CRT GRAPHIC TERMINALS

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## (OUTLINE)

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### INFORMATION DISPLAYS INCORPORATED

Cathode Ray Tube Terminals have been associated with digital computers for the past decade or so. Initially, the terminals were used in military command and control systems. 'Way back in the mid-Fifties, for example, the SAGE system used CRT terminals (not grossly different from present day units) as one of the primary control devices for our air defense system. However, the use of CRT Graphic Terminals for design purposes in a non-military environment is relatively new. Many digital system historians....if there be such a speciality....will date this application of CRT terminals to the pioneering work done by Dr. Sutherland on Sketch-Pad in the early 1960's. My company has been involved in Computer Controlled Display Systems since 1960 and I must admit that for several of the early years, we felt that we had a cure for which there was, as yet, no known disease.

Today, the use of CRT Graphic Terminals in both research and profit-making situations is proliferating rapidly. The inclusion of three lectures on the subject in this Computer Graphics course is an indication of the present and anticipated importance of this tool in the future of computer-aided design. In fact; one authority estimates that in six years from now - 13 cents out of each computer dollar will be spent for CRT terminals.

In the next three days, I plan to discuss CRT Graphic Terminals within the framework of five topics.

1. How a CRT produces a Graphic image.

2. A typical CRT Graphic Terminal block diagram.

3. Performance characteristics of commercially available equipment.

4. Trade-offs.

5. What a typical system specification looks like.

My objective is that by the end of the third day, you have a grasp of what performance can be expected from commercially available equipment, what are some of the alternates you have in configuring a system, and finally...having made your choice...how to be reasonably sure that you can specify the desired performance so that the supplier will provide equipment to meet your needs.

1.    HOW A CRT PRODUCES A GRAPHIC IMAGE - Within the CRT, a stream of electrons is produced which impinges on the phosphor screen.  When the electrons hit the screen, light is emitted.  Due to the nature of the electron beam and the screen, there are five parameters which can be controlled to produce a dynamic or static image.

a.    Beam Deflection -- The electron beam is deflected by both magnetic and electrostatic fields.  A primary advantage of the CRT is that the beam has negligible inertia and therefore can be moved at very high speeds (compared to a plotting pen, for example).

Two basic deflection schemes are used in typical graphic terminals.  One is a system with which you are already familiar - the same as used in your home television set. In a television set, the beam is moved in the X direction. The beam is rapidly reset to the starting horizontal point and moved again horizontally.  At the same time, the beam is moved slowly in the vertical direction.  (See Figure 1A). A typical television picture, for example, consists of 525 of these horizontal scanning lines repeated approximately 30 times a second.  This regular scanning pattern is called a raster scan.

Alternately, the beam could be moved simultaneously in an X and Y direction; along a straight or curved path, to produce the desired line.  (See Figure 1B).  This is essentially the same way that you use a pencil to produce a picture.  This method is commonly referred to as random positioning.

b.    Beam Modulation - By properly modulating either the cathode or the control grid of the CRT, the beam can be turned off while it is being moved to location on the screen and then turned on at the desired spot.  Also, the intensification can be varied so that a number of light output levels are achieved.

Beam modulation can be used either with raster scanning or random positioning. With the raster scan method, as in your home television set, the beam is turned on and off in response to control signals. Areas of dark and light combine to form the desired picture.

With random scanning, the beam is generally turned off until the desired position is reached and then the beam is turned on while the beam is deflected along the programmed path.

c.    Beam Cross-Section - Typically, the CRT beam is focused with an electrical lens system. Usually, one wants to create as round and as small a beam cross-section as possible. However, it is possible to intentionally distort the beam and change its cross-section. In one type of CRT, the beam is extruded through a stencil so that its cross-section is formed into a symbol. When the beam then strikes the phosphor, light is emitted across the entire cross-section and the symbol appears on the screen.

d.    Image Persistance - A system can depend on the eye's memory or on the phosphor persistance to present an image which does not flicker. The light from some phosphor dies out within microseconds after the beam moves to another location.*  With other phosphors, light will continue to be emitted for milliseconds. Special storage tubes are available on which the image stays until intentionally erased.

Except in the special storage tubes, image persistance is not usually controllable, but rather is a function of the phosphor originally chosen.

