GRAPHICS DISPLAY SYSTEM
REFERENCE MANUAL

VECTOR GENERAL

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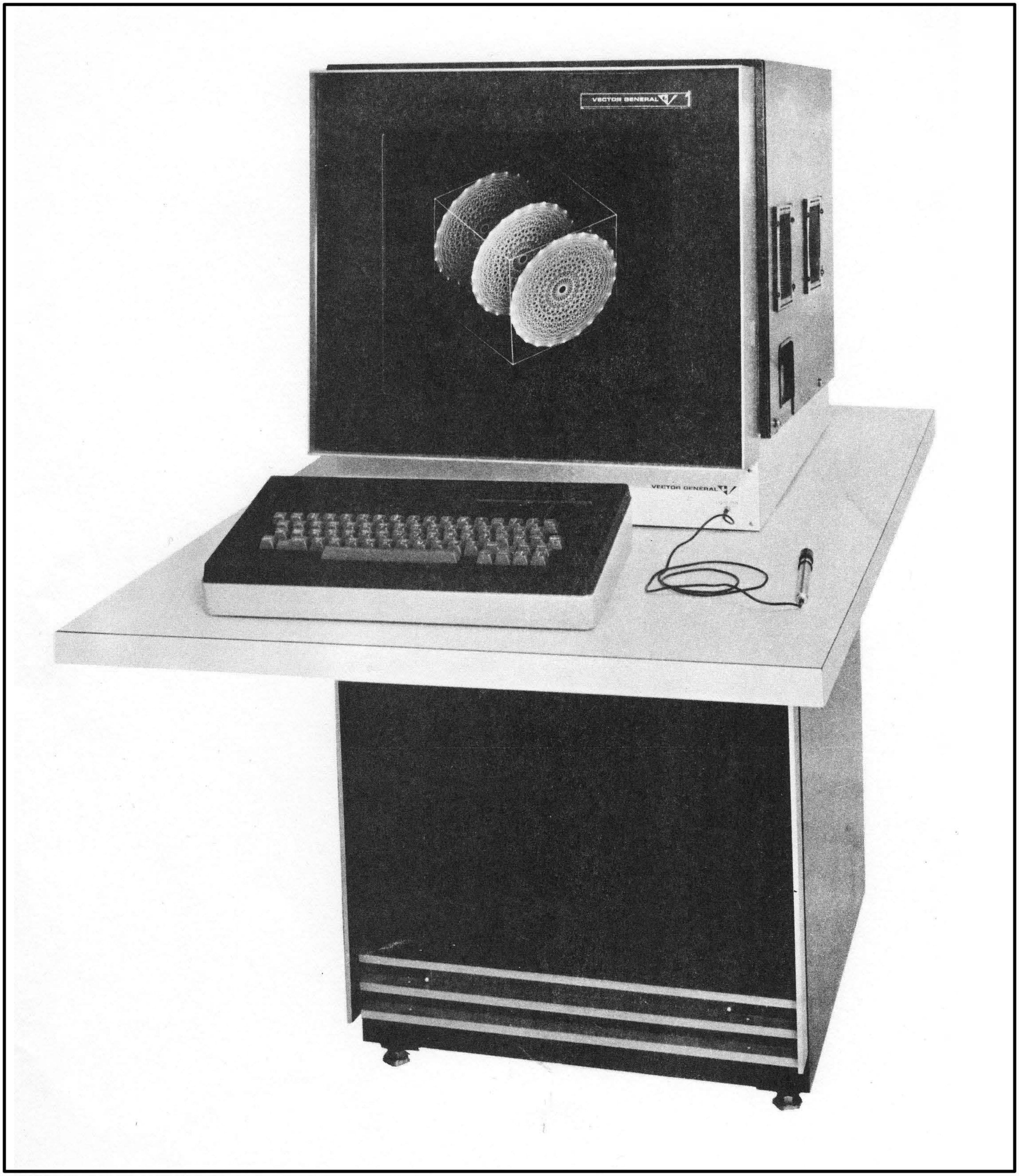
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CONTENTS

CONTENTS (Cont'd.)

Page

SECTION I

GENERAL INFORMATION

1.1 INTRODUCTION

The Vector General Graphics Display System is an interactive graphics cathode ray tube (CRT) display that may be connected to any computer system with standard input/output capability. The display interacts with an on-line user by displaying pictorial information on the surface of the cathode-ray tube and by accepting inputs from external control devices. The inputs are requested and processed by computer programs that alter and maintain the output picture being presented to the user. This manual contains information needed by the programmer to write programs that use the capabilities of the display to the best advantage. The topics included are a system description, an explanation of display principles, a discussion of the functional organization of the system, a description of optional control devices, a description of display interrupt operation, a description of display instructions with directions for their use, and a sample program.

1.2 SYSTEM DESCRIPTION

The display system contains the necessary features for interactive displays plus several optional features. The standard features are an interface unit, a display controller (DC), a dual digital-to-analog converter (DD), a vector generator (VG), and a cathode-ray tube (DM). The optional features are a character generator (CG) and three coordinate transformation generators: two-dimensional (2D), two-dimensional with rotation (2DR), and three-dimensional (3D). Any one of the six interactive control devices may be connected to the system: an alphanumeric keyboard (KB), 16 (or 32 optional) lighted function switches with manual interrupt (FS), a data tablet (DT), a joystick (JS), control dials (CD), and a light pen (LP). A simplified block diagram of the system is shown in Figure 1-1.

1.3 STANDARD FEATURES

The computer communicates with the display controller by way of the interface over the channels described on Page 1-3.

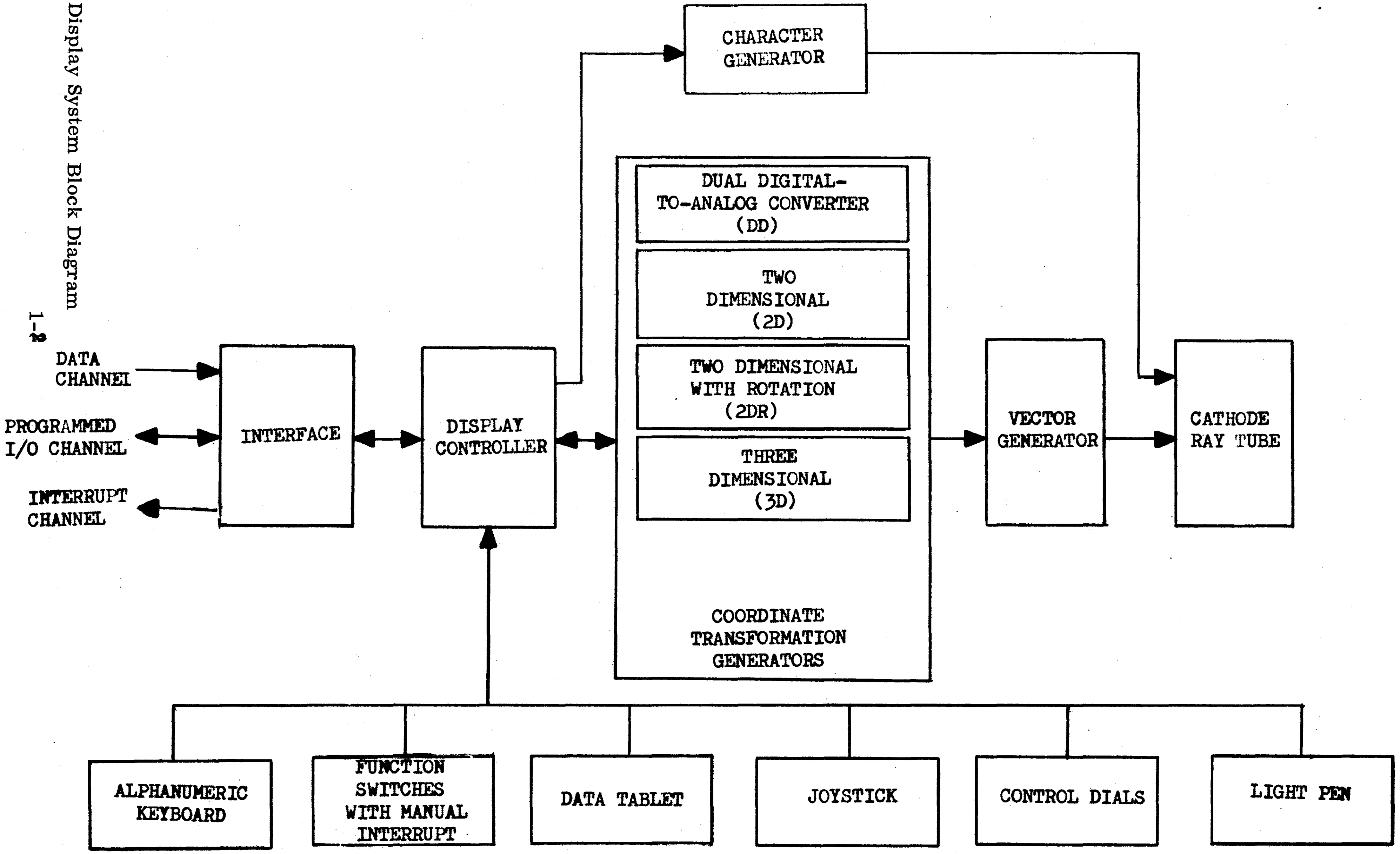


Figure 1-1. Display System Block Diagram

- Data Channel - Direct memory access channel used to output the picture being presented on the CRT screen
- Programmed Input/Output Channel - Used to start the controller, acknowledge interrupts, and provide access to the display controller and device registers
- Interrupt Channel - Used by display and device response interrupt to activate computer programs

The display controller processes all display functions, running asynchronously with the computer central processor. The controller also receives inputs from the external control devices.

The dual digital-to-analog converter (DD) is the standard version of the coordinate transformation generators. It converts the digital values from the display controller into analog signals for use in the vector generator.

The vector generator accepts input from the coordinate transformation generators and uses it to present solid, dashed, or dotted lines between two positions on the display screen or to place a point at any given position.

The cathode-ray tube generates an electron beam that shows as a spot of light on the face of the tube. An electromagnetic deflection system causes the spot to move in any direction on the tube face in response to signals from the vector generator. An input from the vector generator causes the brightness of the spot to vary and turns the spot off completely when desired.

1.4 OPTIONAL FEATURES

The character generator processes a data stream of ASCII* characters and generates the characters as text for the display. Any one of four sizes may be selected by the program.

Three optional coordinate transformation generators are available.

* American National Standard Code for Information Interchange.

- Two-dimensional for Scale and Translation (2D) - Scales and translates two-dimensional constructs and displays them. Scaling changes the size of image portions, and translation moves an image portion along one or both of its axes.

- Two-dimensional for Scale, Translation, and Single-axis rotation (2DR) - Scales and translates two-dimensional constructs and displays them with rotation in a single plane.

- Three-dimensional (3D) - Generates three-dimensional constructs and displays them with scaling, translation, and rotation about any axis.

The external control devices provide the display controller with inputs that can be used by the computer programs.

1.5 SYSTEM SPECIFICATIONS

Table 1-1 lists the general specifications for the display system.

1.6 DISPLAY PRINCIPLES

A cathode-ray tube display is a visible pattern on the face of a cathode-ray tube formed by a fluorescent spot moving on a screen inside the tube. To present a clear image, the pattern traced on the tube is repeated about 30 to 60 times a second. Any such repetition is called a "frame" and the frequency at which it is generated is called the "frame rate".

The Vector General display uses the random scan method of controlling the movement of the spot. Random scan control involves steering the spot in a straight line between two points on the display screen. A series of these straight lines constitutes an image portion. All these directed lines are defined between the previous position of the spot on the screen (the starting point) and the position currently specified by the program (the end point).

Table 1-1. Display System Specifications

Feature	Characteristic	Specification
Interface and Controller	High-Speed I/O Channel	
	Access	Direct memory from CPU
	Word	16 bit
	Arithmetic	Parallel two's complement
	Addressable registers	43 destination; 66 source
	Vector formatting	Absolute, relative, short incremental, long incremental, autoincrement
	Register operations	Load, add, AND, OR
	Controls	Frame clock, vector generator, coordinate transformation generator, character generator, interactive devices
	Channels	1 per controller
	Programmed I/O Channel	
	Operations	Register read Interrupt handling Interactive device input
	Channels	1 per controller

Table 1-1. Display System Specifications (Cont.)

Feature	Characteristic	Specification
Interface and Controller (Cont.)	Interrupt	
	Multiplexing	Priority interrupts multiplexed in controller
	Levels	1 CPU level per controller
Coordinate Transformation Generators	Dual Digital-to-Analog Converter (DD) Speed	1 μs per coordinate pair
	Two Dimensional (2D) Speed	1 μs per coordinate pair 5 μs coefficient settling
	Two Dimensional with Rotation (2DR) Speed	2.5 μs per coordinate pair 5 μs coefficient settling
	Three Dimensional (3D) Speed	2.5 μs per coordinate triple 5 μs coefficient settling
CRT - Vector Generator[†]	Tube shape	21 or 17 inches rectangular
	Display area	21-inch tube: 13 inches high, 14 inches wide 17-inch tube: 10 inches high, 11 inches wide
	Deflection type	Dual electromagnetic
	Spot size	0.020 inch
	Phosphor protection	Hardware
	Brightness	50 foot-Lamberts[††]

[†] These specifications apply to a 10-inch x 10-inch and 8-inch x 8-inch precision area within the display area on the screen for the 21-inch and 17-inch CRT, respectively.

[††] Based on a 50-kHz signal applied to produce a 10-inch x 10-inch flat face raster with P40 phosphor.

Table 1-1. Display System Specifications (Cont.)

Feature	Characteristic	Specification
CRT - Vector Generator (Cont.)	Contrast	4:1
	Intensity levels	32
	Intensity modulation	Optional on 3D models
	Dynamic range	30 inches x 30 inches on 21-inch CRT 24-1/4 inches x 24-1/4 inches on 17-inch CRT
	Addressable locations	4096 x 4096
	Positioning accuracy	2%
	Spot jitter	0.05% peak to peak
	Drawing speed*	
	21" high speed tube:	For "move":
	Vectors longer than 0.625 inch	$[(L - 0.25)\ (0.7) + 3]\ \mu s$ For "draw": $[(L - 0.25)\ (1.5) + 3]\ \mu s$ where L = longest component in inches
	Vectors shorter than 0.625 inch	$3 \mu s$
	21" medium speed tube:	For "move":
	Vectors longer than 0.625 inch	$[(L - 0.25)\ (1.2) + 5]\ \mu s$ For "draw": $[(L - 0.25)\ (2.5) + 5]\ \mu s$ where L = longest component in inches
	Vectors shorter than 0.625 inch	$5\ \mu s$
	17" medium speed tube:	For "move":
	Vectors longer than 0.5 inch	$[(L -.25)(1.2) + 5]\ \mu s$ For "draw": $[(L -.25)\ (2.5) + 5]\ \mu s$ where L = longest component in inches
	Vectors shorter than 0.5 inch	$5 \mu s$
	End matching	0.020 inch
	End closure	0.020 inch

*Refer to Coordinate Transform Generator Specifications for array settling times.

Table 1-1. Display System Specifications (Cont.)

Feature	Characteristic	Specification			
CRT - Vector Generator (cont.)	Scissoring	Hardware			
	Modes	Dot, dash, point, solid			
Control Devices	Alphanumeric Keyboard	70 keys including cursor function			
	Function Switches	16 momentary (32 optional) 1 interrupt			
	Data Tablet				
	Size	10 inches x 10 inches			
	Resolution	0.1%			
	Control Dials				
	Number	10			
	Type	Single turn			
	Function	Programmatic			
	Light Pen				
	Type	Solid state			
	Response time	3μs (1μs optional)			
Character Generator	Type	Draw			
	Character set	96 extended ASCII 96 specials 32 optional specials			
	Aspect ratio	3:2			
	Writing time	10μs, average			
	Cursor	Hardware			
	Sizes	4			
Circular Arc Generator	Size of radius (inches)	Drawing time (μs) for arc-length (degrees)			
		45	90	180	360
	0 - .4	4	4	5	7
	.4 - .8	4	5	7	11
	.8 - 1.6	5	7	11	19
	1.6 - 3. 2	7	11	19	35
	3.2 - 6.4	11	19	35	67
	6.4 - 12.8	19	35	67	131

1.7 VISIBLE SPACE

That rectangular portion of the CRT which can be viewed by a user will be called the "Visible Space". The "Visible Space" is limited by an opaque mask with a rectangular cutout. See Figure 1-2.

The picture being generated is adjusted in size (scaled) to present the desired output by means of two controls:

a. The program controlled "Picture Scale" (PS) register in the transformation hardware (not available on standard DD system).

b. The manually adjustable "gain-controls" on the CRT deflection hardware.

The picture can be generated on a "Picture Space" coordinate system and scaled for viewing through the "Visible Space".

The maximum size "Picture Space" is larger than the "Visible Space". This permits limited "zooming" but primarily allows fully visible objects to be rotated and positioned to the extreme limits of the "Visible Space" and yet draw any remaining visible portions without distortion.

For the 21" CRT with the gain knobs at standard midrange calibrated settings, the maximum "Picture Space" (over which the vector generator accurately reproduces images) is a 30" x 30" plane of which the "Visible Space" (CRT screen visible throughmask) is a 13" by 14" rectangle in the center. (See Figures 1-3 and 1-4.)

1.8 PICTURE SPACE

The hardware transformation options permit the coordinates defining an image portion to be transformed prior to use for display generation. The transformed coordinates used for display will describe a rotated and translated instance of the image portion.

For the input coordinates (X, Y, Z) the output transformed X and Y are used to generate the image portions' horizontal and vertical "Picture Space" position respectively. Thus, the "Picture Space" is the X-Y projection of the transformed image definition space (or (X, Y, Z) "Image Space").

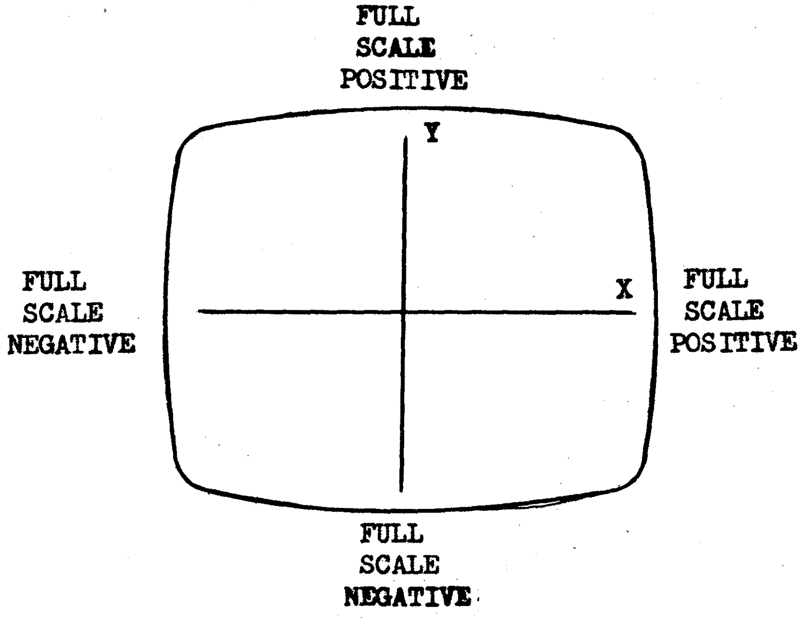


Figure 1-2. Visible Space

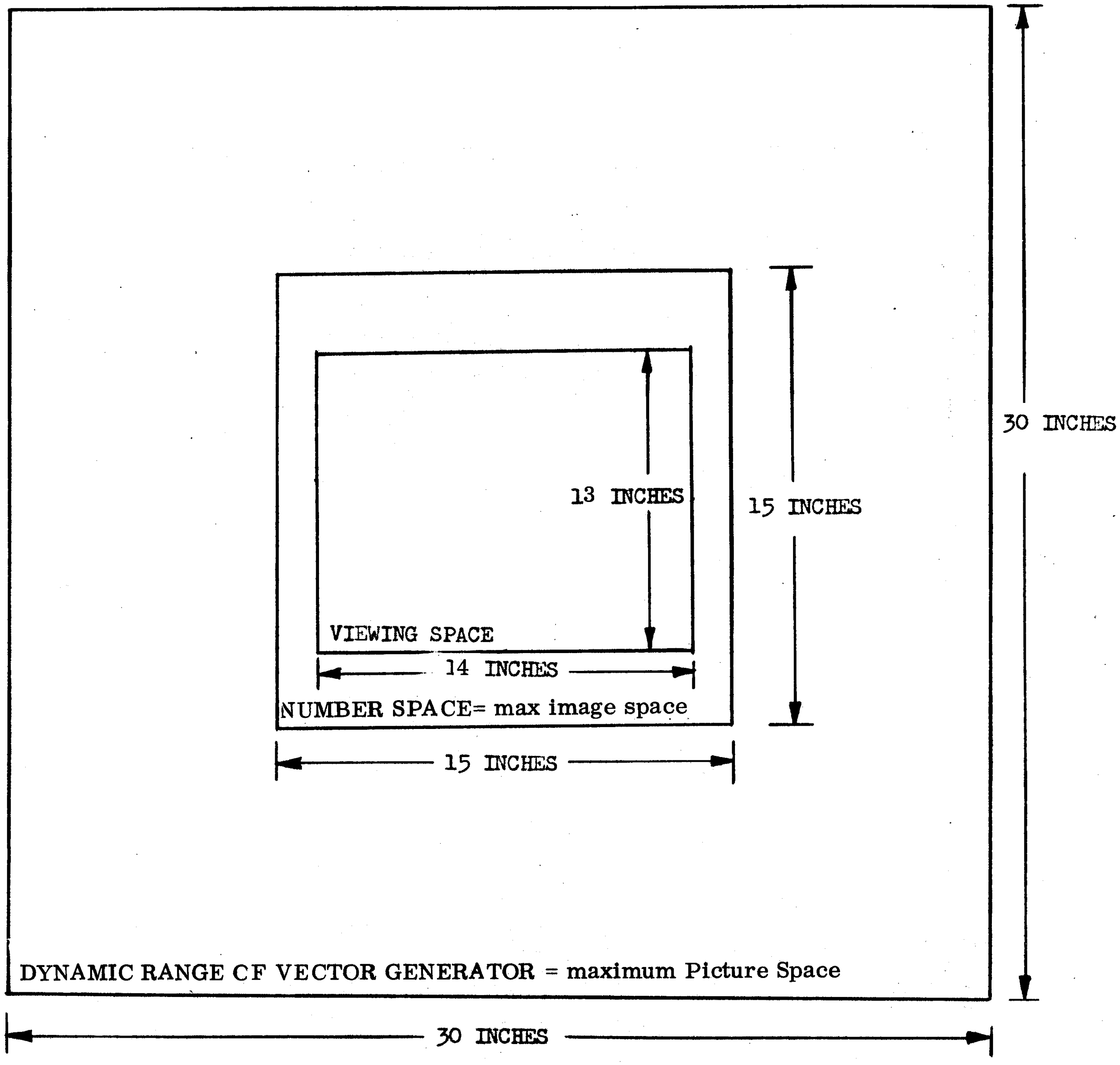

30 INCHES
13 INCHES
15 INCHES
VIEWING SPACE
14 INCHES
NUMBER SPACE= max image space
15 INCHES
DYNAMIC RANGE CF VECTOR GENERATOR = maximum Picture Space
30 INCHES

Figure 1- 3. Image Areas, 21-Inch Display

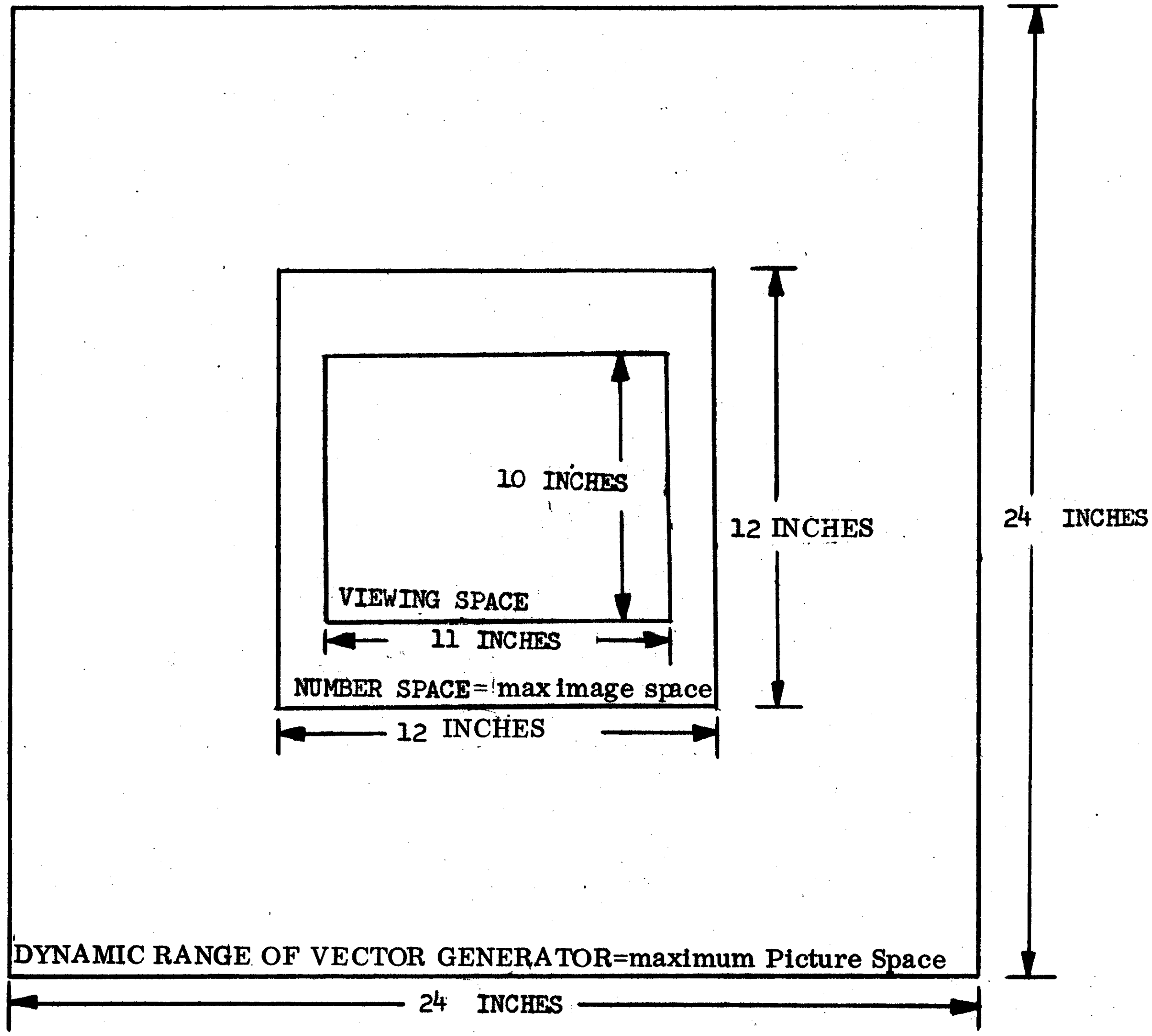

10 INCHES
VIEWING SPACE
11 INCHES
12 INCHES
NUMBER SPACE=max image space
12 INCHES
24 INCHES
DYNAMIC RANGE OF VECTOR GENERATOR=maximum Picture Space
24 INCHES

Figure 1-4. Image Areas, 17-Inch Display

If no transformation is performed, or for zero rotations, zero displacements, and full scale size transformation, an image coordinate (X, Y, Z) will correspond directly to the "Picture Space" (X, Y), with positive X being horizontal towards the right of a viewer and positive Y being vertical. For the 21" CRT with the gain knobs at the calibrated settings, and the Picture Scale register (PS) set to maximum, a plus full scale X image coordinate value transforms into an X Picture Space coordinate value which corresponds to a horizontal displacement 7.5" to the right of center or 1/2" to the right of the Visible Space. Similarly, for no transformation and maximum Picture Scale (PS), a full scale Y image coordinate value corresponds to a Picture Space position 7.5" up from the center.

