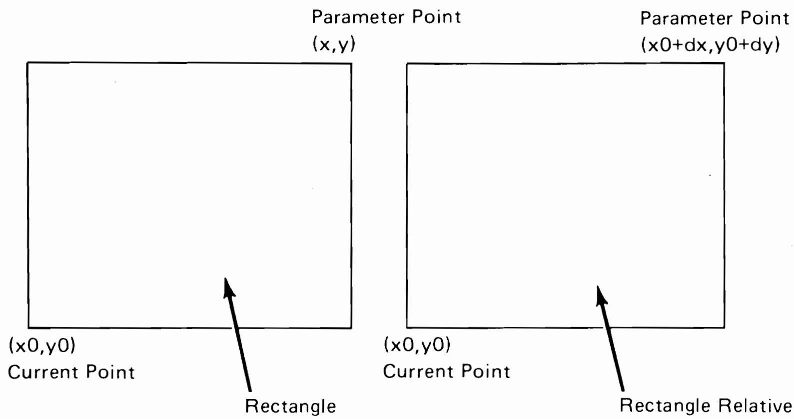
Linear Forms

The high-function graphics mode produces two closed linear forms: rectangles and polygons. Two points define a rectangle. The current point is one corner of the shape. The parameters, given in absolute values (RECT) or in a relative, offset distance (RECTR), specify the opposite corner. The current point does not change for any rectangle command. Rectangles are specified only in two dimensions. The following example shows rectangles:



Each pair of coordinates in a Polygon command declares a vertex of any multisided figure. Two pairs of coordinate values, adjacent within a command's variable string, produce a side between them. The command effectively draws multiple vectors, changing the current point to the location of the last PEL drawn. This pattern continues until a vector has been drawn to the last coordinate. The final draw of the command connects the final coordinates given to the beginning point of the polygon. The current point returns to its original value. Again this command uses either absolute or relative coordinates—POLY or POLYR for two-dimensional, and POLY3 or POLYR3 for three-dimensional. All relative coordinates are expressed relative to the original point. Keep in mind that nonplanar values in three-dimensional polygons may produce undesired effects.

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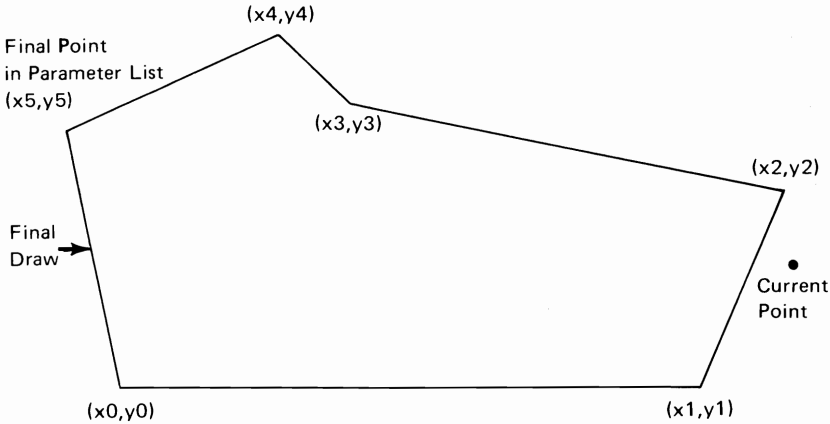
The following is an example of a polygon.



Note: The primitive fill flag in PRMFIL 1 directs the high-function graphics mode to draw any of the above rectangles or polygons as a solid (that is, all enclosed PELs are set to the current color). Undesirable effects may occur if the filled polygon intersects itself.

Nonlinear Forms

The high-function graphics mode also produces some nonlinear geometric shapes. The commands CIRCLE and ELIPSE require only radius values (both an x and y radius value for ELIPSE). The current point specifies the center of both of these figures. The parameters for the command ARC list a radius, a beginning angle value, and an ending angle value. The current point also serves as the center point of rotation for this command. The command SECTOR has the same parameter requirements as an ARC command, but produces a pie-shaped figure. That is, the end-points of the arc connect with vectors to the center point of rotation.

Except when used with the ARC command, a PRMFIL command with the fill flag set on, will instruct the commands to produce solid shapes filled with PELs of the current color. All nonlinear commands draw only in two dimensions.

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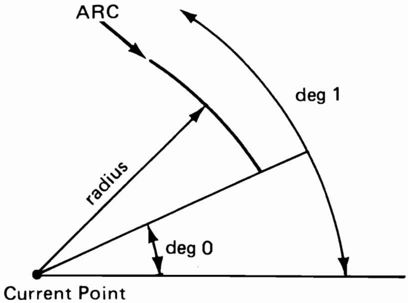
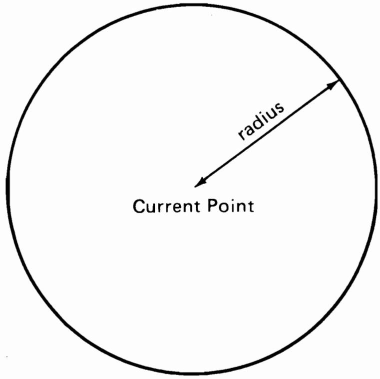
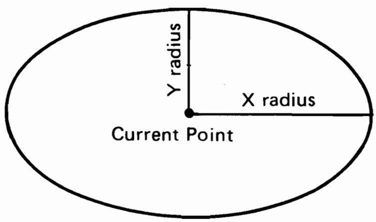
The following illustrations show examples of nonlinear forms.



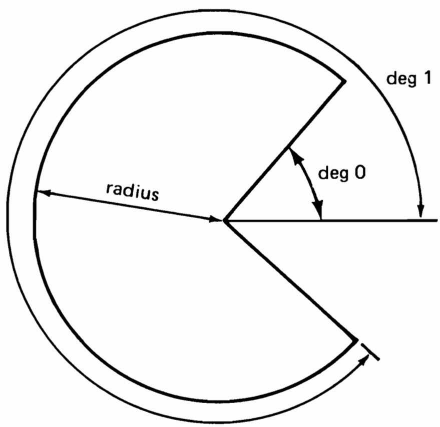
ARC deg 0 deg 1 example



CIRCLE radius example



ELIPSE x radius y radius example



SECTOR deg 0 deg 1 example

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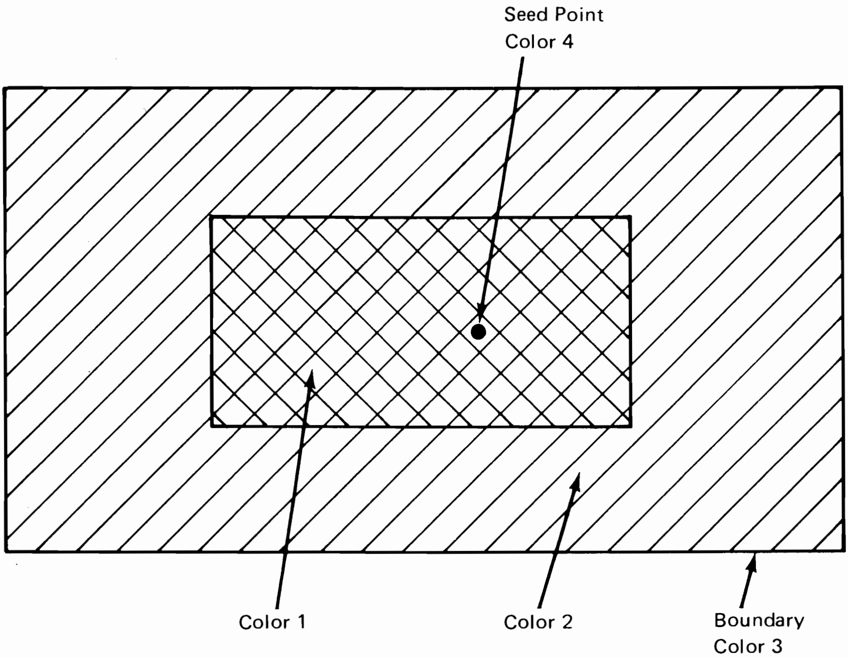
Area Fills

The Area Fill commands employ a *seed* point. Before sending an Area Fill command, place the current point within the area to be filled. The current color must differ from the color being changed. The command AREA changes PELs outward in all directions from the current (seed) point until is encountered a color different from either the one being changed or the current color. The command AREABC allows the user to specify a color to act as a boundary. This command converts PELs from the seed point outward until PELs of the same color as the specified boundary color are encountered. The current color must differ from the boundary color. The following is an Area Fill example.



In the Area Fill example, set the current color to color 4. The Area Fill will fill only the area covered by color 1. The Area Boundary Fill specified with the boundary color set to color 3 will fill the area covered by color 1 and color 2.

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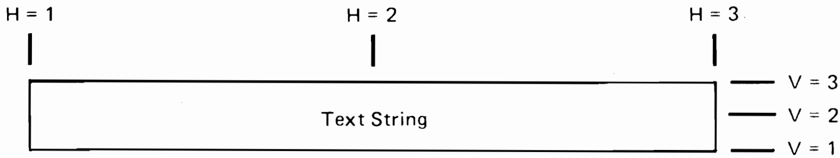
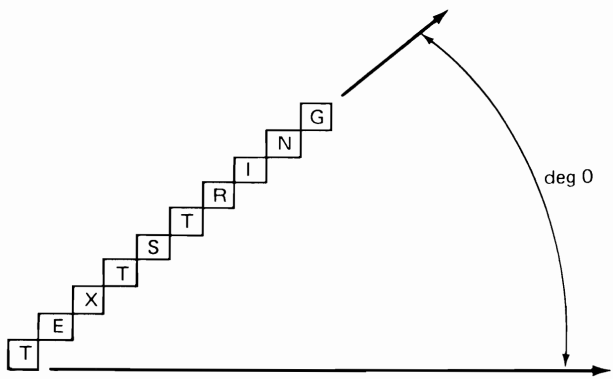
Text

Various Text commands help in placing and moving text. The two-dimensional current point acts as a placement marker. For justifying text, this point defines the horizontal and vertical placement of the text string, using the command TJUST (see the following). The default is H = 1, V = 1.



Altering the angle adjusts the slope of the centering point for each letter but not the rotation of the letter itself. The command TANGLE uses standard Cartesian coordinates to measure the angle, as shown in the following.



To adjust the text size, use the command TSIZE. The parameter of this command specifies a two-dimensional virtual x-distance. Keep in mind that the high-function graphics mode sizes letters using the mapping of the window onto the viewport. For example, a window of 320 PELs by 240 PELs mapped to a viewport of 640 PELs by 480 PELs would draw size 8 letters in a 16-PEL horizontal space. All text that exceeds the viewport

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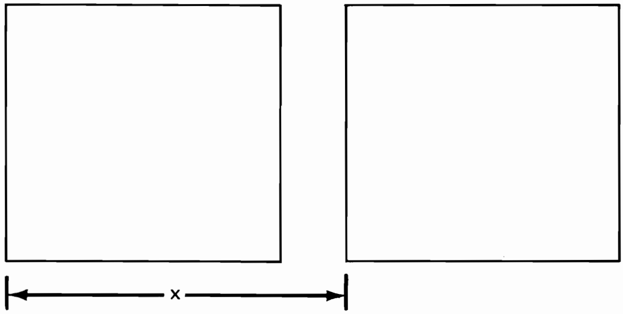
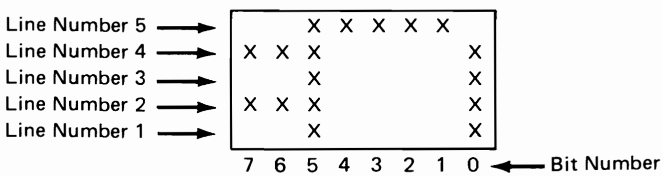
boundary undergoes clipping. The default, size 8, writes a character of 7 by 9 PELs in a cell of 8 by 12 PELs using one column for horizontal spacing between letters (see the following).



Use the commands TEXT or TEXTD to write text to the screen. TEXT uses a default text font; TEXTD uses any text defined in the command TDEFIN. This command requires a size specification followed by a bit value to describe each line of blocks. The first step is to outline an area that encompasses the character (see the following).



Then list each bit; start with the bottom, leftmost block and work to the right and up. The command for this character becomes:

TDEFIN 'x' 8 5
0 0 1 0 0 0 0 1
1 1 1 0 0 0 0 1
0 0 1 0 0 0 0 1
1 1 1 0 0 0 0 1
0 0 1 1 1 1 1 0

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Command Lists

Command lists consist of a series of valid high-function graphics commands executed by a single command. The commands CLBEG and CLEND mark the beginning and end of command lists. Two commands begin execution of command lists. CLRUN executes a single command list once; CLOOP executes a single command list a specified number of times. The commands CLDEL and CLBEG delete a command list previously defined by the specified parameter value. Space permitting, the user can define up to 256 command lists. Any command, except CLBEG, may appear within a command list definition. However, during the execution of a command list, the high-function graphics mode will not execute an imbedded CLDEL.

The following examples show valid formats for command lists.

```
CLBEG 8
   CLEARS 0
   MOVE 0 0
   PRMFIL 1
   COLOR 2
   SECTOR 100 60 359
   MOVE 10 10
   COLOR 3
   SECTOR 90 0 59
   CLEND
CLRUN 8
```

```
CLBEG 17
   CLEARS 0
   PRMFIL 1
   MOVER 10 0
   COLOR 2
   CIRCLE 5
   CLEND
CLOOP 17 5
```

Command list 8 will draw two sectors of different colors. Command list 17 will draw a small circle of radius 5. The command CLOOP repeats command list 17 five times, thus drawing five, small, tangential circles.

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The following example shows an invalid format for a command list.

```
CLBEG 23
   CLEARS 0
   CLBEG 1
      CIRCLE 25
   CLEND 2
   CLDEL 14
   CLEND
```

Command list 23 is invalid because:

- CLBEG cannot appear within a stream of command list commands.
- If the high-function graphics mode receives CLRUN 23, the execution of CLDEL command would produce an error.

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Look-Up Table

The look-up table (LUT) contains the red, green, and blue intensity information associated with each color. A value, or index, identifies each color. The high-function graphics mode provides several default LUT selections, which are accessible with the command LUTINT. The user can change values by using the command LUT or by initializing a new table. The command LUTSAV stores the current LUT values. LUTSAV overwrites any previously saved LUT values. The saved values may be selected by the command LUTINT 255. The following block diagram illustrates LUT generation.

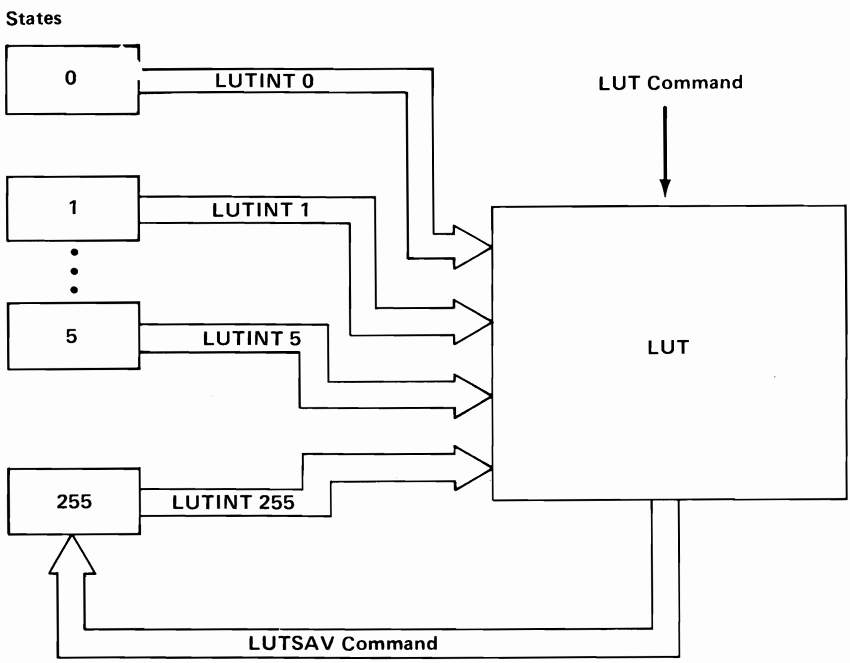

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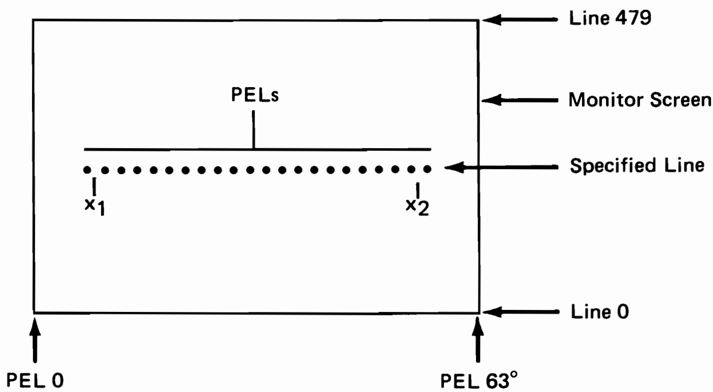
Image Processing

The high-function graphics mode uses limited image-processing techniques. The user can read or write a line of PEL data with variable endpoints. The user specifies a line number and a beginning and ending point within that line. The Image Read command (IMAGER) returns the line data formatted as an Image Write command (IMAGEW). This format makes it easier to use stored image information. The following illustrates image processing.



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Read-Back Commands

The high-function graphics mode allows the user to read various parameters from the color board back to the program. Items readable in this way include LUT entries, both three-dimensional transformation matrixes, and the line pattern and line function flags. The read-back protocol is straightforward. When the high-function graphics mode executes one of the read-back commands (for example, FLAGRD), it puts the value of the requested item in the output buffer. In ASCII mode, the value is written as a decimal number followed by a carriage-return character. A high-level language, such as BASIC, need only execute an Input statement to get the data from the color board. Some data read-back commands return more than one value. The individual commands describe the format of the return in both ASCII and hexadecimal communication modes.

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The following table lists the flags readable by FLAGRD, and the size and type of the value returned.

Flag	Name	Type of Value Returned
1	AREAPT	16 integers
2	CLIPH	1 integer (byte)
3	CLIPY	1 integer (byte)
4	COLOR	1 integer (byte)
5	DISPLA	1 integer (byte)
6	DISTAN	1 real number
7	DISTH	1 real number
8	DISTY	1 real number
9	FILMSK	1 integer (byte)
10	LINFUN	1 integer (byte)
11	LINPAT	1 integer
12	MASK	1 integer (byte)
13	MDORG	3 real numbers
14	2D current point	2 real numbers
15	3D current point	3 real numbers
16	PRMFIL	1 integer (byte)
17	PROJCT	1 integer (byte)
18	TANGLE	1 word
19	TJUST	2 integers (bytes)
20	TSIZE	1 real number
21	VWPORT	4 integers
22	VWRPT	3 real numbers
23	WINDOW	4 real numbers
24	Transformed 3D current point	3 real numbers
25	Free memory available	1 integer

The command LUTRD reads back the red, green, and blue intensity levels for a particular LUT index. To read back either the viewing matrix [V] specified in the command VWMATX, or the modeling matrix [M] specified in the command MDMATX, use the command MATXRD. This command returns a string of 16 values. These values of the 4-by-4 matrix begin at the upper-left corner and read across the rows.

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System Reset

The command RESETF resets all flags. The following table lists the default values of all flags that can be reset.

Flag	Name	Default Value	
1	AREAPT	65535 16 times	Solid area
2	CLIPH	Flag = 0	Disabled
3	CLIPY	Flag = 0	Disabled
4	COLOR	Value = 255	
5	DISPLA	No change after a RESETF	
6	DISTAN	Distance = 500	
7	DISTH	Distance = -30000	
8	DISTY	Distance = 30000	
9	FILMSK	Mask = 255	No PEL draw effect
10	LINFUN	Function = 0	Replacement mode
11	LINPAT	Pattern = 65535	Solid line
12	MASK	Mask = 255	All planes enabled
13	MDORG	OX = OY = OZ = 0	
14	2D current point	X = Y = 0	
15	3D current point	X = Y = Z = 0	
16	PRMFIL	Flag = 0	Primitive fill off
17	PROJCT	Angle = 60	
18	TANGLE	Angle = 0	Horizontal, left-right text
19	TJUST	H = V = 1	Left, bottom justification
20	TSIZE	Size = 8	12 by 8 cell characters
21	VWPORT	0, 639, 0, 479	Entire screen
22	VWRPT	X = Y = Z = 0	
23	WINDOW	-320, 319, -240, 239	
24	Transformed 3D current point	X = Y = Z = 0	

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Communications

The Professional Graphics Controller accepts high-function graphics commands in either ASCII or hexadecimal format. In ASCII mode, English-like commands and their parameters are sent to the board as ASCII character strings. This allows easy transmission of instructions from such high-level languages as BASIC. For example, to draw a circle of radius 55.05 centered at the screen center, execute a BASIC statement to transmit the following character string:

```
MOVE 0,0 CIRCLE 55.05
```

In hexadecimal communication mode, the commands are sent as a stream of bytes for greatest throughput. The statement above could be sent in hexadecimal mode as

```
10 00 00 00 00 00 00 00 00 38 37 00 CD 0C
```

to realize substantial time savings.

ASCII Communications

ASCII mode commands are sent in a format designed to accommodate the restriction of a high-level language. The ASCII command consists of a command word (no more than six letters in length) and parameters, if applicable. Every command word has a short form, which is always three characters or less in length. Parameters may be either decimal numbers or text strings enclosed in quotes.