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*Phosphors are categorized by the length of time required for the image to decay to 10% of its initial value. Phosphor classifications are summarized below:

| Time Required to Decay to 10% of Initial Brightness | Phosphor Classification |
| --- | --- |
| Less than 1 USEC | Very Short (VS) |
| 1 USEC to 10 USEC | Short (S) |
| 10 USEC to 1 MS | Medium Short (MS) |
| 1 MS to 0.1 SEC | Medium (M) |
| 0.1 SEC to 1 SEC | Long (L) |
| Longer than 1 SEC | Very Long (VL) |

e.  Color - There is a broad spectrum of colors available to the users.  Phosphors are available which emit a white, green, blue, yellow, red, or orange light.  Several phosphors can be combined in one tube to achieve multicolor presentations.

In single phosphor CRT's, color is a function of the phosphor chosen.  In multiple phosphor CRT's, the graphic element color can be under program control.

In summary, then, any graphic element can be produced on the CRT by properly controlling the deflection, intensity, beam, cross-section, image persistance and color.  Commercially available systems will program some or all of these parameters to develop a picture.

2.  A TYPICAL CRT GRAPHIC TERMINAL BLOCK DIAGRAM - Consider next, the basic block diagram of a CRT Graphic Terminal, shown in Figure 2.  The factors usually controlled in the CRT are deflection and intensity.  Because of the nature of a CRT, these are normally controlled with analog voltages.  However, the output of digital computer is a multibit digital word....a series of 1's and o's.  Therefore, between the output of the computer and the input to the CRT is required a digital-to-analog (D/A) converter.

This complex D/A between the computer output and the CRT input has two main sections - the Interface and the Display Generator.

A digital word is presented to the input or the Interface, and a digital word is developed as the output.  However, through the Display Generator, the digital input is converted to analog outputs.

There is one additional element in the typical graphic terminal. The block diagram developed so far takes the output of a digital computer and converts it into a graphic symbol on the face of the CRT.  However, one of the powerful features of a graphic terminal is the facility for allowing the operator to communicate back to the computer.  There are a variety of these communication devices available...such as a light pen, keyboard, function keys, joy stick, track ball, Rand tablet, etc.  We will consider these devices in somewhat greater detail later.  But first, let us examine some of the typical elements which comprise each of the major blocks.

A.  CRT DISPLAY - Within this portion of the system is contained the Cathode Ray Tube, the deflection circuits which position the beam, and the video circuits which modulate the beam.  The tube

may be deflected electrostatically or electromagnetically or by a combination of both. The nature of the deflection circuits will depend on whether the system is basically a raster scanning or a random positioning system.

For now, we will assume that the tube uses a conventional phosphor and hence, no control is provided for persistance. Also, we will assume that the tube uses a single phosphor and no control is available to change the color. Finally, we will assume that cross-section of the beam is not varied.

Some CRT's are constructed so that an optical image can be combined with the electronically generated image. These tubes have a port, or window, through which a picture can be projected onto the screen.

B.    DISPLAY GENERATOR - Before going into a detailed discussion of the elements normally found in a display generator, it would be well to examine in detail how digital signal might be used to pro- duce a graphic symbol. In the simplest case, the computer data word designates an X and Y location on the screen to which the beam should be moved and then illuminated. Any graphic symbol can then be made up as a series of these illuminated dots. For example, the letter A can be made up with 16 dots as shown in Figure 3. A line or a circle can also be made up of a series of closely spaced dots.

Therefore, the basic elements required in a display generator are a set of conventional digital-to-analog converters which change the digital X and Y designations into corresponding analog signals to position the beam on the screen, plus a dot generator to turn on the beam after it reaches the programmed position. In this elementary system, each dot requires a separate instruction. If, as in most systems, the screen has 1,024 addressable locations in the X direction and 1,024 addressable locations in the Y direction, 10 digital bits are needed to specify X and 10 digital bits are needed to specify Y.

To draw the letter A then, a series of 16, 20-bit digital words would be needed and at least one computer instruction might be needed for each dot. Therefore, one of the early trade-off de- cisions that one makes, (and we will examine these trade-off decisions in greater detail later) is the decision between the amount of computer software to make a graphic symbol vs. the amount of display hardware to accomplish the same purpose.

A typical graphic terminal uses a number of special purpose function generators to minimize the computer software. Included

among these function generators are a character generator, a vector (line) generator, and a circle generator.

## Character Generator

With a character generator, for example, instead of specifying the letter A as a series of 16,20-bit digital words, it is necessary to specify it only by a 6-bit digital word (which allows the selection of 64 characters) or a 7-bit digital word (which allows a selection of 128 characters) (plus, possibly, one 20-bit word which designates the position of the letter on the screen). In the character generator is the special circuitry which translates the 6-bit word into the necessary analog voltages. Just as in the basic display which produces images with either raster scan or by random positioning, various character generators produce characters the same way. In either case, the character generator acts as a kind of digital-to-analog converter which converts the 6 or 7 bit digital code into the necessary analog voltages.