To view a centered two-dimensional object defined over the entire X-Y coordinate range (such as a page of text), the Picture Scale register can be loaded with .92 or the gain knobs turned down (as required on a DD system). To view an entire centered rotated two-dimensional object, an additional factor of $1/\sqrt{2}$ picture scale is needed (not required on DD system since it does not implement rotation). To view an entire centered three-dimensional object which is defined over the entire (X, Y, Z) Image Space, an $1/\sqrt{3}$ factor is needed to view the maximum length of the projected diagonals of the Image Space.

Due to the larger range of the Picture Space over the Visible Space, each of these views may be positioned out of the viewing area in any direction without distorting any remaining visible portions. This capability is termed the "Hardware Scissoring Facility".

1.9 IMAGE SPACE

Prior to transformation and projection onto the Picture Space for viewing through the Visible Space, an object is defined in a coordinate system which we will refer to as the Image Space. All separately transformed objects of a displayed picture are defined in their respective untransformed image spaces.

To exploit maximum use of transformation ranges and coordinate resolution, all objects should be defined as large as possible in their defining Image Space. Objects are defined primarily in terms of generated visual elements: Vectors and Characters.

In cases where efficient interactive modification, dynamic model presentation, or motion is desired, an object definition may contain as elements "subimage calls" to generate transformed instances of other objects. In these cases, a composite Transformation of the existing transform with that of the called instance must be loaded into the hardware prior to processing elements of the called object definition for display generation. This permits nesting of transformable object definitions which can be directly processed for display.

In addition to the programmable linear vectors, the display system produces sets of ASCII characters generated independently of the computer program by a character generator.

1.10 ABSOLUTE VECTORS

The coordinates of absolute vectors are specified with respect to the zero position in the center of the Image Space (or screen for no transformations). Each new input data value is located directly on the Image Space grid as shown for a two-dimensional vector in Figure 1.5.

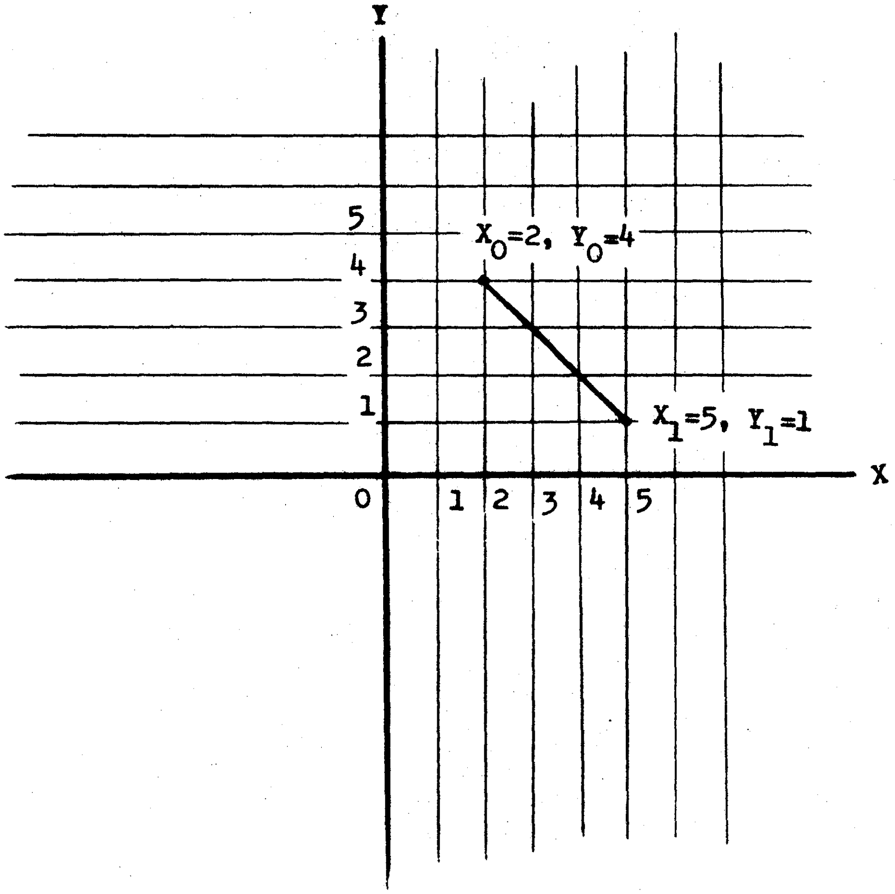


Figure 1-5. Absolute Vector

1.11 RELATIVE VECTORS

The end-point coordinates of a relative vector are located with respect to the starting point coordinates. In other words, relative vector data is specified in the form of increments that are added to or subtracted from the previous coordinate values as shown in Figure 1-6. An entire image construction can be positioned by drawing an initial absolute vector and defining the rest of the image with relative vectors without computing new end-point coordinates. This is an effective means of (unscaled and unrotated) subimage calling when no transformation hardware is available.

1.12 INCREMENTAL VECTORS

Incremental vectors are used when data storage is limited. Data increments can be shorter than relative vector increments, with a resultant reduction in the amount of data needed. Incremental vector display, therefore, requires less data storage and improves performance by increasing the rate of output and presentation. For coarse resolution, increments are added to the high-order end of the previous coordinate values; for fine resolution the increments are added to the low-order end.

1. 13 AUTOINCREMENTING

The autoincrementing feature is used to step one coordinate at regular intervals while the other coordinate is open to program change, as shown in Figure 1-7. This feature, used for graphs and similar presentations, decreases memory requirements by 1/2.

1.14 THREE-DIMENSIONAL DISPLAY

Three-dimensional presentation involves the addition of a third, or Z, axis that is perpendicular to the face of the screen and intersects the X and Y Picture Space axes at the zero point as shown in Figure 1.8. The Z axis represents depth into and out of the display screen. Option: The illusion of depth may be achieved by varying the light intensity of the fluorescent spot in proportion to the value of the Z coordinate. The intensity increases exponentially with the value from minus full-scale to one-half full-scale intensity, with maximum intensity at the face of the screen. For Z values much less than zero or greater than one-half

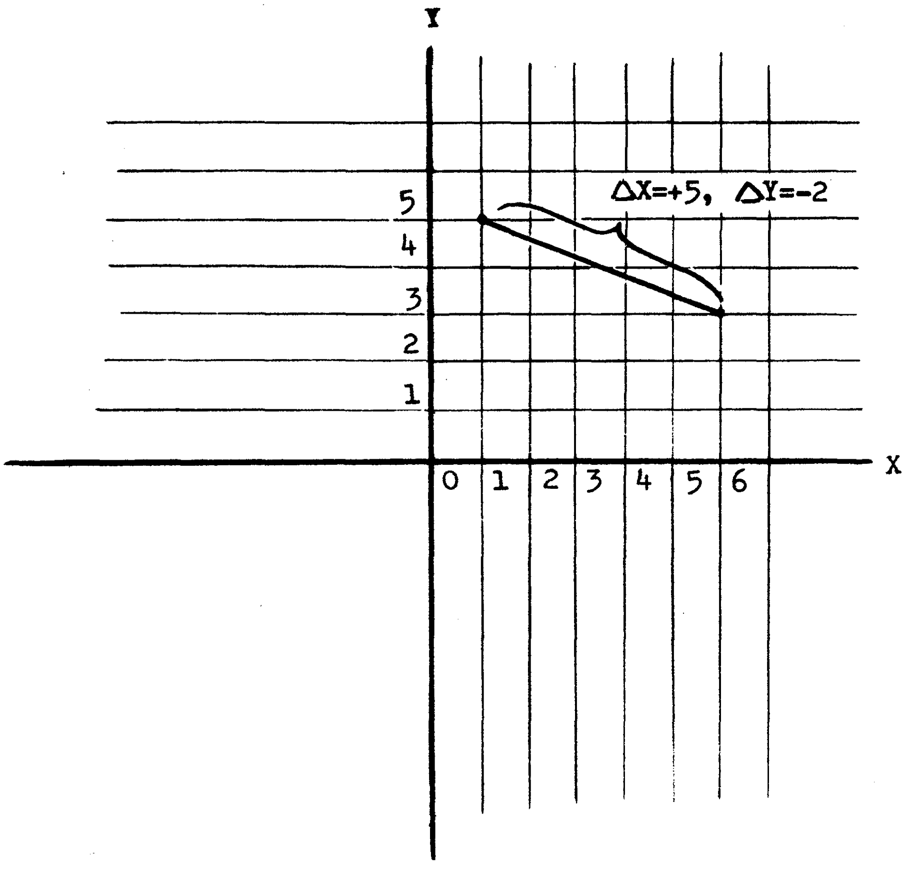


Figure 1-6. Relative Vector

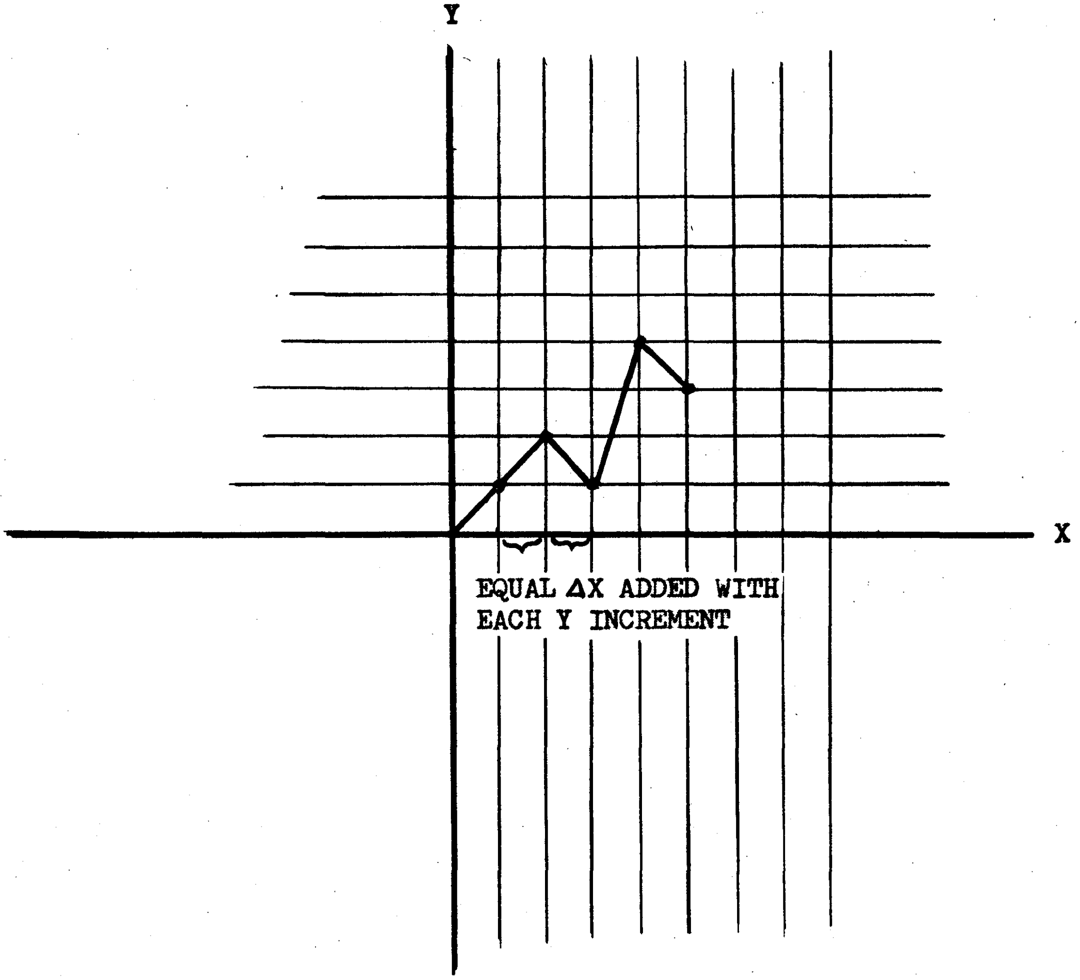


Figure 1-7. Auto-incrementing

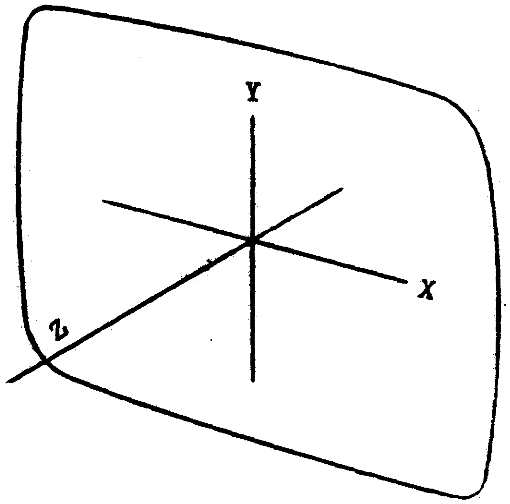


Figure 1-8. X, Y, and Z Axes

full scale, the intensity is zero; that is, the spot is turned off or blanked.

1.15 CHARACTER GENERATION

The character generator accepts coded inputs from the display controller and produces text strings composed of ASCII characters and special characters. Characters are drawn on the screen as a series of short vectors and curves. Unlike the vector generator, however, the character draws are generated automatically by the character generator each time a character code is received.

The program can select one of four character sizes and one of 16 intensity levels. A character scaling option is available for continuous character sizes. This option allows Picture Scale and Coordinate Scale to scale the image and characters proportionately. The program also can specify whether the text lines are to be displayed horizontally on the screen or are to be positioned as if on a page that has been rotated 90^{o} counterclockwise. One of the characters is a cursor, which differs from other displayed characters in that the character following the cursor is drawn in the same place, without a column feed. This feature permits the cursor to be moved over the screen as desired with manual inputs. A hardware feature causes the cursor to blink twice per second.

1.16 CHARACTER FORMATION

The character generator uses the function method of drawing characters, rather than the raster or scanning method sometimes used in display systems. The functional approach involves steering the fluorescent spot through a sequence of strokes to create character shapes. The characters are composed from a set of basic image elements, or draw figures, as shown in Figure 1-9. Any ASCII character can be produced in three draws or fewer, a draw being defined as all or a subset of one of the four shapes illustrated. The spot is blanked while moving through

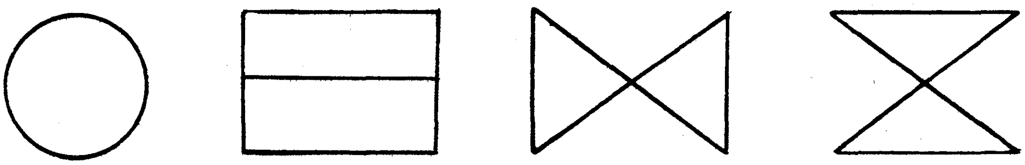


Figure 1-9. Draw Figure Definition

undisplayed sections of a character draw or from one character to another.

1.17 CONTROL CHARACTERS

Twelve codes in the character set are used for control purposes only and do not cause a display on the screen. The control characters and their functions are as follows:

- Null - Displays a blank in the corresponding character position. The spot is not stepped to the next character position
- Delete - Same as Null
- Backspace - Causes the spot to revert to the previous character position
- Line Feed - Causes the spot to move down to the corresponding character position in the line below
- Form Feed - Causes the spot to move to the position of the first character on the page; that is, Line 1, Column 1
- Carriage Return - Causes the spot to move to Column Position 1 on the line below
- DC1 - Causes the spot to move up to the corresponding character position in the line above. Equivalent to backline operation
- DC2 - Decreases the current character size by 1. This permits sub- and superscript sizes to be embedded in the text.
- DC3 - Increases the current character size by 1.
- DC4 - Terminates the data associated with a character generation display instruction.
- Horizontal Tab - Resets the current column position to "horizontal center" and increases the current line position by one line.
- Vertical Tab - Instates current character positioning to "horizontal center" of Line 1.

The first character in a string always starts at the location defined by the current X and Y coordinates.

1.18 INTENSITY LEVELS

For two-dimensional display, 32 constant intensity levels can be selected by the program. These intensities can be applied to vectors and characters.

The spot can be blanked as desired under program control during vector display.

Automatic blanking is an effect in the following operations:

- Presenting dashed or dotted lines between two positions on the display screen - The spot is alternately blanked and unblanked at appropriate intervals while a vector is drawn. The start and end of a vector are always unblanked.

- Placing a point at any given position. The spot is blanked while moving from one location on the screen to another and briefly unblanked at the end of the vector to form a point.

1.19 IMAGE TRANSFORMATION

Image transformation is an optional hardware feature that involves scaling, rotation, and position change (translation). The DD system has no transformation. The 2D system implements scaling and translation only. The 2DR system implements scaling and translation with rotation around the Z axis. The 3D system contains all the image transformation features, including rotation around any axis.

1.20 SCALING

The scaling operation consists of changing the size of an image portion by multiplying each end-point coordinate by the desired scale factor before processing. The scale factor is specified by the program, and the current scale factor is maintained in a hardware register to be multiplied by the X, Y, and Z coordinate values. An example of scaling is shown in Figure 1-10.

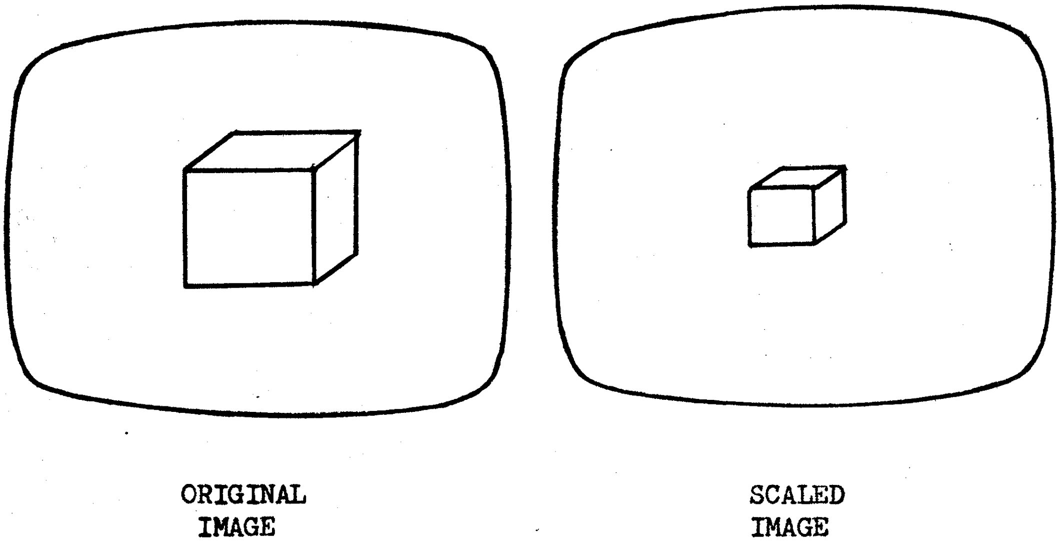


Figure 1-10. Scaling

1.21 ROTATION

An image portion can be rotated around any of its axes by using the optional hardware rotation matrix. The desired rotation is specified by loading direction cosines, or the sums of triple products of trigonometric functions in the more elaborate cases, into the rotation matrix, which has registers for each coordinate axis. The rotated image instance is automatically defined by a linear transformation of the coordinates of the unrotated master, using the direction cosines or the triple products which represent the angles between the coordinate axes of the two images. The 2D system rotation matrix contains only the registers necessary to rotate the X and Y coordinates around the Z axis. An example of rotation is shown in Figure 1-11.

1.22 TRANSLATION

An arbitrary image may be positioned anywhere in 3-dimensional space by adding a value to each of the scaled and rotated coordinate values every time an end point is specified. The value added must be constant for each coordinate to maintain the original image configuration. An example of translation is shown in Figure 1-12.

1.23 PICTURE TRANSFORMATION

When a 3-dimensional image made up of characters and vectors has been transformed to obtain the desired scale, rotation, and translation, a 2-dimensional view can be extracted and presented as a picture on the display screen. The two operations involved in this final presentation are picture scaling, to change the size of the transformed image, and intensity modulation (optional) to give a 3-dimensional depth cueing effect.

1.24 PICTURE SCALING

A hardware register is provided to hold a value that scales all the final transformed X and Y coordinate values. This scaling is used primarily to reduce full-scale, rotated, 3-dimensional images so that they fit into the display screen while permitting untransformed images, such as text pages and graphs, to fill the same display area.

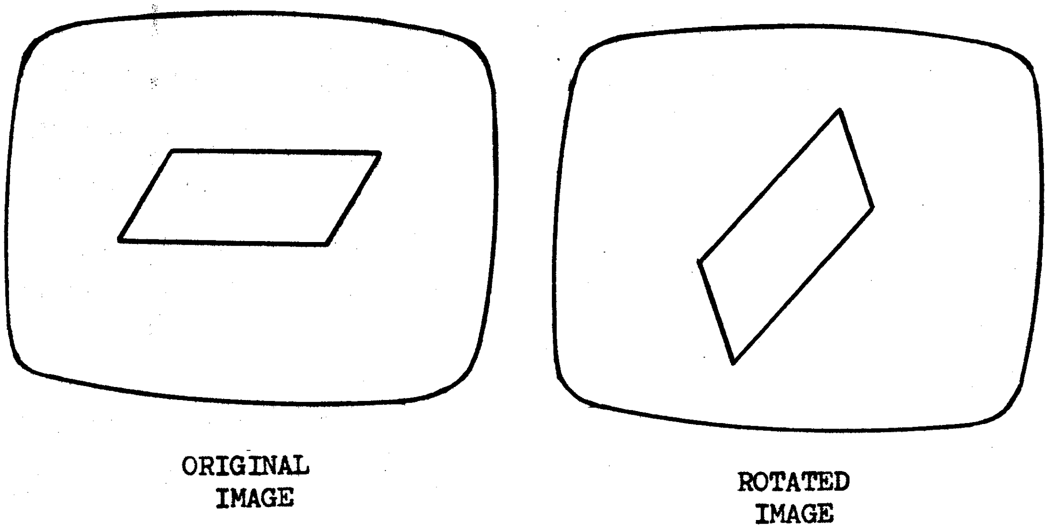
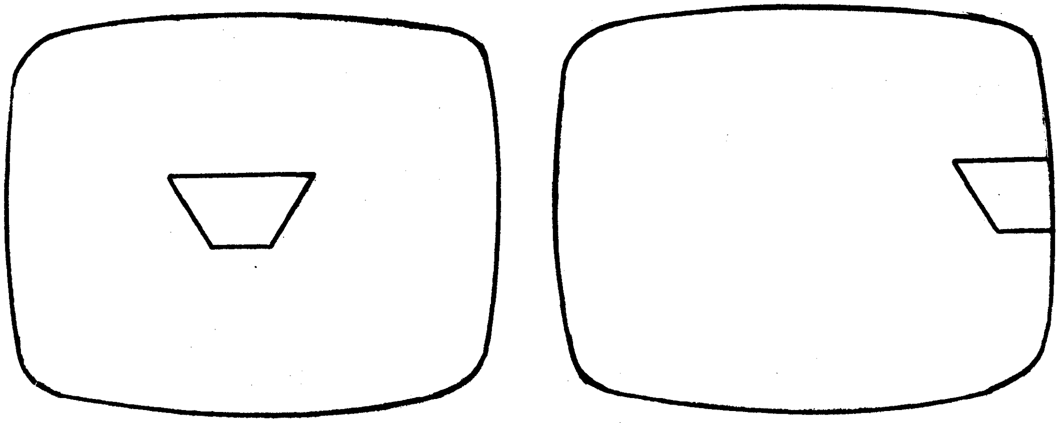


Figure 1-11. Rotation



ORIGINAL IMAGE

TRANSLATED IMAGE

Figure 1-12. Translation

1.25 INTENSITY MODULATION

Intensity modulation is the name given to the depth cueing transformation used in all 3D systems, that shades the intensity of the displayed picture to give a 3-dimensional effect. The value of the transformed Z coordinate is used to represent depth into and out of the display screen, and therefore, controls spot intensity.