Commands and parameters in a command line are separated by delimiters. A delimiter is one or more of the following, except when enclosed by quotation marks:

- Space
- Tab
- Comma
- Semicolon
- Hyphen
- Plus sign

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Commands and parameters consist of letters, numbers, and decimal points. Any other character, except when enclosed in quotes, is illegal and will be ignored.

When a hyphen immediately precedes a numeric parameter, that number is interpreted as negative.

Examples of Legal Commands:

```
"CI 5"                Draw a circle of radius 5.
"RECT 67-88"          Draw a rectangle.
"COLOR 2 FLOOD 3"     Change the current color to 2,
                      and flood the screen to the color 3.
"LUTRD 3"             Read LUT entry 3.
```

Examples of Illegal Commands:

```
"CIR 5"               CIR is not a valid abbreviation.
"RECT%67,-68"         "%" is not a legal character.
"COLOR 2 4 FLOOD 3"   COLOR takes only one parameter.
"LUTRD 3.4"           The parameter to the LUTRD command
                      is an integer.
```


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Communication Protocol

The high-function graphics data is sent and received as a sequential stream of bytes. To realize maximum throughput between the system and the Professional Graphics Controller, a first-in-first-out (FIFO) buffer protocol has been set up. This protocol must be adhered to for proper transmission and reception. These buffers, and their associated pointers and flags, are directly addressable when the system uses addresses in the hexadecimal range C6000 to C63FF.

There are three channels through which data may pass to and from the controller. From the system's point of view, these channels are 'output' (for sending commands and parameters), 'input' (for receiving data read-back commands), and 'error' (for receiving high-function graphics-generated error and warning codes). Each channel has a FIFO buffer associated with it and each buffer has 256 bytes reserved in the 1K-byte communication area. A portion of the remaining 256 bytes is reserved for three sets of buffer pointers—one pair for each channel—as well as the warm and cold restart and diagnostic flags. The following memory map shows the addresses as seen by the system.

Memory Address (in hex)	Function
C6000	Output FIFO (256 bytes)
C6100	Input FIFO (256 bytes)
C6200	Error FIFO (256 bytes)
C6300	Output FIFO Write Pointer
C6301	Output FIFO Read Pointer
C6302	Input FIFO Write Pointer
C6303	Input FIFO Read Pointer
C6304	Error FIFO Write Pointer
C6305	Error FIFO Read Pointer
C6306	Cold Restart Flag
C6307	Warm Restart Flag
C6308	Error Enable Flag

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Each buffer has a one-byte read pointer and a one-byte write pointer, which refer to buffer locations relative to the base of the buffer in question. The read pointer always points to the next byte to be read; the write pointer always points to the next byte to be written. The buffer is empty when the read pointer is equal to the write pointer, because the byte that would be read has not yet been written. Alternately, the buffer is full when the write pointer is one less than the read pointer.

A FIFO write must be done as follows:

1. Ensure the buffer has room by comparing the write pointer to the read pointer. If the read pointer is only one greater than the write pointer, there is no room, and no writing may take place until there is room.

2. Write one byte to the address specified by that buffer's base address plus the value in its write pointer.

3. Increment the write pointer, modulo-255.

More than one byte may be written if the buffer's write pointer is increased by the same number as the number of bytes written.

A FIFO read must be done as follows:

1. Ensure the buffer has data by comparing the write pointer to the read pointer. If the read pointer is equal to the write pointer, the buffer is empty, and no reading may take place until there is data to be read.

2. Read one byte from the address specified by that buffer's base address plus the value in its read pointer.

3. Increment the read pointer, modulo-255.

More than one byte may be read if the buffer's read pointer is increased by the same number as the number of bytes read.

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Error Handling

The high-function graphics mode provides an error-reporting capability. If the host sets the error-enable flag in the communication area, the high-function graphics mode returns errors in the error buffer. In ASCII mode, the error is returned as a message, such as "Arithmetic Overflow." In hexadecimal mode, the error is returned as a single byte code.

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High-Function Graphics Commands

The high-function graphics commands can be logically grouped into the following categories:

- Two-Dimensional Drawing
  - ARC (AR) Arc
  - CIRCLE (CI) Circle
  - DRAW (D) Draw
  - DRAWR (DR) Draw Relative
  - ELIPSE (EL) Ellipse
  - MOVE (M) Move
  - MOVER (MR) Move Relative
  - POINT (PT) Point
  - POLY (P) Polygon
  - POLYR (PR) Polygon Relative
  - RECT (R) Rectangle
  - RECTR (RR) Rectangle Relative
  - SECTOR (S) Sector
- Three-Dimensional Drawing
  - DRAW3 (D3) Draw in 3D
  - DRAWR3 (DR3) Draw Relative in 3D
  - MOVE3 (M3) Move in 3D
  - MOVER3 (MR3) Move Relative in 3D
  - POINT3 (PT3) Point in 3D
  - POLY3 (P3) Polygon in 3D
  - POLYR3 (PR3) Polygon Relative in 3D
- Modeling Transformations
  - MATXRD (MRD) Matrix Read
  - MDIDEN (MDI) Modeling Identity
  - MDMATX (MDM) Modeling Matrix
  - MDORG (MDO) Modeling Origin
  - MDROTX (MDX) Modeling Rotate X Axis
  - MDROTY (MDY) Modeling Rotate Y Axis
  - MDROTZ (MDZ) Modeling Rotate Z Axis
  - MDSCAL (MDS) Modeling Scale
  - MDTRAN (MDT) Modeling Translation
- Viewport/Window/Projection
  - CLIPH (CH) Clip Hither
  - CLIPY (CY) Clip Yon
  - CONVRT (CV) Convert
  - DISTAN (DS) Distance
  - DISTH (DH) Distance Hither

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- DISTY (DY) Distance Yon
- PROJCT (PRO) Projection
- VWIDEN (VWI) Viewing Identity
- VWMATX (VWM) Viewing Matrix
- VWPORT (VWP) Viewport
- VWROTX (VWX) Viewing Rotate X Axis
- VWROTY (VWY) Viewing Rotate Y Axis
- VWROTZ (VWZ) Viewing Rotate Z Axis
- VWRPT (VWR) Viewing Reference Point
- WINDOW (WI) Window

• Command List
  - CLBEG (CB) Command List Begin
  - CLDEL (CD) Command List Delete
  - CLEND (CE) Command List End
  - CLOOP (CL) Command List Loop
  - CLRD (CRD) Command List Read
  - CLRUN (CR) Command List Run
• Mode Set/Read
  - CA (CA) Communications ASCII
  - CX (CX) Communications Hexadecimal
  - DISPLA (DI) Display
  - FLAGRD (FRD) Flag Read
  - RESETF (RF) Reset Flags
  - WAIT (W) Wait
• Color/Fills/Patterns
  - AREA (A) Area Fill
  - AREABC (AB) Area Fill to Boundary Color
  - AREAPT (AP) Area Pattern
  - CLEARS (CLS) Clear Screen
  - COLOR (C) Color
  - FLOOD (F) Flood
  - FILMSK (FM) Fill Mask
  - LINFUN (LF) Line Function
  - LINPAT (LP) Line Pattern
  - MASK (MK) Mask
  - PRMFIL (PF) Primitive Fill
• Image Transmission
  - IMAGER (IR) Image Read
  - IMAGEW (IW) Image Write

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- Look-Up Table Operations
  - LUT (L) Look-Up Table
  - LUTINT (LI) Look-Up Table Initialize
  - LUTRD (LRD) Look-Up Table Read
  - LUTSAV (LS) Look-Up Table Save
- Text
  - TANGLE (TA) Text Angle
  - TDEFIN (TD) Text Define
  - TEXT (T) Text
  - TEXTP (TP) Text Programmed
  - TJUST (TJ) Text Justify
  - TSIZE (TS) Text Size

The high-function graphics commands appear on the following pages in alphabetic order.

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ARC (Arc)

Purpose: Draw an arc in two dimensions.

Command: ARC radius deg0 deg1

Description: ARC draws the arc of a circle in the current color. The center is at the current point. The radius is specified in the attribute radius, starting at the angle given in *deg0* and ending at the angle given in *deg1*. The angles are expressed in degrees and are measured counterclockwise from a ray that is parallel to the X axis, starting at the origin and going toward increasing X values. Radius values are real numbers and may range from -8191 to 8191. Start and end angles are treated as modulo-360. If *radius* is negative, 180 degrees are added to both angles.

Short Form: AR radius deg0 deg1

Hex Format:

3C	lowradius	highradius
	lowfracradius	highfracradius
	lowdeg0	highdeg0
	lowdeg1	highdeg1

Example:

```
ASCII: AR 50.25 45 135

HEX:   3C 32 00 00 40 2D 00 87 00
```

Errors: Radius too large

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AREA (Area Fill)

Purpose: Random area fill.

Command: AREA

Description: AREA sets all PELs in a given closed region to the current color. The region extends from the two-dimensional current point outward in all directions until reaching a boundary of PELs whose colors differ from the original color of the PEL at the current point and the current color. The region to be filled must be continuous. All data read is ANDed against the fill mask and the mask to compare colors. The original color should not be equal to the current color.

Short Form: A

Hex Format: C0

Example:

```
ASCII: A

HEX:   C0
```

Errors: None

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AREABC (Area Fill to Boundary Color)

Purpose: Random area fill to the boundary color.

Command: AREABC bcolor

Description: AREABC sets all PELs in a given closed region to the current color under mask. The region extends from the two-dimensional current point outward until reaching a boundary of PELs with the color specified by *bcolor*. *Bcolor* must be different from the current color. All data read is ANDed against the fill mask and the mask for boundary comparison.

Short form: AB bcolor

Hex Format: C1 bcolor

Example:

```
ASCII: AB 4

HEX:   C1 04
```

Errors: Boundary = current color

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AREAPT (Area Pattern)

Purpose: Define an area pattern mask.

Command: AREAPT pattern

Description: AREAPT defines the area pattern mask. The 16 pattern mask words define a 16-by-16 PEL array to be repeated horizontally and vertically when drawing filled figures. Setting all bits in the mask (sending 16 words of 65535) causes areas to be filled solidly; this is the default after a reset.

Short Form: AP pattern

Hex Format:

```
E7  lowp0  highp0  lowp1  highp1
    lowp2  highp2  lowp3  highp3
    lowp4  highp4  lowp5  highp5
    lowp6  highp6  lowp7  highp7
    lowp8  highp8  lowp9  highp9
    lowp10 highp10 lowp11 highp11

    lowp12 highp12 lowp13 highp13
    lowp14 highp14 lowp15 highp15
```

Example:

```
ASCII: AP 52428 52428 13107 13107
          52428 52428 13107 13107
          52428 52428 13107 13107
          52428 52428 13107 13107

HEX:   E7 CC CC CC CC 33 33 33 33
          CC CC CC CC 33 33 33 33
          CC CC CC CC 33 33 33 33
          CC CC CC CC 33 33 33 33
```

Errors: None

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CA (Communications ASCII)

Purpose: Set the communication mode to ASCII.

Command: CA

Description: This command may be given in either ASCII or hexadecimal mode.

Short Form: CA

Hex Format: 43 41 20

Note: This is the hexadecimal equivalent of the three ASCII characters "CA ".

Example:

```
ASCII: CA

HEX:   43 41 20
```

Errors: None

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CIRCLE (Circle)

Purpose: Draw a circle in two dimensions.

Command: CIRCLE radius

Description: CIRCLE draws a circle of a given radius, with its center at the current point. The circle is drawn in the current color and is filled if the PRMFIL flag is set (see "PRMFIL"). Nothing is drawn if the radius value is outside the range of -8191 to 8191.

Short Form: CI radius

Hex Format: 38 lowradius highradius lowfracradius highfracradius

Example:

```
ASCII: CI 25.5 5 135

HEX:   38 19 00 00 80
```

Errors: Radius too large

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CLBEG (Command List Begin)

Purpose: Begin command-list definition.

Command: CLBEG clist

Description: CLBEG begins the definition of the command list specified by *clist*. Commands sent later to the controller are saved in the command-list definition area for execution (see "CLRUN" and "CLOOP"). CLEND ends the command-list definition. *clist* may be from 0 to 255. Any previous definition of the command-list is erased.

Short Form: CB clist

Hex Format: 70 clist

Example:

```
ASCII: CLBEG 1

HEX:   70 01 07 02 06 01 30 00 C8 00 00 71
```

Errors: Not enough memory; command list running

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CLDEL (Command List Delete)

Purpose: Delete the definition of a command list.

Command: CLDEL clist

Description: CLDEL deletes the definition of the command list specified by *clist*. It also reclaims command-list memory for other definitions. *clist* may be from 0 to 255.

Short Form: CD clist

Hex Format: 74 clist

Example:

```
ASCII: CD 3

HEX:   74 03
```

Error: Command list running

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CLEARS (Clear Screen)

Purpose: Clear the screen to a given color.

Command: CLEARS color

Description: Sets every PEL in the high-function graphics display buffer to the color specified by *color* regardless of the mask. This command does not change the current color. It is similar, but not identical, to the command FLOOD.

Short Form: CLS color

Hex Format: 0F color

Example:

```
ASCII: CLS 23

HEX:   0F 17
```

Errors: None

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CLEND (Command List End)

Purpose: End the definition of a command-list.

Command: CLEND

Description: CLEND ends the definition of a command-list. When the controller receives a CLEND, it resumes executing commands as they are received.

Short Form: CE

Hex Format: 71

Example:

```
ASCII: CE

HEX:   71
```

Errors: None

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CLIPH (Clip Hither)

Purpose: Set the hither clip flag.

Command: CLIPH flag

Description: CLIPH enables or disables hither clipping. Hither clipping is enabled when *flag* is 1 or any odd number, and disabled when *flag* is 0 or any even number (default). Three-dimensional drawing commands draw faster when hither clipping is disabled.

Short Form: CH flag

Hex Format: AA flag

Example:

```
ASCII: CH 0

HEX:   AA 01
```

Errors: None

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CLIPY (Clip Yon)

Purpose: Set the yon clip flag.

Command: CLIPY flag

Description: CLIPY enables or disables yon clipping. Yon clipping is enabled when *flag* is 1 or any odd number, and disabled when *flag* is 0 or any even number (default). Three-dimensional drawing commands draw faster when yon clipping is disabled.

Short Form: CY flag

Hex Format: AB flag

Example:

```
ASCII: CY 0

HEX:   AB 01
```

Errors: None

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CLOOP (Command List Loop)

Purpose: Repeat execution of a command list.

Command: CLOOP clist count

Description: CLOOP executes the command list specified by *clist*, for the number of times specified by *count*. *clist* may be between 0 and 255; *count* can be from 0 to 65535.

Short Form: CL clist count

Hex Format: 73 clist lowcount highcount

Example:

```
ASCII: CL 1 1000

HEX:   73 01 E8 03
```

Errors: Command list running; stack full.

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CLRD (Command List Read)

Purpose: Read back command list.

Command: CLRD clist

Description: In hexadecimal mode, a word representing the number of bytes in the command list is read back (zero if the list is undefined), followed by the bytes as they are stored.

Short Form: CRD clist

Hex Format: 75 clist

Example:

```
ASCII: CRD 1

HEX:   75 01
```

Errors: None

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CLRUN (Command List Run)

Purpose: Execute command list.

Command: CLRUN clist

Description: CLRUN executes commands in the command list specified by *clist*. *clist* must be from 0 to 15.

Short Form: CR clist

Hex Format: 72 clist

Example:

```
ASCII: CR 14

HEX:   72 01
```

Errors: Command list running; stack full; nested command list

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COLOR (Color)

Purpose: Set the current color.

Command: COLOR value

Description: COLOR sets the current color to that specified by *value*. All noncomplement mode drawing is done in the current color. All drawing, including complement mode, is subject to MASK and FILMSK. *value* is treated as modulo-256.

Short Form: C value

Hex Format: 06 value

Example:

```
ASCII: C 2

HEX:   06 02
```

Errors: None

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CONVRT (Convert)

Purpose: Convert three dimension to two dimension.

Command: CONVRT

Description: CONVRT converts the three-dimensional current point to two-dimensional virtual coordinates, using the current transformation matrixes. The result is left in the two-dimensional current point.

Short Form: CV

Hex format: AF

Example:

```
ASCII: CV

HEX:   AF
```

Errors: Arithmetic overflow

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CX (Communications Hexadecimal)

Purpose: Set the communication mode to hexadecimal.

Command: CX

Description: This command may be given in either ASCII or hexadecimal mode.

Short Form: CX

Hex Format: 43 58 20

Note: This is the hexadecimal equivalent of the three ASCII characters “CA ”.

Example:

```
ASCII: CX

HEX:   43 58 20
```

Errors: None

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DISPLA (Display)

Purpose: Select the display mode.

Command: DISPLA flag

Description: DISPLA selects a screen for display. If *flag* is 0, the color high-function graphics screen is displayed. If *flag* is 1, the emulator screen is shown. Color graphics commands are accepted and executed, no matter which screen is displayed.

Short Form: DI flag

Hex Format: D0 flag

Example:

```
ASCII: DI 0

HEX:   D0 01
```

Errors: None

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DISTAN (Distance)

Purpose: Define the distance to the viewing reference point.

Command: DISTAN dist

Description: DISTAN defines the distance (*dist*) from the eye to the viewing reference point.

Short Form: DS dist

Hex Format: B1 lowdist highdist lowfracdist highfracdist

Example:

```
ASCII: DS 1200

HEX:   B1 B0 04 9A 59
```

Errors: None

DISTH (Distance Hither)

Purpose: Define the hither clip plane.

Command: DISTH dist

Description: DISTH defines the distance to the hither clip plane from the viewing reference point. The hither clip plane is parallel to the view plane, and the distance (*dist*) is relative. When hither clipping is enabled, no points before the hither clip plane are displayed. Hither clipping affects only three-dimensional drawing commands.

Short Form: DH dist

Hex Format:

A8	lowdist	highdist
	lowfracdist	highfracdist

Examples:

```
ASCII: DH 15.01

HEX:   A8 0F 00 8F 02
```

Errors: None

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DISTY (Distance Yon)

Purpose: Define the yon clip plane.

Command: DISTY dist

Description: DISTY defines the distance to the yon clip plane from the viewing reference point. The yon clip plane is parallel to the view plane, and the distance (*dist*) is relative. When yon clipping is enabled, no points beyond the yon clip plane are displayed. Yon clipping affects only three-dimensional drawing commands.

Short Form: DY dist

Hex Format:

A9	lowdist	highdist
	lowfracdist	highfracdist

Example:

```
ASCII: DY 15.999

HEX:   A9 0F 00 BE FF
```

Errors: None

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DRAW (Draw)

Purpose: Absolute draw in two dimensions.

Command: DRAW x y

Description: DRAW draws a line from the current point to the point specified by *x,y*. The current point moves to the *x* and *y* value.

Short Form: D x y

Hex Format:

28	lowx	highx
	lowfracx	highfracx
	lowy	highy
	lowfracy	highfracy

Example:

```
ASCII: D 23.5 -90.71

HEX:   20 17 00 00 80 A5 FF C3 B5
```

Errors: Arithmetic overflow

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DRAWR (Draw Relative)

Purpose: Relative draw in two dimensions.

Command: DRAWR dx dy

Description: DRAWR draws a line from the current point to a point *dx,dy* from the current point. The current point moves to the end point of the line.

Short Form: DR dx dy

Hex Format:

29	lowdx	highdx
	lowfracdx	highfracdx
	lowdy	highdy
	lowfracdy	highfracdy

Example:

```
ASCII: DR 65.8 12.2

HEX:   21 41 00 CD CC 0C 00 34 33
```

Errors: Arithmetic overflow

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DRAW3 (Draw in 3D)

Purpose: Draw absolute in three dimensions.

Command: DRAW3 x y z

Description: DRAW3 draws a line from the current point to the point in the three-dimensional space given. After the draw, the current point moves to *x,y,z*.

Short Form: D3 x y z

Hex Format:

2A	lowx	highx
	lowfracx	highfracx
	lowy	highy
	lowfracy	highfracy
	lowz	highz
	lowfracz	highfracz

Example:

```
ASCII: D3 943, -266, 100

HEX:   22 AF 03 00 00 F6 FE 00 00 64 00 00 00
```

Errors: Arithmetic overflow

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DRAWR3 (Draw Relative in 3D)

Purpose: Draw relative in three dimensions.

Command: DRAWR3 dx dy dz

Description: DRAWR3 draws a line to the point offset from the current point by *dx,dy,dz* and moves the current point to this new point.

Short Form: DR3 dx dy dz

Hex Format:

2B	lowdx	highdx
	lowfracdx	highfracdx
	lowdy	highdy
	lowfracdy	highfracdy
	lowdz	highdz
	lowfracdz	highfracdz

Example:

```
ASCII: DR3 835.02 44.62 98

HEX:   23 43 03 1F 05 2C 00 B8 9E 62 00 00 00
```

Errors: Arithmetic overflow

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ELIPSE (Ellipse)

Purpose: Draw an ellipse in two dimensions.

Command: ELIPSE xradius yradius

Description: ELIPSE draws an ellipse centered on the two-dimensional current point whose x and y axis lengths are given in *xradius* and *yradius*. The ellipse is filled if the PRMFIL flag is set.

Short Form: EL xradius yradius

Hex Format:

39	lowxradius	highxradius
	lowfracxradius	highfracxradius
	lowyradius	highyradius
	lowfracyradius	highfracyradius

Example:

```
ASCII: EL 50 100

HEX:   39 25 00 00 80 19 00 00 00
```

Errors: Radius too large

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FILMSK (Fill Mask)

Purpose: Set area fill mask.