One exception to this method was referred to earlier, in the paragraph on beam cross-section. The separate character function generator is replaced by a stencil mask in the tube. Instead of deflecting the beam to form the character, the beam is positioned to a location on the mask and then extruded through the mask. In this instance then, the character function is included within the CRT.

## Vector Generator

The vector generator relieves the computer programming problem of forming a line by programming a series of closely spaced dots. Instead, the vector generator receives computer instructions which define the starting point of the line, perhaps as a 10-bit X and 10-bit Y word,and the end point of the line, also a 10-bit X and 10-bit Y word. In the vector generator is the circuitry required to deflect the beam along the desired path.

Depending on the type of vector generator, the line may appear on the CRT screen as a solid, continuous line or as a series of closely spaced dots.

## Circle Generator

Hardware circle generators are also available. To program a circle, it is necessary only to digitally specify the center of the circle and the radius. The hardware generates the necessary analog voltages to move the beam along the desired path.

## Function Generator Modifiers

To further reduce computer software requirements, the typical CRT graphic terminal contains several other elements which modify the outputs of the various function generators.

For example, usually associated with the character generator is a digital size control. By using one or two digital bits, several character sizes can be programmed. The digital size control is generally a digitally controlled attenuator operating on the analog output voltages of the character generator.

At the output of the vector generator, it is possible to connect a line structure control. Instead of the line being drawn solid, it can be programmed to be dotted, dashed or dash-dotted. This could be done with software, but the hardware alternate allows the control to be done with one or two digital bits. Also, in the typical system, modification of the line structure can be accomplished without affecting the time in which the line is drawn.

Video outputs from the dot generator, character generator, vector generator, and circle generator can be routed through a digitally controlled intensity modifier so that the intensity of any of these symbols can be varied by a one or two bit digital word. The intensity can be further modified under program control so that any of the symbols can be made to blink. This blink control is available as a hardware element.

## Mode Control

With all the function generators and function generator modifiers, it is necessary to provide logic which decodes the computer data word and routes the information to the appropriate function generator and modifiers. This is a block that can be called a mode control. In the simplest form, the mode control simply acts as a decoder. In more complex systems, several other hardware functions are assigned to the mode control.

For example, the stringing of characters across the line in a typewriter page-like format can be done by logic in the mode control. Only the initial position of the first character in the line needs to be programmed. Subsequently, characters are streamed out and the hardware takes care of advancing the character to the next location. Spacing can be made the hardware function of the character size. Provision can be made so that when the characters reach the end of the line, the line automatically resets to the left hand margin (or to a programmed margin) and advances by the appropriate space to begin the next line of characters. Circuits can be included in the mode control so that characters can be rotated by

90° and plotted vertically instead of horizontally, or the
characters can be superscripted and subscripted.

The mode control might also include logic for stringing line
segments so that once the first line is established, only the new
endpoints of the line segments need be outputed to the display
generator.  Depending on the configuration of the mode control,
these successive end points can be given either as absolute
positions on the screen or can be defined as relative positions
from the starting point.

Other hardware functions can also be built into the mode
control.  For example, a mode can be provided which allows for
automatic plotting of a series of points or vertical lines where
the horizontal spacing is a preprogrammable increment; or a mode
can be provided that allows the incremental positioning of a
series of dots.

Mode control complexity is part of the hardware-software
trade-off.

## Display Refreshing

Earlier it was stated that the typical phosphor used in a CRT
emits light for only the time that the beam impinges on the phosphor.
There may be some persistance..(or after glow), but generally this
does not exceed several milliseconds.  This means that something is
required to create the impression of a continuous image.

If the screen has short persistance, the eye's memory must be
used and the picture must be repainted many times a second to give
the eye the impression that it's on continuously.  The number of
times per second that needs to be painted is the function of the
phosphor.  In practical systems this will range between 10 to 40
times per second.  If there were no storage element in display
generator, this refreshing of the display must come from repeated
outputs of the computer.  Assume, for example, that 500 data words
are required to form a complete image and, to give the viewer the
impression that the image is constant, the image must be repainted
30 times each second.  Therefore, the computer would be required
to output 500 words every 30th of a second in order to refresh the
display.

As an alternate to this, it is possible to include within the
display generator a storage of some kind.  (This can be random
access core memory, a delay line, or a drum).  If the storage is
available in the display, it is necessary only for the computer
to load the memory with a frame of data (500 words, from the
previous example).  The display then would recycle the data out
of the store as frequently as necessary to refresh the picture.