The picture transformation hardware includes the facility to blank any part of the picture that falls out of the screen towards the viewer. The cutoff plane can be moved toward or away from the viewer by the program so that sectional views may be obtained. This feature is an advantage when it is desirable to remove parts of cluttered images for clearer visibility. Since there is also a cutoff at the rear of the image, this transformation can be used to hide certain lines at the back of a 3-dimensional construct to achieve desired effects.

SECTION II

SYSTEM ORGANIZATION

2.1 INTRODUCTION

This section contains a functional description of the system components, including the hardware registers. The optional control devices that may be used with the system are also described.

2.2 FUNCTIONAL DESCRIPTION

A functional block diagram of the CRT Display System showing the basic operational elements and data flow through these elements is shown in Figure 2-1. The basic elements can be grouped into the following functional sections: vector coordinate registers; coordinate scaling and displacement option; rotation option; picture control option; character generator; vector generator; cathode ray tube; and input/output facility. The optional control devices are not shown in the block diagram but also are basic to the system if included.

2.3 VECTOR COORDINATES

The display system maintains the coordinates of the current position of the fluorescent spot in the 12-bit X- and Y-registers, with the inclusion of a 12-bit Z-register for the 3D option. These registers hold the X, Y, and Z coordinates respectively. The values in these registers are updated as new coordinate values are received on the data channel.

When relative vectors are specified, a coordinate increment is received on the data channel and added to the current coordinate value. The sum is then loaded into the proper register. If incremental vectors are specified, the increment is added to either the high-order or low-order end of the current coordinate value, depending on the scale specified by the program.

2.4 COORDINATE SCALE OPTION

To change the overall size of the image without changing its shape, a

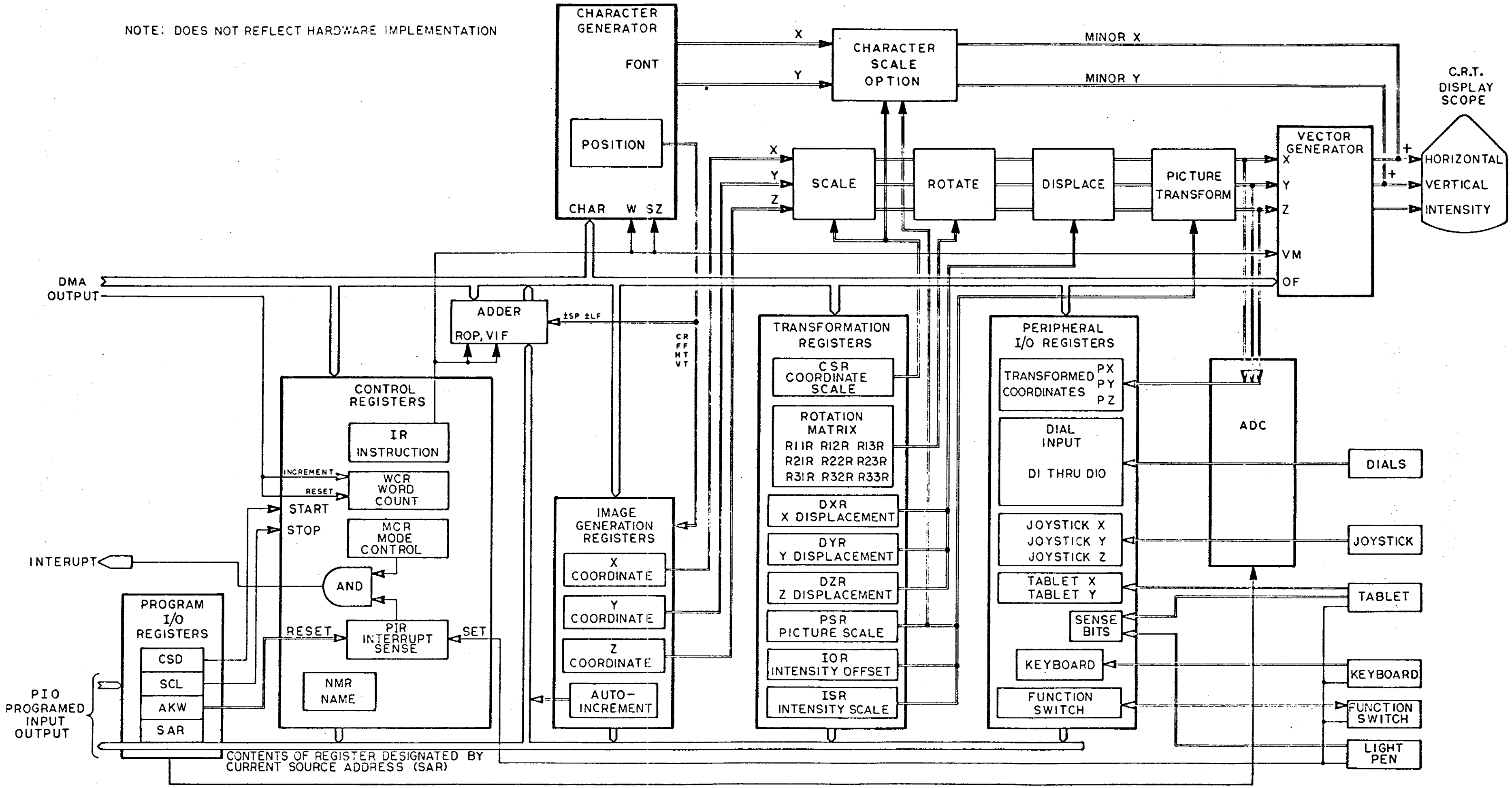


FIGURE
DISPLAY FUNCTIONAL BLOCK DIAGRAM

Figure 2-1

scale factor is loaded by the program into a 12-bit coordinate scale register. This number is multiplied by the current coordinate values from the X, Y, and Z coordinate registers. Characters also are scaled in proportion to the rest of the image with the character scale option.

2.5 ROTATION OPTION

To rotate the image around any of the three axes, trigonometric values are loaded into rotation matrix registers R11R through R33R. Registers R13R, R31R, R32R, R23R, and R33R are used only for 3D rotation. If the three scaled input coordinates are defined as X_0, Y_0, and Z_0 and the three computed outputs are X_1, Y_1, and Z_1, the following computation is performed:

$$X_1 = R11R \cdot X_0 + R12R \cdot Y_0 + R13R \cdot Z_0$$

$$Y_1 = R21R \cdot X_0 + R22R \cdot Y_0 + R23R \cdot Z_0$$

$$Z_1 = R31R \cdot X_0 + R32R \cdot Y_0 + R33R \cdot Z_0$$

The coefficients of an object after rotation may be continuously computed from the coordinates of the unrotated master by loading coefficients defining the desired rotation into registers R11R through R33R.

Figure 2-2 illustrates the effect on a point of two-dimensional rotation about the Z axis by the angle θ. The coordinates of the rotated point in terms of its original unrotated coordinates are as follows:

$$X' = X \cos \theta + Y \sin \theta$$

$$Y' = X(-\sin \theta) + Y \cos \theta$$

$$Z' = Z$$

The values of R11 through R33 that would perform the illustrated rotation are as follows:

$$R_{11} = R_{22} = \cos \theta$$

$$R_{12} = \sin \theta$$

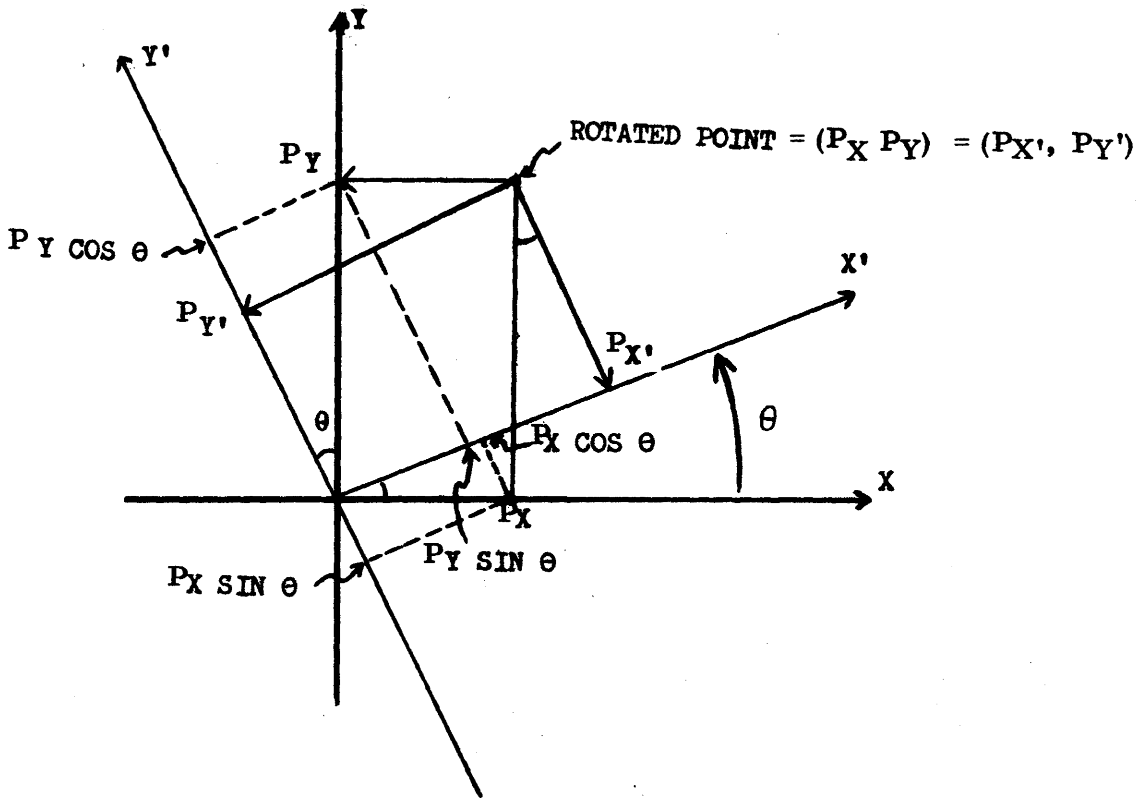
$$R_{21} = -\sin \theta$$

$$R_{33} = 1$$

$$R_{13} = R_{23} = R_{31} = R_{32} = 0$$

2.6 DISPLACEMENT VECTOR OPTION

The displacement vector option performs the translation function in the image transformation feature by moving the image intact along any of the three axes. The X-displacement, Y-displacement, and Z-displacement registers are used to implement this feature. A displacement constant loaded by the program into any one of these registers is added to the associated rotated coordinate values being maintained by the rotation, scale, and coordinate registers. The result is a displacement of the entire image along any axis whose displacement register is



$$P_{X'} = P_X \text{ COS } \theta + P_Y \text{ SIN } \theta$$

$$P_{Y'} = P_X \text{ SIN } \theta + P_Y \text{ COS } \theta$$

Figure 2-2. Two-Dimensional Rotation

loaded. An example of the displacement operation in an X, Y plane is shown in Figure 2-3. The X displacement register contains a 2 and the Y displacement register contains a 3. The value 2 is added to each X coordinate and the value 3 is added to each Y coordinate asfollows:

register contains a 3. The value 2 is added to each X coordinate and the value 3 is added to each Y coordinate as follows:

Original Position	New Position
$X_0 = 2$	$X_0 = 2 + 2 = 4$
$Y_0 = 2$	$Y_0 = 2 + 3 = 5$
$X_1 = 3$	$X_1 = 3 + 2 = 5$
$Y_1 = 1$	$Y_1 = 1 + 3 = 4$
$X_2 = 5$	$X_2 = 5 + 2 = 7$
$Y_2 = 2$	$Y_2 = 2 + 3 = 5$
$X_3 = 6$	$X_3 = 6 + 2 = 8$
$Y_3 = 1$	$Y_3 = 1 + 3 = 4$

2.7 PICTURE CONTROL OPTION

The picture control option is used for picture transformation after the transformation of individual images on the screen has been completed. The registers used for this feature are the 12-bit intensity offset register, the 12-bit intensity scale register, and the 12-bit picture scale register. The value in the picture scale register is multiplied by each of the transformed

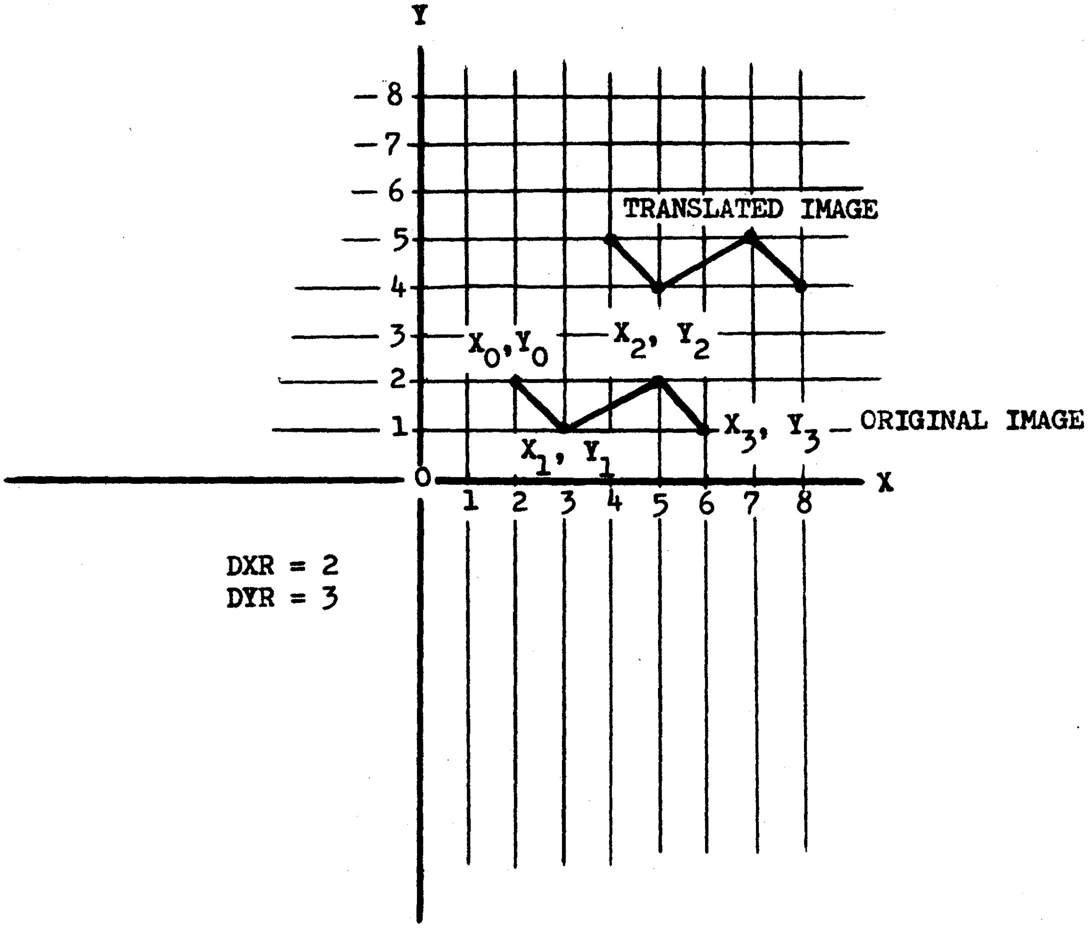


Figure 2-3. Two-Dimensional Translation

X, Y, and Z coordinates to establish the final picture size. This scaling applies also to characters in the picture, with the char-scale option.

In a two-dimensional system, the 12-bit intensity offset register (IOR) is loaded by the program to specify 1 of 32 intensity levels. Only the high-order five bits of the register are used for this purpose. The intensity levels apply to characters as well as to two-dimensional vectors. Full scale in the intensity offset register designates maximum intensity, and the intensity decreases exponentially as the value decreases to minus full scale.

In a three-dimensional system with the Intensity Modulation option the intensity scale register is used in conjunction with the intensity offset register to provide depth cueing, or shading of the intensity of the picture according to the value of the Z coordinate. The intensity of the spot at any instant is represented by the following equation:

$$\text{if } IS_{sign} = 0: \qquad I = I_{max} \cdot e^{k\,(Z' - 1)}$$

$$\text{else if } IS_{sign} = 1: \qquad I = I_{max} \cdot e^{k\ Z'} \quad \text{when } Z' \leq 0$$

$$= 0 \quad \text{when } Z' > 0$$

where:

$$Z' = IS_{mag} * Z_{rotated} + IO$$

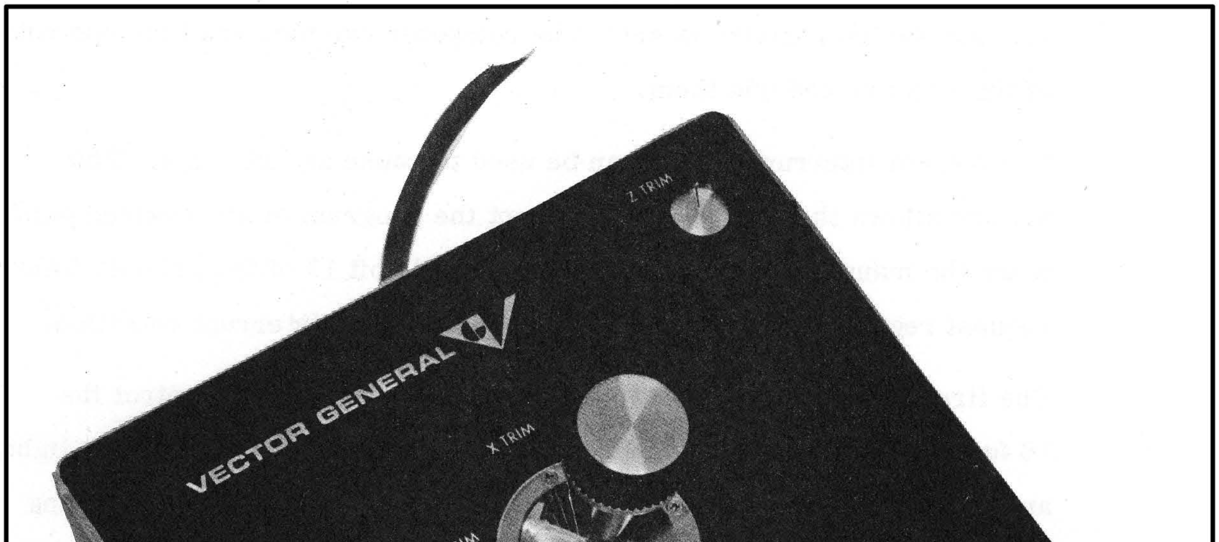
This equation provides for exponential shading of the intensity along the length of vectors drawn between coordinates of different intensity values. A "screen-cutoff" can be imposed at Z' = 0 by setting the sign bit of ISR, then if Z is greater than $\frac{1 - 2 * IOR}{2 * ISR_{mag}}$, the intensity is 0 and the spot is blanked.

The intensity cutoff plane is established by the value in the intensity offset register. Within the depth range of an image, the intensity is blanked between the viewer and the screen. The intensity is at its maximum at the face of the screen and decreases exponentially with decreasing values of Z toward the back of the image. Figure 2-4 shows a simplified cross section of a CRT with a three-dimensional image in two different positions with respect to the intensity cutoff plane. As the value in the intensity offset register is changed, the image moves forward or backward through the intensity range, to vary the section that is intensified and the part that is blanked out.

The intensity range, or apparent depth of the image, is determined by the value in the intensity scale register. If the value is 1, the maximum intensity range is achieved. If the value is 0, the intensity is constant and the image has no depth-cueing. Figure 2-5 shows how a variation in intensity scale changes the depth of the image.

2.8 VECTOR GENERATOR

The vector generator accepts as inputs the transformed coordinate values and the display controller instruction. Two outputs from the vector generator move the flouresent spot in a horizontal and vertical direction on the screen. A third output varies the intensity of the display. Programmed vector mode information is stored in the vector generator and used to provide blank and unblank inputs to the CRT to


VECTOR GENERAL
Z TRIM
X TRIM
Y TRIM

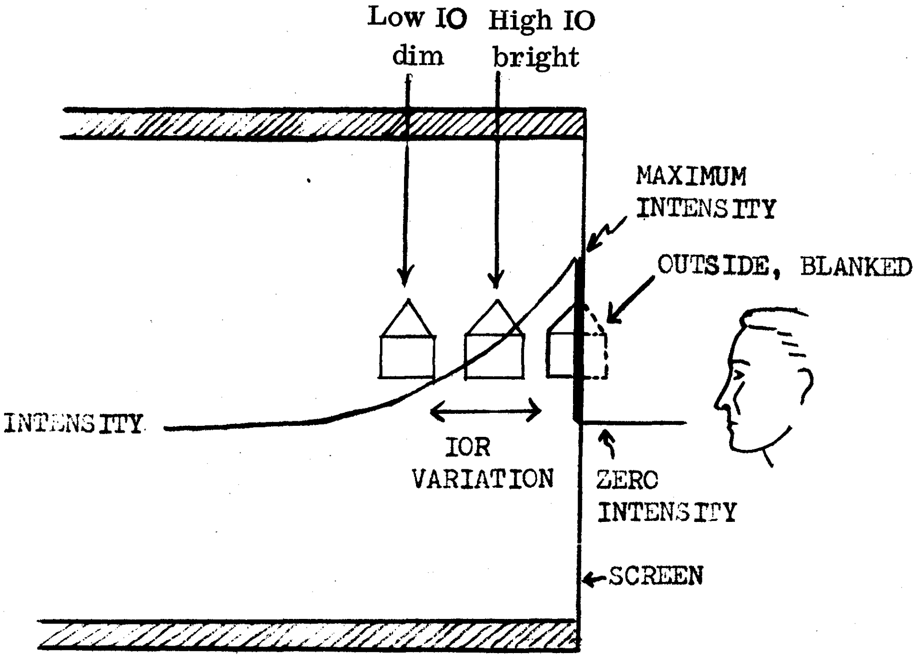


Figure 2-4. Effect of Intensity Offset Variation

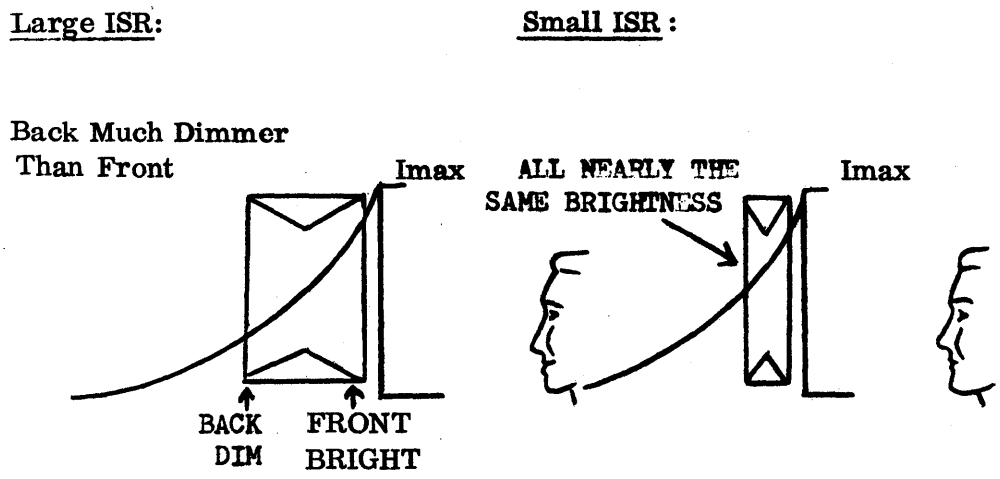


Figure 2-5. Effect of Intensity Scale Variation

specify lines, dashes, dots, or points. Vector operation information, also stored in the vector generator, determines whether the spot on the CRT will draw a vector, move from one location to another without drawing a vector, or remain stationary while new current coordinates are being received from the computer.

2.9 CHARACTER GENERATOR

The character generator interprets character codes received from the display controller and provides small X- and Y-axis deflection inputs to the cathode ray tube.

Inputs to the character generator are in the form of a stream of ASCII codes and information specifying size and the character fonts.