Command: FILMSK mask

Description: FILMSK sets the 8-bit area fill mask to *mask*. All PELs read by the Area Fill commands are ANDed against this mask, and also MASK, before comparison with the boundary color.

Short Form: FM mask

Hex Format: EF mask

Example:

```
ASCII: FM 254

HEX:   EF FE
```

Errors: None

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FLAGRD (Flag Read)

Purpose: Read flag value.

Command: FLAGRD flag

Description: FLAGRD loads the current value of the flag specified by *flag* into the output buffer for later reading by the host. The flag numbers assigned are as follows.

Flag	Name	Type of Value Returned
1	AREAPT	16 integers
2	CLIPH	1 integer (byte)
3	CLIPY	1 integer (byte)
4	COLOR	1 integer (byte)
5	DISPLA	1 integer (byte)
6	DISTAN	1 real number
7	DISTH	1 real number
8	DISTY	1 real number
9	FILMSK	1 integer (byte)
10	LINFUN	1 integer (byte)
11	LINPAT	1 integer
12	MASK	1 integer (byte)
13	MDORG	3 real numbers
14	2D current point	2 real numbers
15	3D current point	3 real numbers
16	PRMFIL	1 integer (byte)
17	PROJCT	1 integer (byte)
18	TANGLE	1 word
19	TJUST	2 integers (bytes)
20	TSIZE	1 real number
21	VWPORT	4 integers
22	VWRPT	3 real numbers
23	WINDOW	4 real numbers
24	Transformed 3D current point	3 real numbers
25	Free memory available	1 integer

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Each value is read in the same order as provided to the command that sets it. For example, the three-dimensional current point is read as one real number each for x, y, and z. In ASCII mode, commas separate multiple return values, with a carriage return at the end.

Short Form: FRD flag

Hex Format: 51 flag

Example:

```
ASCII: FRD 3

HEX:   51 03
```

Error: None

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FLOOD (Flood)

Purpose: Flood the screen to the color given.

Command: FLOOD color

Description: FLOOD sets every PEL in the defined viewport, to the color specified by *color* subject to MASK. This command does not change the current color.

Short Form: F color

Hex Format: 07 color

Example:

```
ASCII: F 4

HEX:   07 04
```

Errors: None

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IMAGER (Image Read)

Purpose: Read image from the display.

Command: IMAGER line x1 x2

Description: IMAGER reads a line from the image being displayed. If the communication mode is ASCII (CA) the image is placed in the output buffer as one ASCII number for each PEL, separated by carriage returns. If communication is in hexadecimal mode (CX) the image output is in a run-length encoded format. *line, x1,* and *x2* are expressed in PELs measured from the lower-left corner of the screen.

Short Form: IR line x1 x2

Hex Format:

D8	lowline	highline
	lowx1	highx1
	lowx2	highx2

Example:

```
ASCII: IR 100 0 127

HEX: D8 64 00 00 00 7F 00
```

Errors: Value out of range

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IMAGEW (Image Write)

Purpose: Write image to the display.

Command: IMAGEW line x1 x2

Description: IMAGEW writes a line of PELs to the display. If communication is in ASCII (CA) each parameter represents one PEL. If communication is in hexadecimal (CX) the image is sent in run-length encoded format. *line, x1,* and *x2* are expressed in PELs measured from the lower-left corner of the screen.

Short Form: IW line x1 x2

Hex Format:

D9	lowline	highline
	lowx1	highx1
	lowx2	highx2
	. . . .	data

Example:

```
ASCII: IW 100 50 60

HEX:   D9 64 00 32 00 3C 00 82 2C
          18 42 03 0C 01 0E 81 18 2C
```

Errors: Value out of range

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LINFUN (Line Function)

Purpose: Select drawing function.

Command: LINFUN function

Description: LINFUN sets the drawing function to that specified by *function*. Available functions are:

0 Draw by writing PELs of the current color (default).

1 Draw by complementing PEL. The current color will be ignored.

Note: With both functions, drawing is subject to MASK and FILMSK where appropriate.

Short Form: LF function

Hex Format: EB function

Example:

```
ASCII: LF 0

HEX:   EB 00
```

Errors: None

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LINPAT (Line Pattern)

Purpose: Set line pattern.

Command: LINPAT pattern

Description: LINPAT sets the line-drawing pattern from a 16-bit number. The line pattern is used to implement dotted or dashed lines. As each PEL is generated, the line-pattern mask is rotated right. If there is a 1 in the least-significant bit (LSB), a PEL is drawn. If that bit is a 0 then no PEL is drawn and the background remains visible. A line-pattern mask of all 1's (65535) produces solid lines, and is the default following a RESETF. The line pattern affects the following commands except when drawing a filled primitive:

ARC, CIRCLE, DRAW, DRAW3, DRAWR, DRAWR3, ELIPSE, POLY, POLY3, POLYR, POLYR3, RECT, RECTR, SECTOR

Short Form: LP pattern

Hex Format: EA lowpattern highpattern

Example:

```
ASCII: LP 65280

HEX:   EA 00 FF
```

Errors: None

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LUT (Look-Up Table)

Purpose: Set an entry in the look-up table.

Command: LUT index r g b

Description: LUT loads red, green, and blue intensity levels into the LUT entry specified by *index*. Intensity values are treated as modulo-16 numbers.

Short Form: L index r g b

Hex Format: EE index r g b

Example:

```
ASCII: L 3 0 15 0

HEX:   EE 04 00 00 0F
```

Errors: None

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LUTINT (Look-Up Table Initialize)

Purpose: Initialize the look-up table.

Command: LUTINT state

Description: LUTINT sets the LUT to one of the following states specified by *state*:

State	
0	Color-cone distribution
1	Foreground/background colors in the low 4-bits of a value code will be visible only if the high 4-bits is 0 (or "invisible")
2	Value codes interpreted as: R R G G G B B B
3	Value codes interpreted as: R R R G G B B B
4	Value codes interpreted as: R R R G G G B B
5	6-level RGB
255	Load LUT from LUT storage area (opposite of LUTSAV)

Short Form: LI state

Hex Format: EC state

Example:

```
ASCII: LI 4

HEX:   EC 04
```

Errors: Value out of range

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LUTRD (Look-Up Table Read)

Purpose: Read the look-up table entry.

Command: LUTRD index

Description: LUTRD loads the red, green, and blue entries at the LUT entry specified by *index* into the output buffer for reading by the host.

In ASCII mode, the LUT entries are read as red, green, and blue intensities, separated by commas, and ended by a carriage return.

In hexadecimal mode, the LUT entries are read one byte for each entry for a total of three bytes.

Short Form: LRD index

Hex Format: 50 index

Example:

```
ASCII: LRD 2

HEX:   50 02
```

Errors: None

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LUTSAV (Look-Up Table Save)

Purpose: Save the look-up table in the look-up table storage area.

Command: LUTSAV

Description: LUTSAV saves all 256 LUT entries in the LUT storage area. These values may be reloaded with a "LUTINT 255" command. Each LUTSAV overwrites any previous LUTSAV.

Short Form: LS

Hex Format: ED

Example:

```
ASCII: LS

HEX:   ED
```

Errors: None

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MASK (Mask)

Purpose: Set bit-plane mask.

Command: MASK planemask

Description: MASK sets the 8-bit, read/write, bit-plane mask to the value specified by *planemask*. A zero in any position in the mask means that no bits in that plane are written to; when read, bits in that plane return zero. Because of the organization of display memory, the fastest drawing speed occurs when *planemask* is FF, 0F, or F0.

Short Form: MK planemask

Hex Format: E8 planemask

Example:

```
ASCII: MK 15

HEX:   E8 0F
```

Errors: None

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MATXRD (Matrix Read)

Purpose: Read the matrix contents.

Command: MATXRD matrix

Description: MATXRD reads the contents of the 4-by-4 matrix specified by *matrix* into the output buffer for later reading by the host. The matrix number assignments are:

1 Three-dimensional modeling transformation matrix

2 Three-dimensional viewing transformation matrix

In ASCII mode, the matrix entries are read in four lines. Each line has four entries separated by commas.

In hexadecimal mode, four bytes for each matrix entry are read, for a total of 64 bytes. The reading order is:

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

Short Form: MRD matrix

Hex Format: 52 matrix

Example:

```
ASCII: MRD 1

HEX:   52 01
```

Errors: Value out of range

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MDIDEN (Modeling Identity)

Purpose: Reset the modeling transformation matrix.

Command: MDIDEN

Description: MDIDEN sets the modeling transformation matrix to the identity matrix.

Short Form: MDI

Hex Format: 90

Example:

```
ASCII: MDI

HEX:  90
```

Errors: None

MDMATX (Modeling Matrix)

Purpose: Define the modeling matrix.

Command: MDMATX array

Description: MDMATX loads the modeling matrix directly from the 4-by-4 real-number array.

Short Form: MDM array

Hex Format:

```
97 lowm11 highm11 lowfracm11 highfracm11
   lowm12 highm12 lowfracm12 highfracm12
   lowm13 highm13 lowfracm13 highfracm13
   lowm14 highm14 lowfracm14 highfracm14
   lowm21 highm21 lowfracm21 highfracm21
   lowm22 highm22 lowfracm22 highfracm22
   lowm23 highm23 lowfracm23 highfracm23
   lowm24 highm24 lowfracm24 highfracm24
   lowm31 highm31 lowfracm31 highfracm31
   lowm32 highm32 lowfracm32 highfracm32
   lowm33 highm33 lowfracm33 highfracm33
   lowm34 highm34 lowfracm34 highfracm34
   lowm41 highm41 lowfracm41 highfracm41
   lowm42 highm42 lowfracm42 highfracm42
   lowm43 highm43 lowfracm43 highfracm43
   lowm44 highm44 lowfracm44 highfracm44
```

Example:

```
ASCII: MDM 68.25 12.5   253    17
           65503 0.25   306.75 34.5
           8418  324.75 1.25   0
           313.5 50     1.25   1

HEX:    97 44 00 00 40 0C 00 00 80 FD 00 00 00
           11 00 00 00 DF FF 00 00 00 00 00 40
           32 01 00 C0 22 00 00 80 E2 20 00 00
           44 01 00 C0 01 00 00 40 00 00 00 00
           39 01 00 80 32 00 00 00 01 00 00 40
           01 00 00 00
```

Errors: Arithmetic overflow

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MDORG (Modeling Origin)

Purpose: Define the modeling origin.

Command: MDORG ox oy oz

Description: MDORG defines the origin for modeling-transformation scaling and rotating specified by *ox,oy,oz*.

Short Form: MDO ox oy oz

Hex Format: 91 lowox highox lowfracox highfracox
lowoy highoy lowfracoy highfracoy
lowoz highoz lowfracoz highfracoz

Example:

```
ASCII: MDO 1.7 0.2 1.5

HEX:   91 01 00 33 B3 00 00 33 33 01 00 00 80
```

Errors: None

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MDROTX (Modeling Rotate X Axis)

Purpose: Rotate about the X axis.

Command: MDROTX deg

Description: MDROTX defines the rotation about the x axis component of the modeling matrix.

Short Form: MDX deg

Hex Format: 93 lowdeg highdeg

Examples:

```
ASCII: MDX 30

HEX:   93 2D 00
```

Errors: Arithmetic overflow

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MDROTY (Modeling Rotate Y Axis)

Purpose: Rotate about the Y axis.

Command: MDROTY deg

Description: MDROTY defines the rotation about the y axis component of the modeling matrix.

Short Form: MDY deg

Hex Format: 94 lowdeg highdeg

Example:

```
ASCII: MDY 15

HEX:   94 0F 00
```

Errors: Arithmetic overflow

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MDROTZ (Modeling Rotate Z Axis)

Purpose: Rotate about the Z axis.

Command: MDROTZ deg

Description: MDROTZ defines the rotation about the z axis component of the modeling matrix.

Short Form: MDZ deg

Hex Format: 95 lowdeg highdeg

Example:

```
ASCII: MDZ 33

HEX:   95 21 00
```

Errors: Arithmetic overflow

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MDSCAL (Modeling Scale)

Purpose: Set modeling scaling.

Command: MDSCAL sx sy sz

Description: MDSCAL defines the scaling components for the image transformation.

Short Form: MDS sx sy sz

Hex Format 92 lowsx highsx lowfracsx highfracsx
lowsy highsy lowfracsy highfracsy
lowsz highsz lowfracsz highfracsz

Example:

```
ASCII: MDS 2 2 2

HEX:   92 02 00 00 80 01 00 00 00 01 00 00 80
```

Errors: Arithmetic overflow

MDTRAN (Modeling Translation)

Purpose: Define the modeling translation.

Command: MDTRAN tx ty tz

Description: MDTRAN defines the translation components for the image transformation specified by *tx,ty,tz*.

Short Form: MDT tx ty tz

Hex Format:

```
96 lowtx  hightx  lowfractx   highfractx
   lowty  highty  lowfracty   highfracty
   lowtz  hightz  lowfractz   highfractz
```

Example:

```
ASCII: MDT 50 0 0

HEX:   96 32 00 00 00 00 00 00 00 00 00 00 00
```

Errors: Arithmetic overflow

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MOVE (Move)

Purpose:	Absolute move in two dimensions.
Command:	MOVE x y
Description:	MOVE moves the two-dimensional current point to the x and y coordinates given.
Short Form:	M x y
Hex Format:	10 lowx highx lowfracx highfracx lowy highy lowfracy highfracy

Example:

```
ASCII: M 300 -400

HEX:   10 2C 01 00 00 70 FE 00 00
```

Errors: None

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MOVER (Move Relative)

Purpose: Relative move in two dimensions.

Command: MOVER dx dy

Description: MOVER moves the two-dimensional current point a relative amount specified by *dx,dy*.

Short Form: MR dx dy

Hex Format: 11 lowdx highdx lowfracdx highfracdx
lowdy highdy lowfracdy highfracdy

Example:

```
ASCII: MR 20.44 59

HEX:   11 14 00 A2 71 3B 00 00 00
```

Errors: Arithmetic overflow

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MOVE3 (Move in 3D)

Purpose: Absolute move in three dimensions.

Command: MOVE3 x y z

Description: MOVE3 moves the three-dimensional current point to the coordinates specified by *x,y,z*.

Short Form: M3 x y z

Hex Format: 12 lowx highx lowfracx highfracx
lowy highy lowfracy highfracy
lowz highz lowfracz highfracz

Example:

```
ASCII: M3 -1300 -233 519

HEX: 12 EC FA 00 00 17 FF 00 00 07 02 00 00
```

Errors: None

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MOVER3 (Move Relative in 3D)

Purpose: Relative move in three dimensions.

Command: MOVER3 dx dy dz

Description: MOVER3 moves the three-dimensional current point a relative amount specified by *dx,dy,dz*.

Short Form: MR3 dx dy dz

Hex Format:

13	lowdx	highdx	lowfracdx	highfracdx
	lowdy	highdy	lowfracdy	highfracdy
	lowdz	highdz	lowfracdz	highfracdz

Example:

```
ASCII: MR3 722 0 0

HEX: 13 D2 02 00 00 00 00 00 00 00 00 00 00
```

Errors: Arithmetic overflow

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POINT (Point)

Purpose: Set the PEL to the current color in two dimensions.

Command: POINT

Description: POINT writes the current color to the PEL at the two-dimensional current point.

Short Form: PT

Hex Format: 08

Example:

```
ASCII: PT

HEX:   08
```

Errors: None

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POINT3 (Point in 3D)

Purpose: Set the PEL to the current color in three dimensions.

Command: POINT3

Description: POINT3 writes the current color to the PEL at the current three-dimensional point.

Short Form: PT3

Hex Format: 09

Example:

```
ASCII: PT3

HEX:   09
```

Errors: None

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POLY (Polygon)

Purpose: Draw a polygon.

Command: POLY npts x1 y1 x2 y2 . . . . . xn yn

Description: POLY draws an absolute polygon in two dimensions, where *npts* is the number of points, and *x* and *y* are the coordinates of the points. The polygon is filled if the PRMFIL flag is set. The current point is not changed.

Short Form: P npts x1 y1 x2 y2 . . . . . xn yn

Hex Format:

```
30 npts lowx1   highx1   lowfracx1   highfracx1
        lowy1   highy1   lowfracy1   highfracy1
        lowx2   highx2   lowfracx2   highfracx2
        lowy2   highy2   lowfracy2   highfracy2
        . . . . . . . . . .
        lowxN   highxN   lowfracxN   highfracxN
        lowyN   highyN   lowfracyN   highfracyN
```

Example:

```
ASCII: P 3 0 0  10 10  -10 30

HEX:   30 03 00 00 00 00 00 00 00 00
             0A 00 00 00 F6 FF 00 00
             F6 FF 00 00 E2 FF 00 00
```

Errors: Not enough memory; arithmetic overflow

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POLYR (Polygon Relative)

Purpose: Draw a relative polygon.

Command: POLYR npts dx1 dy1 dx2 dy2 . . . . . dxn dyn

Description: POLYR draws a relative polygon in two dimensions, where *npts* is the number of points, and *dx* and *dy* are the offsets from the current point. The polygon is filled if the PRMFIL flag is set. The current point is not changed.

Short Form: PR npts dx1 dy1 dx2 dy2 . . . . . dxn dyn

Hex Format:

```
31 npts lowdx1  highdx1  lowfracdx1  highfracdx1
        lowdy1  highdy1  lowfracdy1  highfracdy1
        lowdx2  highdx2  lowfracdx2  highfracdx2
        lowdy2  highdy2  lowfracdy2  highfracdy2
        . . . . . . . . .
        lowdxN  highdxN  lowfracdxN  highfracdxN
        lowdyN  highdyN  lowfracdyN  highfracdyN
```

Example:

```
ASCII: PR 3 0 0  20 20 -20 40

HEX:   31 03 00 00 00 00 00 00 00 00
             0A 00 00 00 0A 00 00 00
             F6 FF 00 00 E2 FF 00 00
```

Errors: Not enough memory; arithmetic overflow

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POLY3 (Polygon in 3D)

Purpose: Draw a polygon in three dimensions.

Command: POLY3 npts x1 y1 z1 . . . . . xn yn zn

Description: POLY3 draws an absolute polygon in three dimensions, where *npts* is the number of points, and *x, y,* and *z* are the coordinates of the points. The polygon is filled if the PRMFIL flag is set. The current point does not change.

Short Form: P3 npts x1 y1 z1 . . . . . xn yn zn

Hex Format:

```
32 npts lowx1   highx1  lowfracx1  highfracx1
        lowy1   highy1  lowfracy1  highfracy1
        lowz1   highz1  lowfracz1  highfracz1
        lowx2   highx2  lowfracx2  highfracx2
        lowy2   highy2  lowfracy2  highfracy2
        lowz2   highz2  lowfracz2  highfracz2
        . . . . . . . . .
        lowxN   highxN  lowfracxN  highfracxN
        lowyN   highyN  lowfracyN  highfracyN
        lowzN   highzN  lowfraczN  highfraczN
```

Example:

```
ASCII:
P3 3 0 0 0  10 10 10 -10 30 -10

HEX:
32 03 00 00 00 00 00 00 00 00 00 00 00 00
      0A 00 00 00 0A 00 00 00 0A 00 00 00
      F6 FF 00 00 E2 FF 00 00 F6 FF 00 00
```

Errors: Not enough memory; arithmetic overflow

POLYR3 (Polygon Relative in 3D)

Purpose: Draw a relative polygon in three dimensions.

Command: POLYR3 npts dx1 dy1 dz1 . . . . . dxn dyn dzn

Description: POLYR3 draws a relative polygon in three dimensions, where *npts* is the number of points, and *dx, dy,* and *dz* are the offsets from the current point. The polygon is filled if the PRMFIL flag is set. The current point is not affected.

Short Form: PR3 npts dx1 dy1 dz1 . . . . . dxn dyn dzn

Hex Format:

```
33 npts lowdx1   highdx1  lowfracdx1  highfracdx1
        lowdy1   highdy1  lowfracdy1  highfracdy1
        lowdz1   highdz1  lowfracdz1  highfracdz1
        lowdx2   highdx2  lowfracdx2  highfracdx2
        lowdy2   highdy2  lowfracdy2  highfracdy2
        lowdz2   highdz2  lowfracdz2  highfracdz2
        . . . . . . . . .
        lowdxN   highdxN  lowfracdxN  highfracdxN
        lowdyN   highdyN  lowfracdyN  highfracdyN
        lowdzN   highdzN  lowfracdzN  highfracdzN
```

Example:

```
ASCII:
PR3 3 0 0 0  10 10 10 -10 30 -10

HEX:
33 03 00 00 00 00 00 00 00 00 00 00 00 00
      0A 00 00 00 0A 00 00 00 0A 00 00 00
      F6 FF 00 00 E2 FF 00 00 F6 FF 00 00
```

Errors: Not enough memory; arithmetic overflow

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PRMFIL (Primitive Fill)

Purpose: Set primitive fill flag.

Command: PRMFIL flag

Description: PRMFIL sets the primitive fill flag to the value specified by *flag*. If *flag* is 0, closed figures are drawn in outline only. If *flag* is 1, closed figures are drawn filled with the current color. If *flag* is 2, there is a performance improvement but degenerate polygons will fill unpredictably. PRMFIL affects the following commands:

CIRCLE, ELIPSE, POLY, POLYR, POLY3, POLYR3, RECT, RECTR, SECTOR

Short Form: PF flag

Hex Format: E9 flag

Example:

```
ASCII: PF 1

HEX:   E9 01
```

Errors: None

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PROJCT (Projection)

Purpose: Set the type of projection.