The only time the computer would be required is when a picture needed to be changed. Then the computer would address the storage as needed and the new information would appear on the screen.

It is also possible to use a CRT on which the image does not die out immediately. There are several electronic storage tubes available in which the image will remain until intentionally erased. By using this type of CRT, the computer need only program the frame once and the data will remain on the screen until intentionally erased and new information is programmed.

The choice of whether to use the computer to refresh the display or whether to use a memory within the display or whether to use a storage type tube is one of the trade off decisions that faces the user. Also entering the storage trade-off decision is the possibility that the storage and part of the mode control can be replaced by a small, general purpose digital computer.

## Display Generator Output

The analog signals from the various function generators and function generator modifiers are combined into appropriate deflection and video line drivers which feed the CRT display analog inputs. Frequently, the character deflection voltages (which often require wide bandwidth but small deflection channels) are separated from the other deflection voltages. Therefore, the output of the display generator would consist of major deflection analog signals, minor deflection analog signals, and a video signal.

Several line drivers may be included in the display generator and may feed more than one CRT display. These auxiliary line drivers may, for example, feed a wall size display, a microfilm display, a hardcopy device, or another direct view display.

The presentations on all displays may be identical, or they have, as a result of suitably programming the video channels, different presentations.

C. INTERFACE - The input to the display generator is a multi-bit digital word. The number of bits required will depend on the specific design of the display generator and may not be the same as a number of bits available from the output of the driving computer (particularly where the CRT Graphic Terminal is supplied by one manufacturer, and the computer supplied by another). Also, logic levels of the display generator may not be identical to the logic levels of the computer. Therefore, an interface block is needed

between the computer and the display generator. The interface
has three functions:

1.  To reorganize the computer data word (which may vary
    from 8 bits to 48 bits) into the word structure re-
    quired for the display generator.

2.  To convert the computer logic levels into the display
    generator logic levels.

3.  To provide the necessary sequence signals so that
    the computer can properly communicate with the dis-
    play generator.

D.   INPUT DEVICES - The discussion thus far has been about a
one-way device; information is received from the computer, con-
verted in the display generator and presented as a graphic image
on the CRT. However, one of the basic reasons for the increasing
acceptance of CRT Graphic Terminals is the availability of an opera-
tor channel from the display back to the computer. The operator
can converse with the computer on-line and in real-time, using
input devices such as a light pen, joy stick, track ball, Rand
tablet, and function keys.

Light Pen

A commonly used communication device is the light pen. This
is simply a photosensitive device which detects presence of light
on the screen. The pen may use a photodiode or phototransistor as
the light sensitive element, or it may use a fibre optics bundle
to pipe the light to a photo multiplier.

If the display does not use a storage tube, the events which
occur on the screen occur in time sequence (even though to the eye
they appear to be occurring simultaneously).

A light pen pointed at the screen will detect light at a
discrete time and generate a computer interrupt at that time. It
is generally a function of the computer software to decide what to
do about the interrupt. Since the interrupt is a time dependent
function, normal light pen operation is not possible with a storage
tube because the time reference is lost.

The light pen can be used either in a pointing mode or a draw-
ing mode. That is, it can be used to point at information which
already appears on the screen or to designate a location at which
information is to appear; or it could be used to enter information
directly.

Because the light pen only responds to displayed information, some kind of symbol must appear wherever a light pen signal is desired. For example, if one wishes to use the light pen to draw a line, a tracking symbol must first be generated, generally by software. With software, the tracking symbol is made to follow the pen as the pen is moved across the screen. The operator, by activating the appropriate function keys, can designate what action the system is to take as a result of the light pen motion; i.e., draw a series of dots along the light pen path, or connect a straight line between the starting position and the present light pen position.

## Joy Stick and Track Ball

There are other devices which can indicate locations on the screen independent of time and therefore, can be used with storage screens. These are units which allow the operator to mechanically control two orthogonal analog-to-digital converters.

The output of the converters are sensed and a spot appears on the screen at the location determined by these positions. It is generally a software function to compare the dot position generated by device with computer generated data.

## Rand Tablet

Another operator input device is the Rand Tablet. The Rand Tablet is an electronic unit which consists of a rectangular grid of 1024 x 1024 lines. These lines are pulsed and signals are induced in a stylus moved by the operator. The location of the stylus relative to the tablet is determined by decoding the signals. A spot or line corresponding to the stylus position can be made to appear on the screen.