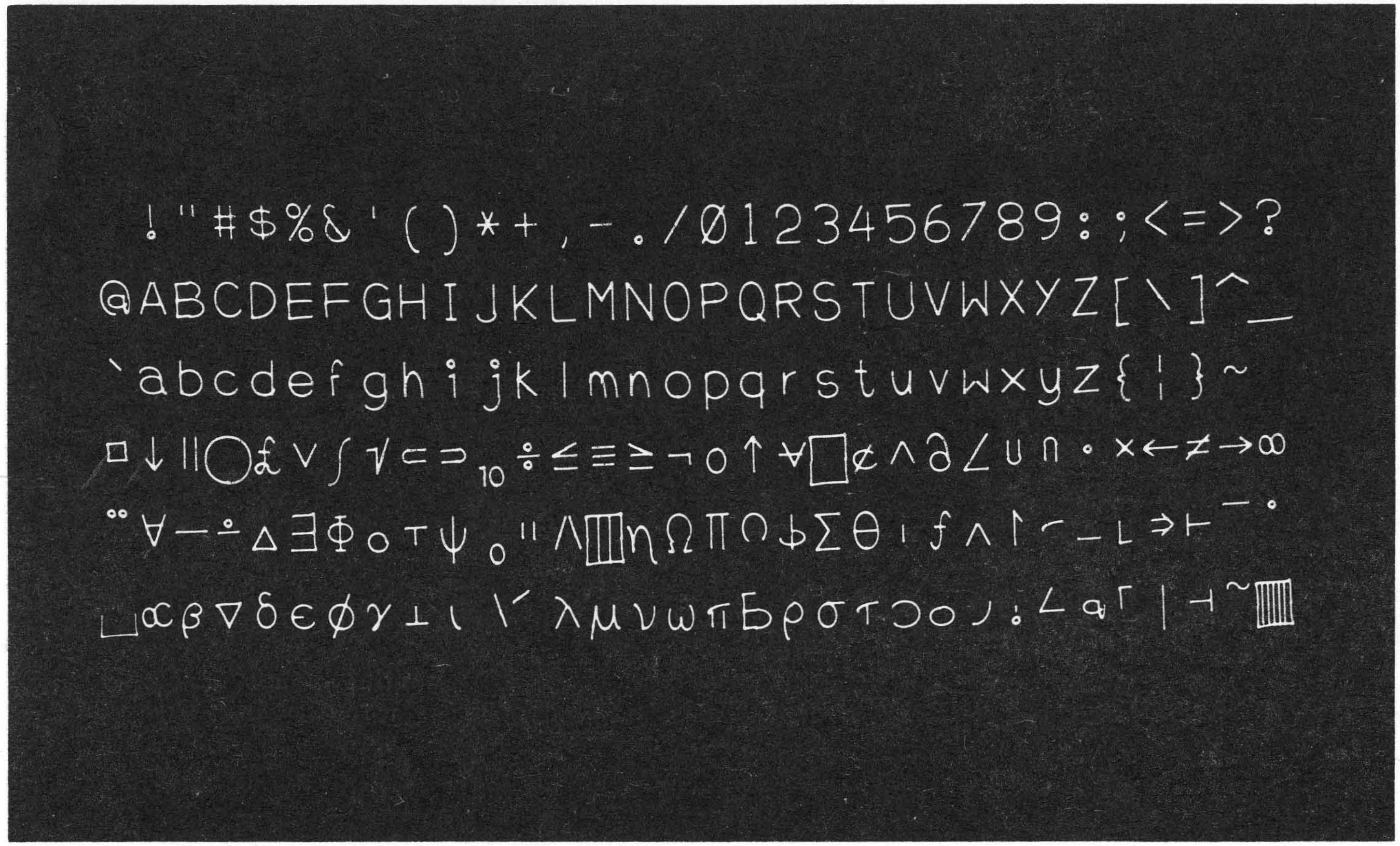
Character positioning signals from the character generator are sent to the adder for combination with the current X and Y coordinates to locate the starting point for each new character. Size information is decoded to control the minor deflection signals in four different ways to produce the four character sizes. Two-dimensional scaling inputs from the coordinate scale option and from the picture scale control option are used in the character generator so that character strings may be scaled and translated with their associated picture structures; that is, images and their labels may be transformed as a single construct.

The dimensions for character generator outputs in Number Space units are given in Figure 2-6.

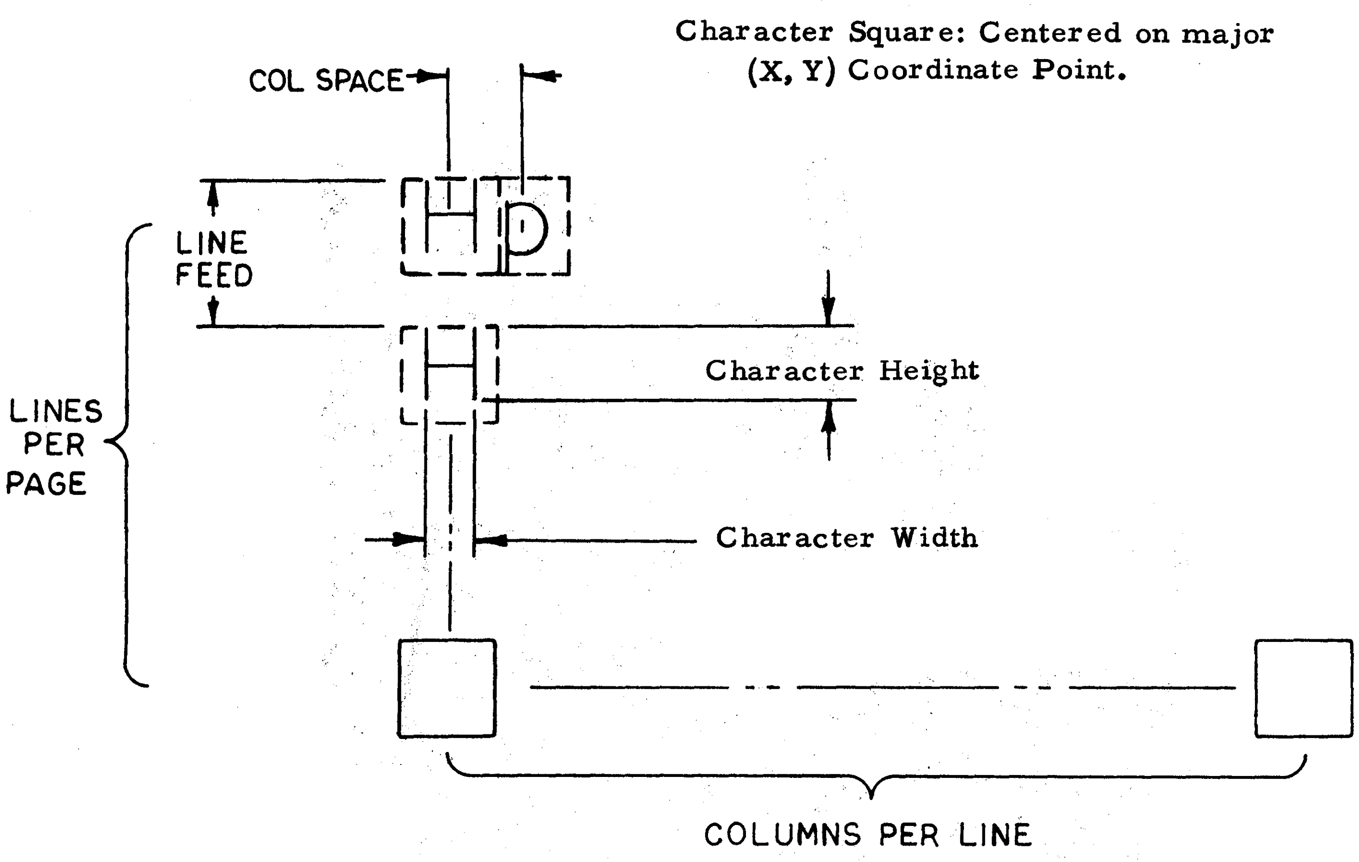
The following picture shows the standard character set font. The codes for each character can be found in Appendix A.

2.10 CIRCULAR ARC GENERATOR

The arc generator accepts as inputs the transformed coordinate values and the display controller instruction. Two outputs from the arc generator move the fluorescent spot in a horizontal and vertical direction on the screen. A third output varies the intensification of the display.



```
 !"#$%&'()*+,-./Ø123456789:;<=>?
@ABCDEFGHIJKLMNOPQRSTUVWXYZ[\]^_
`abcdefghijklmnopqrstuvwxyz{¦}~
□↓‖◯£∨∫√⊂⊃₁₀÷≤≡≥¬○↑∀▯⊄∧∂∠∪∩∘×←≠→∞
¨∀—∸△∃Φ○⊤ψ₀″Λ▥ηΩΠ∩ȸΣΘıƒ∧↾⌐_∟⇒⊢¯°
␣∝β∇δ∈∅γ⊥ι\´λμνωπБρστ⊃o⌡⁏∠ɑ⌈|⊣~▥
```



			(In Octal)			
Char. Size	(In Decimal)		Col. Space	Linefeed	Character	Char.
Code	Cols./Line	Lines/Page	Size	Size	Height	Width
S0	120	60	42	104	42	26-2/3
S1	80	40	62	144	62	41-1/3
S2	60	30	104	210	104	55-1/3
S3	32	16	200	400	200	125-1/3

Char. Size Code	Character Square (Octal)
S0	55-1/3 X 55-1/3
S1	102-2/3 X 102-2/3
S2	132-2/3 X 132-2/3
S3	252-2/3 X 252-2/3

Figure 2-6

The generated arcs are coded anywhere within any of the following types of vector lists:

Vector Relative
Vector Relative Auto-X
Vector Relative Auto-Y
Vector Relative Auto-Z
Vector Absolute
Vector Absolute Auto-X
Vector Absolute Auto-Y
Vector Absolute Auto-Z

Thus, arcs can have line texture (solid, dotted, or dashed) and can be mixed with vectors.

The arc generator draws arcs from the initial beam position to the given end-point (omitted for 360° circle) about the following center-point.

The center and endpoints of the arcs are properly transformed in both two and three space, but the arcs are drawn in a plane parallel to the screen (as are characters).

Thus, all arcs are properly transformed by DD, 2D, and 2DR systems, and only rotatable about Z in 3D systems.

2.11 CATHODE RAY TUBE

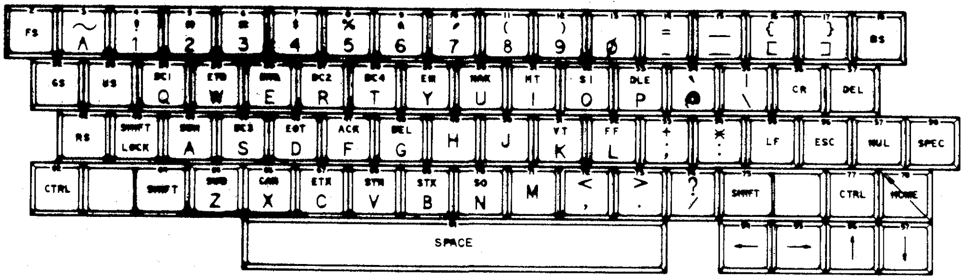
The three inputs to the CRT are horizontal and vertical deflection, to control the movement of the fluorescent spot, and intensity, to control the brightness. The intensity input is received as two signals. One is an intensity level signal, and the other is an on/off blanking signal. The major deflection signals are received from the vector generator, and minor deflection inputs from the character generator are superimposed.

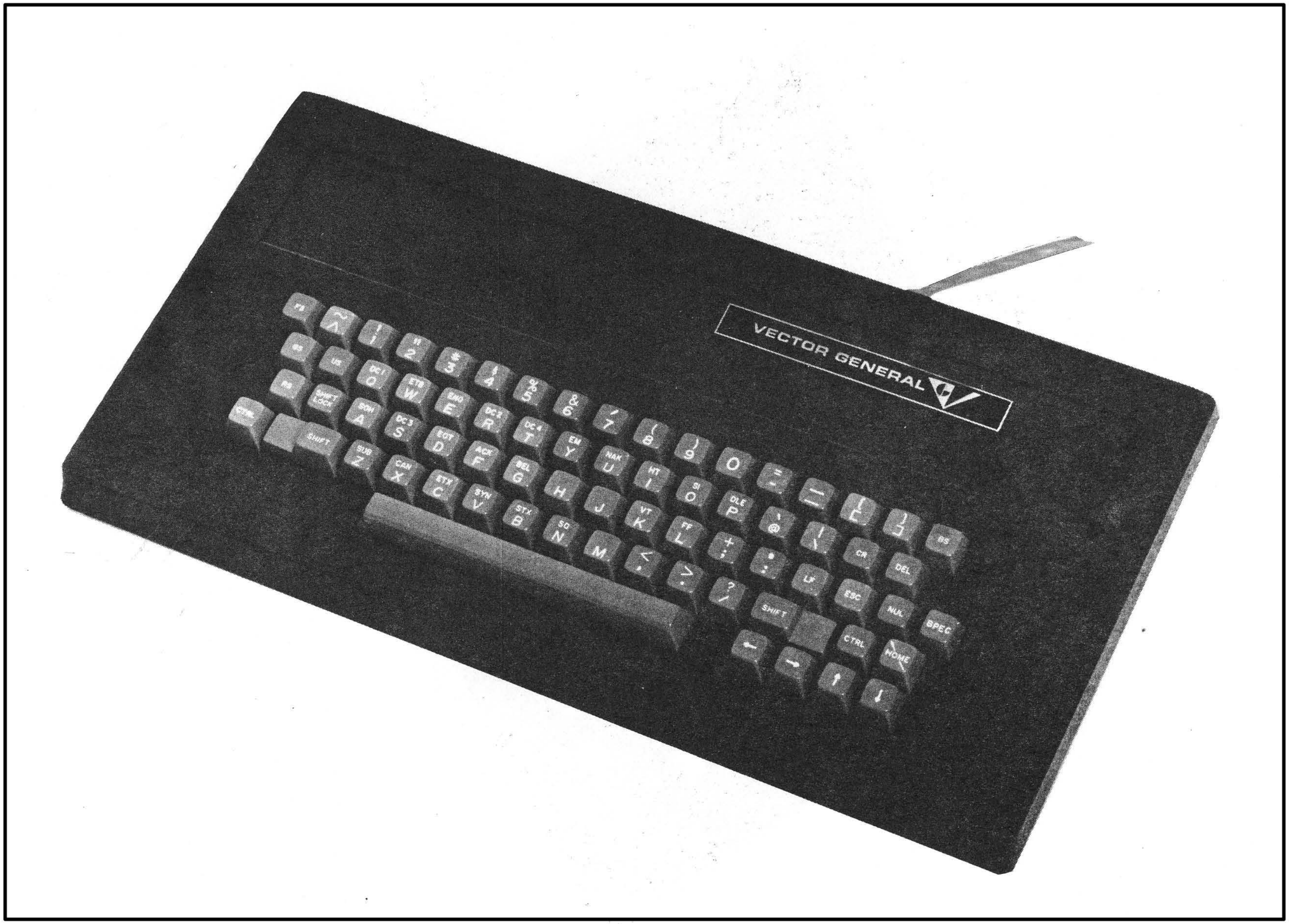
2.12 OPTIONAL CONTROL DEVICES

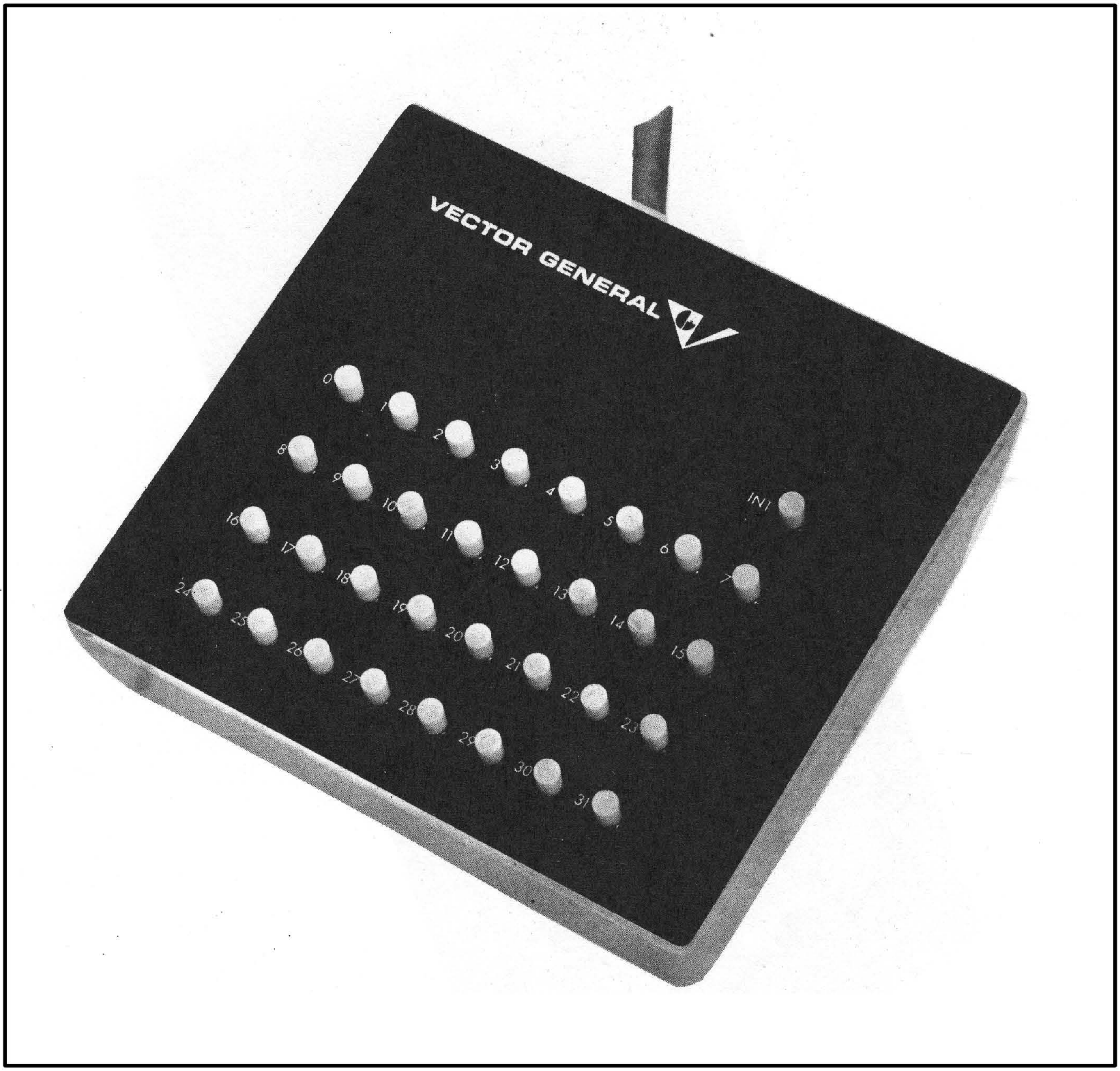
The functions of the interactive control devices that may be used with the CRT display are described below.

2.13 ALPHANUMERIC KEYBOARD

The alphanumeric keyboard is used as en entry device for manual input to the display system. Pressing a key on the keyboard enters an eight-bit character code into the keyboard register in the display controller and sets bit 12 of the priority interrupt request register (MEK) to indicate a keyboard interrupt condition. The character entered in the keyboard register does not directly affect the display on the screen. The program can read the keyboard register contents and use the information in its operation. One function of the program may be to place the character into a display list being presented on the screen. Holding any key down will maintain the correct code in the keyboard register and, after an initial delay, will repetitively raise the MEK (keyboard interrupt request) to repeat any character. Appendix A lists the codes generated by the keyboard for shifted and unshifted key combinations. The following diagram gives the keyboard layout:




VECTOR GENERAL



VECTOR GENERAL
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
INT

2.14 LIGHTED FUNCTION SWITCHES WITH MANUAL INTERRUPT

This device contains 16 or 32 function switches plus a manual interrupt switch. The function switch register in the display controller has one bit corresponding to each function switch; that is, bit 0 for function switch 1, bit 1 for function switch 2, and so on through bit 15 for function switch 16. While any function switch is depressed, the corresponding bit in the function switch register is set. The computer can then read the contents of the register and use them.

The manual interrupt switch can be used to cause an interrupt. This feature allows the operator to intercept the program at any desired point. When the manual interrupt switch is pressed, bit 13 of the priority interrupt request register (MES) is set to indicate a manual interrupt condition.

The first 8 bits of the first two output-register addresses control the 16 function switch lights. Sending ones will light the corresponding light, and zeroes turn them off. Note: as with all display registers, ANDing and ORing operations permit independent manipulation of fields.

2.15 JOYSTICK

The joystick is a mechanical device used to enter coordinate values in the 12-bit joystick X, Y, and Z input registers. A forward or backward motion of the joystick increases or reduces the value for the joystick Y-input register. A motion from side to side changes the joystick X-input value. The joystick Z-input value are decreased or increased when the joystick is twisted in a clockwise or counterclockwise direction. All three motions have a spring return to an adjustable null center position. These input registers may be read by the computer, and, if desired, the joystick values may be added into the X, Y, and Z displacement registers to move the display accordingly. Note input values range at least over ±1/2 F.S.

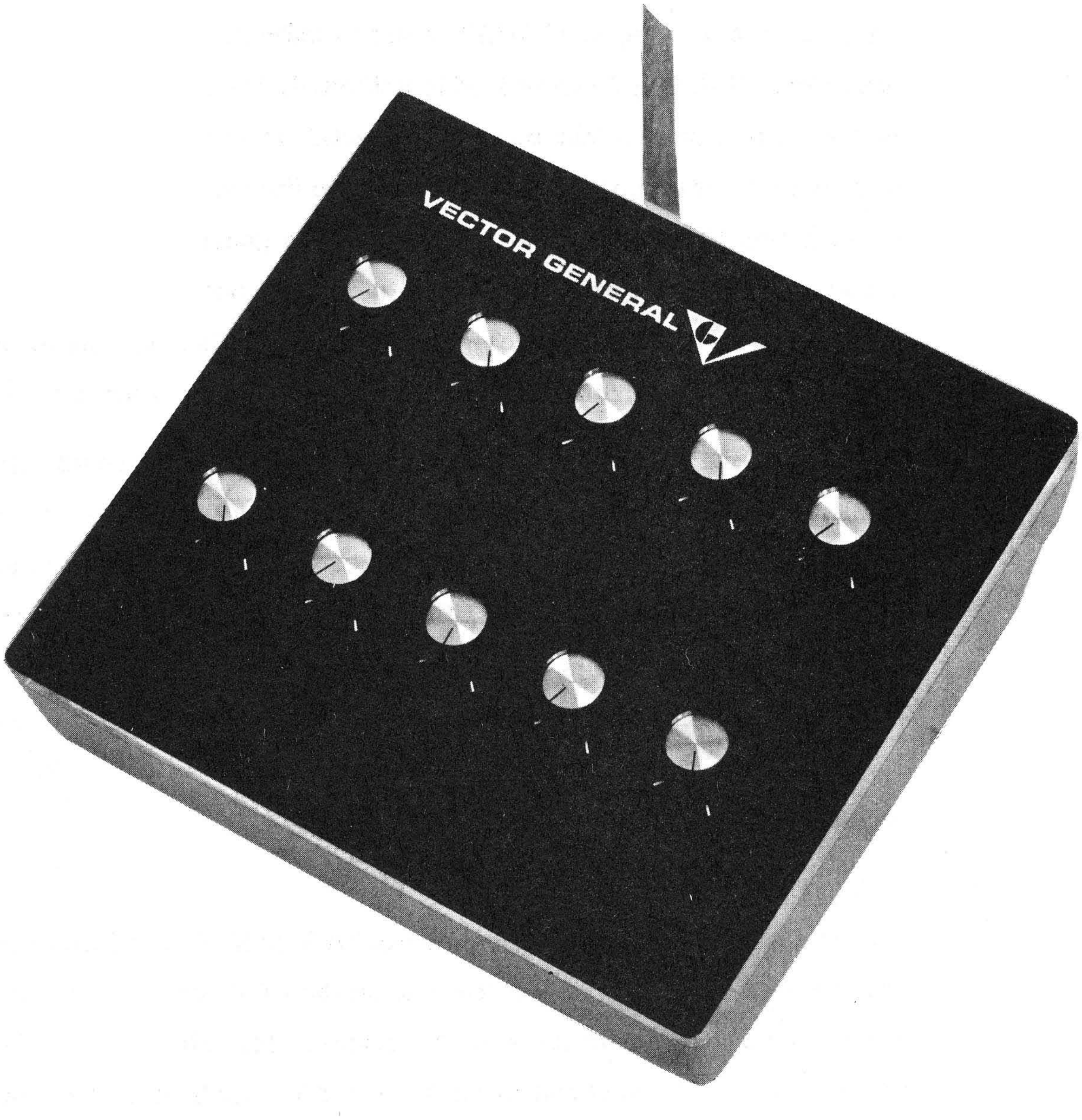
2.16 LIGHT PEN

The light pen is used to point at an element of a display or to create information by "drawing" on the display. The light pen, a wand containing a photocell, is held over the face of the CRT by the viewer. When the light pen is held over a line or point on the display, bit 10 of the priority interrupt request register (MEP) is set to indicate a light pen interrupt condition. If the light pen switch is activated, bit 15 of the PIR register is set. The light pen may be used to identify an existing element of a display or to introduce new information into the system. In the latter case, a small light pattern (tracking cross) is generated on the screen by the program and acquired by the light pen. The position of the pen in the pattern can be continuously computed from the pen's response to the pattern, and the coordinates can be maintained by the computer program.