Command: PROJCT angle

Description: PROJCT defines the type of projection used in the three-dimensional to two-dimensional transformation. If *angle* is 0, the projection is orthographic parallel (non-oblique). Otherwise, the projection is perspective, with *angle* being the view angle (default is 60). The range of *angle* is 0 to 179 degrees.

Short Form: PRO angle

Hex Format: B0 angle

Example:

```
ASCII: PR 0

HEX:   B0 3C
```

Errors: Value out of range; arithmetic overflow

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RECT (Rectangle)

Purpose: Draw an absolute rectangle in two dimensions.

Command: RECT x y

Description: RECT draws a rectangle with one corner at the current point and its diagonally opposite corner at the point given. The current point does not move. If the PRMFIL flag is set, the rectangle is drawn filled.

Short Form: R x y

Hex Format: 34 lowx highx lowfracx highfracx
lowy highy lowfracy highfracy

Example:

```
ASCII: R 70.50 90.75

HEX:   34 46 00 00 80 5A 00 00 C0
```

Errors: None

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RECTR (Rectangle Relative)

Purpose: Draw a relative rectangle in two dimensions.

Command: RECTR dx dy

Description: RECTR draws a rectangle. One corner is at the current point, and its diagonally opposite corner is offset by *dx,dy*. The current point does not move. If the PRMFIL flag is set, the rectangle is drawn filled.

Short Form: RR dx dy

Hex Format: 35 lowdx highdx lowfracdx highfracdx lowdy highdy lowfracdy highfracdy

Example:

```
ASCII: RR -12.5 60

HEX:   35 F3 FF 00 80 3C 00 00 00
```

Errors: Arithmetic overflow

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RESETF (Reset Flags)

Purpose: Reset program parameters.

Command: RESETF

Description: Reset all settable flags to their default values.

Flag	Name	Default Value	
1	AREAPT	65535 16 times	Solid area
2	CLIPH	Flag = 0	Disabled
3	CLIPY	Flag = 0	Disabled
4	COLOR	Value = 255	
5	DISPLA	No change after a RESETF	
6	DISTAN	Distance = 500	
7	DISTH	Distance = -30000	
8	DISTY	Distance = 30000	
9	FILMSK	Mask = 255	No PEL draw effect
10	LINFUN	Function = 0	Replacement mode
11	LINPAT	Pattern = 65535	Solid line
12	MASK	Mask = 255	All planes enabled
13	MDORG	OX = OY = OZ = 0	
14	2D current point	X = Y = 0	
15	3D current point	X = Y = Z = 0	
16	PRMFIL	Flag = 0	Primitive fill off
17	PROJCT	Angle = 60	
18	TANGLE	Angle = 0	Horizontal, left-right text
19	TJUST	H = V = 1	Left, bottom justification
20	TSIZE	Size = 8	12 by 8 cell characters
21	VWPORT	0, 639, 0, 479	Entire screen
22	VWRPT	X = Y = Z = 0	
23	WINDOW	-320, 319, -240, 239	
24	Transformed 3D current point	X = Y = Z = 0	

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Short Form: RF

Hex Format: 04

Example:

```
ASCII: RF

HEX:   04
```

Errors: None

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SECTOR (Sector)

Purpose: Draw a sector in two dimensions.

Command: SECTOR radius deg0 deg1

Description: SECTOR draws a pie-shaped sector that consists of an arc with a given radius, with the arc spanning two given angles, and a vector from the center of the arc to each of the arc's endpoints. If the PRMFIL flag is set, the sector is drawn filled. *radius* is a real number. Angles are integers and treated modulo-360. If *radius* is negative, 180 degrees are added to each angle.

Short Form: S radius deg0 deg1

Hex Format:

3D	lowradius	highradius
	lowfracradius	highfracradius
	lowdeg0	highdeg0
	lowdeg1	highdeg1

Example:

```
ASCII: S 50 -90 30

HEX:   3D 32 00 00 00 A6 FF 1E 00
```

Errors: Arithmetic overflow

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TANGLE (Text Angle)

Purpose: Set text angle.

Command: TANGLE deg

Description: TANGLE specifies the angle for drawing text. An angle of 0 (default) causes the text to be drawn normally from left to right.

Short Form: TA deg

Hex Format: 82 lowdeg highdeg

Example:

```
ASCII: TA 90

HEX:   82 5A 00
```

Errors: None

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TDEFIN (Text Define)

Purpose: Define programmable text character.

Command: TDEFIN N x y array

Description: TDEFIN stores the character image given by *x, y,* and *array* for a character with the ASCII value of *N*. If communication is in ASCII, the character image is to be sent as a series of 0's and 1's. If communication is in hexadecimal, the character is sent as a series of bytes, as many for each line as required, for as many lines as specified.

Short Form: TD N x y array

Hex Format:

```
84 N x y line1byte1   line1byte2 . . .  line1byteX
         line2byte1   line2byte2 . . .  line2byteX
         . . . . . . . .

         lineYbyte1   lineYbyte2 . . .  lineYbyteX
```

Example:

```
ASCII: T 65 70 12 14

HEX:   84 62 05 07 1E 11 11 1E 10 10 10
```

Errors: Not enough memory

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TEXT (Text)

Purpose: Draw hardware font text.

Command: TEXT ‘string’
TEXT “string”

Description: TEXT writes a text string to the screen, justified about the current point as specified by the last TJUST command. The string may be delimited by either single or double quotes.

Short Form: T ‘string’
T "string"

Hex Format: 80 22 c1 c2 c3
. . . . . cN 22
or
80 27 c1 c2 c3
. . . . . cN 27

Example:

```
ASCII: T 'This is a test'

HEX:   80 27 58 20 65 71 75 61
          6C 73 20 31 2E 34 27
```

Errors: Not enough memory

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TEXTP (Text Programmed)

Purpose: Draw text using a programmed font.

Command: TEXTP 'string'
TEXTP "string"

Description: TEXTP draws text with the user-programmed font. The size is that specified by the latest TSIZE command, and the angle is that specified by TANGLE. The text is justified about the current point.

Short Form: TP 'string'
TP "string"

Hex Format: 83 22 c1 c2 c3
. . . . . cN 22
or
83 27 c1 c2 c3
. . . . . cN 27

Example:

```
ASCII: TP 'Hello'

HEX:   83 27 48 65 6C 6F 27
```

Errors: Not enough memory

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TJUST (Text Justify)

Purpose: Set text justification

Command: TJUST horiz vert

Description: The TJUST command specifies the text justification, where *horiz* is one of the following:

1 Left justify text at current point.
2 Center the text string about the current point.
3 Right justify text at current point.

vert is one of the following:

1 Bottom of text at Y coordinate of current point.
2 Center text string vertically about the current point.
3 Top of text at Y coordinate of current point.

The default is H = 1, V = 1.

Short Form: TJ horiz vert

Hex Format: 85

Example:

```
ASCII: TJ 2 1

HEX:   85 02 01
```

Errors: Value out of range

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TSIZE (Text Size)

Purpose: Set the text size.

Command: TSIZE size

Description: TSIZE sets text size by specifying the virtual x distance from one character to the next when displayed.

Short Form: TS size

Hex Format: 81 lowsize highsize lowfracsize highfracsize

Example:

```
ASCII: TS 10

HEX:   81 0A 00 00 00
```

Errors: Arithmetic overflow

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VWIDEN (Viewing Identity)

Purpose: Reset the viewing matrix.

Command: VWIDEN

Description: VWIDEN sets the viewing transformation matrix to the identity matrix.

Short Form: VWI

Hex Format: A0

Example:

```
ASCII: VWI

HEX:   A0
```

Errors: None

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VWMATX (Viewing Matrix)

Purpose: Define the viewing matrix.

Command: VWMATX array

Description: VWMATX loads the viewing matrix directly from the 4-by-4 array.

Short Form: VWM array

Hex Format:

```
A7 lowm11  highm11  lowfracm11  highfracm11
   lowm12  highm12  lowfracm12  highfracm12
   lowm13  highm13  lowfracm13  highfracm13
   lowm14  highm14  lowfracm14  highfracm14
   lowm21  highm21  lowfracm21  highfracm21
   lowm22  highm22  lowfracm22  highfracm22
   lowm23  highm23  lowfracm23  highfracm23
   lowm24  highm24  lowfracm24  highfracm24
   lowm31  highm31  lowfracm31  highfracm31
   lowm32  highm32  lowfracm32  highfracm32
   lowm33  highm33  lowfracm33  highfracm33
   lowm34  highm34  lowfracm34  highfracm34
   lowm41  highm41  lowfracm41  highfracm41
   lowm42  highm42  lowfracm42  highfracm42
   lowm43  highm43  lowfracm43  highfracm43
   lowm44  highm44  lowfracm44  highfracm44
```

Example:

```
ASCII: VWM 68       12.5    253    17.25
           65503.5 0       306.25 34
           8418    2628.25 1.75   0.5
           313.75  50.25   1      1.5

HEX:   A7 44 00 00 00 0C 00 00 80 FD 00
          00 00 11 00 00 40 DF FF 00 80
          00 00 00 00 32 01 00 40 22 00
          00 00 E2 20 00 00 44 0A 00 40
          01 00 00 C0 00 00 00 80 39 01
          00 C0 32 00 00 40 01 00 00 00
          01 00 00 80
```

Errors: Arithmetic overflow

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VWPORT (Viewport)

Purpose: Define a viewport.

Command: VWPORT x1 x2 y1 y2

Description: VWPORT defines a viewport within the viewplane and is measured in PELs from the lower-left corner of the screen. Clipping is always enabled. The default is the entire screen (0,639 and 0,479). *x1* must be less than *x2*; otherwise, a warning is generated and the coordinates are swapped. The same is true for *y1* and *y2*. A warning is generated if any of the coordinates fall outside the screen boundary.

Short Form: VWP x1 x2 y1 y2

Hex Format: B2 lowx1 highx1 lowx2 highx2
lowy1 highy1 lowy2 highy2

Example:

```
ASCII: VWP 50 450 30 250

HEX:   B2 32 00 C4 01 1E 00 FA 00
```

Errors: Arithmetic overflow

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VWROTX (Viewing Rotate X Axis)

Purpose: Rotate viewing about the x axis.

Command: VWROTX deg

Description: VWROTX defines the rotation about the x axis component of the viewing matrix.

Short Form: VWX deg

Hex Format: A3 lowdeg highdeg

Example:

```
ASCII: VWX 30

HEX:   A3 2D 00
```

Errors: Arithmetic overflow

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VWROTY (Viewing Rotate Y Axis)

Purpose: Rotate viewing about the y axis.

Command: VWROTY deg

Description: VWROTY defines the rotation about the y axis component of the viewing matrix.

Short Form: VWY deg

Hex Format: A4 lowdeg highdeg

Example:

```
ASCII: VWY 45

HEX:   A4 1E 00
```

Errors: Arithmetic overflow

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VWROTZ (Viewing Rotate Z Axis)

Purpose: Rotate viewing about the z axis.

Command: VWROTZ deg

Description: VWROTZ defines the rotation about the z axis component of the viewing matrix.

Short Form: VWZ deg

Hex Format: A5 lowdeg highdeg

Example:

```
ASCII: VWZ 30

HEX:   A5 44 00
```

Errors: Arithmetic overflow

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VWRPT (Viewing Reference Point)

Purpose: Define the viewing reference point.

Command: VWRPT x y z

Description: VWRPT defines the viewing reference point (the point the user is looking at); specified by *x,y,z*.

Short Form: VWR x y z

Hex Format:

A1	lowx	highx	lowfracx	highfracx
	lowy	highy	lowfracy	highfracy
	lowz	highz	lowfracz	highfracz

Example:

```
ASCII: VWR 50 75 -25

HEX:   A1 32 00 00 00 4B 00 00 00 E7 FF 00 00
```

Errors: Arithmetic overflow

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WAIT (Wait)

Purpose: Insert a delay in execution.

Command: WAIT frames

Description: WAIT inserts a delay in the execution of commands by waiting the number of frames specified by *frames*. A frame is 1/60 second. With the maximum of 65535 frames, a delay of up to 20 minutes may be inserted.

Short form: W frames

Hex Format: 05 lowframes highframes

Example:

```
ASCII: W 60

HEX:   05 3C 00
```

Errors: None

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WINDOW (Window)

Purpose: Define the viewport coordinates.

Command: WINDOW x1 x2 y1 y2

Description: WINDOW defines the corner coordinates of the viewport. These two-dimensional real coordinates will map to the screen's PEL locations specified by the most recent VWPORT command.

Short Form: WI x1 x2 y1 y2

Hex Format:

B3	lowxleft	highxleft
	lowfracxleft	highfracxleft
	lowxright	highxright
	lowfracxright	highfracxright
	lowybottom	highybottom
	lowfracybottom	highfracybottom
	lowytop	highytop
	lowfracytop	highfracytop

Example:

```
ASCII: WI -100 100 100 100

HEX:   B3 96 FF 00 00 64 00 00 00
          64 00 00 00 64 00 00 00
```

Errors: Arithmetic overflow

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Run-Length Encoding

In hexadecimal mode, the commands IMAGER and IMAGEW send and receive data in run-length encoded format. This format allows for extremely high data rates. The format is described as follows:

Command (1 byte) IMAGER or IMAGEW
Line # (1 word)
Start x
End x
One or more PEL packets

A PEL packet is either of the following:

- A solid block of one color:

  Count (1 byte: N - 1)
  Color (1 byte)
  The count may range from 0 to 127 (N = 1 to 128), with the most-significant bit set to 0. This packet defines multiple occurrences of the same color and requires only two bytes to specify up to 128 PELs.

- PELs of different colors:

  Count (1 byte: N - 1 + 128)
  PEL 0
  PEL 1
  PEL 2
  . . . .
  PEL N - 1 (N bytes)
  The count may range from 128 to 255 (N = 1 to 128), with the most-significant bit set to 1. This packet defines strings of color codes that are different from one another.

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Default LUT Selections for LUTINT

Each state provides a distinct way for initializing the look-up table (LUT). Following are descriptions for each currently defined state. The descriptions include a list of the default values for that LUT.

State 0

State 0 reproduces a color-cone distribution. The 8-bit LUT value divides into two 4-bit hexadecimal digits. The least-significant digit supplies the luminance value, and the most-significant digit supplies the color scale, each of the 16 values corresponding to a color. The color scale shades from black through the given color to white.

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The following table shows the default values of state 0 for the various colors.

Color	Default Values (in Hex) for State 0							
Black to Grey to White	000	111	222	333	444	555	666	777
	888	999	AAA	BBB	CCC	DDD	EEE	FFF
Black to Red to White	000	200	400	600	800	A00	C00	E00
	F00	F22	F44	F66	F88	FAA	FCC	FEE
Black to Red-magenta to White	000	201	402	603	904	A05	C06	E07
	F08	F29	F4A	F6B	F8C	FAD	FCE	FEF
Black to Magenta to White	000	202	404	606	808	A0A	C0C	E0E
	F0F	F2F	F4F	F6F	F8F	FAF	FCF	FEF
Black to Magenta-blue to White	000	102	204	306	408	50A	60C	70E
	80F	92F	A4F	B6F	C8F	DAF	ECF	FEF
Black to Blue to White	000	002	004	006	008	00A	00C	00E
	00F	22F	44F	66F	88F	AAF	CCF	EEF
Black to Blue-cyan to White	000	012	042	036	048	05A	06C	07E
	08F	29F	4AF	6BF	8CF	ADF	CEF	EFF
Black to Cyan to White	000	022	044	066	088	0AA	0CC	0EE
	0FF	2FF	4FF	6FF	8FF	AFF	CFF	EFF
Black to Cyan-green to White	000	021	042	063	084	0A5	0C6	0E7
	0F8	2F9	4FA	6FB	8FC	AFD	DFE	EFF
Black to Green to White	000	020	040	060	080	0A0	0C0	0E0
	0F0	2F2	4F4	6F6	8F8	AFA	CFC	EFE
Black to Green-yellow to White	000	120	240	360	480	5A0	6C0	7E0
	8F0	9F2	AF4	BF6	CF8	DFA	EFC	EFF
Black to Yellow to White	000	220	440	660	880	AA0	CC0	EE0
	FF0	FF2	FF4	FF6	FF8	FFA	FFC	FFE
Black to Yellow-red to White	000	210	420	630	840	A50	C60	E70
	F80	F92	FA4	FB6	FC8	FDA	FEC	FFE
Black to Unsaturated Red to White	000	211	422	633	844	A55	C66	E77
	F88	F99	FAA	FBB	FCC	FDD	FEE	FFF
Black to Unsaturated Green to White	000	121	242	363	484	5A5	6C6	7E7
	8F8	9F9	AFA	BFB	CFC	DFD	EFE	FFF
Black to Unsaturated Blue to White	000	112	224	336	448	55A	66C	77E
	88F	99F	AAF	BBF	CCF	DDF	EEF	FFF

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State 1

State 1 divides the 8-bit LUT value into two 4-bit hexadecimal digits. The least-significant digit provides the background color, and the most-significant digit defines the foreground color. The high-function graphics mode interprets a value of 0000 for the most-significant digit as a transparent foreground, allowing the background color to be displayed. Otherwise, the high-function graphics mode ignores the background color.

The following table lists the colors represented by each 4-bit value for State 1.

Value	Color	RGB
0	Sky Blue (background only)	68D
1	Black	000
2	Dark Brown	742
3	Light Brown	A74
4	Dark Red	700
5	Light Red	F00
6	Orange	F70
7	Yellow	FF0
8	Yellow-Green	AF0
9	Light Green	0F0
A	Dark Green	070
B	Green-Blue	077
C	Dark Blue	007
D	Light Burnt-Sienna	E96
E	Grey	777
F	White	FFF

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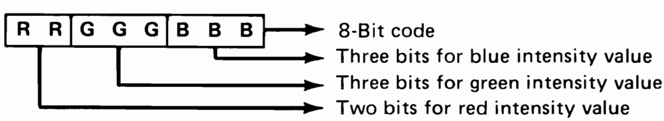
States 2 through 4

For states 2 through 4, red, green, and blue LUT values employ either two or three bits of information. For each state, one color receives two bits while the other two colors each receive three. Each bit value then translates to an RGB intensity of that color. The following tables give the corresponding intensity values for each bit value.

2-Bit Intensity Values		
Decimal Value	**Bit Value**	**Intensity Level**
0	0 0	0
1	0 1	5
2	1 0	10
3	1 1	15

3-Bit Intensity Values		
Decimal Value	**Bit Value**	**Intensity Level**
0	0 0 0	0
1	0 0 1	3
2	0 1 0	5
3	0 1 1	7
4	1 0 0	9
5	1 0 1	11
6	1 1 0	13
7	1 1 1	15

State 2 uses two bits for red (R), three bits for green (G), and three bits for blue (B). Thus, R R G G G B B B means:



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Similarly, state 3 uses two bits for green and three bits each for red and blue (R R R G G B B B). State 4 allows two bits for blue and three bits each for red and green (R R R G G G B B).

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The following table shows the default values for state 2.

Default Values (in Hex) for State 2							
000	003	005	007	009	00B	00D	00F
030	033	035	037	039	03B	03D	03F
050	053	055	057	059	05B	05D	05F
070	073	075	077	079	07B	07D	07E
090	093	095	097	099	09B	09D	09F
0B0	0B3	0B5	0B7	0B9	0BB	0BD	0BF
0D0	0D3	0D5	0D7	0D9	0DB	0DD	0DF
0F0	0F3	0F5	0F7	0F9	0FB	0FD	0FF
050	503	505	507	509	50B	50D	50F
530	533	535	537	539	53B	53D	53F
550	553	555	557	559	55B	55D	55F
570	573	575	577	579	57B	57D	57F
590	593	595	597	599	59B	59D	59F
5B0	5B3	5B5	5B7	5B9	5BB	5BD	5BF
5D0	5D3	5D5	5D7	5D9	5DB	5DD	5DF
5F0	5F3	5F5	5F7	5F9	5FB	5FD	5FF
A00	A03	A05	A07	A09	A0B	A0D	A0F
A30	A33	A35	A37	A39	A3B	A3D	A3F
A50	A53	A55	A57	A59	A5B	A5D	A5F
A70	A73	A75	A77	A79	A7B	A7D	A7F
A90	A93	A95	A97	A99	A9B	A9D	A9F
AB0	AB3	AB5	AB7	AB9	ABB	ABD	ABF
AD0	AD3	AD5	AD7	AD9	ADB	ADD	ADF
AF0	AF3	AF5	AF7	AF9	AFB	AFD	AFF
F00	F03	F05	F07	F09	F0B	F0D	F0F
F30	F33	F35	F37	F39	F3B	F3D	F3F
F50	F53	F55	F57	F59	F5B	F5D	F5F
F70	F73	F75	F77	F79	F7B	F7D	F7F
F90	F93	F95	F97	F99	F9B	F9D	F9F
FB0	FB3	FB5	FB7	FB9	FBB	FBD	FBF
FD0	FD3	FD5	FD7	FD9	FDB	FDD	FDF
FF0	FF3	FF5	FF7	FF9	FFB	FFD	FFF

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The following table shows the default values for state 3.