## Keyboards

Several kinds of keyboards are often used with CRT Graphic Terminals. An alphanumeric keyboard allows the operator to compose messages or make inquiries. Function keys permit the operator to make coded inquiries or to establish operating modes. Some function keyboards use coded, changeable overlays so that the meaning of the function keys can be changed by the operator.

Figure 4 is a detailed block diagram of a typical CRT Graphic Terminal.

E.    DATA ORGANIZATION - Before leaving this general discussion of
CRT Graphic Terminals, it will be of interest to examine in some
detail how the computer data word can be used to program a picture.

There are several ways in which the computer word can be
organized.  These depend on how large the data word is and on how
complex the display generator is.

.     The data word may be completely self-contained, with each word
containing information about the mode of operation (character
writing, line drawing, and position).  Figure 5A is an example of
this organization.

More often, two types of words are used.  One type is a control
word, which established the mode and sets some parameters (such as
intensity and line structure) for the succeeding data words which
contain locations or characters.  All succeeding words are inter-
preted as the same kind of data words until a new control word is
encountered.  A typical example of this kind of data organization
is given in Figure 5B.  The word organization is used in a
representative CRT Graphic Terminal (manufactured by IDI, and
described in Appendix A, Data Sheet 134-966) which can be driven
from a Digital Equipment Company PDP-8 Computer.  The PDP-8 has a
12-bit data word, and the word organization shown (Figure 1 of the
Data Sheet and Figure 5B) are designed for the 12-bit word.

How are these words used to produce a graphic image?  Suppose
one wished to display the schematic shown in Figure 6.  First,
Figure 6 would be drawn as shown in Figure 7 to designate reference
points.  Data words would then be appropriately coded to produce
the required CRT beam motions.  The first several words will be
coded in detail to illustrate the process.  A complete listing is
given in Section 3, Table 1.  Data word designations correspond to
those given in Data Sheet 134-966, Figure 1.

At the beginning of a program, the beam is at the lower, left
hand corner of the display.  Therefore, a group of data words must
be programmed to move the beam, unintensified, to point 1.  The
first word is a Vector Mode Control Word.  This sets the display
mode control logic so that the following words will be interpreted
as Vector Data Word Pairs, until a new control word is encountered.
The second and third data words are Vector Data words which specify
the X and Y locations of reference point 1.  By making bit 11, in
the second data word a logic 1,  the display generator is
programmed to deflect the beam, unintensified, from the starting
location to point 1.

From point 1, a solid line must be drawn to point 2.  Because
the display mode control logic is still set in the vector mode, it

is only necessary to program two more Vector Data words to move the beam from point 1 to point 2. Therefore, the fourth and fifth data words are Vector Data words which specify the X and Y location of point 2. By making bit 11 in the fourth data word a logic 0, the display generator is programmed to deflect the beam, intensified, from point 1 to point 2. The appropriate deflection voltages are developed by the vector generator.

In similar fashion, the beam is caused to move from point to point, intensified or unintensified as required. So long as the vector mode is maintained, no additional control words are necessary.

Suppose the line drawing has been completed and characters are to be added. A Vector Data word pair is programmed to move the beam to point 104. Next, a Symbol Mode Control word is programmed so that the next data word is interpreted as a symbol data word. The next word is a Symbol Data word, and bits 1-6 contain the digital code for the letter A. After the letter A is written, a Vector Mode control word - Vector Data word pair sequence is required to move the beam to point 106. To write the letter B, the Symbol Mode Control word - Symbol Data word sequence must then be programmed.

To write the IDI NOR GATE label, a Vector Mode control word - Vector Data word pair sequence would be programmed to move the beam to point 110. Because the label is a string of characters, the Packed Symbol mode is an efficient way to program the sequence. Therefore, the next data words programmed would be a Packed Symbol mode control word followed by a sequence of seven Packed Symbol Data words. The first six Packed Symbol Data words would contain the appropriated codes for the letters and spaces in the label (2 characters per word). Character 1 of the seventh Packed Symbol Data word will be the escape character, so that the following word would be interpreted by the display as a control word. The appropriate sequence would be continued for the balance of the labels. After the last element of the frame (point 135) - the sequence from the computer would be repeated.

Note that the control words and data words contain bits which set character size, line structure, margin, intensity, blink, margin, and to control the light pen...in addition to bits which define the character, X and Y location and mode.

3. PERFORMANCE CHARACTERISTICS OF COMMERCIALLY AVAILABLE EQUIPMENT - Over the past few years a number of CRT Terminals have become commercially available. Before reviewing the general characteristics of graphic terminals, it is helpful to see how these

fit into the spectrum of computer driven CRT displays.