It should be noted that when reading the display list word count register to identify the word that caused a pen halt, that the count can be further resolved to the halfword field during packed-data and character modes via the Pen-byte-resolution (PB) field of the mode register. A hardware delay feature that inhibits proceeding to a new instruction until the light pen has had a chance to respond to the last draw is included in the display controller and can be useful for precision pen position in data list identification.

2.17 DATA TABLET

The data tablet is a graphic input device with an X-Y coordinate grid which may be used corresponding to the grid on the CRT screen. Information is entered through the data tablet with a stylus. The tablet senses the location of the stylus on the grid and loads the X and Y coordinates of the stylus location into the tablet X and tablet Y registers whenever a PIO operation is performed. When the stylus is pressed down on the tablet, a switch is activated that sets bit 15 (ST) of the tablet X register.


VECTOR GENERAL

2.18 CONTROL DIALS

Ten optional control dials may be used to send digital numerical information to the computer for any purpose specified by the program. Each dial is associated with a 12-bit dial input register in the display controller. As the dial is turned, the corresponding register will read back a succession of numbers. These numbers can be read by the computer at any time.

2.19 PROGRAMMED INPUT/OUTPUT CHANNEL

The display is stopped or started and interrupts may be acknowledged by the computer over the programmed input/output channel. This channel also is used to read the contents of the display registers. A source address is sent to the controller to specify which register is to be read first. If further reading is programmed, the contents of other registers are read in numerical order by adding one to the source address each time a register is read.

2.20 INTERRUPT CHANNEL

A bit in the priority interrupt register is set when an interrupt condition is detected. If the corresponding enable bit is set in the mode control register, an interrupt is sent to the computer.

SECTION III

DISPLAY SYSTEM PROGRAMMING

3.1 INTRODUCTION

This section contains a discussion of the priority interrupt system as well as a functional description of each display instruction with its applicable data lists. The display system registers available to the programmer are described, and descriptions of the various word formats used in programming the Display System are given.

Operation of the display system consists of processing data words in accordance with their associated instructions. Instructions that draw lines or text strings process data words giving the end point coordinates of the lines or character codes of the text. Register destination instructions are followed by data words containing the information to be acted upon and written into the addressed register.

3.2 PROGRAMMATIC INTERFACE

The interface between the display system and the computer consists of:

a. A single programmed I/O channel

b. A single priority interrupt level

c. A single direct memory access channel

The display presented to the viewer is sent by means of a direct memory access (DMA) block transfer data channel. A computer program must service the DMA to output the lists of display instructions.

Programmatic I/O operations are used by computer programs to control the display system, read its status, and communicate with any peripheral I/O devices.

The interrupt is used to support the peripheral I/O devices and to execute programs required by the display lists being output. The use of the interrupt system is further elaborated in Paragraph 3.9.

3.3 DISPLAY SYSTEM REGISTERS

The display system contains registers directly addressable by the program. Registers with DAR addresses (Figure 3-1) may be changed by display instructions and are therefore referred to as destination registers. All registers with SAR addresses (Figure 3-1) may be input by a program with a programmed I/O read operation and are therefore referred to as source registers. The address of a register to be changed by a display instruction is held in a nonaccessible destination address register (DAR), and the address of the next register to be read via programmed input is held in the source address register (SAR).

3.4 DESTINATION REGISTERS

Registers with listed DAR addresses are directly addressable as destination registers, and their contents can be changed by register setting display instructions. Figure 3-1 illustrates the registers and gives the register names and their mnemonics.

Register 6 is the instruction register (IR) which holds the current display instruction of the list being processed from DMA output. Register 7 is the word count register (WCR) and is reset to zero each time the data channel is restarted. As each display list word is transmitted for display processing, the word count is increased by one count.

REGISTER BIT POSITIONS

DD	2D	2DR	3D			DAR	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	SAR
				Function Switch #1	FS1		S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	0
				FS Lamp #1	LT1H	0	L0	L1	L2	L3	L4	L5	L6	L7									
				Keyboard #1	KB1		K0	K1	K2	K3	K4	K5	K6	K7									1
				FS Lamp #1	LT1L	1	L8	L9	L10	L11	L12	L13	L14	L15									
				Tablet X #1	T1X		TX0	TX1	TX2	TX3	TX4	TX5	TX6	TX7	TX8	TX9						ST	2
				Tablet Y #1	T1Y		TY0	TY1	TY2	TY3	TY4	TY5	TY6	TY7	TY8	TY9							3
x	x	x	x	Name & Interrupt Request	NMR, PIR	4	NAME								PID	PIC	PIP	PIT	PIK	PIS	PIW	SP1	4
x	x	x	x	Mode Control	MCR	5	MED	MEC	MEP	MET	MEK	MES	MDB	MPH	MS1	MS2	MS3	MS4	PB		MDR	MDW	5
x	x	x	x	Display Instruction	IR	6	P	INST			ADDR MODE				MODIFIERS								6
x	x	x	x	Word Count	WCR	7																	7
x	x	x	x	X Coordinate	XR	8	±																8
x	x	x	x	Y Coordinate	YR	9	±																9
			x	Z Coordinate	ZR	10	±																10
x	x	x	x	Auto Increment Constant	AIR	11	±																11
x	x	x	x	Dimming Control	IOR	12	±																12
			x	Depth Cueing Control	ISR	13																	13
				Memory Address*	MAR	14	DISPLACEMENT												PAGE				14
				Stack Pointer*	SPR	15	DISPLACEMENT												PAGE				15
				Temp. General	TGR	16	±																16
	x	x	x	Picture Scale	PSR	17	±																17
x	x	x	x	Name	NMR	18	NAME																18
	x	x	x	Coordinate Scale	CSR	19	±																19
	x	x	x	X Displacement	DXR	20	±																20
	x	x	x	Y Displacement	DYR	21	±																21
			x	Z Displacement	DZR	22	±																22
		x	x	Rotation Matrix	R11R	23	±																23
					R12R	24	±																24
					R13R	25	±																25
					R21R	26	±																26
					R22R	27	±																27
					R23R	28	±																28
					R31R	29	±																29
					R32R	30	±																30
					R33R	31	±																31
				Window Mode Control	WMCR	32	MBI	MBO	MEI	MEO	MWH	MWP	PWI	PWC	PXH	PXL	PYH	PYL	PZH	PZL			32
				Window Boundry X High	XHR	33	±																33
				X Low	HLR	34	±																34
				Y High	YHR	35	±																35
				Y Low	YLR	36	±																36
				Z High	ZHR	37	±																37
				Z Low	ZLR	38	±																38
						39																	39
						40																	40
						41																	41
						42																	42
						43																	43
						44																	44
						45																	45
				Multi-Device Interrupt	DPIR	46	PIP2	PIP3	PIP4	PIK2	PIK3	PIK4	PIS2	PIS3	PIS4					SP2	SP3	SP4	46
				Multi-Device Mode Cont.	DMCR	47	MEP2	MEP3	MEP4	MEK2	MEK3	MEK4	MES2	MES3	MES4								47
						48																	48
						49																	49
						50																	50
						51																	51
				Function Switch #2	FS2		S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	52
				F S Lamp #2	LT2H	52	L0	L1	L2	L3	L4	L5	L6	L7									
				Keyboard #2	KB2		K0	K1	K2	K3	K4	K5	K6	K7									53
				F S Lamp #2	LT2L	53	L8	L9	L10	L11	L12	L13	L14	L15									
																							54
																							55
				Function Switch #3	FS3		S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	56
				F S Lamp #3	LT3H	56	L0	L1	L2	L3	L4	L5	L6	L7									
				Keyboard #3	KB3		K0	K1	K2	K3	K4	K5	K6	K7									57
				FS Lamp #3	LT3L	57	L8	L9	L10	L11	L12	L13	L14	L15									
																							58
																							59
				Function Switch #4	FS4		S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	60
				F S Lamp #4	LT4H	60	L0	L1	L2	L3	L4	L5	L6	L7									
				Keyboard #4	KB4		K0	K1	K2	K3	K4	K5	K6	K7									61
				F S Lamp #4	LT4L	61	L8	L9	L10	L11	L12	L13	L14	L15									
																							62
																							63
				Transformed X	PX		±																64
				Transformed Y	PY		±																65
				Transformed Z	PZ		±																66
				Joystick X	JX		±																67
				Joystick Y	JY		±																68
				Joystick Z	JZ		±																69
				Dials	D1		±																70
					D2		±																71
					D3		±																72
					D4		±																73
					D5		±																74
					D6		±																75
					D7		±																76
					D8		±																77
					D9		±																78
					D10		±																79
				Intersection Coord, X	CX		±																80
				Y	CY		±																81
				Z	CZ		±																82
																							83
																							84
																							85

DAR = Destination Address for Register Change Instruction
SAR = Source Address for Programmed Inputs
DD = Dual DAC System
2D = 2 Dimensional System
2DR = 2 Dimensional with Rotation Display System
3D = 3 Dimensional System

* Subroutine/Stack Option (See Appendix D.)

Figure 3-1

3.5 SOURCE REGISTERS

All SAR registers maybe read by means of a programmed input read operation. The register to be read must first be selected by setting its address in the source address register (SAR) through a programmed output write. After the designated register is read, the SAR is stepped by one, allowing successive registers to be read in sequence by successive programmed read operations. Registers which correspond to analog values (i.e., SAR = 64 - 82) will initiate an analog-to-digital conversion operation to obtain the input value. The conversion is automatically initiated whenever SAR addresses a new analog input value.

Figure 3-1 gives the source and destination addresses for all display system registers and gives the register names and their mnemonics.

3.6 PROGRAMMED I/O

There are two programmed I/O operations: Programmed input read and programmed output write.

Programmed input is used by any computer program to read display state or status, transform or coordinate values, peripheral inputs, etc. The format of the word input matches that of the display register being read. For example, if the SAR specifies source register 4 (PIR), then bits 8 through 13 of the word read via programmed input constitute the interrupt request bits and are set by the individual device requesting an interrupt. Bit positions 0 through 7 of the input word can be used as a name field to identify interrupt requirements as on different pen-sensitive image constructs.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Name								Interrupt Request Bits						▨	

PIO Sample Input of PIR

Bit positions 0 through 5 of the word written via programmed output are interrupt acknowledge bits. These are used to reset the applicable interrupt request bit in the interrupt condition sense register (PIR) after the requested interrupt has been processed. Bit positions 6 and 7 control the starting and stopping of the display. Bit positions 9 through 15 of the output word indicate which source register is to be read next on the programmed input. The word format for programmed output words is shown in the following diagram.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Interrupt Acknowledge						Cntrl		▨	SAR						

Programmed Output Write Format

3.7 PROGRAMMED OUTPUT

The programmed output write word is sent on the programmed I/O channel to the interrupt acknowledge and source address register. Bits 0 through 5, the interrupt acknowledge field, reset interrupt request bits in the priority interrupt request register (PIR). Bit 7 of the acknowledge field is used to clear and restart the display system processing of an instruction/data stream. Bit 6 is used to stop and clear the display system.

The programmed write output word can perform the following three functions:

- o Acknowledge and release any enabled active requested interrupts which are pending, and restart the display if it was waiting
- o Clear current display activities and start or stop display processing
- o Designate the initial display register for subsequent programmed read operations

The programmed output write word is shown in the following diagram.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P 0	P 1	P 2	P 3	P 4	P 5	P 6	P 7	▨	SAR						

P0 Acknowledge Display Interrupt (AKD)

P1 Acknowledge Frame Clock Interrupt (AKC)

P2 Acknowledge Light Pen Interrupt (AKP) (and continue if waiting)

P3 Acknowledge Data Tablet Interrupt (AKT)

P4 Acknowledge Keyboard Interrupt (AKK)

P5 Acknowledge Function Switch Interrupt (AKS)

P6 Stop and Clear Display Controller (SCL)

P7 Reset and Start Display (CSD)

SAR Source Address Register (to be read) (P9 through P15)

3.8 PROGRAMMED INPUT

The word input by the programmed I/O channel contains the current contents of the display system register addressed by the source address register (SAR). The source address register is loaded by a programmed output operation, and after each programmed read the source address register is advanced by one count to indicate the next register to be read. Thus, any set of registers may be read consecutively after a programmed output specifying the address of the first.

The source address registers and their contents are illustrated in Figure 3-1.

3.9 PRECISION OF ADC VALUES

The conversion of an input analog value is triggered by SAR addressing the values register (whether SAR was set directly via PIO output or stepped after a previous read). The conversion generates the sign after 3μs; the remaining bits of the value are generated at one per 1.1μs.

Thus, if programmed PIO input-store-step and test loop takes 16μs, the full 12-bit precision values will be obtained without the need for any delays. In the case of many devices (dials, joystick), the original data is of much lower precision so that higher-speed input loops also need not wait.

3.10 PRIORITY INTERRUPTS

The priority interrupts in the display system are controlled by the contents of the display system's mode control register (MCR, Register 5) and the priority interrupt request register (PIR, Register 4).

Interrupt conditions set selected bits in the PIR register. These bits can be sensed by a programmed input read of PIR.

Interrupt enabling is performed by the MCR. If an interrupt condition occurs and its corresponding enabling bit in MCR is set, an interrupt request is sent to the computer.

3.11 MODE CONTROL REGISTER (MCR)

Interrupts are enabled by including in the display list a display instruction to set the mode control bits to 1 for each interrupt to be enabled. The following diagram illustrates the mode control register and its bit configuration:

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M E D	M E C	M E P	M E T	M E K	M E S	M D B	M P H	M S 1	M S 2	M S 3	M S 4	PB		M D R	M D W

MED	Enable display interrupt on P-bit halt
MEC	Enable frame clock interrupt
MEP	Enable light pen hit detect interrupt
MET	Enable data tablet interrupt
MEK	Enable keyboard character-ready interrupt
MES	Enable sense switch interrupt
MDB	Enable display blink
MPH	Enable light pen halt
MS1	Display 1 scope select
MS2	Display 2 scope select
MS3	Display 3 scope select
MS4	Display 4 scope select
PB	Pen Hit Byte (Ø Ø = word, 1 1 = right byte, 1 Ø = left byte)
MDR	Run mode (input only)
MDW	Wait mode (input only)

A particular interrupt activity can be disabled by sending a display list with a register change instruction to set the applicable mode control interrupt-enabling bit to zero.

3.12 INTERRUPT REQUESTS

The device desiring an interrupt causes its interrupt bit in the PIR register to be set to 1. The following diagram illustrates the configuration of the PIR register and its interrupt/sense bit configuration.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NMR								PID	PIC	PIP	PIT	PIK	PIS	PIW	SP

NMR	Name field
PID	Display P-bit interrupt request
PIC	Frame clock interrupt request
PIP	Light pen interrupt request
PIT	Data tablet interrupt request
PIK	Keyboard character ready interrupt request
PIS	Manual interrupt switch interrupt request
PIW	Any window interrupt request
SP	Light Pen 1 switch sense

If an interrupt request bit is set and its corresponding enabling bit in the MCR register is a 1, an interrupt request is generated and transmitted to the computer on the priority interrupt line. The computer program may then read the contents of the PIR register to determine the device requesting the interrupt. After the interrupt request is serviced, the program writes a word on the programmed I/O line to acknowledge the interrupt (Paragraph 3.7). The interrupt acknowledge bit resets the interrupt request bit in the PIR register.

3.13 DISPLAY P-BIT INTERRUPT (SUBROUTINE, JUMP FACILITY)

Display-interrupt generation is controlled by the P-bit (bit position 0) of all DMA display instructions. If the P-bit is a 1 in the NOOP or Halt instruction and the display interrupt has been enabled (MED in register 5 is set), display processing is halted and an interrupt request is generated.

On all other instructions, if the P-bit is a 1 and the display interrupt has been enabled, an interrupt request is generated when the terminate bit or terminate character is decoded in the last word of its data list.

If the P-bit is a zero, display processing continues with the next word following the terminate used as the next instruction.

The P-bit interrupt can be used to call a program which outputs data stored in noncontiguous areas of computer memory, thereby allowing for such operations as subimaging. For example, if a portion of a display, such as a circle, is required numerous times during the construction of the display, the coordinate data for generation of the circle can be stored in a contiguous area of memory disjoint from the main display list. Each time the circle is required during the display construction, the instruction for the desired circle display can be coded as a NOOP with the circle-list address and the P-bit. When processed, it will generate an interrupt request. The interrupt request can then be used to execute a driver program which will output the addressed circle display list prior to continuing with the main display list. The P and terminate bits in the circle sublist can then be used to cause a return to the main display list.

The P and terminate bits can also be used to call up routines to compose transforms for nested sublists with transformations, cause execution of programs to effect constraints, slave the display to a user program, or slave the display to on-line interactive device inputs. Use of the P and terminate bits is dependent on the desires of the user. If the user has the Subroutine/Stack option (see Appendix B), the above facility can be performed totally by hardware.

3.14 DISPLAY CONTROLLER STATUS

The last two bits of the MCR, bits MDR and MDW, indicate the current state of the display system.

By use of the programmed I/O, a programmed output write can acknowledge and reset PIR conditions and stop or start the display system. If bit 7 is a 1, the reset and start display operation is performed placing the display system in the run state:

MDR = 1

MDW = 0

While in the run state, the display system accepts words from the data channel and processes them for display. Instructions with associated data cause the successive words to be processed under the control of the instruction until a data word coded with a terminate condition is processed.

If a Halt instruction or an instruction with the P-bit set to 1 is processed, the display system halts or waits after the instruction and all its data have been processed.

The display system is then placed in the stop state:

MDR = 0

MDW = 0

No further information is accepted from the data channel.

The display system can also be set to pause upon detection of a light pen hit on any of a selected set of display elements by setting the pen-halt enable bit (MPH). The display system is then in a wait state:

MDR = 1

MDW = 1

During the processing of a light pen interrupt with pen-halt on, the display does not request or process any further instruction or data words from the data channel. Once the light pen hit has been processed, acknowledging and resetting the light pen interrupt request causes the display system to leave the wait state, and resume operation in the run state.

If the pen-halt is not on, a light pen interrupt will not cause the display system to leave run state. While the pen-interrupt program is being executed, the display will continue its processing beyond the display instruction at which the hit was detected.

If the pen interrupt (MEP) is not enabled (set = 1), no interrupt will occur. As with any interrupt condition, the corresponding PIR bit will be set and can be used by an executing background program as a sense bit.

3.15 DISPLAY INSTRUCTIONS

Instructions used in the display system fall into three main types: output instructions, used to generate image vectors or characters on the display; control instructions; and register change instructions, used to alter the contents of display system registers.

The following paragraphs contain functional descriptions of the various display-list instruction configurations processed by the display system as received over the DMA. Each instruction discussion includes a format diagram, a listing of both the octal and hexadecimal codes for the instruction variations, a definition of the applicable code, and a description of the purpose of the instruction.

The octal code given assumes the instruction to be an 18-bit instruction with the first two bits 0's. The hexadecimal code is given in single quotation marks and preceded by the letter X. For example, the hexadecimal notation for the decimal number 21 is written as X'15'.

The codes for fields are combined with the given instruction codes or data fields by a logical OR operation to obtain the value corresponding to any selection of mnemonics.

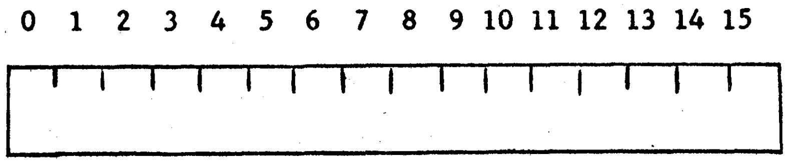
3.16 DATA LISTS

Operation of the display system consists of processing data words in accordance with their associated instructions. Instructions that draw lines or text strings process data words giving the end point coordinates of the lines or character codes of the text. Register destination instructions are followed by data words containing the information to be acted upon and written into the addressed register.

Data words are transmitted in a string or block following the applicable instruction. The last data word in the string must contain a coded terminate bit, field, or character to indicate that it is the last data word for that instruction.

3.17 WORD FORMATS

The display system uses as its basic informational element a 16-bit word with the bit positions numbered 0 through 15 as shown in the following diagram.

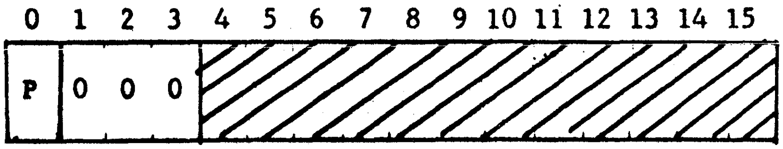


Bit position 0 represents the most significant portion of the word, and bit position 15 represents the least significant portion. This basic informational scheme is reflected in the operational registers and the internal elements of the display system.

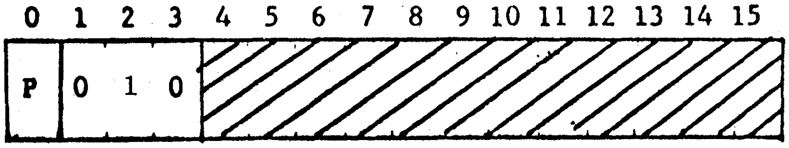
3.18 CONTROL DISPLAY INSTRUCTIONS

3.19 NO OPERATION

NOP 000000_8 X'0000'



SPC 020000_8 X'2000'



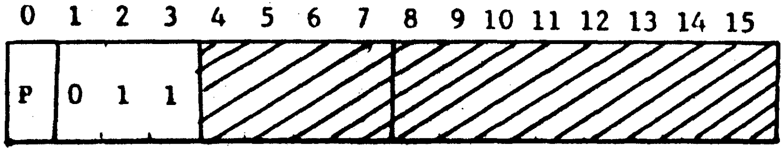
P Interrupt request

The NOP or Special display instruction may be used to hold data or addresses. These can be used to label image portions or pass arguments to subimages or interrupt-called subprograms.

The P-bit permits extending the available display instructions or calling for the execution of arbitrary computer subroutines; the remaining bits (and/or following words) may give name, address, or arguments.

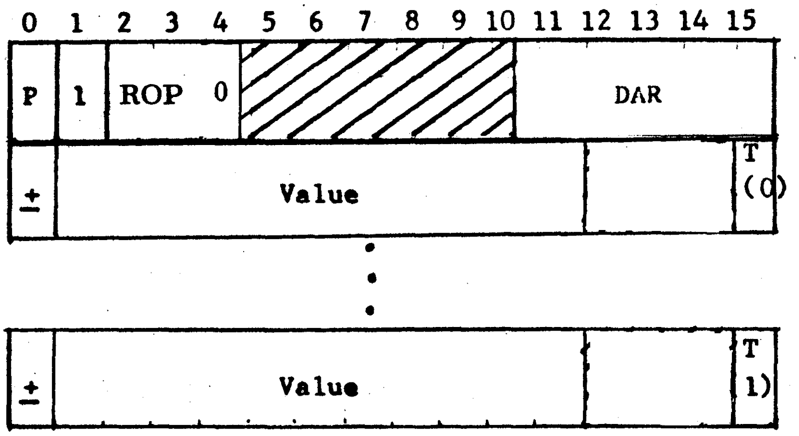
3.20 HALT

HLT 030000$_8$ X'3000'



The Halt instruction causes the display system to cease all operations. No further instructions or data words are accepted. The display system state is set to not-run, not-wait (MDR = 0, MDW = 0).

3.21 REGISTER CHANGE DISPLAY INSTRUCTIONS



P	Interrupt request
ROP	Register operation
DAR	Initial register address
T	Terminate data-list bit

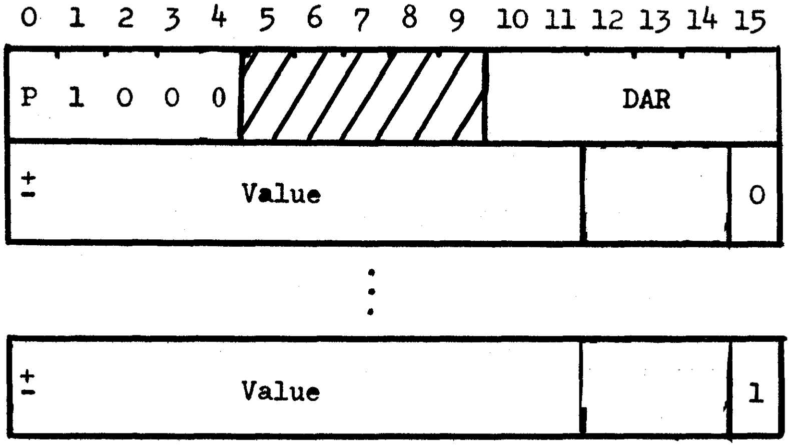
The register-change instructions are used to alter the contents of any of the display system registers. The instruction designates whether new data is to be loaded into the register or an ADD, AND, or OR operation is to be performed between succeeding data and successive registers. The address contained in the DAR portion of the instruction specifies the first register in a sequence of registers to be affected by the data stream.

The register change data list words contain the new information to be placed into the destination register indicated by the destination address register (DAR). This information may be used to replace the data in the addressed register, added to the existing contents of the register, or logically OR'ed or AND'ed with the contents of the register. The word format for a register change data list is as shown.