Default Values (in Hex) for State 3							
000	003	005	007	009	00B	00D	00F
050	053	055	057	059	05B	05D	05F
0A0	0A3	0A5	0A7	0A9	0AB	0AD	0AF
0F0	0F3	0F5	0F7	0F9	0FB	0FD	0FF
300	303	305	307	309	30B	30D	30F
350	353	355	357	359	35B	35D	35F
3A0	3A3	3A5	3A7	3A9	3AB	3AD	3AF
3F0	3F3	3F5	3F7	3F9	3FB	3FD	3FF
500	503	505	507	509	50B	50D	50F
550	553	555	557	559	55B	55D	55F
5A0	5A3	5A5	5A7	5A9	5AB	5AD	5AF
5F0	5F3	5F5	5F7	5F9	5FB	5FD	5FF
700	703	705	707	709	70B	70D	70F
750	753	755	757	759	75B	75D	75F
7A0	7A3	7A5	7A7	7A9	7AB	7AD	7AF
7F0	7F3	7F5	7F7	7F9	7FB	7FD	7FF
900	903	905	907	909	90B	90D	90F
950	953	955	957	959	95B	95D	95F
9A0	9A3	9A5	9A7	9A9	9AB	9AD	9AF
9F0	9F3	9F5	9F7	9F9	9FB	9FD	9FF
B00	B03	B05	B07	B09	B0B	B0D	B0F
B50	B53	B55	B57	B59	B5B	B5D	B5F
BA0	BA3	BA5	BA7	BA9	BAB	BAD	BAF
BF0	BF3	BF5	BF7	BF9	BFB	BFD	BFF
D00	D03	D05	D07	D09	D0B	D0D	D0F
D50	D53	D55	D57	D59	D5B	D5D	D5F
DA0	DA3	DA5	DA7	DA9	DAB	DAD	DAF
DF0	DF3	DF5	DF7	DF9	DFB	DFD	DFF
F00	F03	F05	F07	F09	F0B	F0D	F0F
F50	F53	F55	F57	F59	F5B	F5D	F5F
FA0	FA3	FA5	FA7	FA9	FAB	FAD	FAF
FF0	FF3	FF5	FF7	FF9	FFB	FFD	FFF

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The following table shows the default values for state 4.

Default Values (in Hex) for State 4							
000	005	00A	00F	030	035	03A	03F
050	055	05A	05F	070	075	07A	07F
090	095	09A	09F	0B0	0B5	0BA	0BF
0D0	0D5	0DA	0DF	0F0	0F5	0FA	0FF
300	305	30A	30F	330	335	33A	33F
350	355	35A	35F	370	375	37A	37F
390	395	39A	39F	3B0	3B5	3BA	3BF
3D0	3D5	3DA	3DF	3F0	3F5	3FA	3FF
500	505	50A	50F	530	535	53A	53F
550	555	55A	55F	570	575	57A	57F
590	595	59A	59F	5B0	5B5	5BA	5BF
5D0	5D5	5DA	5DF	5F0	5F5	5FA	5FF
700	705	70A	70F	730	735	73A	73F
750	755	75A	75F	770	775	77A	77F
790	795	79A	79F	7B0	7B5	7BA	7BF
7D0	7D5	7DA	7DF	7F0	7F5	7FA	7FF
900	905	90A	90F	930	935	93A	93F
950	955	95A	95F	970	975	97A	97F
990	995	99A	99F	9B0	9B5	9BA	9BF
9D0	9D5	9DA	9DF	9F0	9F5	9FA	9FF
B00	B05	B0A	B0F	B30	B35	B3A	B3F
B50	B55	B5A	B5F	B70	B75	B7A	B7F
B90	B95	B9A	B9F	BB0	BB5	BBA	BBF
BD0	BD5	BDA	BDF	BF0	BF5	BFA	BFF
D00	D05	D0A	D0F	D30	D35	D3A	D3F
D50	D55	D5A	D5F	D70	D75	D7A	D7F
D90	D95	D9A	D9F	DB0	DB5	DBA	DBF
DD0	DD5	DDA	DDF	DF0	DF5	DFA	DFF
F00	F05	F0A	F0F	F30	F35	F3A	F3F
F50	F55	F5A	F5F	F70	F75	F7A	F7F
F90	F05	F9A	F9F	FB0	FB5	FBA	FBF
FD0	FD5	FDA	FDF	FF0	FF5	FFA	FFF

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State 5

In state 5, the 8-bit value becomes the arithmetic result of the formula (R x 36) + (G x 6) + B, where R, G, and B represent coded values of intensity levels ranging from 0 to 5. The following table defines which coded values correspond to which intensity levels.

Coded RGB Values	Actual Intensity Levels
0	0
1	3
2	6
3	9
4	12
5	15

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The following table shows the default values for state 5:

Default Values (in Hex) for State 5							
000	003	006	009	00C	00F	030	033
036	039	03C	03F	060	063	066	069
06C	06F	090	093	096	099	09C	09F
0C0	0C3	0C6	0C9	0CC	0cF	0F0	0F3
0F6	0F9	0FC	0FF	300	303	306	309
30C	30F	330	333	336	339	33C	33F
360	363	366	369	36C	36F	390	393
396	399	39C	39F	3C0	3C3	3C6	3C9
3CC	3Cf	3F0	3F3	3F6	3F9	3FC	3FF
600	603	606	609	60C	60F	630	633
636	639	63C	63F	660	663	666	669
66C	66F	690	693	696	699	69C	69F
6C0	6C3	6C6	6C9	6CC	6CF	6F0	6F3
6F6	6F9	6FC	6FF	900	903	906	909
90C	90F	930	933	936	939	93C	93F
960	999	99C	99F	9C0	9C3	9C6	9C9
996	999	99C	99F	9C0	9C3	9C6	9C9
9CC	9CF	9F0	9F3	9F6	9F9	9FC	9FF
C00	C03	C06	C09	C0c	C0F	C30	C33
C36	C39	C3C	C3F	C60	C63	C66	C69
C6C	C6F	C90	C93	C96	C99	C9C	C9F
CC0	CC3	CC6	CC9	CCC	CCF	CF0	CF3
CF6	CF9	CFC	CFF	F00	F03	F06	F09
F0C	F0F	F30	F33	F36	F39	F3C	F3F
F60	F99	F9C	F9F	FC0	Fc3	FC6	FC9
F96	F99	F9C	F9F	FC0	FC3	FC6	FC9
FCC	FCF	FF0	FF3	FF6	FF9	FFC	FFF
000	000	000	000	000	000	000	000
000	000	000	000	000	000	000	000
000	000	000	000	000	000	000	000
000	000	000	000	000	000	000	000
000	000	000	000	000	000	000	000

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State 255

State 255 restores the LUT values that were previously saved with the command LUTSAV. These tables can include user-defined values.

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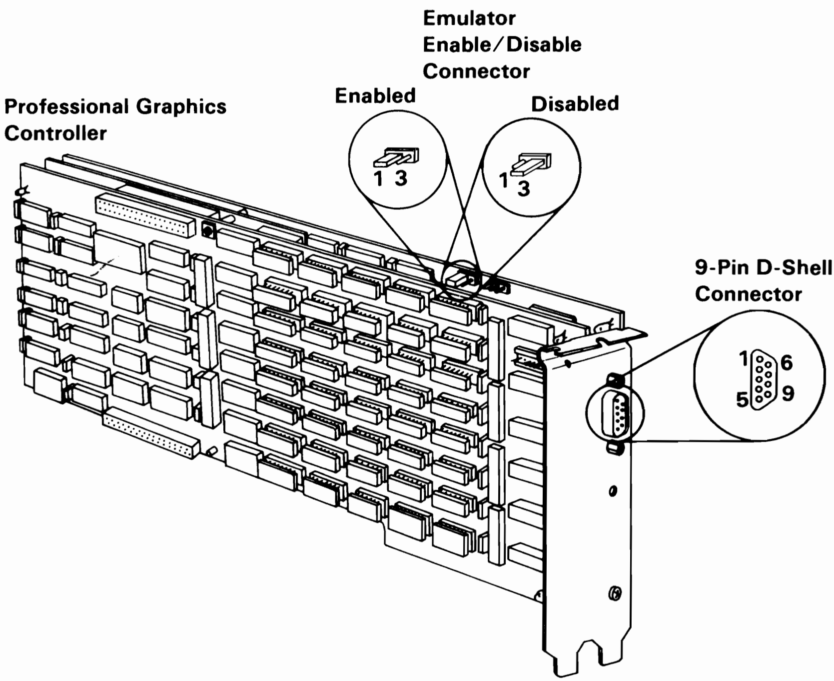
Interface

The following illustration shows the location of the connectors and jumper on the Professional Graphics Controller.



Connector Specifications

The following table shows the pin numbers and their respective signals.

	Signal Name/Description	Pin	
Professional Graphics Display	Red Video	1	**Professional Graphics Controller**
	Green Video	2	
	Blue Video	3	
	Horizontal and Vertical Sync	4	
	Mode Control	5	
	Ground for Pin 1	6	
	Ground for Pin 2	7	
	Ground for Pin 3	8	
	Ground for Pins 4 and 5	9	

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Specifications

The following is a description of the Professional Graphics Controller specifications.

Size:

Length: 668 mm (4.2 in.)

Depth: 32 mm (1.26 in.)

Height: 210 mm (3.36 in.)

Weight: 90.72 kg (2 lb)

Power Requirements:

Voltage: 5 VDC (+/-5%)

Current: 5 A Maximum

Power Dissipation: 25 W Maximum

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Notes:

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Logic Diagrams

This section shows the logic diagrams for:

- Professional Graphics Controller's processor card
- Professional Graphics Controller's emulator card
- Professional Graphics Controller's memory card

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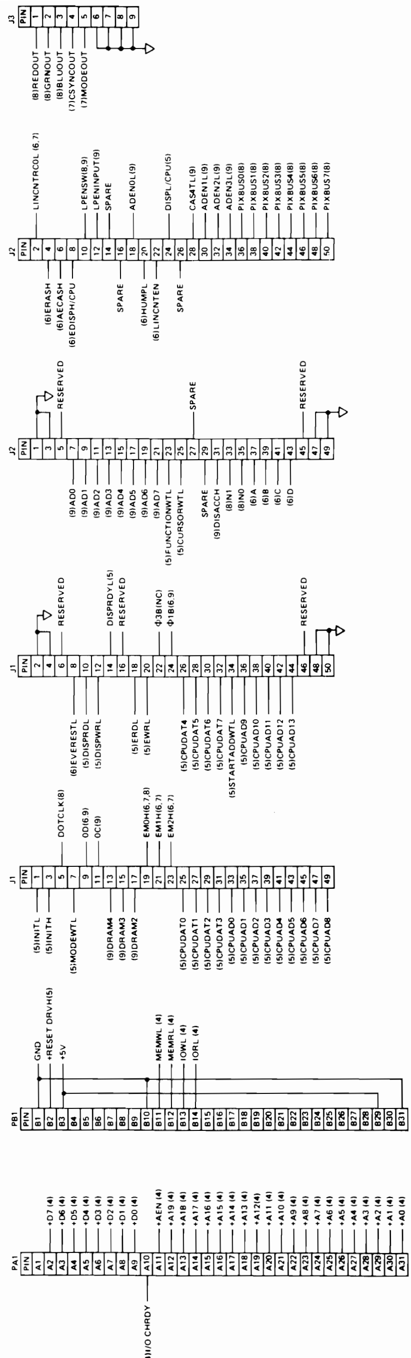

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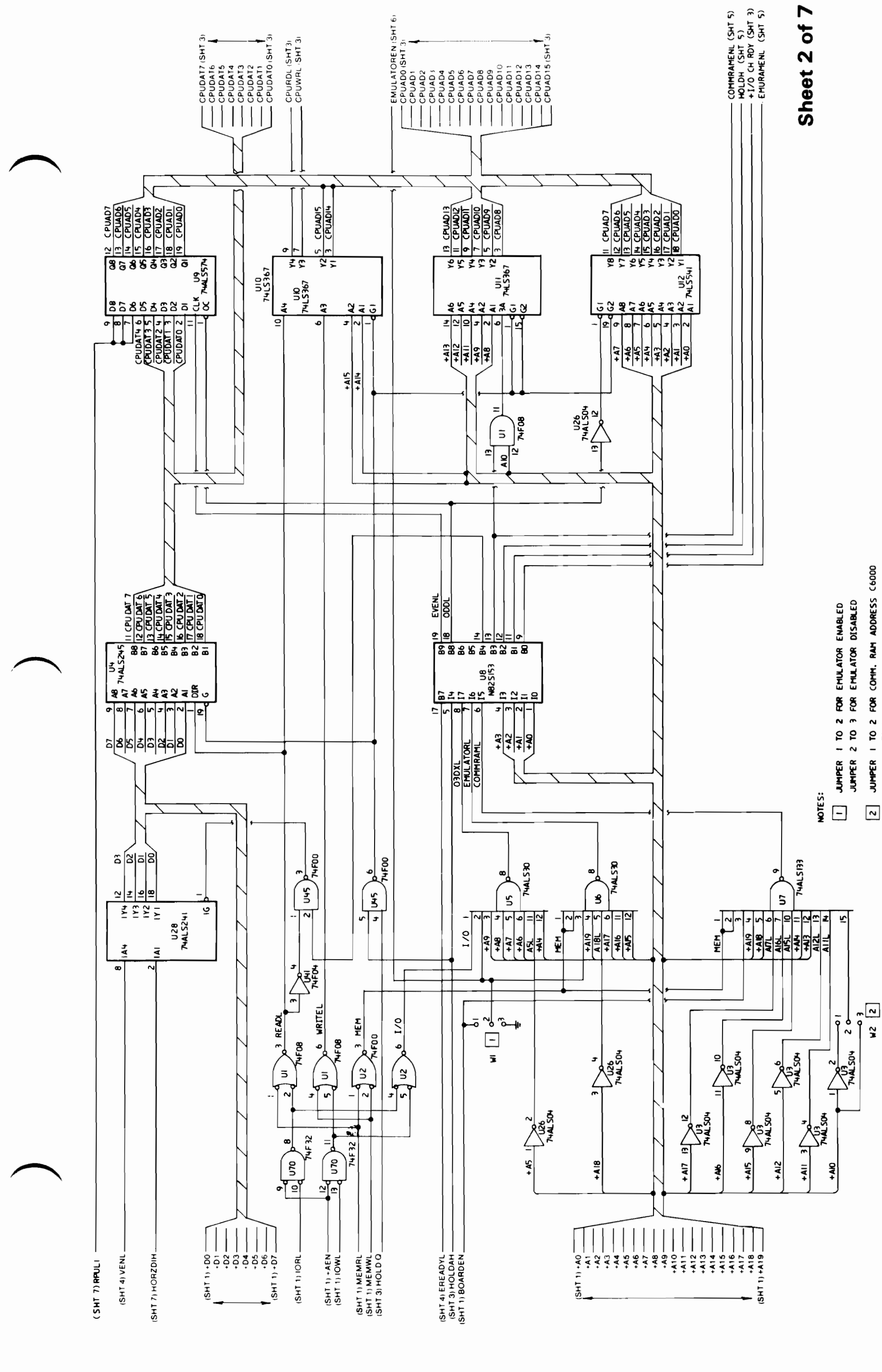

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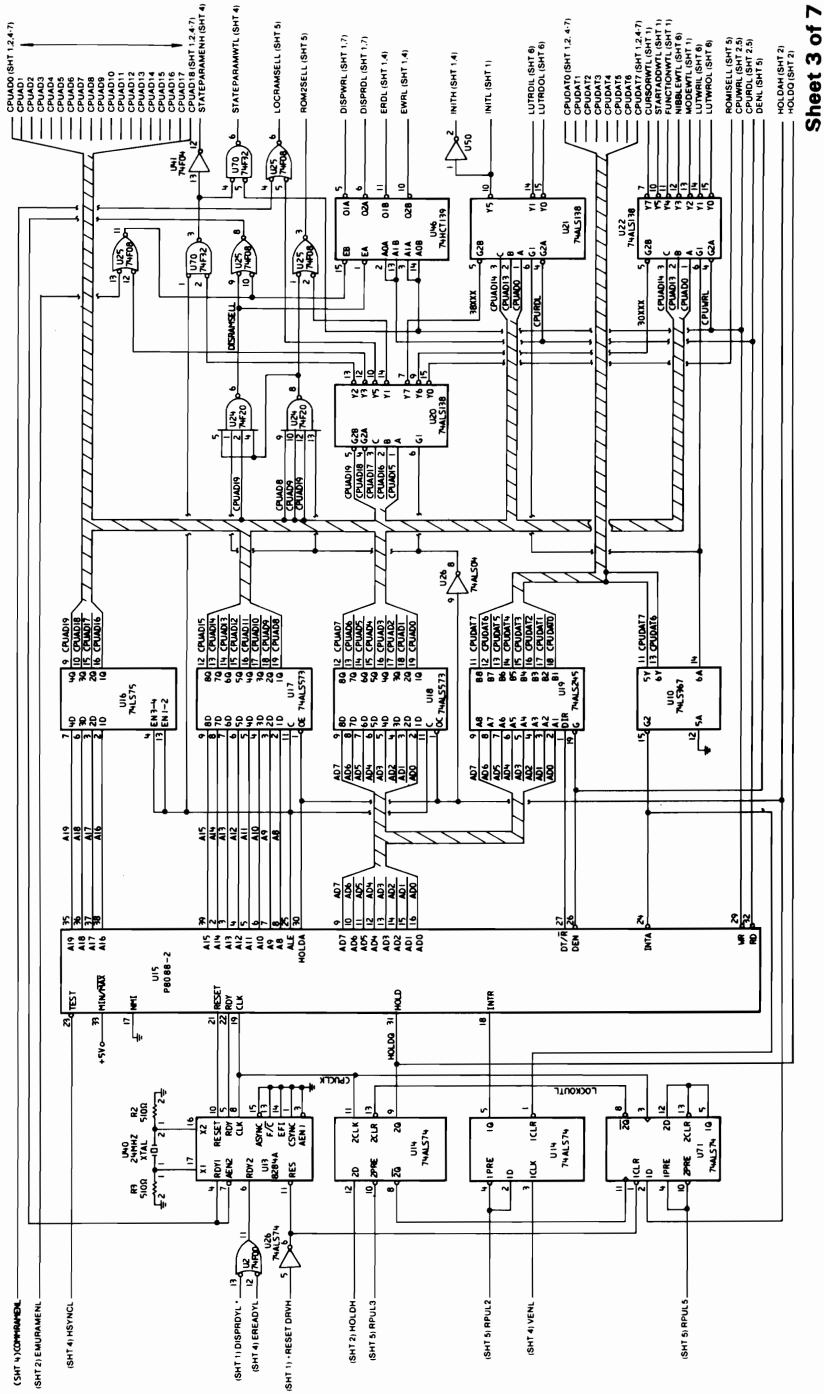

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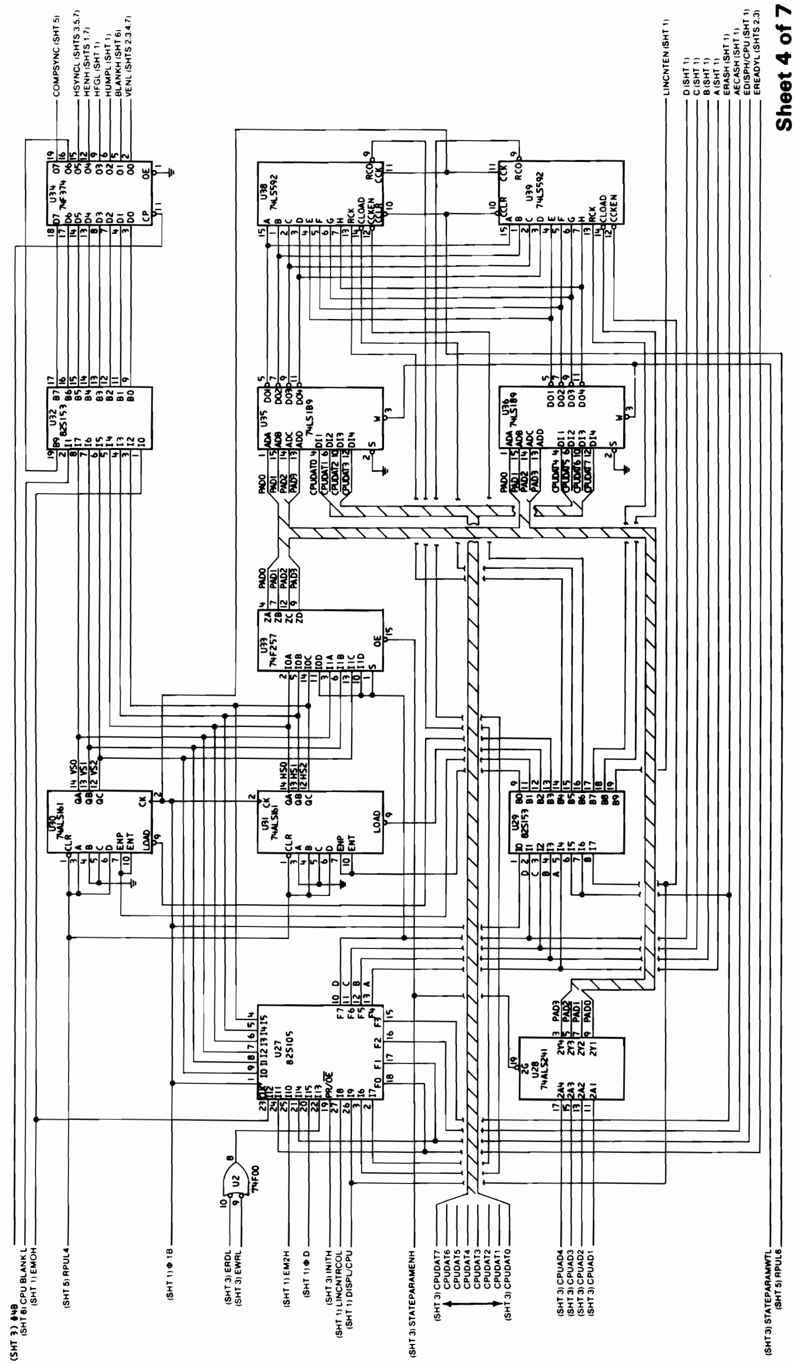