There are basically three types of display systems:

Point Plotting

Alphanumeric

and

Graphic

Each type of display system can be divided into three broad categories:

low cost/low performance

medium cost/medium performance

high cost/high performance

Figure 8 illustrates these divisions.  Also shown in Figure 8 is an indication of the first basic characteristics of commercially available equipment...the approximate price.  The price divisions are rather arbitrary and are intended only to show the approximate range for each device.  Shading in Figure 8 represents which categories of equipment are commercially available.  This section is concerned with graphic CRT Displays...and the second character- istic to be observed about commercially available equipment is that there are no low cost units.  This is not because of a lack of market for them (which is the explanation for the lack of com- mercially available high cost alphanumeric units), but because no one seems yet to have found a way to produce them!

We will concentrate on commercially available equipment currently being marketed.  Undoubtedly, in the future, the equipment will be faster, more accurate, less expensive...and perhaps, even habit forming.

As can be inferred from earlier discussions, a graphic CRT terminal is a conglomerate of devices, each of which has a range of characteristics which can affect the performance and useability of the terminal.  For convenience, the various factors which contribute to the effectiveness of the terminal can be grouped into three categories.

1.    Those which affect the data content...that is, how much information can be displayed simultaneously

without flickering objectionally and with the
graphic symbols large enough to be easily read,
or when small, to be easily distinguishable.

2.    Those which affect the quality of the display...
      that is, how the display looks aesthetically to
      the observer, and

3.    Those which affect the ease of use...both from a
      human factors standpoint and from a systems pro-
      gramming standpoint.

Characteristics which affect each of these categories are
discussed in this section.  Where appropriate, typical ranges
for commercially available equipment are given.

A.    DATA CONTENT - The amount of data which can be displayed
simultaneously, without appearing to flicker is affected by the
following:

Frame Rate

The more time that can be taken to write a frame of data,
the more data can be displayed per frame.  In the limiting case,
using a phosphor with indefinitely long storage, the amount of
information which can be displayed simultaneously will depend
only upon the resolution of the CRT.

However, in the more typical case, the CRT phosphor retains
the image for times ranging from 1 USEC to 100 MS.  The eye needs
to have an image without any persistence repeated about 35-40 times
per second before successive images merge without flickering.  As
the persistence of the image increases, the number of times it needs
to be repeated decreases.  Typical phosphors used in CRT terminals
produce displays that need to be refreshed from 10 frames/second
(with a long persistent phosphor such as the J, or L3) to
40 frames/second for the medium-short persistent phosphors such as
the P4 and P31.

Because less persistent phosphors tend to be more efficient,
and more resistant to damage, most manufacturers prefer to use them
in their terminals.  Therefore, all frame-time dependent values -
and references to flicker-free presentations - in the following
discussion are based on a 40 cycle frame rate (or 25 MS frame
interval).  Keep in mind, however, that the data content can be
increased in direct proportion to frame interval.  For example,
if a flicker-free data content of 250 points is quoted, it is
understood that the calculations are based on 25 MS frame interval.
If, in a particular system, with a particular phosphor, a frame
interval of 100 MS (frame rate=10/second) were acceptable, the

number of points could be increased to 1000.

## Deflection Amplifier Response

A primary parameter of a CRT display is the speed with which the beam can be positioned. In random positioned systems, the beam can be moved anywhere on the screen in times ranging from 3 USEC to 100 USEC. Therefore, the number of random dots which could be displayed, flicker-free, ranges from 250 to 8300.

If the data can be properly formatted, it may be possible to organize the information so that full screen random positioning is not required. Under these circumstances, the small angle positioning time of the deflection amplifier is critical. In commercially available equipment, this ranges from 1 USEC to 10 USEC. Therefore, the number of dots which can be displayed flicker-free ranges from 2500 to 25000.

Note that these factors are based on the assumption that the system uses random positioning. There are systems, however, which use a raster scan similar to that used in a conventional television set. Such systems require complete formatting of the data. However, by doing so, as many as 1,000,000 dots can be displayed flicker-free, compared to a maximum of 25,000 dots in a random positioning system.

A second, wide bandwidth, small angle deflection channel with bandwidth ranging from DC to 10 MC is also included in some terminals.

## Character Writing Time

Character generators available in commercially available terminals, write a character in times ranging from 2 USEC to 100 USEC. To these times, must be added the positioning time (ranging from 3 USEC to 100 USEC random or 1 USEC to 10 USEC, small angle). Therefore, the number of random characters that can be displayed flicker-free ranges from 125 to 5000, and the number of formatted character (text) that can be displayed flicker-free ranges from 220 to 8300. As a comparison, a typical double spaced typewritten page contains about 2500 characters.