When a register setting display instruction is processed, sequential addressing of the destination address register occurs until a terminate bit is decoded in the last of its data words. When the terminate bit is decoded the display beam position will be updated (blanked) to reflect the current values in the affected DARs.

3.22 LOAD REGISTERS

LD 040000$_8$ X'4000'



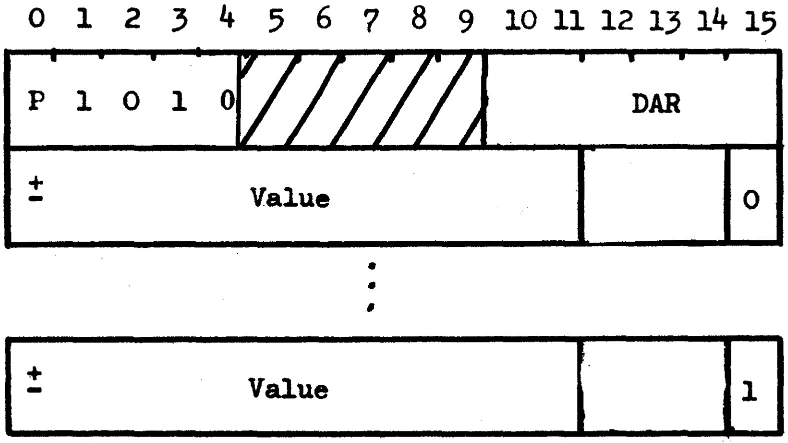
The Load Registers display instruction extracts the value field from its successive data words and loads them into succeeding display system registers, starting with the one designated by the DAR field.

Initial destination register address DAR:

PIR & NMR	04_8	X'4'	ISR	15_8	X'D'	R12R	30_8	X'18'
			PSR	21_8	X'11'	R13R	31_8	X'19'
MCR	05_8	X'5'	NMR	22_8	X'12'	R21R	32_8	X'1A'
XR	10_8	X'8'	CSR	23_8	X'13'	R22R	33_8	X'1B'
YR	11_8	X'9'	DXR	24_8	X'14'	R23R	34_8	X'1C'
ZR	12_8	X'A'	DYR	25_8	X'15'	R31R	35_8	X'1D'
AIR	13_8	X'B'	DZR	26_8	X'16'	R32R	36_8	X'1E'
IOR	14_8	X'C'	R11R	27_8	X'17'	R33R	37_8	X'1F'

3.23 OR TO REGISTERS

OR 050000_8 X'5000'

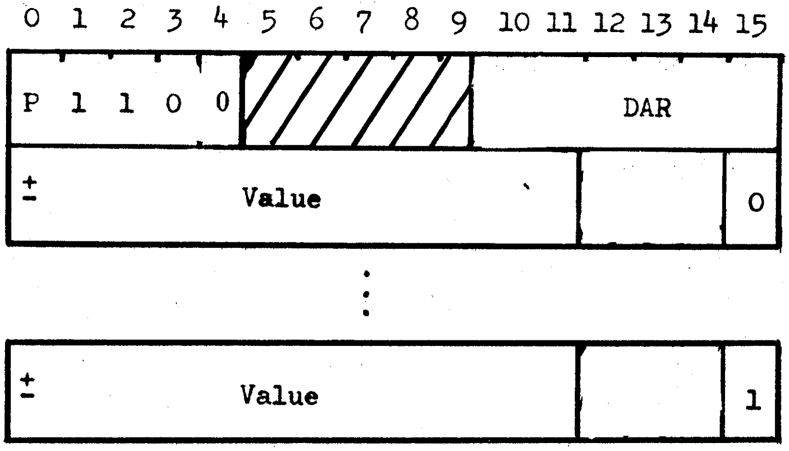


The OR to Registers display instruction extracts the value field from its successive data words and OR's them to succeeding display system registers, starting with the one designated by the DAR field.

The DAR assignments are given in Paragraph 3.22.

3.24 AND TO REGISTERS

AN 060000$_8$ X'6000'

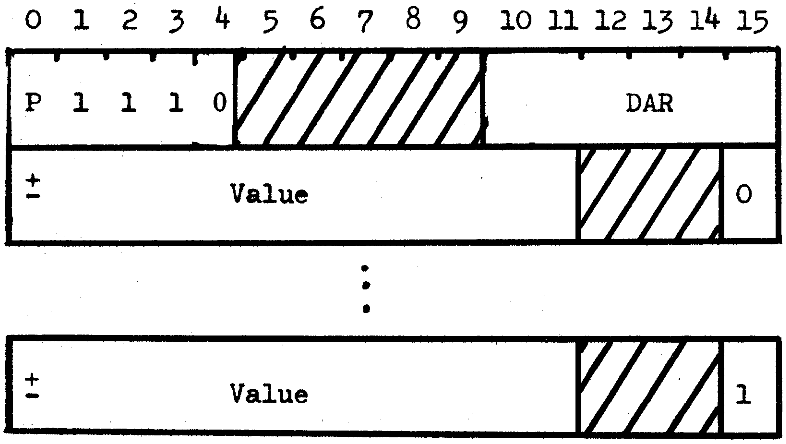


The AND to Registers display instruction extracts the value field from its successive data words and AND's them to succeeding display system registers, starting with the one designated by the DAR field.

The DAR assignments are given in Paragraph 3.22.

3.25 ADD TO REGISTERS

AD 070000$_8$ X'7000'

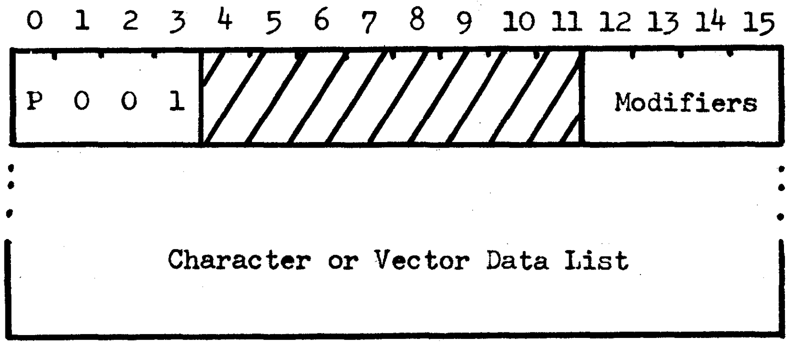


The Add to Registers display instruction extracts the value field from its successive data words and adds them to the high order 12-bits(0-11) of succeeding display system registers, starting with the one designated by the DAR field.

The DAR assignments are given in Paragraph 3.22.

3.26 DISPLAY WRITE INSTRUCTIONS

These display instructions and their following data are output as lists over the DMA channel to generate visual display elements. The basic word format is as shown in the following diagram:



P Interrupt request

The image generation instructions are used to present display elements consisting of solid lines, dashed lines, or dotted lines between two positions on the display screen, points, and characters.

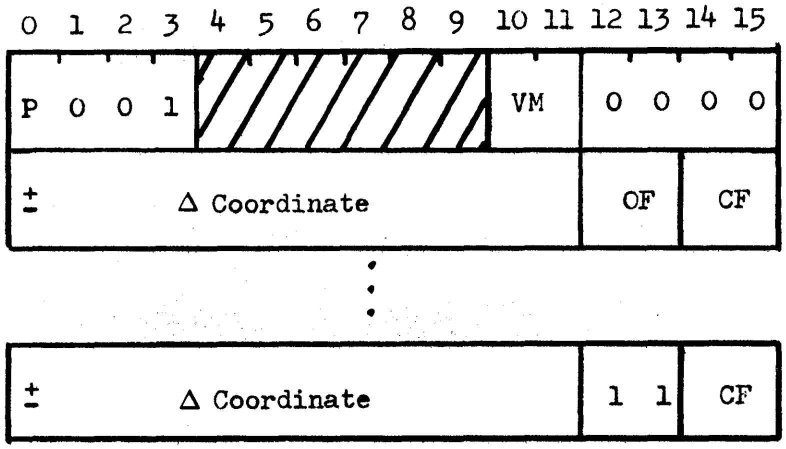
The modifier bits (12 through 15) of the image generation instruction specify if the data words that follow it are to be used for characters, absolute or relative vectors, X, Y, or Z autoincrementing, or 2D or 3D incremental vectors. The instruction also indicates the type of display (normal, dashed, dot, or point) and the incremental resolution or character scaling to be used.

The character generation instruction indicates the size of the characters to be displayed and whether they are to be displayed horizontally or vertically.

The following descriptions are given for no transformations imposed on the generated image prior to display. The user must load any transformation hardware with parameters to effect the desired transformation prior to processing any display generating instructions whose output is to be affected.

3.27 VECTOR RELATIVE

VR 010000_8 X'1000'



The display instruction for relative vectors generates a vector display whose coordinates are relative to the initial contents of the coordinate registers (XR, YR, ZR).

VM Vector mode

Line	blank	0	0
Dashed line	DSH	000020_8	X'0010'
Dotted line	DOT	000040_8	X'0020'
End-point	PNT	000060_8	X'0030'

The type of display generated by the moving beam is specified by the vector mode (VM) field.

OF Operation field

Load register	L	0	0
Load, then draw vector	D	000004_8	X'0004'
Load, then move beam (no draw!)	M	000010_8	X'0008'
Load, draw, terminate	DT	000014_8	X'000C'

The operation field (OF) of each data word specifies if the beam is to be moved to a new position held in the coordinate registers; also, when moving the beam, it specifies if a vector (type VM) is to be drawn. The OF field also specifies the end of the data list.

CF Coordinate field

Autoincrement register (AIR)	AI	000000_8	X'0000'
X-coordinate register (XR)	X	000001_8	X'0001'
Y-coordinate register (YR)	Y	000002_8	X'0002'
Z-coordinate register (ZR)	Z	000003_8	X'0003'

Each data word has a signed 12-bit coordinate increment to be added to a coordinate register or to the autoincrement register (AIR). The coordinate field (CF) of each data word specifies which register is to be updated by the coordinate increment.

When the circular arc generator is included, the following OF-CF combinations will set an arc endpoint from the new position as held in the coordinate registers and prepare to process the next "draw" coordinates as a centerpoint for drawing of a circle or arc in a plane parallel to the surface of the CRT screen.

Load clockwise arc endpoint	CW	000004_8	X'0004'
Load counterclockwise arc endpoint	CCW	000010_8	X'0008'

The next draw operation will update the coordinate registers as specified above and transfer the new coordinate values as the position of the arc center.

If CW or CCW is given after a M or D, the start and endpoint will be the same and a 360^o circle will be generated.

If the radius to start and endpoint are not given as equal, that of the start point is used.

3.28 VECTOR RELATIVE AUTO-X

VR IX 010001$_8$ X'1001'

0	1	2	3	4	5	6	7	8	9	10	n11	12	13	14	15
P	0	0	1	▨	▨	▨	▨	▨	▨	VM		0	0	0	1
±				Δ Coordinate								OF			CF

.
.
.

±	ΔCoordinate	1 1	CF

The display instruction for Vector Relative Auto-X processes its data as relative vectors. Each Δ coordinate value is added to the register designated by CF; then the vector generator performs any function specified by VM and OF. But, after each draw or move operation (OF = D, M), the X-coordinate register (XR) is incremented by the value in the autoincrement register (AIR).

The type of vectors generated is specified by VM as described in Paragraph 3.27.

Control of beam motion and blanking or list termination is specified by OF as described in Paragraph 3.27.

Specification of the register to be incremented by the Δ-coordinate value is given by CF as described in Paragraph 3.27.

3.29 VECTOR RELATIVE AUTO-Y

VR IY 010002$_8$ X'1002'

<table>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td></tr>
<tr><td>P</td><td>0</td><td>0</td><td>1</td><td colspan="6"></td><td colspan="2">VM</td><td>0</td><td>0</td><td>1</td><td>0</td></tr>
<tr><td colspan="12">± Δ Coordinate</td><td colspan="2">OF</td><td colspan="2">CF</td></tr>
</table>

⋮

<table>
<tr><td colspan="12">± Δ Coordinate</td><td>1</td><td>1</td><td colspan="2">CF</td></tr>
</table>

The display instruction for Vector Relative Auto-Y processes its data list as relative vectors. Each Δ coordinate value is added to the register designated by CF; then, the vector generator performs any function specified by VM and OF. But, after each draw or move operation (OF = D, M), the Y-coordinate register (YR) is stepped by the increment in the autoincrement register (AIR). The VM, OF, and CF fields are as described in Paragraph 3.27.

3.30 VECTOR RELATIVE AUTO-Z

VR IZ 010003$_8$ X'1003'

<table>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td></tr>
<tr><td>P</td><td>0</td><td>0</td><td>1</td><td colspan="6"></td><td colspan="2">VM</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td colspan="12">± Δ Coordinate</td><td colspan="2">OF</td><td colspan="2">CF</td></tr>
</table>

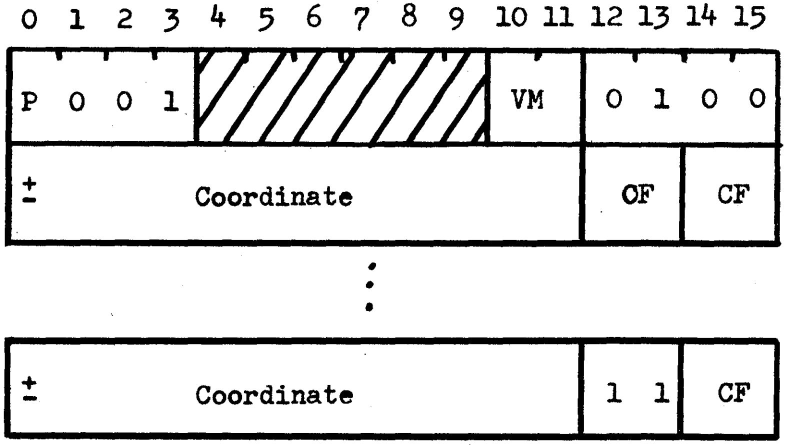
⋮

<table>
<tr><td colspan="12">± Δ Coordinate</td><td>1</td><td>1</td><td colspan="2">CF</td></tr>
</table>

The display instruction for Vector Relative Auto-Z processes its data list as relative vectors. Each Δ coordinate value is added to the register designated by CF; then, the vector generator performs any function specified by VM and OF. But, after each draw or move operation (OF = D, M), the Z-coordinate register (ZR) is stepped by the increment in the autoincrement register (AIR). The VM, OF, and CF fields are as described in Paragraph 3.27.

3.31 VECTOR ABSOLUTE

VA 010004_8 X'1004'



The Vector Absolute display instruction loads the coordinate value from each of its data words directly into the register specified by CF, replacing the previous contents. The beam position is moved if called for by OF and a vector of type VM is drawn if required by CF. The VM, OF and CF fields for absolute vectors are described as follows:

VM Vector mode

Line	blank	0	0
Dashed line	DSH	000020_8	X'0010'
Dotted line	DOT	000040_8	X'0020'
End-point	PNT	000060_8	X'0030'

The type of display generated by the moving beam is specified by the vector mode (VM) field.

OF Operation field

Load register	L	0	0
Load, then draw vector	D	000004_8	X'0004'
Load, then move beam (no draw!)	M	000010_8	X'0008'
Load, draw, terminate	DT	000014_8	X'000C'

The operation field (OF) of each data word specifies if the beam is to be moved to a new position held in the coordinate registers; also, when moving the beam, it specifies if a vector (type VM) is to be drawn. The OF field also specifies the end of the data list.

CF Coordinate field

Autoincrement register (AIR)	AI	000000_8	X'0000'
X-coordinate register (XR)	X	000001_8	X'0001'
Y-coordinate register (YR)	Y	000002_8	X'0002'
Z-coordinate register (ZR)	Z	000003_8	X'0003'

Each data word has a signed 12-bit coordinate value to be loaded into a coordinate register or to the autoincrement register (AIR). The coordinate field (CF) of each data word specifies which register is to be changed to the coordinate value.

When the circular Arc Generator is included, the following OF-CF combinations will set an arc endpoint from the new position as held in the coordinate registers and prepare to process the next "Draw" coordinates as a centerpoint for drawing of a circle or arc in a plane parallel to the surface of the CRT screen.

Load clockwise arc endpoint	CW	000004_8	X'0004'
Load counterclockwise arc endpoint	CCW	000010_8	X'0008'

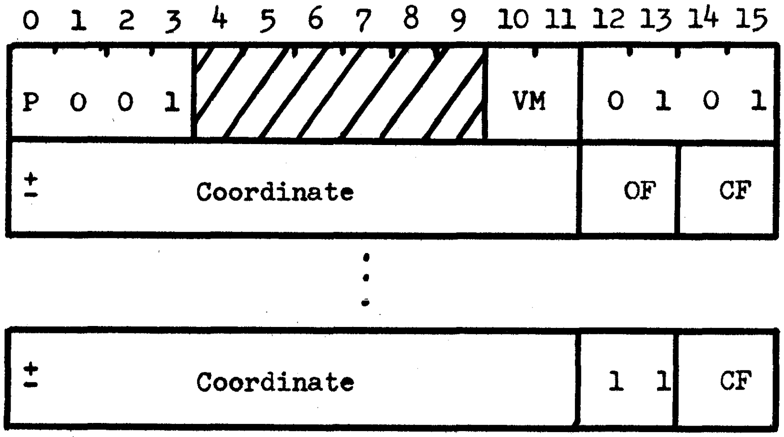
The next draw operation will update the coordinate registers as specified above and transfer the new coordinate values as the position of the arc center.

If CW or CCW is given after a M or D, the start and end point will be the same and a 360° circle will be generated.

If the radius to start and end point are not given as equal, that of the start point is used.

3.32 VECTOR ABSOLUTE AUTO-X

VA IX 010005$_8$ X'1005'

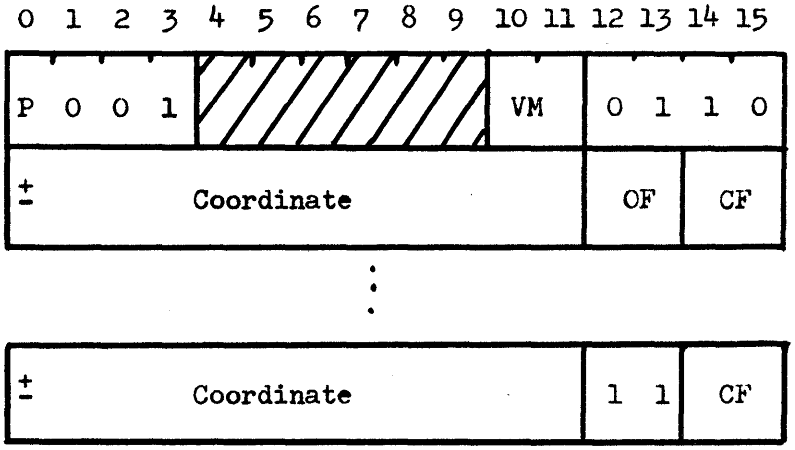


The display instruction for Vector Absolute Auto-X processes its data list as absolute vectors: Each coordinate value is loaded into the register designated by CF; then, the vector generator performs any move or VM-type draw operation if called for by OF. But, after each move or draw operation, (OF = D,M), the X-coordinate register (XR) is stepped by adding the value from the auto-increment register (AIR).

The VM, OF, and CF fields are used as described inParagraph 3.31.

3.33 VECTOR ABSOLUTE AUTO-Y

VA IY 010006_8 X'1006'

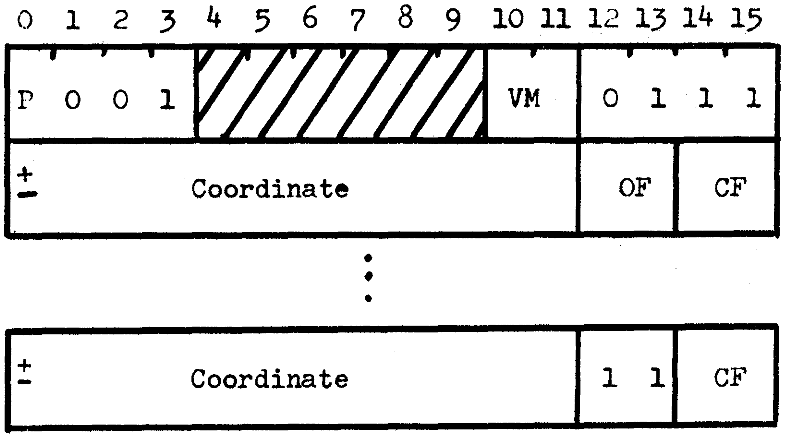


The display instruction for Vector Absolute Auto-Y processes its data list as absolute vectors: Each coordinate value is loaded into the register designated by CF; then, the vector generator performs any move or VM-type draw operation if called for by OF. But, after each move or draw operation, (OF = D,M), the Y-coordinate register (YR) is stepped by adding the value from the auto-increment register (AIR).

The VM, OF, and CF fields are used as described in Paragraph 3.31.

3.34 VECTOR ABSOLUTE AUTO-Z

VA IZ 010007_8 X'1007'

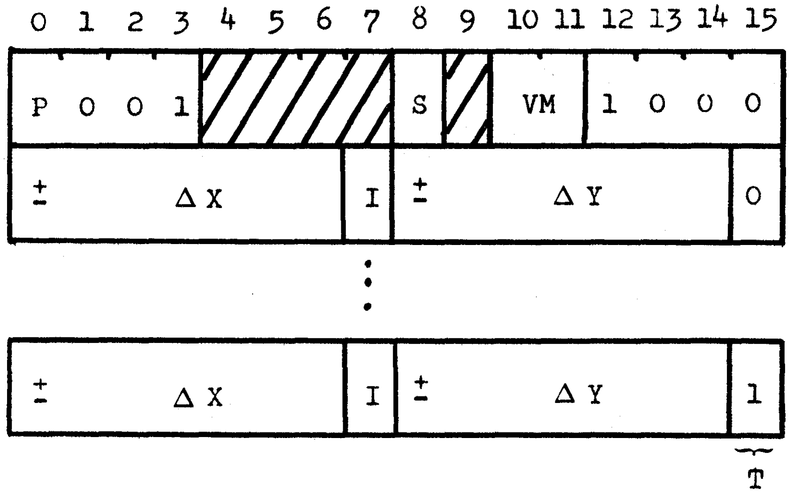


The display instruction for Vector Absolute Auto-Z processes its data list as absolute vectors: Each coordinate value is loaded into the register designated by CF; then, the vector generator performs any move or VM-type draw operation if called for by OF. But, after each move or draw operation, (OF = D,M), the Z-coordinate register (ZR) is stepped by adding the value from the auto-increment register (AIR).

The VM, OF, and CF fields are used as described in Paragraph 3.31.

3.35 INCREMENTAL VECTORS, 2D

DVXY 010010_8 X'1008'

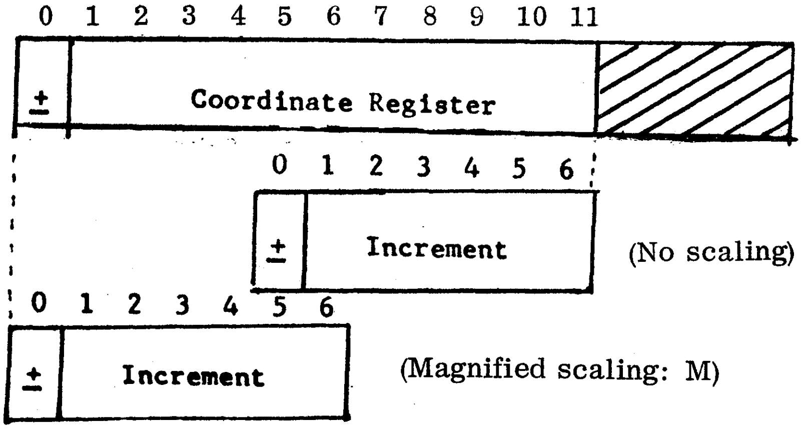


The 2D Incremental Vector display instructions generate an XY vector display whose coordinates are relative to the initial contents of the coordinate registers. Also, the maximum possible data rate has been doubled and the storage requirements halved (over those of relative vectors). This is done by reducing the Δ coordinate data field width by 7/12 and packing two values per data word. This performance increase can be exploited where the lower resolution data is adequate and the processing of packed values is not detrimental. The applicability of incremental vectors is enhanced by the scale field (S) which permits the data values to be applied as increments over a coarse or fine grid.

S Increment scale

No magnification: add Δ to 7 low-order bits	blank	000000_8	X'0000'
Magnified: add Δ to 7 high-order bits	M	000200_8	X'0080'

By specifying magnification, the coordinate increments are added to the high-order bits of the register being updated; otherwise the increment is sign-extended and added to the low-order bits:



VM Vector mode

Line	blank	0	0
Dashed line	DSH	000020_8	X'0010'
Dotted line	DOT	000040_8	X'0020'
End-point	PNT	000060_8	X'0030'

The type of display generated by the moving beam is specified by the vector mode (VM) field.

I Intensify field

Move beam with no intensification	M	000000_8	X'0000'
Move beam and draw VM-type vector	D	000400_8	X'0100'

The I-field of the incremental vector data word controls beam blanking for processing of the entire data word.