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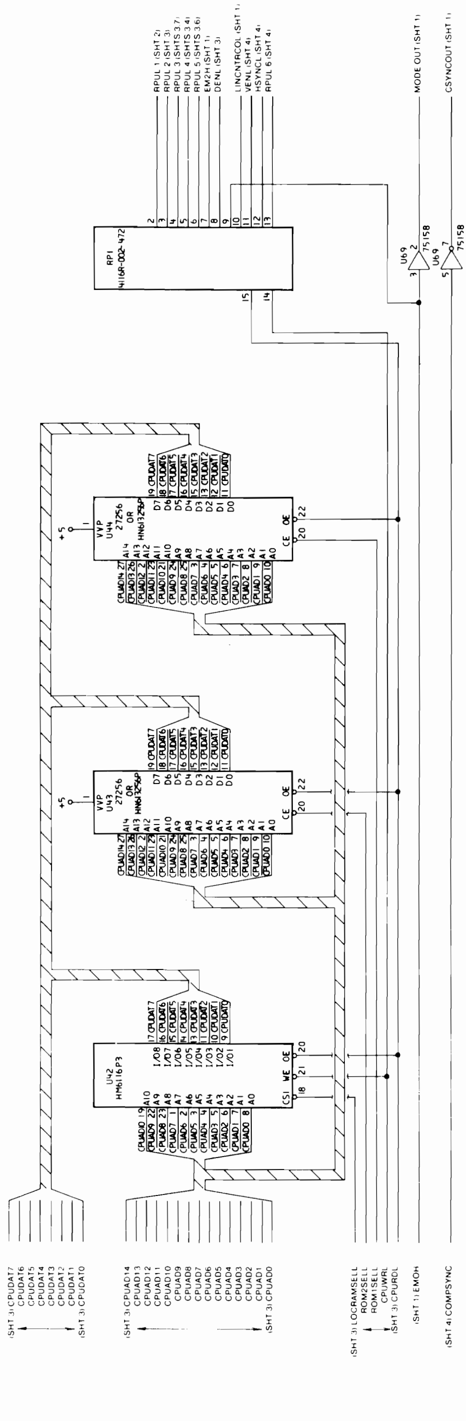

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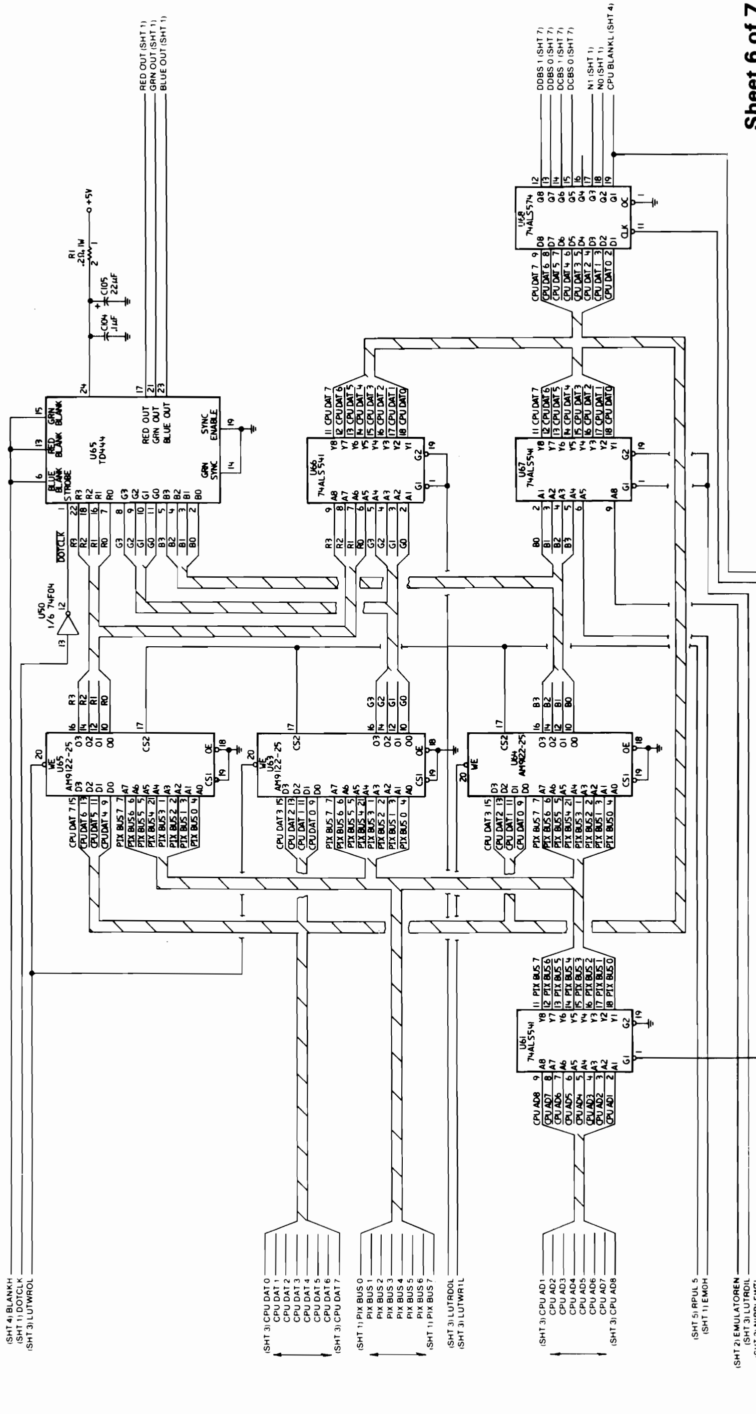
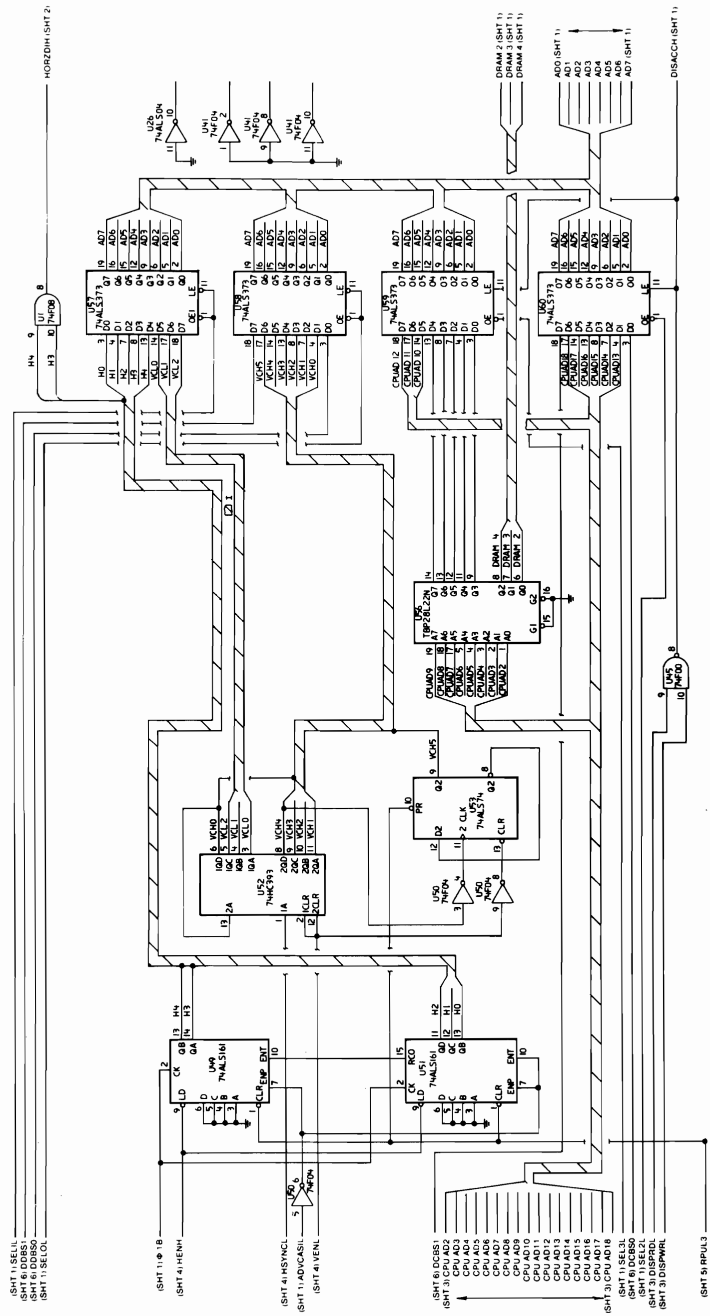

U65 TD444
U50 1/6 74F04
U66 74ALS541
U67 74ALS541
U68 74ALS574
U61 74ALS541
U65 AM9122-25
U63 AM9122-25
U64 AM9122-25
R1 .2Ω 1W
C104 .1µF
C105 22µF
+5V
RED OUT (SHT 1)
GRN OUT (SHT 1)
BLUE OUT (SHT 1)
DDBS 1 (SHT 7)
DDBS 0 (SHT 7)
DCBS 1 (SHT 7)
DCBS 0 (SHT 7)
N1 (SHT 1)
N0 (SHT 1)
CPU BLANKL (SHT 4)
(SHT 4) BLANKH
(SHT 1) DOTCLK
(SHT 3) LUTWR0L
(SHT 3) CPU DAT 0
(SHT 3) CPU DAT 7
(SHT 1) PIX BUS 0
(SHT 1) PIX BUS 7
(SHT 3) LUTRD0L
(SHT 3) LUTWR1L
(SHT 3) CPU AD1
(SHT 3) CPU AD8
(SHT 5) RPUL 5
(SHT 1) EMOH
(SHT 2) EMULATOREN
(SHT 3) LUTRDIL
(SHT 3) NIBBLEWTL



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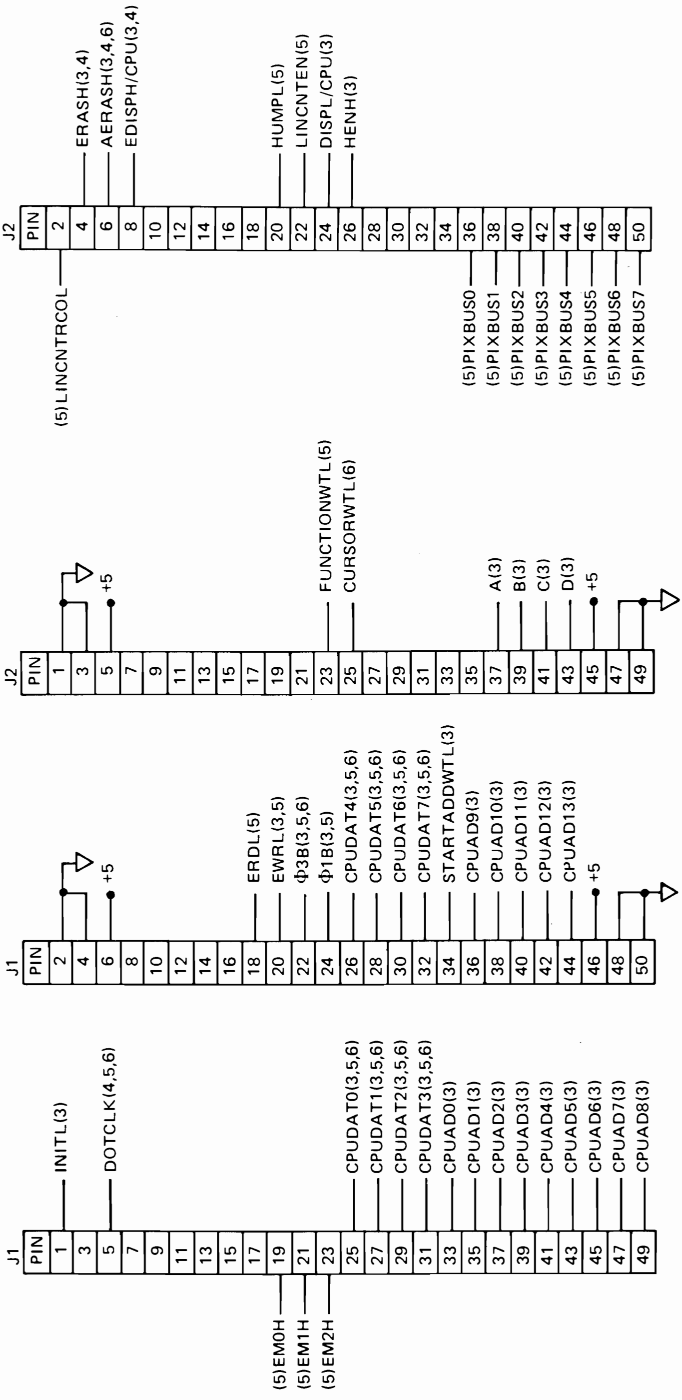
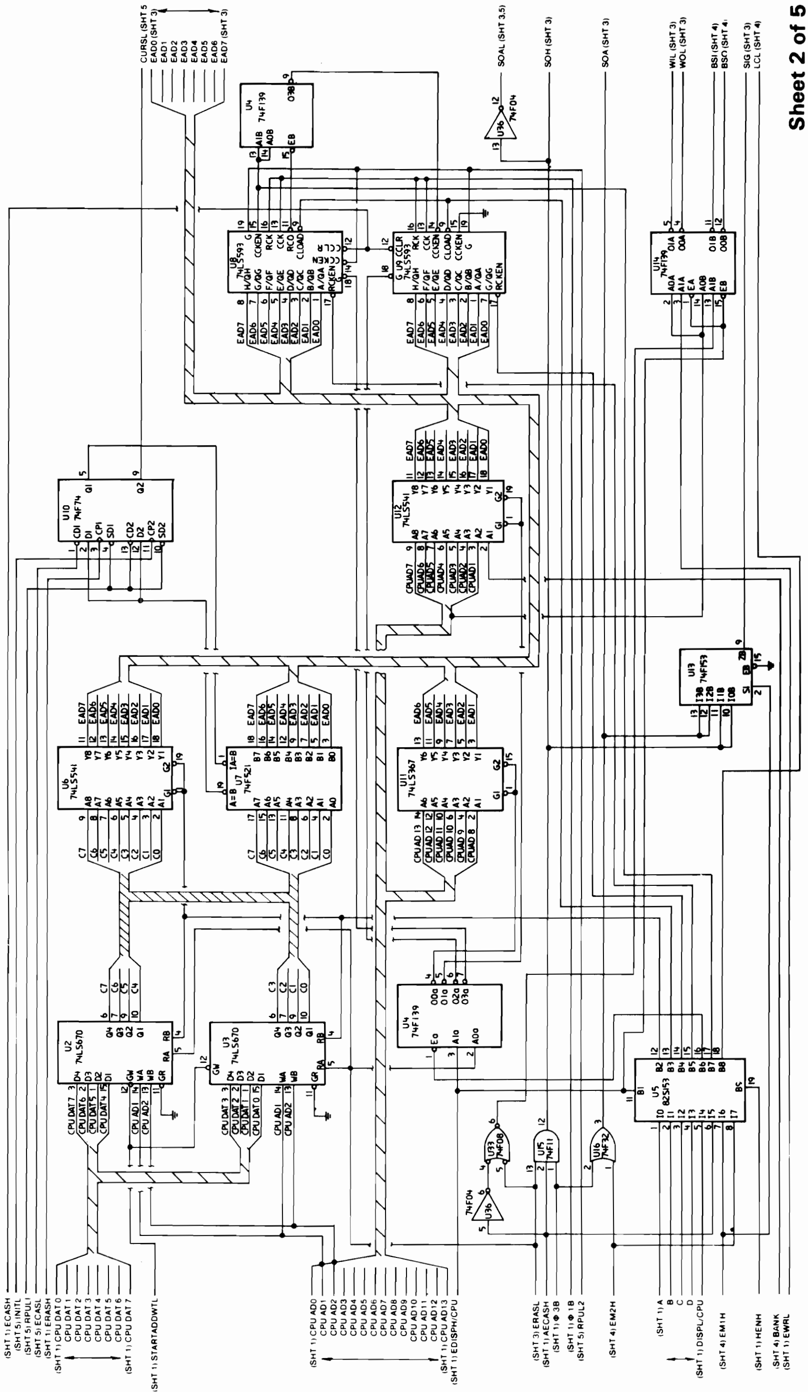

J1
PIN
INITL(3)
DOTCLK(4,5,6)
CPUDAT0(3,5,6)
CPUDAT1(3,5,6)
CPUDAT2(3,5,6)
CPUDAT3(3,5,6)
CPUAD0(3)
CPUAD1(3)
CPUAD2(3)
CPUAD3(3)
CPUAD4(3)
CPUAD5(3)
CPUAD6(3)
CPUAD7(3)
CPUAD8(3)
(5)EM0H
(5)EM1H
(5)EM2H
+5
ERDL(5)
EWRL(3,5)
Φ3B(3,5,6)
Φ1B(3,5)
CPUDAT4(3,5,6)
CPUDAT5(3,5,6)
CPUDAT6(3,5,6)
CPUDAT7(3,5,6)
STARTADDWTL(3)
CPUAD9(3)
CPUAD10(3)
CPUAD11(3)
CPUAD12(3)
CPUAD13(3)
J2
FUNCTIONWTL(5)
CURSORWTL(6)
A(3)
B(3)
C(3)
D(3)
ERASH(3,4)
AERASH(3,4,6)
EDISPH/CPU(3,4)
HUMPL(5)
LINCNTEN(5)
DISPL/CPU(3)
HENH(3)
(5)LINCNTRCOL
(5)PIXBUS0
(5)PIXBUS1
(5)PIXBUS2
(5)PIXBUS3
(5)PIXBUS4
(5)PIXBUS5
(5)PIXBUS6
(5)PIXBUS7

Sheet 1 of 5



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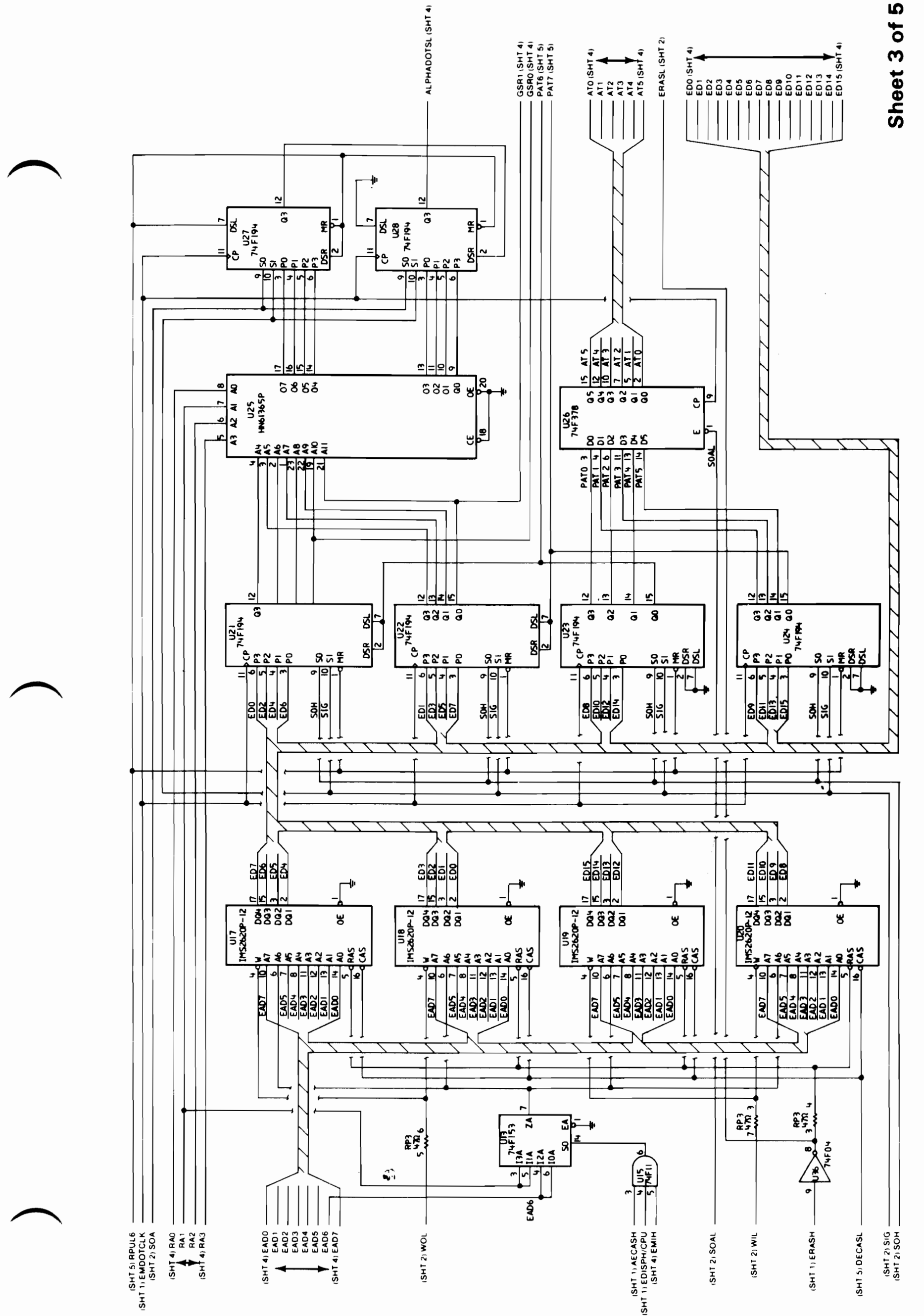
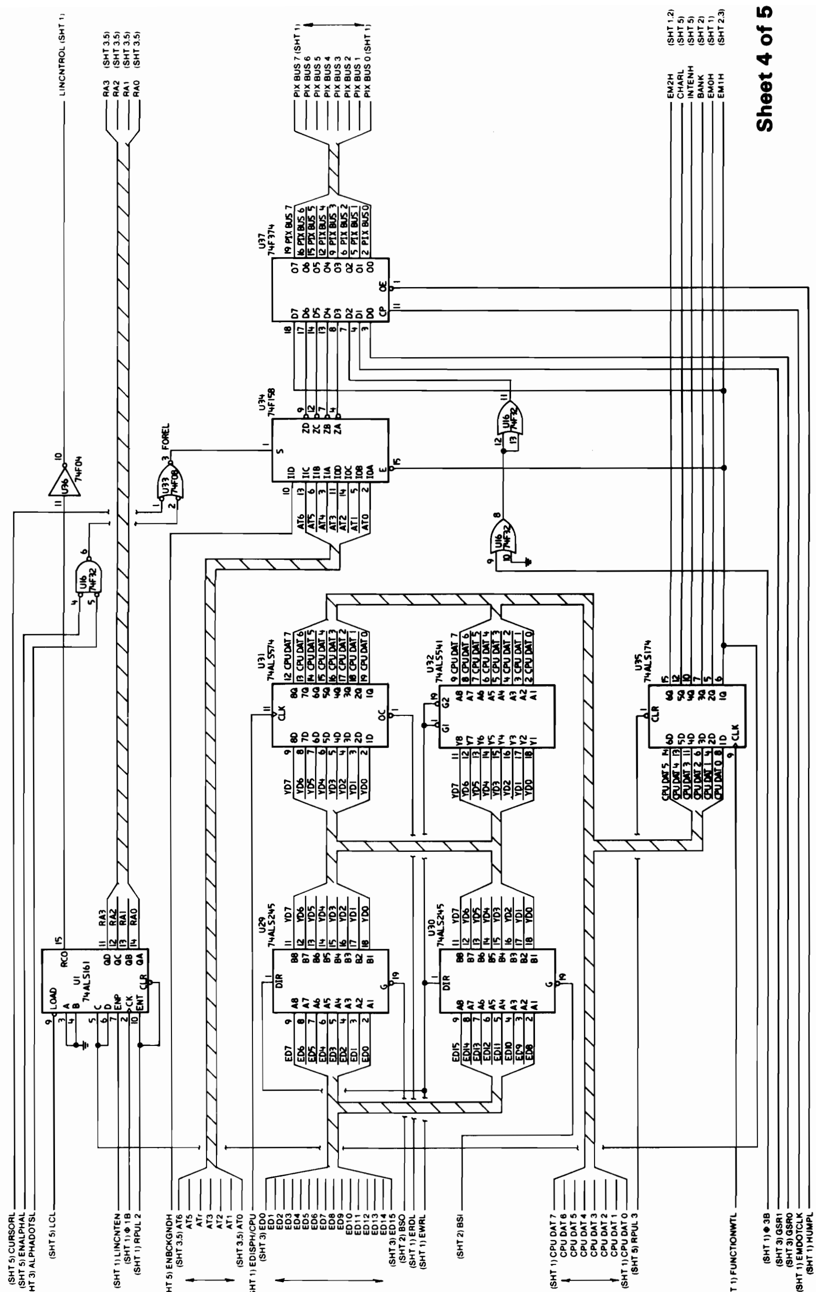