## Line Drawing Time

Two types of vector (line) generators are offered in commercially available equipments. One type requires a fixed time to draw a line regardless of line length, while the other requires a time proportional to line length. Typical fixed time vector

generators require from 30 to 150 USEC to draw lines up to full screen size, while the proportional vector generators have line drawing speeds ranging from 0.5 USEC per inch to 150 USEC per inch. This means that the fixed time vector generators can draw between 160 and 830 flicker-free line segments per frame. Depending on CRT screen size, this can represent up to 16,000 inches of line. Proportional vector generators can draw from 160 to 50,000 inches of flicker-free line per frame.

## Circle Drawing Time

Hardware circle generators available with terminals can generally draw any size circle in from 100 USEC to 300 USEC. This means that from 83 circles to 250 circles can be displayed flicker-free.

## Logic Time

In addition to the actual time required to deflect a beam and write the various functions, the logic in the display generator, the logic of the computer, and the memory cycle time will affect the amount of data which can be displayed. For example, the word organization of the terminal may require that the generation of each graphic element be controlled by several data words. Elapsed time from the display's request for a data word and the terminal's set-up is in the order of 1 to 4 USEC. If 1,000 data words were required per frame (a typical value) and between 1 and 4 USEC were consumed in data transfer and logic set-up, 4% to 16% of the frame time is consumed and the data content would be reduced by that amount.

## Resolution

Resolution determines such things as the smallest readable character that can be displayed, and the minimum spacing that can be discerned between lines. Basically, CRT beam spot size determines resolution. In commercially available terminals, the nominal spot will range from .01" diameter to .03" diameter. However, spot size might vary by a factor of 3:1 (on the same terminal) because of beam intensity and spot position on the screen (better in the center, poorer at the edges). Some terminals use dynamic focussing techniques to keep the spot size relatively constant over the display area.

For purposes of comparison, the range from 30 lines per inch (.03" diameter spot) to 100 lines per inch (.01" diameter spot) will be used. To read a character with minimum chance of error, it is generally agreed that at least five and preferably seven

lines of resolution per character are needed. Two more lines are needed in the space between characters. Therefore, assuming that a typical character and its space needs nine resolution lines, the character density with a 30 line/inch resolution display is approximately 3 characters per inch and with a 100 line/inch resolution is approximately 11 characters per inch. For comparison, a Pica Typewriter spaces characters 10 per inch, and an Elite Typewriter spaces characters 12 per inch.

Addressability is sometimes confused with resolution. Addressability is a statement of how many digital positions can be programmed (but not necessarily distinguished) along each axis. Typical terminals offer 9 bit (512) or 10 bit (1024) addressable locations.

## Screen Size

Screen size affects data content primarily from the standpoint of resolution. CRT's used in commercial terminals generally range from 16" round to 24" round, with available display areas of from 10" x 10" to 16" x 16". Therefore, the number of readable characters per line can range from 30 (10 inch line of a resolution of 30 lines per inch) to 176 (16 inch line with a resolution of 100 lines per inch).

## Overlays

Static information can be superimposed on the beam written data by projecting pictures (slides) through an optical port in the CRT. Typical systems can select from among 25-150 slides.

## Data Content of a Typical Data Frame

The word organization of Figure 5B and the coding sequence of Figure 7 can be used to illustrate the way to determine the number of computer words needed per frame, plus the time required per frame. To calculate timing, we will use the values given in Appendix A, Data Sheet 134-966. These are:

|  | Code |
|---|---|
| Vector Mode Control: 4 USEC | VC |
| Vector Data (Blanked): 17 USEC | VDB |
| Vector Data: 50 USEC | VD |
| Symbol Mode Control: 4 USEC | SC |
| Symbol Data: 13 USEC | SD |
| Packed Symbol Mode Control: 4 USEC | PSC |
| Packed Symbol Data: 26 USEC | PSD |

Table 1 shows the sequence of data and control words required
to produce Figure 7. The time, and number of words are also shown.
As indicated in Table 1, 268 12-bit computer words would be re-
quired to produce the display shown in Figure 6. Based on the
times given in the above and in Table 1, the display would be
written in 4242 USEC, resulting in a frame rate of

$$\text{Frame Rate} = \frac{1}{4242 \text{ USEC}} \cong 236 \text{ Frames/Second}$$

Because this rate is much higher than necessary for a flicker-
free display, the programmer could take advantage of the frame
rate control feature (Figure 5B, Bit 6 of the vector mode control
word) and program one additional vector mode control word as word
136. A typical display would maintain a frame rate of 40 f/s (or
less). Therefore, after completing the frame in 4242 USEC, the
display would wait 20758 USEC (25,000-4242) before generating the
next request for the first word of the frame.