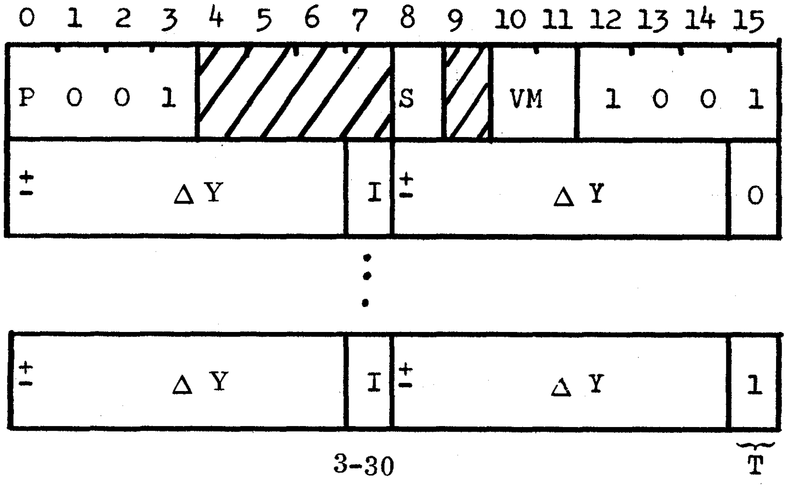
T Terminate field

Continue data list	blank	000000_8	X'0000'
Last word of data	T	000001_8	X'0001'

The last bit of an incremental vector data-list word is used to flag the end of the data list.

3.36 INCREMENTAL VECTORS, 2D AUTO-X

DVYY 010011_8 X'1009'



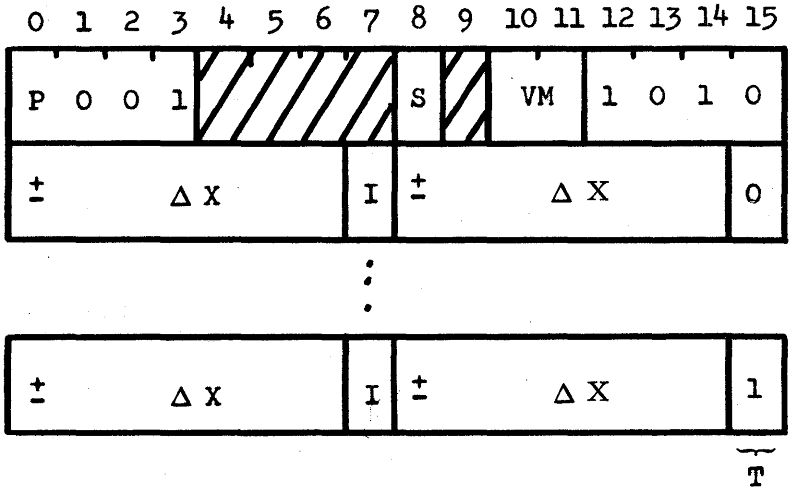
The 2D Auto-X display instruction generates a two-dimensional, relative, vector display from packed data increments; but the data words supply only Y-coordinate increments. The corresponding X-increments are taken as the constant held in the autoincrement register (AIR). This further doubles the possible vector rate and halves the core requirements for displays such as graphs, where one coordinate is stepped by a constant.

Each data word supplies two Y-increments and, therefore, is used to generate two vectors.

The S, VM, I, and T fields are coded and used as described in Paragraph 3.35, but the I-field applies to both vectors generated from its data word, and both vectors are generated from the final data word (T = 1).

3.37 INCREMENTAL VECTORS, 2D AUTO-Y

DVXX 010012$_8$ X'100A'



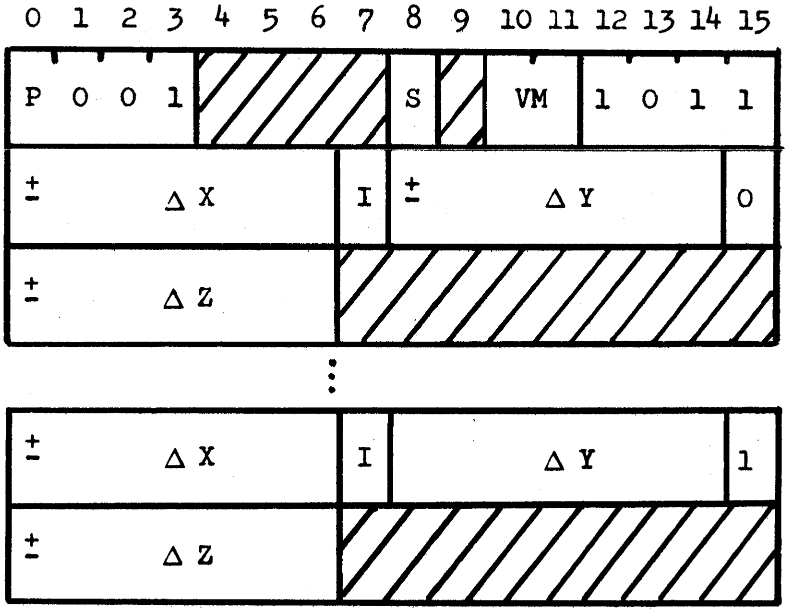
The 2D Auto-Y display instruction generates a two-dimensional, relative, vector display from packed data increments; but the data words supply only X-coordinate increments. The corresponding Y-increments are taken as the constant held in the autoincrement register (AIR). This further doubles the possible vector rate and halves the core requirements for displays such as graphs, where one coordinate is stepped by a constant.

Each data word supplies two X-increments and, therefore, is used to generate two vectors.

The S, VM, I, and T fields are coded and used as described in Paragraph 3.35, but the I-field applies to both vectors generated from its data word, and both vectors are generated from the final data word (T = 1).

3.38 INCREMENTAL VECTORS, THREE DIMENSIONAL

DV3D 010013_8 X'100B'



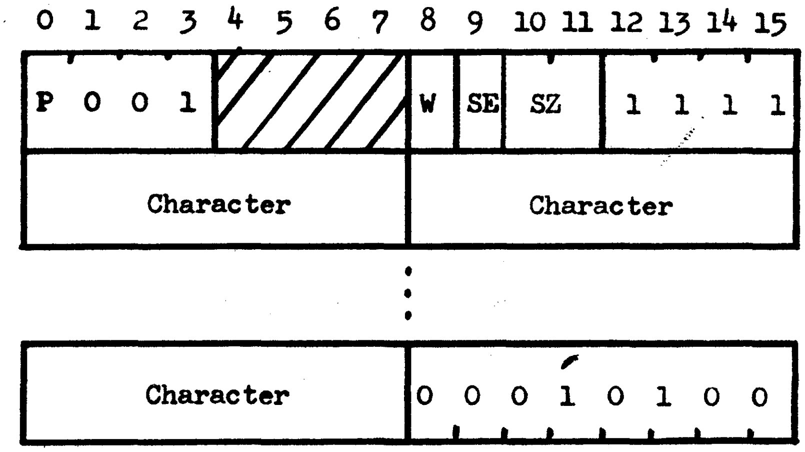
The 3D Incremental Vector display instructions generate an XYZ vector display whose coordinates are relative to the initial contents of the coordinate registers. Also, the maximum possible data rate has been increased and the storage requirements reduced (over those of relative vectors). This is done by shortening the Δ coordinate data field width by 7/12 and packing up to two values per data word. This performance increase can be exploited where the lower resolution data is adequate and the processing of packed values is not detrimental. The applicability of incremental vectors is enhanced by the scale field (S) which permits the data values to be applied as increments over a coarse or fine grid.

One vector is generated for every two data words processed.

The S, VM, I, and T fields are coded and used as described in Paragraph 3.35.

3.39 CHARACTER GENERATION

CH 010017$_8$ X'100F'



The Character Generation display instruction processes its data as a string of extended ASCII character codes packed two per word.

Each successive character displays a symbol or performs a control function until a terminate character ASCII code DC4) is processed signaling the end of the instruction's data list.

The symbols available include all of the 94 ASCII graphics, plus a standard set of 96 additional symbols (programming, math, Greek, etc.), and an optional set of 32 user-specified special symbols.

The standard symbols and their codes are given in appendix A.

W Character write-direction

Write characters horizontally	blank	000000_8	X'0000'
Write characters vertically	V	000200_8	X'0080'

The direction field (W), when set, causes the characters to be displayed as if on a page which has been rotated 90° counterclockwise.

SE, SZ Character size control

Use previous character size	blank	000000_8	X'0000'
Set size to 120 columns x 60 lines	S0	000100_8	X'0040'
Set size to 80 columns x 40 lines	S1	000120_8	X'0050'
Set size to 60 columns x 30 lines	S2	000140_8	X'0060'
Set size to 32 columns x 16 lines	S3	000160_8	X'0070'

The size field (SZ) is used to specify one of the four available string-controlled character sizes. The size-enable bit (SE) causes the contents of the SZ field to be instated as the new character size for subsequent character generation.

Control Characters

Function	Character	Codes	
No display is generated and the beam is not stepped to the next character position	DELETE	X'7F'	077400_8 lh 000177_8 rh
	NULL	X'00'	000000_8 lh 000000_8 rh
Causes positioning to revert to the previous character position	BACKSPACE	X'08'	004000_8 lh 000010_8 rh

Control Characters (Cont.)

Function	Character	Codes	
Causes the current line position to be increased by one line	LINE FEED	X'0A'	005000_8 lh 000012_8 rh
Instates current character positioning at the first character of line 1, column 1	FORM FEED	X'0C'	006000_8 lh 000014_8 rh
Resets current column position to position 1, the left margin, and increases the current line position by one line	CARRIAGE RETURN (New line)	X'0D'	006400_8 lh 000015_8 rh
Reduces the current line position by one line	DC1	X'11'	010400_8 lh 000021_8 rh
Decreases the current character size by one size. Permits sub- and superscript sizes to be embedded in text	DC2	X'12'	011000_8 lh 000022_8 rh
Increases the current character size by one size	DC3	X'13'	011400_8 lh 000023_8 rh
Terminates the data associated with a character generation instruction. If the instruction had P-bit set, display halts; if P-bit was not set, display continues and takes next word as a new instruction	DC4	X'14'	012000_8 lh 000024_8 rh
Resets the current column position to "horizontal center" and increases the current line position by one line	HORIZONTAL TAB (New line displaced)	X'09'	004400 lh 000011 rh
Instates current character positioning to "horizontal center" of line one	VERTICAL TAB (Form feed displaced)	X'0B'	005400 rh 000013 rh

SECTION IV

PROGRAM EXAMPLE

4.1 INTRODUCTION

This section contains a sample program for generating a simple display. Only a flow chart of computer instructions for the driver is given in the sample program since the actual instructions are dependent upon the individual computer. The sample program contains the display instructions and associated data words required to construct the display. The driver sends the display instructions and associated data words through the data channel in the form of block transfers.

4.2 SAMPLE PROGRAM

Figure 4-1 is a flow diagram for the sample program driver code. This program constructs a large box and a small box each containing zigzag lines and the word BOX as illustrated in Figure 4-3.

The program can be called up by a display interrupt request. The memory address associated with that interrupt request contains a branch instruction to the driver program illustrated in Figure 4-1. As indicated in Figure 4-1, the display pointer table points to one of eight display lists. On the first pass, I = 1, the pointer table points through TABLE (1) to the location for list INITIAL. After the channel has been started by the computer, a PIO control word is sent to the display system to start the display. The contents of the first list are then sent to the display system. A one is added to the index of the pointer table and the process is repeated when the next display interrupt occurs.

The contents of lists at TABLE (1) through TABLE (4) are used to generate the large box, the zigzag, and the word BOX; lists at TABLE (5) through TABLE (7) are used to generate the small box, zigzag, and the word BOX. The contents of the tables used to generate the display are listed inFigure 4-2.

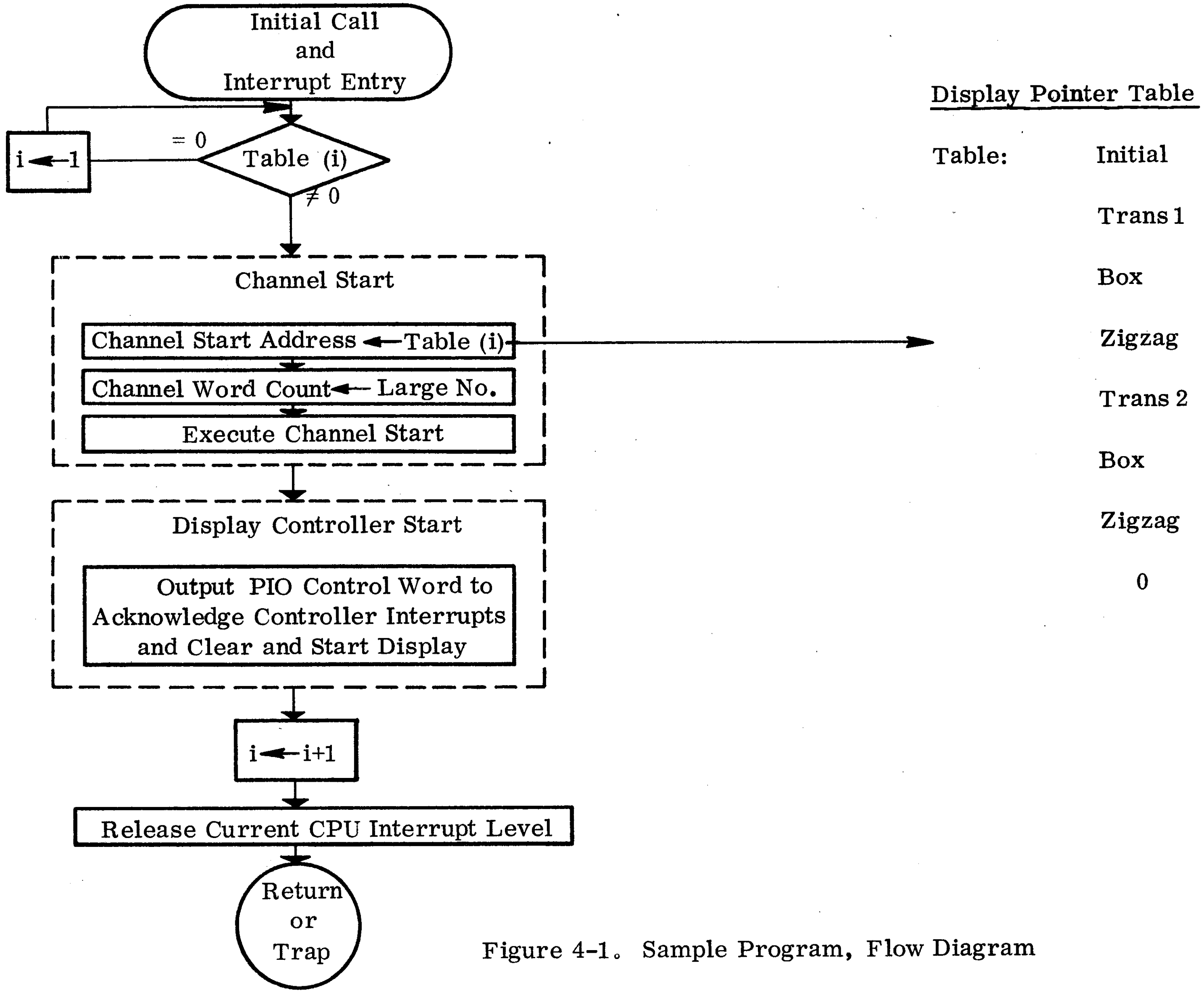

Initial Call and Interrupt Entry
= 0
i ← 1
Table (i)
≠ 0
Channel Start
Channel Start Address ← Table (i)
Channel Word Count ← Large No.
Execute Channel Start
Display Controller Start
Output PIO Control Word to Acknowledge Controller Interrupts and Clear and Start Display
i ← i+1
Release Current CPU Interrupt Level
Return or Trap
Display Pointer Table
Table:
Initial
Trans 1
Box
Zigzag
Trans 2
Box
Zigzag
0

Figure 4-1. Sample Program, Flow Diagram

```
4005    040005   INITIAL    LD, MCR           LOAD MODE CONTROL

8081    100201              MS1, MED, T       ENABLE DISPLAY INTERRUPT

400C    040014              LD, IOR           LOAD INTENSITY

7FF1    077761              2047,, T          FULL SCALE BRIGHT

C011    140021             *LD, PSR           LOAD PICTURE SCALE

3FF1    037761              1023 , T          HALF SCALE


C013    140023   TRANS1    *LD, CSR           LOAD BEGINNING WITH SCALE

3FF0    037760              1023              CSR:  HALF SCALE

E000    160000              -511              DXR:  -1/4 OFFSET LEFT

E001    160001              -511  , T         DYR:  -1/4 OFFSET DOWN

1004    010004   BOX        VA                VECTOR ABSOLUTE INSTRUCTION

8001    100001              -2048, L, X       LOAD X COORDINATE

800A    100012              -2048, L, Y       LOAD Y COORDINATE AND MOVE

7FF5    077765              2047 , D, X       LOAD X COORDINATE AND DRAW

7FF6    077766              2047 , D, Y       LOAD Y COORDINATE AND DRAW

8005    100005             -2048,   D, X      LOAD X COORDINATE AND DRAW

800E    100016             -2048,   DT, Y     LOAD Y COORDINATE, DRAW AND

                                              TERMINATE

906F    110157             * CH, S2           CHARACTER GENERATION INSTRUCTION

1120    010440              'DC1 SP'          ASCII  BYTES, NEGATIVE LINE FEED

                                              AND SPACE

426F    041157              "BO"              ASCII  BYTES, B AND O

7814    074024              "X"  'DC4'        ASCII  BYTES, X AND TERMINATE
```

NOTE: CODES ARE PRESENTED IN BOTH HEXADECIMAL AND OCTAL. FIRST CODE IS IN HEXADECIMAL NOTATION; SECOND CODE IS IN OCTAL NOTATION

*Interrupt (Display)

Figure 4-2. Sample Program Display Lists

```
4008    040010 ZIGZAG     LD, XR              LOAD STARTING WITH X-COORD

C000    140000            -2048               LOAD X COORDINATE WITH HALF FS

0001    000001            0, T                LOAD Y COORDINATE WITH ZERO

400B    040013            LD, AIR             LOAD INCREMENT REGISTER

07F1    003761            255, T              WITH 255

9009    110011          * DVYY                2D VECTOR INCREMENTAL,

                                              X AUTOINCREMENT

7E7E    077176            +255, M, +255       MOVE Y

7F82    077602            +255, D, -255       INCREMENT X, DRAW Y

7F82    077602            +255, D, -255       INCREMENT X, DRAW Y

7F82    077602            +255, D, -255       INCREMENT X, DRAW Y

7F82    077602            +255, D, -255       INCREMENT X, DRAW Y

7F82    077602            +255, D, -255       INCREMENT X, DRAW Y

7F82    077602            +255, D, -255       INCREMENT X, DRAW Y

7F83    077603            +255, D, -255, T    INCREMENT X, DRAW Y AND TERMINATE


C013    140023 TRANS2   * LD, CSR             LOAD BEGINNING WITH COORD SCALE

1FF0    017400            1008                LOAD CSR

3FF0    037760            1023                LOAD DXR

3FF1    037761            1023, T             LOAD DYR
```

NOTE: CODES ARE PRESENTED IN BOTH HEXADECIMAL AND OCTAL.
FIRST CODE IS IN HEXADECIMAL NOTATION; SECOND CODE
IS IN OCTAL NOTATION

Figure 4-2. Sample Program Display Lists (Cont.)

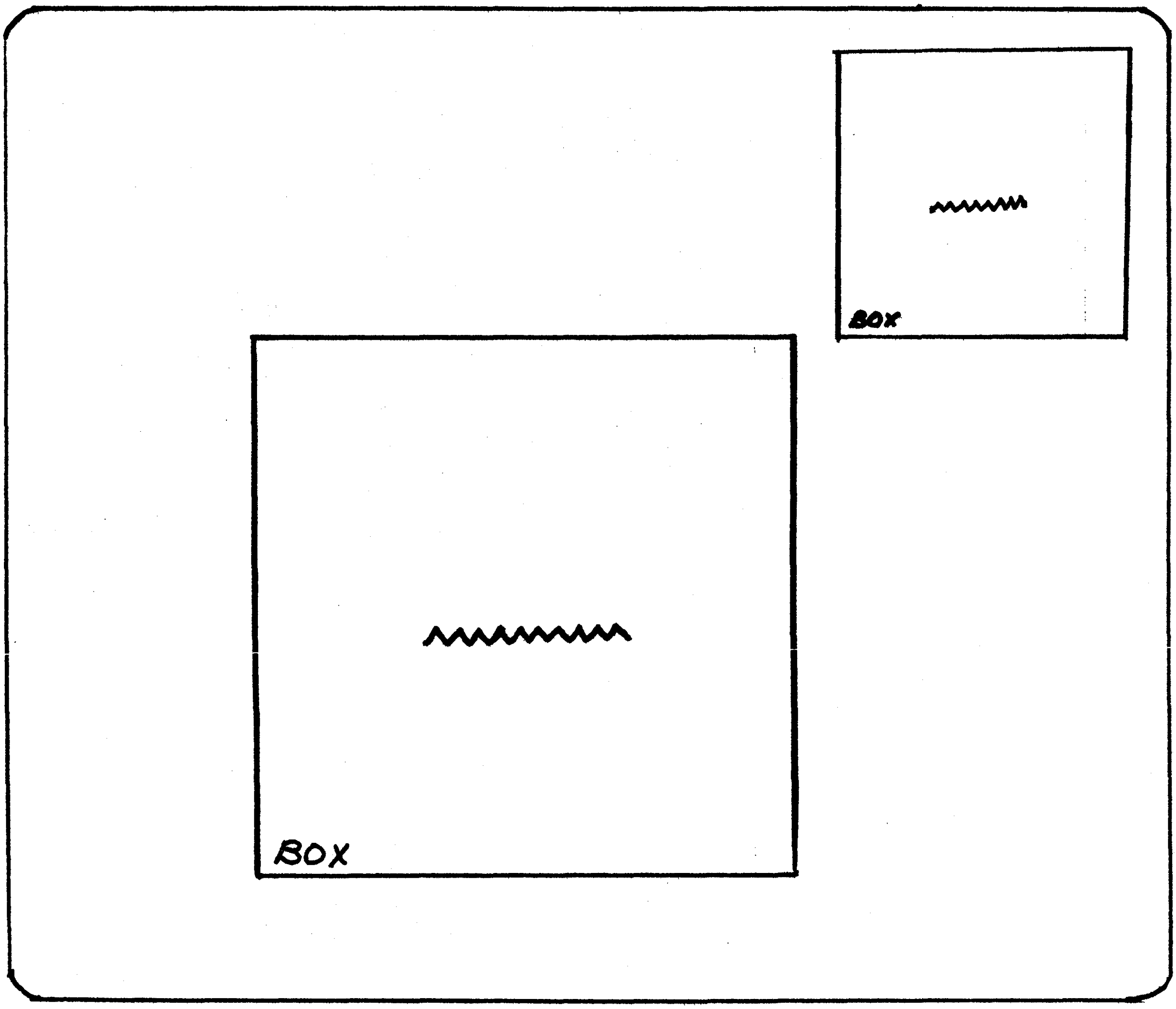


Figure 4-3. Sample Program, Typical Display

APPENDIX A

A.1 CHARACTER CODES

Table A-1 lists the ASCII* codes used by the display system for the various general and special characters. The codes are given in both octal and hexadecimal notation. The octal codes are given as though there were 18 bits in the data word instead of 16 bits. Since two characters can be given in each data word, the octal codes are given for the right half-word and the left half-word. The left half-word code is given as though there were no character in the right half-word. To obtain the complete code for the two characters in a word, the user must add the two codes together. For example, if the character C is to be in the left half-word and the character A is to be in the right half-word, the code would be:

C	041400	43
A	101	41
CA	041501_8	X'4341'

*American National Standard Code for Information Exchange.

TABLE A-1. ASCII CHARACTER CODES

Hex	Octal Left	Octal Right	Char. Gen. Sym.	Alpha. Num. Keyb. Keys
08	004000	010	BS	BS
09	004400	011	HT	I ctrl
0A	005000	012	LF	LF
0B	005400	013	VT	K ctrl
0C	006000	014	FF	L ctrl
0D	006400	015	NL	CR
11	010400	021	DC1	Q ctrl
12	011000	022	DC2(-SZ)	R ctrl
13	011400	023	DC3(+SZ)	S ctrl
14	012000	024	DC4(term)	T ctrl
20	020000	040	Space	Sp bar
21	020400	041	!	1 shft
22	021000	042	"	2 shft
23	021400	043	#	3 shft
24	022000	044	$	4 shft
25	022400	045	%	5 shft
26	023000	046	&	6 shft
27	023400	047	'	7 shft
28	024000	050	(	8 shft
29	024400	051	)	9 shft
2A	025000	052	*	: shft
2B	025400	053	+	; shft
2C	026000	054	,	,
2D	026400	055	-	-
2E	027000	056	.	.
2F	027400	057	/	/
30	030000	060	Ø	Ø
31	030400	061	1	1
32	031000	062	2	2
33	031400	063	3	3
34	032000	064	4	4
35	032400	065	5	5
36	033000	066	6	6
37	033400	067	7	7
38	034000	070	8	8
39	034400	071	9	9
3A	035000	072	:	:
3B	035400	073	;	;
3C	036000	074	<	, shft
3D	036400	075	=	- shft
3E	037000	076	>	. shft
3F	037400	077	?	/ shft
40	040000	100	@	@
41	040400	101	A	A shft
42	04100	102	B	B shft
43	041400	103	C	C shft
44	042000	104	D	D shft
45	042400	105	E	E shft
46	043000	106	F	F shft
47	043400	107	G	G shft
48	044000	110	H	H shft
49	044400	111	I	I shft
4A	045000	112	J	J shft
4B	045400	113	K	K shft
4C	046000	114	L	L shft
4D	046400	115	M	M shft
4E	047000	116	N	N shft
4F	047400	117	O	O shft
50	050000	120	P	P shft
51	050400	121	Q	Q shft
52	051000	122	R	R shft
53	051400	123	S	S shft
54	052000	124	T	T shft
55	052400	125	U	U shft
56	053000	126	V	V shft
57	053400	127	W	W shft
58	054000	130	X	X shft
59	054400	131	Y	Y shft
5A	055000	132	Z	Z shft
5B	055400	133	[	[
5C	056000	134	\	\
5D	056400	135	]	]
5E	057000	136	^ (superscript)	^
5F	057400	137	(subscript)	_
60	060000	140	`	@ shft
61	060400	141	a	A
62	061000	142	b	B
63	061400	143	c	C
64	062000	144	d	D
65	062400	145	e	E
66	063000	146	f	F
67	063400	147	g	G
68	064000	150	h	H
69	064400	151	i	I

TABLE A-1. ASCII CHARACTER CODES (Cont.)