Sheet 3 of 5



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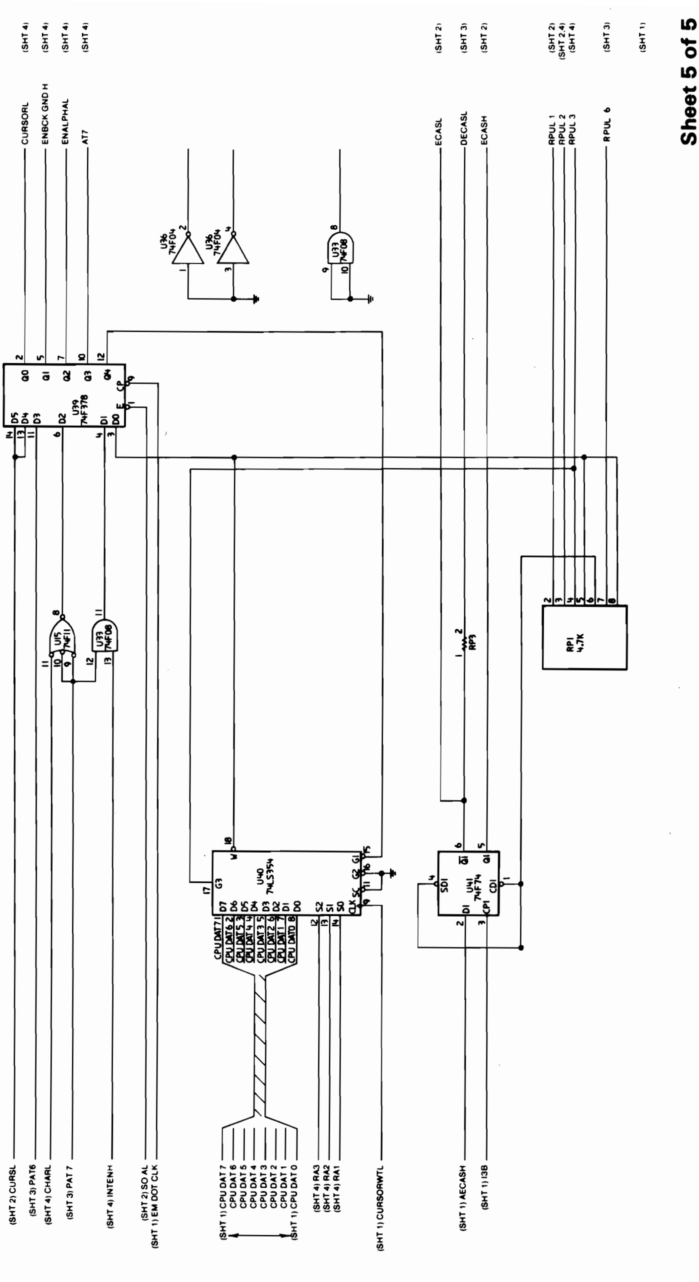
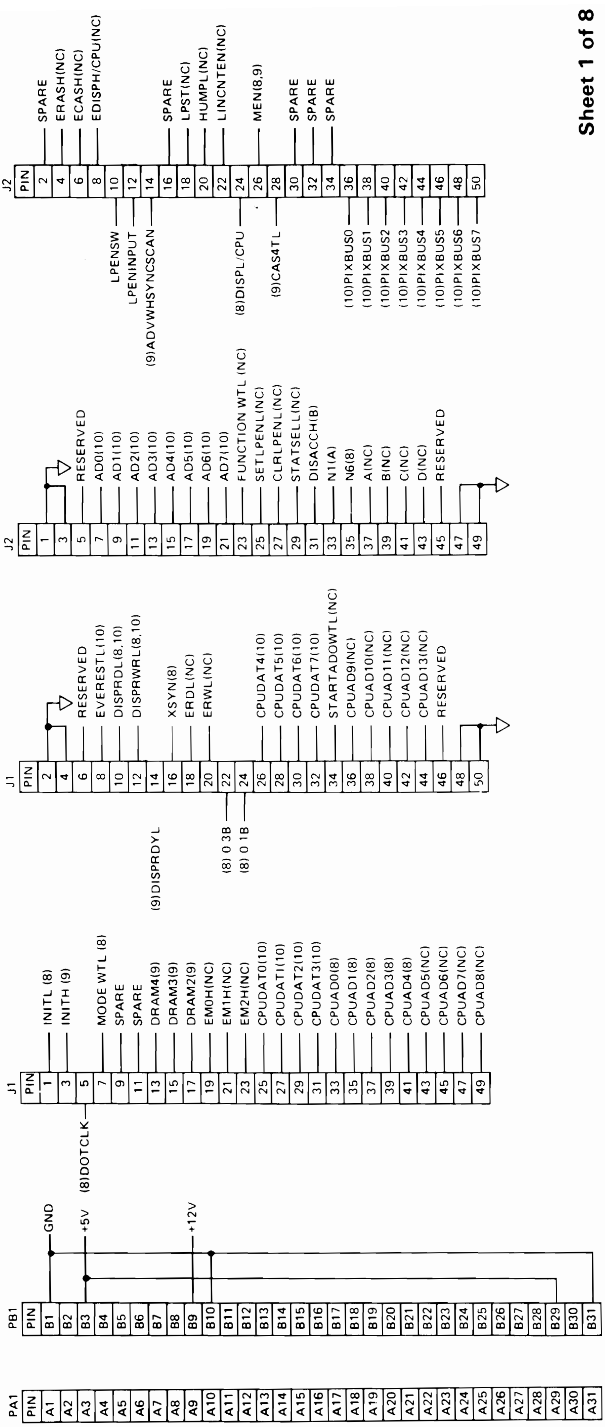

Sheet 5 of 5
U39 74F378
U40 74LS354
U41 74F74
U45 74F11
U33 74F08
U36 74F04
RP1 4.7K
RP3
(SHT 2) CURSL
(SHT 3) PAT6
(SHT 4) CHARL
(SHT 3) PAT 7
(SHT 4) INTENH
(SHT 2) SO AL
(SHT 1) EM DOT CLK
(SHT 1) CPU DAT 7
CPU DAT 6
CPU DAT 5
CPU DAT 4
CPU DAT 3
CPU DAT 2
CPU DAT 1
(SHT 1) CPU DAT 0
(SHT 4) RA3
(SHT 4) RA2
(SHT 4) RA1
(SHT 1) CURSORWTL
(SHT 1) AECASH
(SHT 1) I3B
CURSORL (SHT 4)
ENBCK GND H (SHT 4)
ENALPHAL (SHT 4)
AT7 (SHT 4)
ECASL (SHT 2)
DECASL (SHT 3)
ECASH (SHT 2)
RPUL 1 (SHT 2)
RPUL 2 (SHT 2,4)
RPUL 3 (SHT 4)
RPUL 6 (SHT 3)
(SHT 1)



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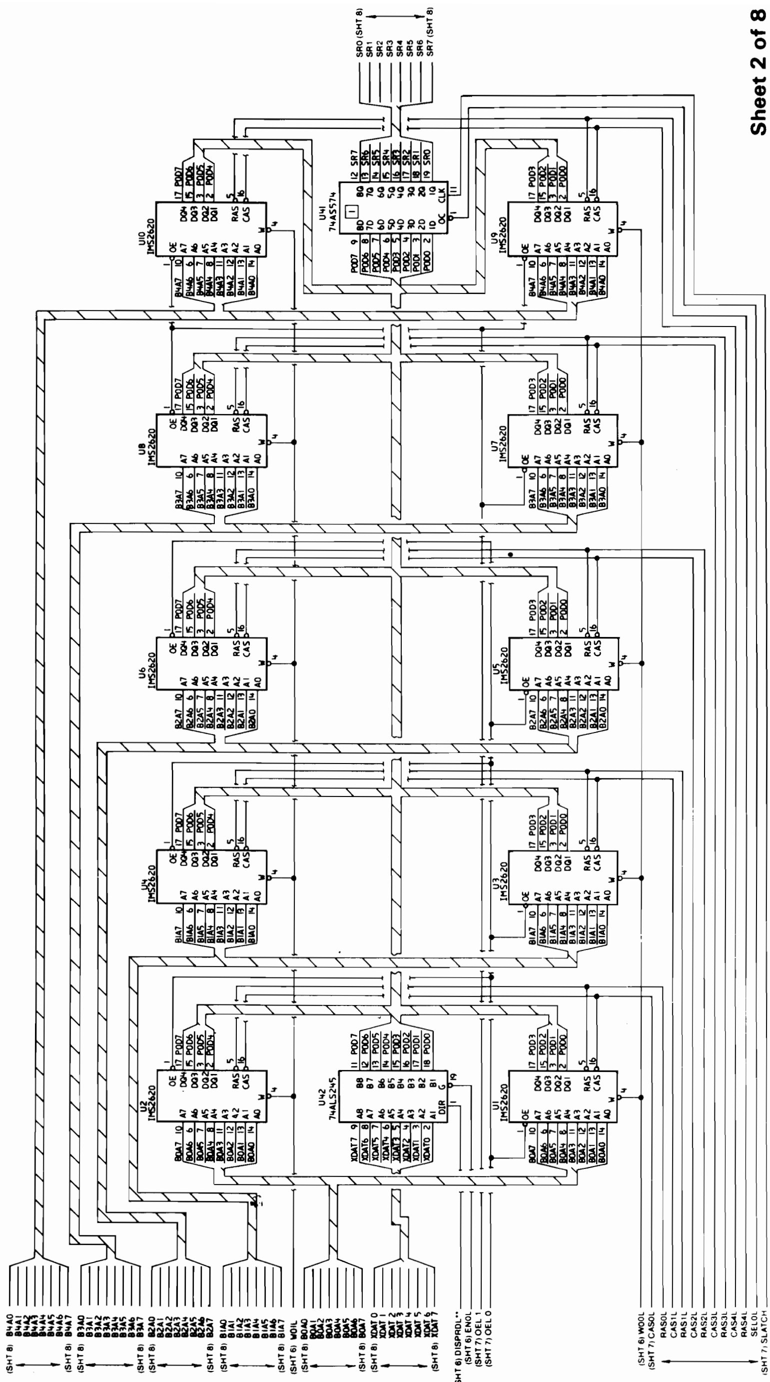
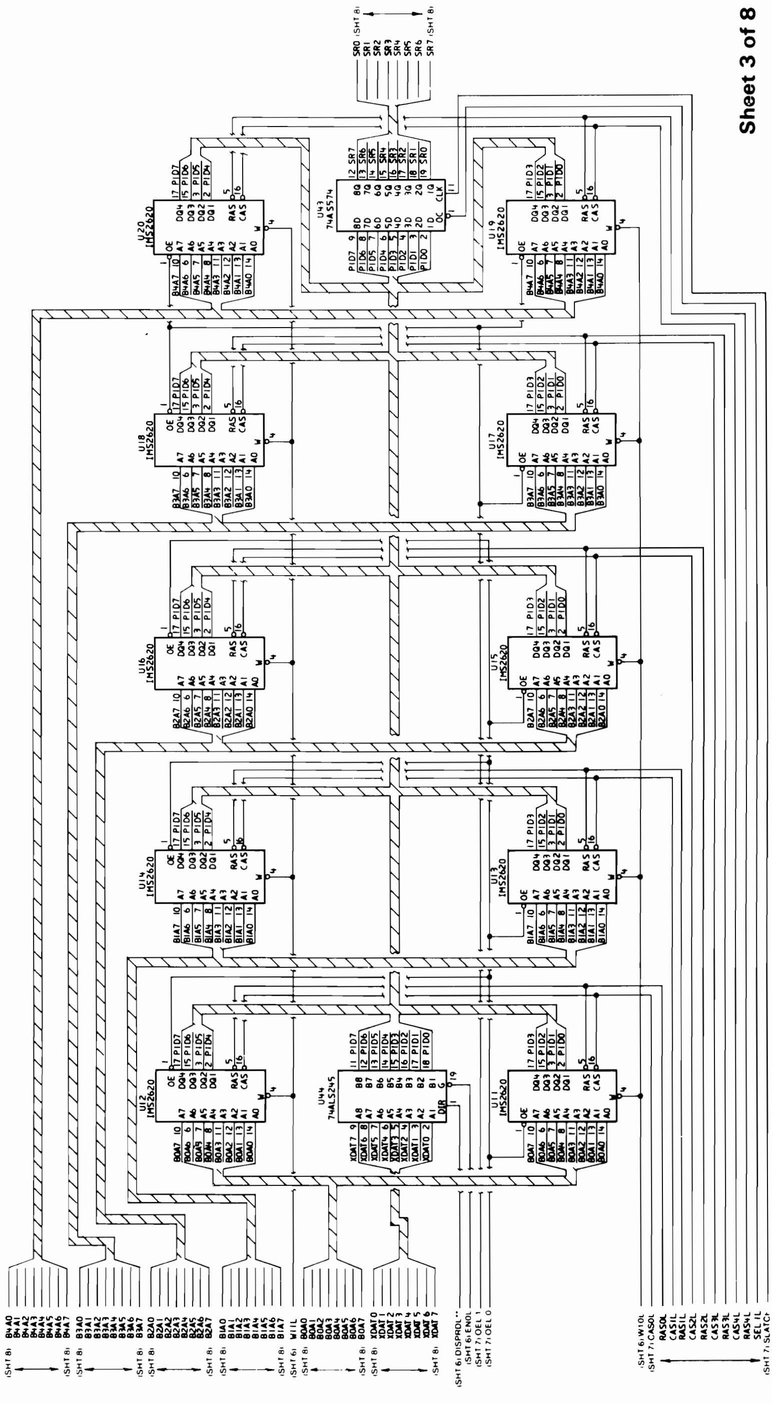


Sheet 2 of 8



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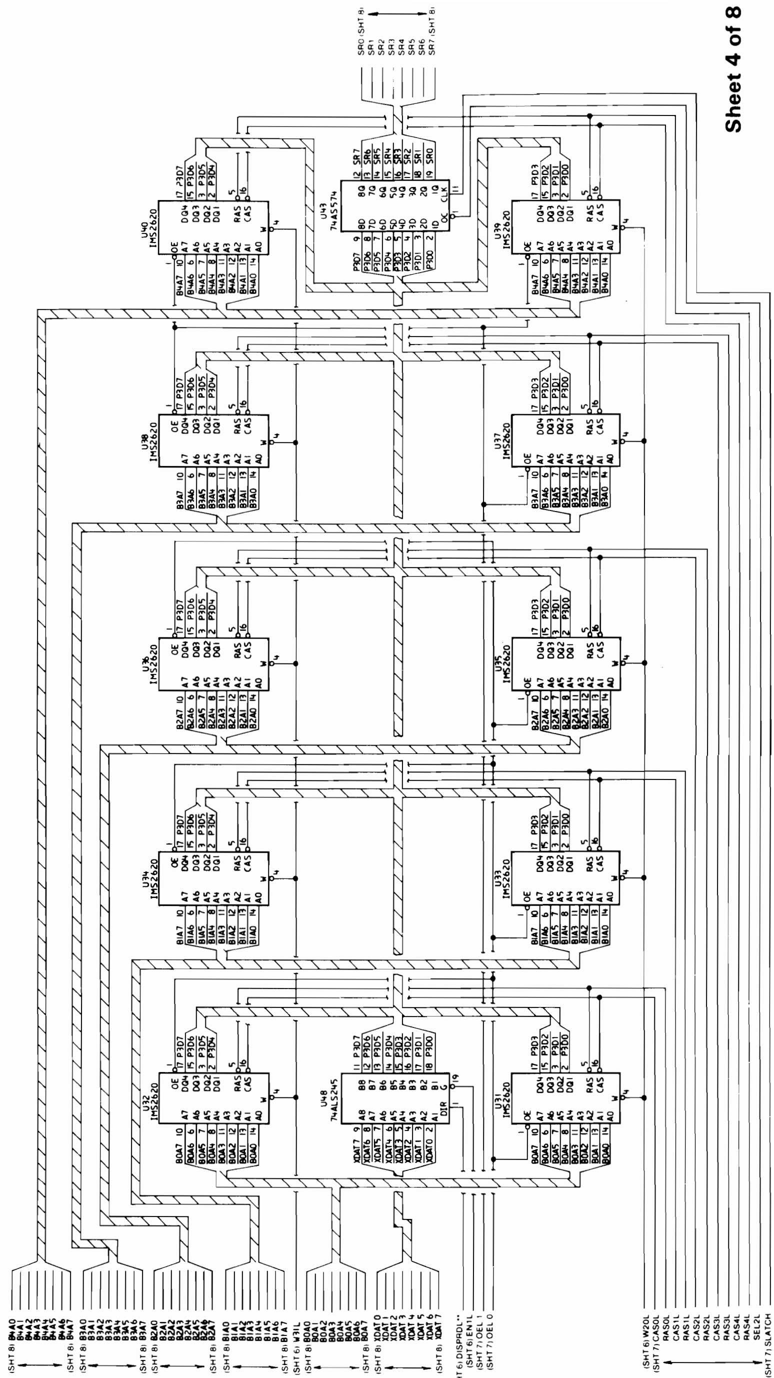