Hex	Octal Left	Right	Char. Gen. Sym.	Alpha. Num. Keyb. Keys
6A	065000	152	j	J
6B	065400	153	k	K
6C	066000	154	l	L
6D	066400	155	m	M
6E	067000	156	n	N
6F	067400	157	o	O
70	070000	160	p	P
71	070400	161	q	Q
72	071000	162	r	R
73	071400	163	s	S
74	072000	164	t	T
75	072400	165	u	U
76	073000	166	v	V
77	073400	167	w	W
78	074000	170	x	X
79	074400	171	y	Y
7A	075000	172	z	Z
7B	075400	173	{	[shft
7C	076000	174	¦	\ shft
7D	076400	175	}	] shft
7E	077000	176	~	^shft
7F	077400	177	del	DEL
80-90F	100000- 117400	200- 237	*	**
A0	120000	240	⌑	space spec
A1	120400	241	↓	1 shft spec
A2	121000	242	‖	2 shft spec
A3	121400	243	○	3 shft spec
A4	122000	244	£	4 shft spec
A5	122400	245	∨ (cntrd.)	5 shft spec
A6	123000	246	∫	6 shft spec
A7	123400	247	√	7 shft spec
A8	124000	250	⊂	8 shft spec
A9	124400	251	⊃	9 shft spec
AA	125000	252	10***	:
AB	125400	253	†	;

Hex	Octal Left	Right	Char. Gen. Sym.	Alpha. Num. Keyb. Keys
AC	126000	254	≤	, spec
AD	126400	255	≡	- spec
AE	127000	256	≥	. spec
AF	127400	257	¬	/ spec
B0	130000	260	∘	0 spec
B1	130400	261	↑	1 spec
B2	131000	262	¥	2 spec
B3	131400	263	□	3 spec
B4	132000	264	¢	4 spec
B5	132400	265	∧ (centered)	5 spec
B6	133000	266	∂	6 spec
B7	133400	267	∠	7 spec
B8	134000	270	∪	8 spec
B9	134400	271	∩	9 spec
BA	135000	272	• (center dot)	: spec
BB	135400	273	×	; spec
BC	136000	274	←	, shft spec
BD	136400	275	≠	- shft spec
BE	137000	276	→	. shft spec
BF	137400	277	∞	/ shft spec
C0	14000	300	¨ (superscript)	@ spec
C1	140400	301	∀	A shft spec
C2	141000	302	−	B shft spec
C3	141400	303	∸	C shft spec
C4	142000	304	Δ	D shft spec
C5	142400	305	∃	E shft spec
C6	143000	306	Φ	F shft spec
C7	143400	307	• (superscript)	G shft spec
C8	144000	310	⊤	H shft spec
C9	144400	311	ψ	I shft spec
CA	145000	312	∘	J shft spec
CB	145400	313	"	K shft spec
CC	146000	314	Λ	L shft spec

* optional special characters

** ctrl and spec and [A - Z] or [@[\] ^_]

***subscript

TABLE A-1. ASCII CHARACTER CODES (Cont.)

Hex	Octal Left	Right	Char. Gen. Sym.	Alpha. Num. Keyb. Keys
CD	146400	315	▥	M shft spec
CE	147000	316	η	N shft spec
CF	147400	317	Ω	O shft spec
D0	150000	320	∏	P shft spec
D1	150400	321	∩	Q shft spec
D2	151000	322	þ	R shft spec
D3	151400	323	Σ	S shft spec
D4	152000	324	θ	T shft spec
D5	152400	325	ı	U shft spec
D6	153000	326	ƒ	V shft spec
D7	153400	327	∧	W shft spec
D8	154000	330	↾	X shft spec
D9	154400	331	╭	Y shft spec
DA	155000	332	—	Z shft spec
DB	155400	333	L	[spec
DC	156000	334	⇒	spec
DD	156400	335	⊢	] spec
DE	157000	336	_ *	∧ spec
DF	157400	337	• *	____spec
E0	160000	340	⎵ (blinking)	@ shft spec
E1	160400	341	α	A spec
E2	161000	342	β	B spec
E3	161400	343	∇	C spec
E4	162000	344	δ	D spec
E5	162400	345	ϵ	E spec
E6	163000	346	ϕ	F spec
E7	163400	347	γ	G spec
E8	164000	350	⊥	H spec
E9	164400	351	ι	I spec
EA	165000	352	╲	J spec
EB	165400	353	/ *	K spec
EC	166000	354	λ	L spec
ED	166400	355	μ	M spec
EE	167000	356	ν	N spec
EF	167400	357	ω	O spec
F0	170000	360	π	P spec
F1	170400	361	Б	Q spec
F2	171000	362	ρ	R spec
F3	171400	363	σ	S spec
F4	172000	364	τ	T spec
F5	172400	365	ɔ	V spec
F6	173000	366	○	V spec
F7	173400	367	/	W spec
F8	174000	370	!	X spec
F9	174400	371	∠	Y spec
FA	175000	372	ɥ	Z spec
FB	175400	373	Γ	[spec shft
FC	176000	374	|	spec shft
FD	176400	375	⊣	] spec shft
FE	177000	376	~*	∧ spec shft
FF	177400	377	▥	DEL spec

*(superscript)

APPENDIX B

DISPLAY SUBROUTINE/STACK OPTION

The facilities described in this section are available as an optional extension to the display-computer interface in certain cases. These normally comprise those systems in which the display is not interfaced through a standard DMA data channel-- in which case, the interface must implement the core-access and data channel functions.
The provision for the following extensions is made possible by the accessability of the Memory-address register used for core data-word transfers.

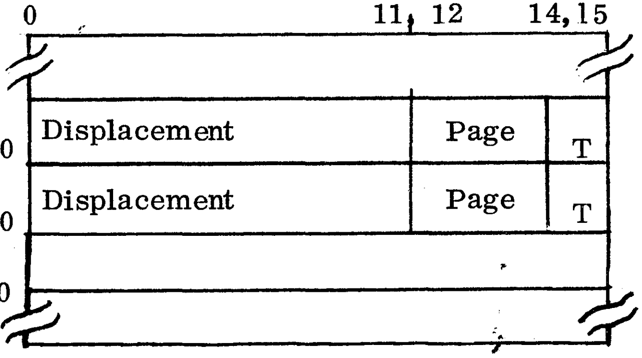
The following facilities can all be implemented in the display driver programs and encoded in the display lists using P-bit interrupt calls as described in the Display System Reference Manual.

The advantage of hardware implementation is improved display speed, reduced processor execution time requirements and reduced core storage requirements for driver coding.

DISPLAY REGISTERS

This option provides the following three additional 15-bit registers:

		SAR, DAR
MAR	Memory Address:	16_8 E_{16} 14_{10}
SPR	Stack Pointer:	17_8 F_{16} 15_{10}
TGR	Temp General:	20_8 10_{16} 16_{10}



The MAR holds the core address normally used when words are sent from memory to the display. Address registers are extended to 15 bits to permit addressing of 32K words. The low order 12 bits (displacement) are in the value field to permit address arithmetic within 4K pages.

The MAR normally holds the address of the next display-list word to be processed. After use, it is incremented.

The SPR holds the core address used whenever words are sent from Display Registers back to memory. It can also be used to fetch words back to display system registers.

After use, the SPR is decremented on store operations. Prior to use on fetch operations, the SPR is incremented.

The TGR is a general purpose 15-bit register useful for temporary storage of the stack-pointer when SPR is being used as a write address.

As with all other registers, the MAR and SPR can be input via PIO, and loaded, OR-ed And-ed, or Add-ed to via Display list Register-Operations (cannot add to bits 12, 13, 14, and 15).

DISPLAY INSTRUCTIONS

Load from Stack

LDS 044000_8 X'4800

0	3	4	9	10 15
P	1 0 0	1	▨	DAR

The load from Stack display instruction extracts the value field from a list of words in core and loads them into succeeding display system registers, starting with the one designated by the DAR field (DAR assignments are given in Section 3.21)

The list of values is stored in successively preceeding (lower address) cells of memory.

The first value (highest address) is in the cell initially addressed by the contents of SPR (bits 0 to 14).

The list is terminated by a word with bit 15 set to one (terminate).

After each word is transferred, its address held in SPR, is decremented.

Or from Stack

ORS 054000_8 X'5800

0	1 3	4	9	10 15
P	1 0 1	1	▨	DAR

The Or from Stack display instruction extracts the value field from a list of words in core and OR's them into succeeding display system registers, starting with the one designated by the DAR field.

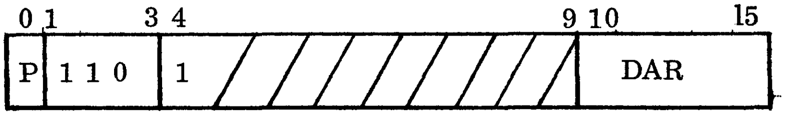
The first fetched word of the list, stored at the highest core location of the list, is at the address held in SPR.

The list extends through preceeding (lower) addresses to one containing a terminate bit (15) set to one.

The SPR is decremented after each word is fetched.

And from Stack

ANS 064000_8 X'6800



The And from Stack display instructionextracts the value field from a list of words in core and AND's them into succeeding display system registers, starting with the one designated by the DAR field.

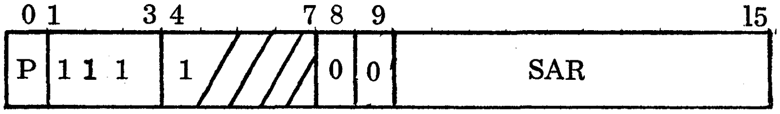
The first fetched word of the list, stored at the highest core location of the list is at the address held in SPR.

The list extends through preceeding (lower) addresses to one containing a terminate bit (15) set to one.

The SPR is decremented after each word is fetched.

Store in Stack

STS 074000_8 X'7800

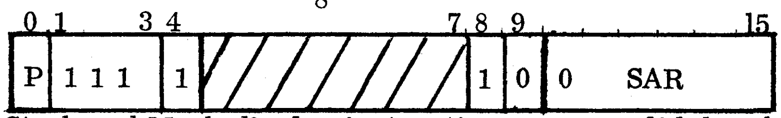


The Store in Stack display instruction causes valid data bits in the display system register designated by instruction field SAR to be stored into the memory word addressed by the contents of SPR after incrementing it by one.
Note: SAR must be less than 64_{10} and

If SAR = 14_{10}, (MAR), the MAR contents are incremented by 2 prior to storing

Store in Stack and Mark

STSM 074200_8 X'7880



The Store in Stack and Mark display instruction causes valid data bits in display register at SAR to be stored into memory with bit 15 set = 1 terminate.

Store in Stack and Mark - Continued

The SPR is incremented and the result used as the core address into which the value is stored.

Notes: SAR must be less than 64_{10} and
If SAR = 14_{10}, the MAR is incremented by two prior to storing.

EXAMPLES

The following series of display-code segments illustrate how the optional display-instructions may be used to code some desirable display functions.

Branch in list

```
JUMP (LOC)      LD  MAR
                Loc T
```

This sequence may be used to link disjointed display-list segments for processing as if they were one continuous display definition.

Subroutine list-jump

```
CALL (LIST)     STSM  MAR
                LD    MAR
                LIST  T
```

This sequence permits a single picture-defining display list to be processed many times as a sub-item used in defining a composite display.

This sequence also permits composite display-lists (containing sub-list call's) to be called as sub-lists of another display-list. Thus user defined displays may be used as basic elements in defining further displays.

Subroutine Exit

```
RETURN      LDS MAR
```

This display instruction can be used to terminate a sub-list definition and return to the calling list to resume its display generation, (if it was called as by the previous "CALL" sequence).

Stuff Data

```
PUSH (Reg, n)  =    STSM  REG
                    STS   REG+1
                    :
                    STS   REG+n
```

This sequence may be used for nested saving and restoring of register data.

This need arises in making display-lists transparent to the effect of sub-list calls (i.e. alteration of coordinate registers, pen enable/detect, transformation state, etc)

Another use is for bracketing the effect of transformations over selected sequences of display-list items, and/or the nesting of such transformation effects.

Restore Data

```
POP  =  LDS REG + n
```

This display instruction will restore the registers saved by the preceeding (matching) PUSH operation.

Save Data

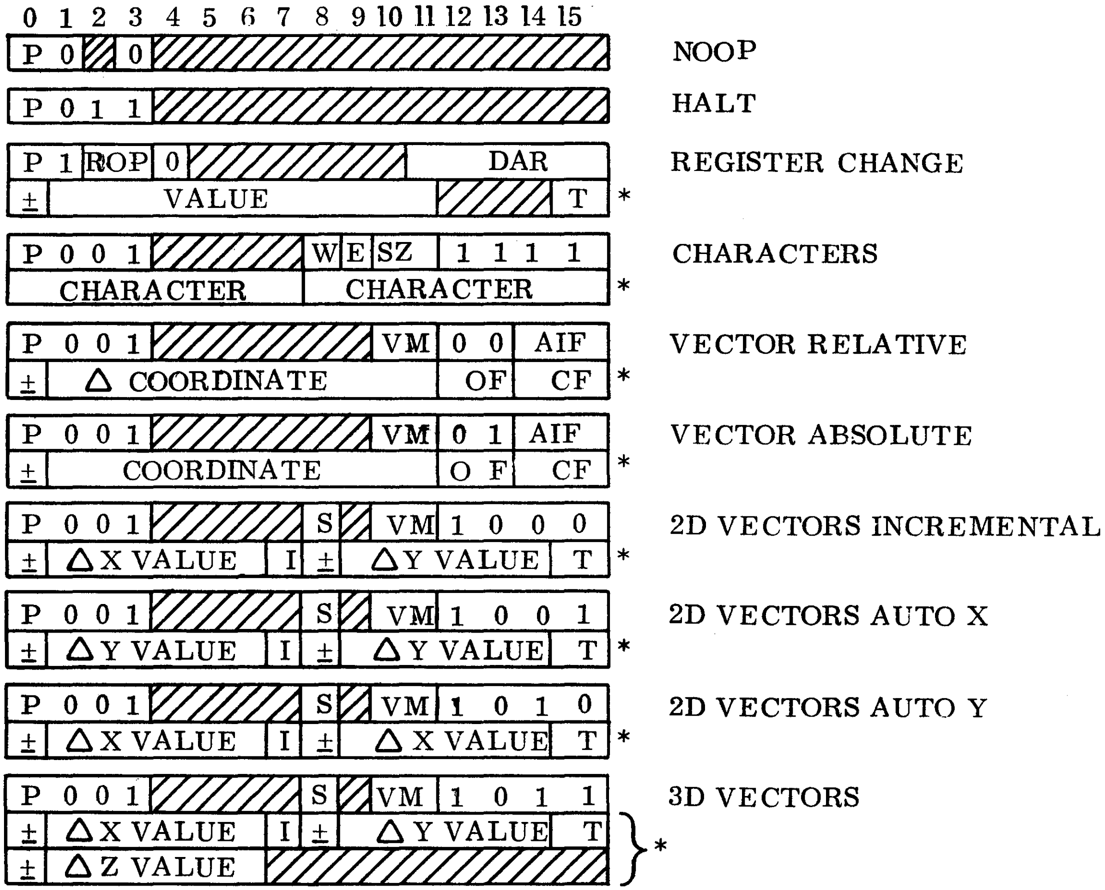
```
INPUT (REG, n, TABLE) = STSM     TREG
                        STSM     SPR
                        LDS      TREG
                        LD       SPR
                        TABLE    T
                        STSM     REG
                        STS      REG + 1
                        :
                        STS      REG + n
                        STSM     TREG
                        LDS      SPR
                        LDS      TREG
```

This sequence may be used to read a set of successive display registers into core without using programmed PIO, interrupt processing, or any display driver coding execution.

In the example as given, the input buffer TABLE has an extra word used in restoring the stack-pointer, SPR, and the temporary register, TREG, must be any display register with sufficient low-order bits to hold the memory addresses used.

APPENDIX C

SUMMARY OF DISPLAY CONTROLLER INSTRUCTION AND DATA FORMATS



* REPEAT UNTIL TERMINATE CODED

	I	W	T	S
0	MOVE	HORIZ	CONT	LO ORDER Δ
1	DRAW	VERT	TERM	HI ORDER Δ

	VM	AIF	ROP	OF	CF	SIZE
0 0	LINES	NO AUTO INCR	LOAD	LOAD (NO STEP)	AIR	120 COL x60 LINES
0 1	DASHES	STEP XR	OR	LOAD & DRAW	XR	80 COL x40 LINES
1 0	DOTS	STEP YR	AND	LOAD & MOVE	YR	60 COLx 30 LINES
1 1	POINTS	STEP ZR	ADD	LOAD & DRAW & TERMINATE	ZR	32 COLx 16 LINES

P = STOP AND INTERRUPT ON TERMINATE
SZ = CHARACTER SIZE
E = ENABLE SIZE
DAR = CONTROLLER INITIAL DESTINATION ADDRESS REGISTER
OFCF = 0100: LOAD CLOCKWISE ARC ENDPOINT
1000: LOAD COUNTERCLOCKWISE ARC ENDPOINT
(FOLLOWING DRAW SETS CENTER)

APPENDIX D

Table D-1 and D-2 list the operation codes and variable field codes of the display system instructions and data with the applicable page numbers where the items are discussed.

Table D-1 lists the display instructions, the mnemonics, variable fields, and the field formats of their data words. The instruction codes are given in both octal and hexadecimal notation. The variable fields for both the instructions and the data words are given in Table D-2.

The correct code for the instruction desired can be determined by using the code given for the instruction and adding the code listed for the variable field to be used. For example, if a Vector Relative instruction is to be used with the variable field VM in the dash mode, the hexadecimal code for the Vector Relative instruction, X'1000', is obtained from Table D-1; the hexadecimal code for the variable field VM in the DOT mode, X'0020', is obtained from Table D-2. The resulting code would then be:

```
X'1000'
X'0020'
-------
X'1020'
```

Table D-1. Operation Codes

Pages	Display Instruction		Mnemonic-Fields/Data	Codes	
3-14	No Operation		p NOP/-	000000	X'0000'
3-20	Vector Relative		p VR vm/+ Δ of cf	010000	X'1000'
3-21	"	Auto-X	p VR IX vm/± Δ of cf	010001	X'1001'
3-22	"	Auto-Y	p VR IY vm/± Δof cf	010002	X'1002'
3-22	"	Auto-Z	p VR IZ vm/± Δof cf	010003	X'1003'
3-23	Vector Absolute		p VA vm/± Value of cf	010004	X'1004
3-24	"	Auto-X	p VA IX vm/± Value of cf	010005	X'1005'
3-25	"	Auto-Y	p VA IY vm/± Value of cf	010006	X'1006'
3-26	"	Auto-Z	p VA IZ vm/± Value of cf	010007	X'1007'
3-26	Incremental 2D		p DVXY s vm/Δx i Δy t	010010	X'1008'
3-28	"	Auto-X	p DVYY s vm/Δy i Δy t	010011	X'1009'
3-29	"	Auto-Y	p DVXX s vm/Δx i Δx t	010012	X'100A'
3-30	Incremental 3D		p DV3D s vm/Δx i Δy t/Δz	010013	X'100B'
3-31	Character		p CH w sz/ch ch	010017	X'100F'
3-14	Special No Operation		p SPC/-	020000	X'2000'
3-15	Halt		p HLT/-	030000	X'3000'
3-16	Load Registers		p LD dar/Value t	040000	X'4000'
3-17	OR to Registers		p OR dar/Value t	050000	X'5000'
3-18	AND to Registers		p AN dar/Value t	060000	X'6000'
3-18	ADD toRegisters		p AD dar/Value t	070000	X'7000'

INSTRUCTION FIELDS

Pages	Field Name (Mnemonic)	Value (Mnemonic)	Codes	
3-9, 3-10	Interrupt Request (1)			
	Continue		000000	X'0000'
	Halt and Interrupt	*	100000	X'8000'
3-19 thru 3-31	Vector Mode (vm)			
	Lines	--	000000	X'0000'
	Dashes	DSH	000020	X'0010'
	Dots	DOT	000040	X'0020'
	Point	PNT	000060	X'0030'
3-26-thru 3-31	Increment Scale(s)			
	No Magnification	--	000000	X'0000'
	Magnify	M	000200	X'0080'
3-31, 3-32	Character Write Direct. (w)			
	Horizontal	--	000000	X'0000'
	Vertical	V	000200	X'0080'
3-31, 3-32	Character Size Control (sz) (SE = 1)			
	Use Previous	--	000000	X'0000'
	120 x 60	S0	000100	X'0040'
	80 x 40	S1	000120	X'0050'
	60 x 30	S2	000140	X'0060'
	32 x 16	S3	000160	X'0070'
3-2 thru 3-4,	Destination Address Register (dar)			
	Function lights (hi)	LTH	000000	X'0000'
	Function lights (lo)	LTL	000001	X'0001'
	Interrupt Request & Name	PIR	000004	X'0004
	Mode Control	MCR	000005	X'0005'
3-17	X Coordinate	XR	000010	X'0008'
	Y Coordinate	YR	000011	X'0009'
	Z Coordinate	ZR	000012	X'000A'
	Auto-Increment	AIR	000013	X'000B'
	Dimming	IOR	000014	X'000C'
	Depth Cueing	ISR	000015	X'000D'
	Fetch Addr	MAR	000016	X'000E'
	Stack Ptr	SPR	000017	X'000F'
	Temp	TGR	000020	X'0010'
	Picture Scale	PSR	000021	X'0011'
	Name	NMR	000022	X'0012'
	Coordinate Scale	CSR	000023	X'0013'
	X Displacement	DXR	000024	X'0014'
	Y Displacement	DYR	000025	X'0015'
	Z Displacement	DZR	000026	X'0016'
	Rotation Matrix	R11R	000027	X'0017'
	Rotation Matrix	R12R	000030	X'0018'
	Rotation Matrix	R13R	000031	X'0019'
	Rotation Matrix	R21R	000032	X'001A'
	Rotation Matrix	R22R	000033	X'001B'
	Rotation Matrix	R23R	000034	X'001C'
	Rotation Matrix	R31R	000035	X'001D'
	Rotation Matrix	R32R	000036	X'001E'
	Rotation Matrix	R33R	000037	X'001F'

Table D-2. Variable Field Codes

DATA FIELDS

Pages	Field Name (Mnemonic)	Value (Mnemonic)	Codes	
3-20 thru 3-26	Operation Field (of)			
	Load	L	000000	X'0000'
	Draw	D	000004	X'0004'
	Move	M	000010	X'0008'
	Draw and Terminate	DT	000014	X'000C'
3-20 thru 3-26	Coordinate Field (cf)			
	AIR	AI	000000	X'0000'
	XR	X	000001	X'0001'
	YR	Y	000002	X'0002'
	ZR	Z	000003	X'0003'
	Combined (of cf)			
	Clockwise arc	CW	000004	X'0004'
	Counterclockwise arc	CCW	000010	X'0008'
3-26 thru 3-31	Intensity Field (i)			
	Move	M	000000	X'0000'
	Draw	D	000400	X'0100'
3-15	Terminate Field (t)			
3-28 thru 3-30	Continue	--	000000	X'0000'
	Last word of data	T	000001	X'0001'
	Mode Control Bits			
	Enable P-Bit Halt	MED	1000000	X'8000'
	Enable Frame Clock Interrupt	MEC	040000	X'4000'
	Enable Pen Hit Detect Interrupt	MEP	020000	X'2000'
	Enable Tablet Interrupt	MET	010000	X'1000'
	Enable Keyboard Interrupt	MEK	004000	X'0800'
3-7, 3-8	Enable Sense Switch Interrupt	MES	002000	X'0400'
	Enable Display Blink	MDB	001000	X'0200'
	Enable Light Pen Halt	MPH	000400	X'0100'
	Select Scope 1	MS1	000200	X'0080'
	Select Scope 2	MS2	000100	X'0040'
	Select Scope 3	MS3	000040	X'0020'
	Select Scope 4	MS4	000020	X'0010'

Table D-2. Variable Field Codes