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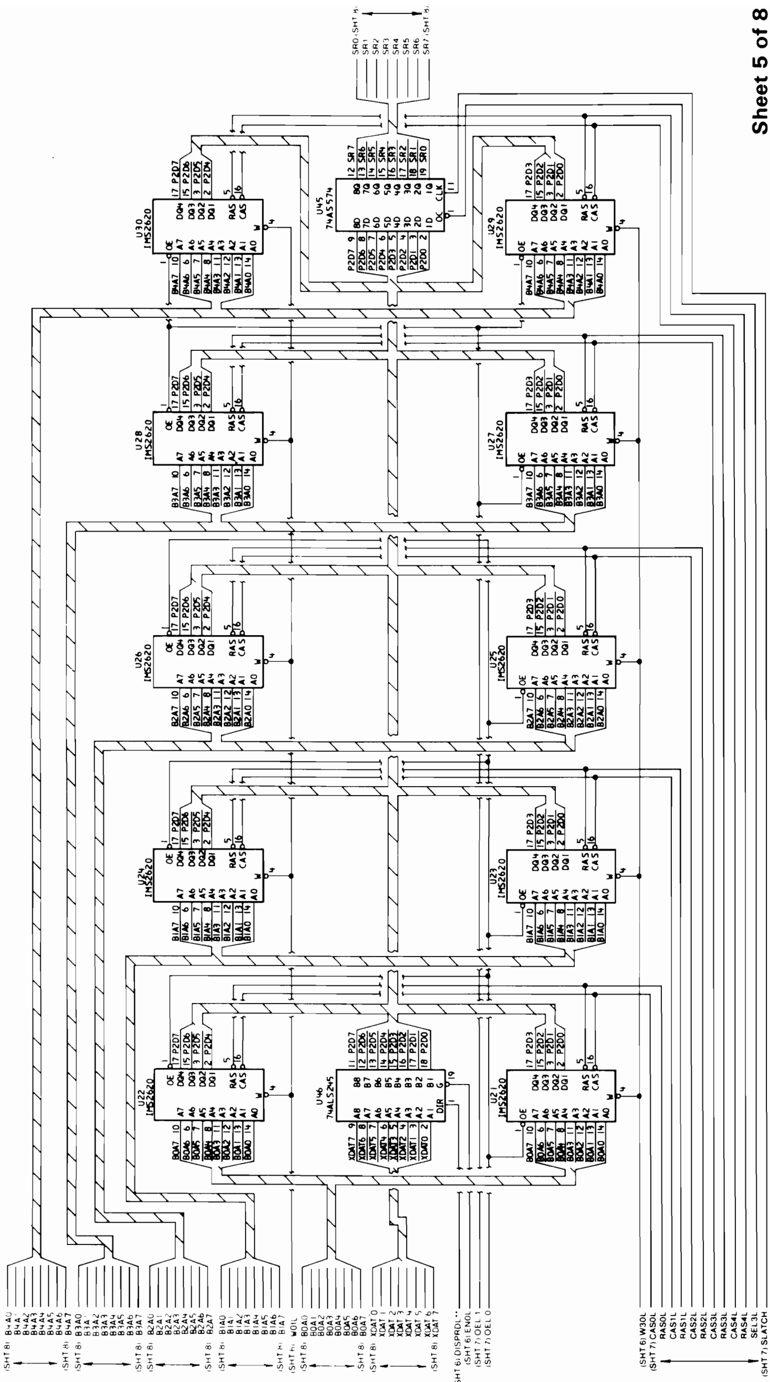

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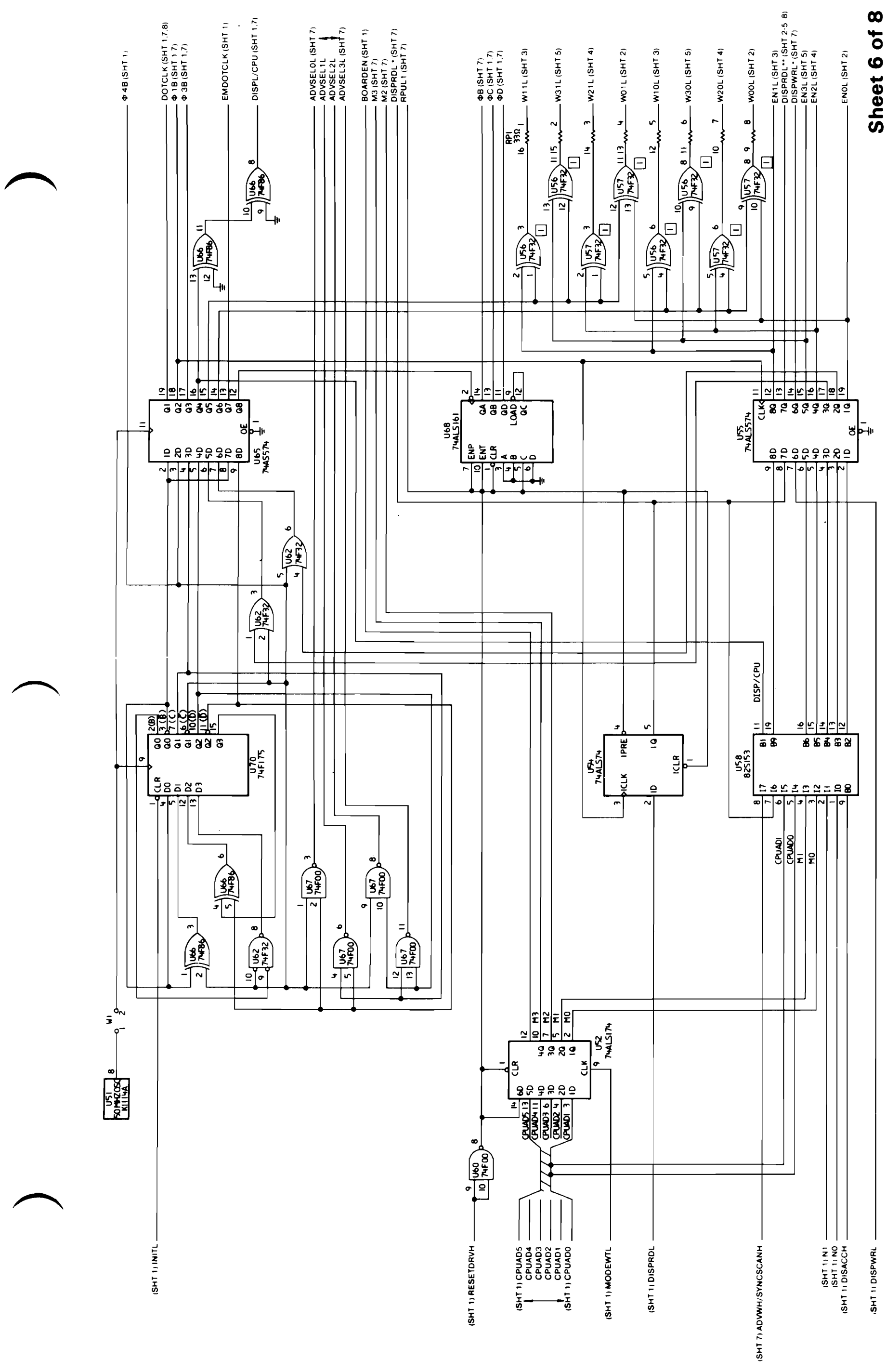
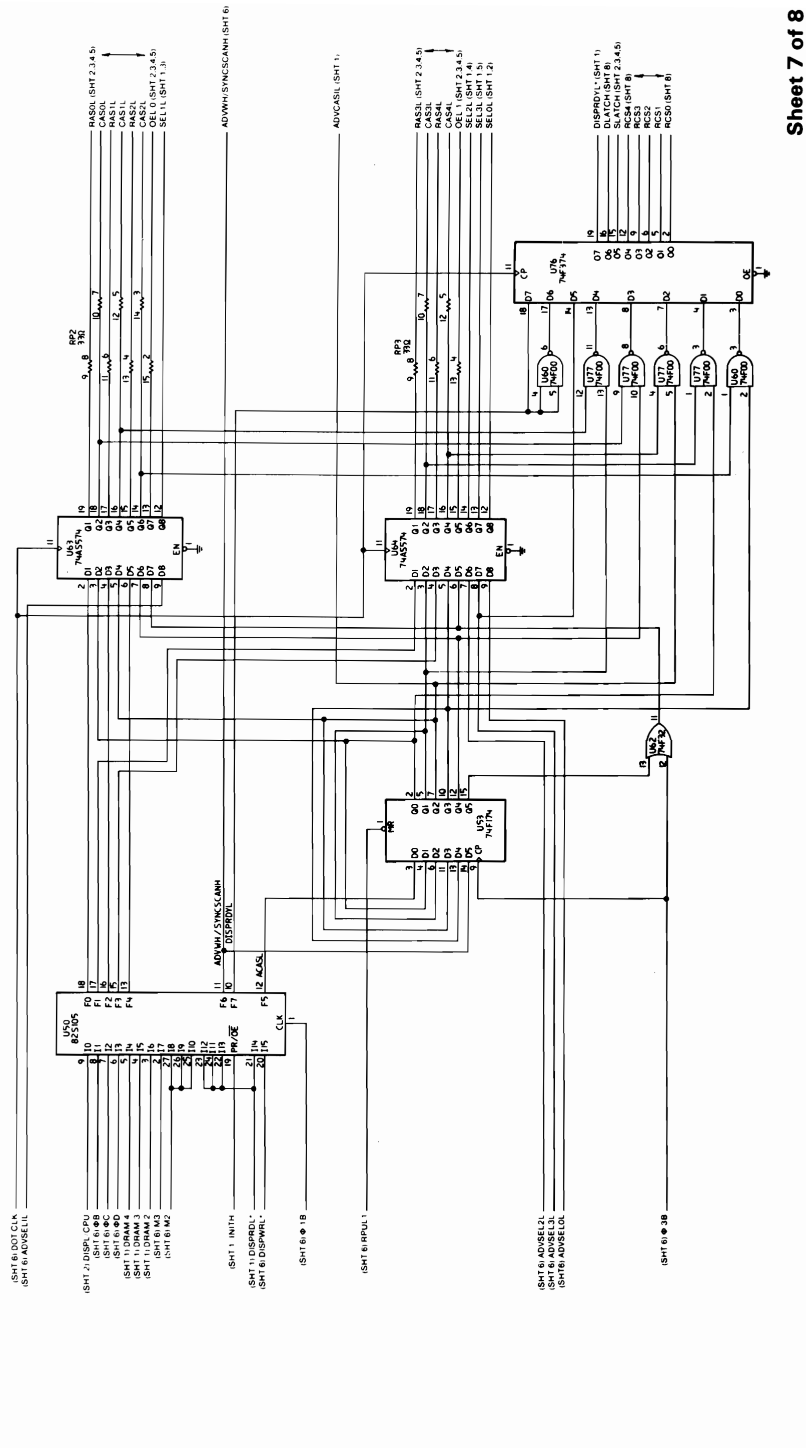

Sheet 6 of 8
Φ4B (SHT 1)
DOTCLK (SHT 1,7,8)
Φ1B (SHT 1,7)
Φ3B (SHT 1,7)
EMDOTCLK (SHT 1)
DISPL/CPU (SHT 1,7)
ADVSEL0L (SHT 7)
ADVSEL1L
ADVSEL2L
ADVSEL3L (SHT 7)
BOARDEN (SHT 1)
M3 (SHT 7)
M2 (SHT 7)
DISPRDL* (SHT 7)
RPUL1 (SHT 7)
ΦB (SHT 7)
ΦC (SHT 1,7)
ΦD (SHT 1,7)
W11L (SHT 3)
W31L (SHT 5)
W21L (SHT 4)
W01L (SHT 2)
W10L (SHT 3)
W30L (SHT 5)
W20L (SHT 4)
W00L (SHT 2)
EN1L (SHT 3)
DISPRDL** (SHT 2-5 8)
DISPWRL* (SHT 7)
EN3L (SHT 5)
EN2L (SHT 4)
EN0L (SHT 2)
RP1 330Ω
U65 74AS574
U68 74ALS161
U55 74ALS574
U70 74F175
U54 74ALS74
U58 82S153
U52 74ALS174
U51 50MHZ OSC K1114A
U60 74F00
U62 74F32
U66 74F86
U67 74F00
U56 74F32
U57 74F32
W1
DISP/CPU
CPUAD1
CPUAD0
M1
M0
(SHT 1) INITL
(SHT 1) RESETDRVH
(SHT 1) CPUAD5
CPUAD4
CPUAD3
CPUAD2
CPUAD1
(SHT 1) CPUAD0
(SHT 1) MODEWTL
(SHT 1) DISPRDL
(SHT 7) ADVWH/SYNCSCANH
(SHT 1) N1
(SHT 1) N0
(SHT 1) DISACCH
(SHT 1) DISPWRL



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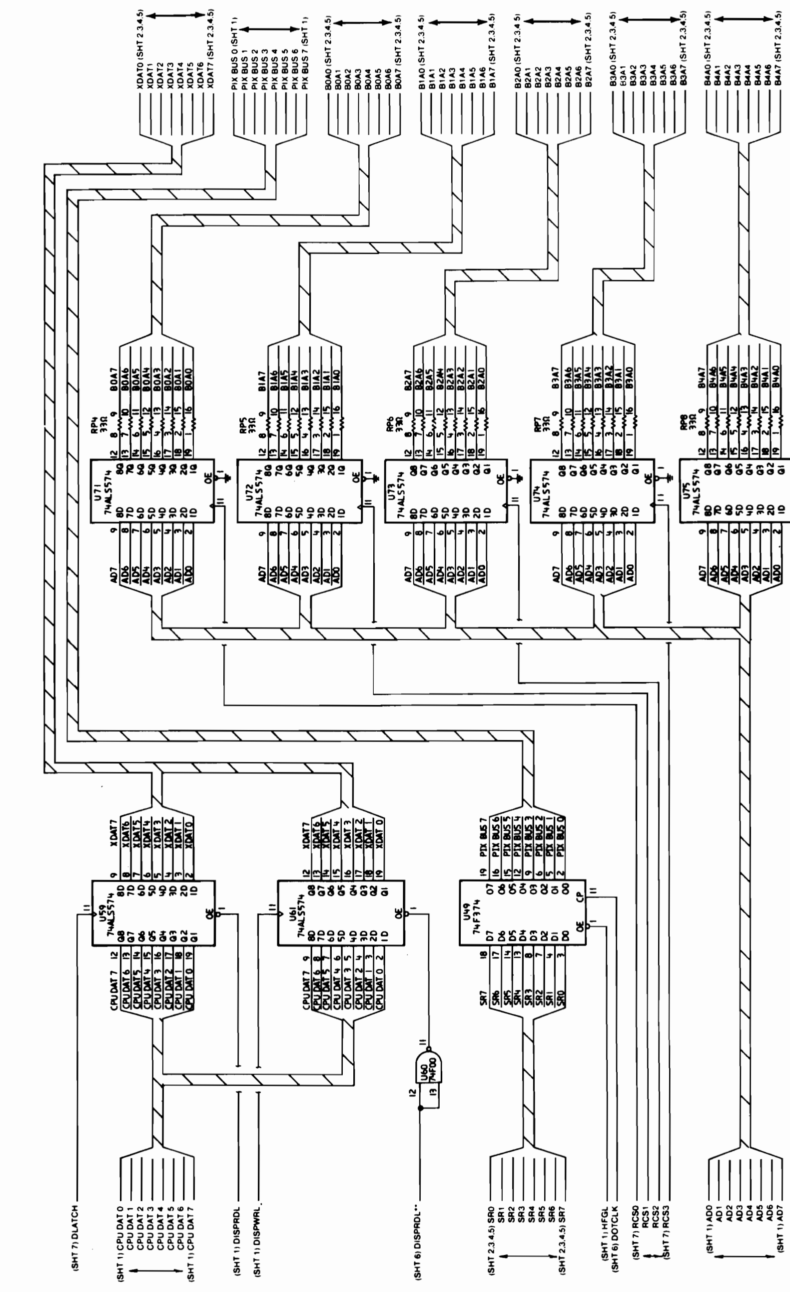

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Glossary

algorithm. A finite set of well-defined rules for the solution of a problem in a finite number of steps.

alphanumeric (A/N). Pertaining to a character set that contains letters, digits, and usually other characters, such as punctuation marks.

American National Standard Code for Information Exchange (ASCII). The standard code, using a coded character set consisting of 7-bit coded characters (8 bits including parity check) used for information exchange between data processing systems, data communication systems, and associated equipment. The ASCII set consists of control characters and graphic characters.

A/N. Alphanumeric

ASCII. American National Standard Code for Information Exchange.

Cartesian coordinates. A system of coordinates for locating a point on a plane by its distance from each of two intersecting lines, or in space by its distance from each of three mutually perpendicular planes.

cathode ray tube (CRT). A vacuum tube in which a stream of electrons is projected onto a fluorescent screen producing a luminous spot. The location of the spot can be controlled.

cathode ray tube display (CRT display). (1) A CRT used for displaying data. For example, the electron beam can be controlled to form alphanumeric data by use of a dot matrix. (2) Synonymous with monitor.

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clipping. In computer graphics, removing parts of a display image that lie outside a window.

color cone. An arrangement of the visible colors on the surface of a double-ended cone where lightness varies along the axis of the cone, and hue varies around the circumference. Lightness includes both the intensity and saturation of color.

complement. A number that can be derived from a specified number by subtracting it from a second specified number.

coordinate space. In computer graphics, a system of Cartesian coordinates in which an object is defined.

cursor. (1) In computer graphics, a movable marker that is used to indicate a position on a display. (2) A displayed symbol that acts as a marker to help the user locate a point in text, in a system command, or in storage. (3) A movable spot of light on the screen of a display device, usually indicating where the next character is to be entered, replaced, or deleted.

debounce. (1) An electronic means of overcoming the make/break bounce of switches to obtain one smooth change of signal level. (2) The elimination of undesired signal variations caused by mechanically generated signals from contacts.

display. (1) A visual presentation of data. (2) A device for visual presentation of information on any temporary character imaging device. (3) To present data visually. (4) See cathode ray tube display.

display attribute. In computer graphics, a particular property that is assigned to all or part of a display; for example, low intensity, green color, blinking status.

display element. In computer graphics, a basic graphic element that can be used to construct a display image; for example, a dot, a line segment, a character.

display group. In computer graphics, a collection of display elements that can be manipulated as a unit and that can be further combined to form larger groups.

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display image. In computer graphics, a collection of display elements or display groups that are represented together at any one time in a display space.

display space. In computer graphics, that portion of a display surface available for a display image. The display space may be all or part of a display surface.

display surface. In computer graphics, that medium on which display images may appear; for example, the entire screen of a cathode ray tube.

drawing primitive. A group of commands that draw defined geometric shapes.

field-programmable-logic-sequencer (FPLS). An integrated circuit containing a programmable, read-only memory that responds to external inputs and feedback of its own outputs.

FIFO (first-in-first-out). A queuing technique in which the next item to be retrieved is the item that has been in the queue for the longest time.

FPLS. Field-programmable-logic-sequencer.

hither plane. In computer graphics, a plane that is perpendicular to the line joining the viewing reference point and the view point and which lies between these two points. Any part of an object between the hither plane and the view point is not seen. See also yon plane.

intensity. In computer graphics, the amount of light emitted at a display point.

interleave. To arrange parts of one sequence of things or events so that they alternate with parts of one or more other sequences of the same nature and so that each sequence retains its identity.

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least-significant digit. The rightmost digit.

look-up table (LUT). (1) A technique for mapping one set of values into a larger set of values. (2) In computer graphics, a table that assigns a color value (red, green, blue intensities) to a color index.

luminance. The luminous intensity per unit projected area of a given surface viewed from a given direction.

LUT. Look-up table.

mask. (1) A pattern of characters that is used to control the retention or elimination of portions of another pattern of characters. (2) To use a pattern of characters to control the retention or elimination of portions of another pattern of characters.

matrix. (1) A rectangular array of elements, arranged in rows and columns, that may be manipulated according to the rules of matrix algebra. (2) In computers, a logic network in the form of an array of input leads and output leads with logic elements connected at some of their intersections.

mode. (1) A method of operation; for example, the binary mode, the interpretive mode, the alphanumeric mode. (2) The most frequent value in the statistical sense.

modeling transformation. Operations on the coordinates of an object (usually matrix multiplications) which cause the object to be rotated about any axis, translated (moved without rotating), and/or scaled (changed in size along any or all dimensions). See also viewing transformation.

modulo-N check. A check in which an operand is divided by a number N (the modulus) to generate a remainder (check digit) that is retained with the operand. For example, in a modulo-7 check, the remainder will be 0, 1, 2, 3, 4, 5, or 6. The operand is later checked by again dividing it by the modulus; if the remainder is not equal to the check digit, an error is indicated.

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modulus. In a modulo-N check, the number by which the operand is divided.

monitor. Synonym for cathode ray tube display (CRT display).

most-significant digit. The leftmost (non-zero) digit.

nanosecond (ns). 0.000 000 001 second.

ns. Nanosecond; 0.000 000 001 second.

PEL. Picture element.

picture element (PEL). The smallest displayable unit on a display.

raster. A predetermined pattern of lines that provides uniform coverage of a display space.

saturation. In computer graphics, the purity of a particular hue. A color is said to be saturated when at least one primary color (red, green, or blue) is completely absent.

scaling. In computer graphics, enlarging or reducing all or part of a display image by multiplying the coordinates of the image by a constant value.

vector. In computer graphics, a directed line segment.

view point. In computer graphics, the origin from which angles and scales are used to map virtual space into display space.

viewing reference point. In computer graphics, a point in the modeling coordinate space that is a defined distance from the view point.

viewing transformation. Operations on the coordinates of an object (usually matrix multiplications) which cause the view of

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the object to be rotated about any axis, translated (moved without rotating), and/or scaled (changed in size along any or all dimensions). Viewing transformations differ from modeling transformations in that perspective is taken into account. See also modeling transformation.

viewplane. In computer graphics, a two-dimensional coordinate system onto which images are projected and which contains the display space.

viewport. In computer graphics, a predefined part of the display space.

virtual space. In computer graphics, a space in which the coordinates of the display elements are expressed in terms of user coordinates.

window. (1) In computer graphics, a predefined part of the virtual space. (2) In computer graphics, the visible area of a viewplane mapped into a viewport.

yon plane. In computer graphics, a plane that is perpendicular to the line joining the viewing reference point and the view point and which lies beyond the viewing reference point. Any part of an object beyond the yon plane is not seen. See also hither plane.

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