## TABLE I
## DATA AND CONTROL WORD SEQUENCE

| TERMINAL POINTS | DATA OR CONTROL WORDS | TIME (USEC) | WORDS |
|---|---|---|---|
| Beam Start | VC | 4 | 1 |
| Beam Start-1 | VDB | 17 | 2 |
| 1-2 | VD | 50 | 2 |
| 2-3 | VDB | 17 | 2 |
| 3-4 | VD | 50 | 2 |
| 4-5 | VDB | 17 | 2 |
| 5-6 | VD | 50 | 2 |
| 6-7 | VD | 50 | 2 |
| 7-8 | VD | 50 | 2 |
| 8-9 | VDB | 17 | 2 |
| 9-10 | VD | 50 | 2 |
| 10-11 | VDB | 17 | 2 |
| 11-20 | Same As 1-10 | | |
| 20-21 | VDB | 17 | 2 |
| 21-30 | Same As 1-10 | | |
| 30-31 | VD | 50 | 2 |
| 31-38 | VD (7) | 350 | 14 |
| 38-39 | VDB | 17 | 2 |
| 39-40 | VD | 50 | 2 |
| 40-41 | VDB | 17 | 2 |
| 41-42 | VD | 50 | 2 |
| 42-43 | VD | 50 | 2 |
| 43-44 | VD | 50 | 2 |
| 44-45 | VDB | 17 | 2 |
| 45-46 | VD | 50 | 2 |
| 46-47 | VDB | 17 | 2 |
| 47-55 | Same As 39-47 | | |
| 55-56 | VD | 50 | 2 |
| 56-57 | VDB | 17 | 2 |
| 57-58 | VD | 50 | 2 |
| 58-59 | VDB | 17 | 2 |

| TERMINAL POINTS | DATA OR CONTROL WORDS | TIME (USEC) | WORDS |
|---|---|---|---|
| 59-60 | VD | 50 | 2 |
| 60-61 | VDB | 17 | 2 |
| 61-65 | VD (4) | 200 | 8 |
| 65-66 | VDB | 17 | 2 |
| 66-67 | VD | 50 | 2 |
| 68-69 | VD | 50 | 2 |
| 69-70 | VDB | 17 | 2 |
| 70-71 | VD | 50 | 2 |
| 71-72 | VDB | 17 | 2 |
| 72-73 | VD | 50 | 2 |
| 73-74 | VD | 50 | 2 |
| 74-81 | Same As 31-38 | | |
| 81-82 | VDB | 17 | 2 |
| 82-83 | VD | 50 | 2 |
| 83-84 | VDB | 17 | 2 |
| 84-85 | VD | 50 | 2 |
| 85-86 | VDB | 17 | 2 |
| 86-87 | VD | 50 | 2 |
| 87-88 | VD | 50 | 2 |
| 88-89 | VD | 50 | 2 |
| 89-90 | VDB | 17 | 2 |
| 90-91 | VD | 50 | 2 |
| 91-92 | VDB | 17 | 2 |
| 92-93 | VD | 50 | 2 |
| 93-94 | VDB | 17 | 2 |
| 94-95 | VD | 50 | 2 |
| 95-103 | VD (8) | 400 | 16 |
| 103-104 | VDB | 17 | 2 |
|  | SC | 4 | 1 |
| 104-105 | SD | 13 | 1 |
|  | VC | 4 | 1 |

| TERMINAL POINTS | DATA OR CONTROL WORDS | TIME (USEC) | WORDS |
|---|---|---|---|
| 105-106 | VDB | 17 | 2 |
|  | SC | 4 | 1 |
| 106-107 | SD | 13 | 1 |
|  | VC | 4 | 1 |
| 107-108 | VDB | 17 | 2 |
|  | SC | 4 | 1 |
| 108-109 | SD | 13 | 1 |
|  | VC | 4 | 1 |
| 109-110 | VDB | 17 | 2 |
|  | PSC | 4 | 1 |
| 110-116 | PSD | 156 | 6 |
|  | VC | 4 | 1 |
| 116-117 | VDB | 17 | 2 |
|  | PSC | 4 | 1 |
| 117-119 | PSD | 52 | 2 |
|  | VC | 4 | 1 |
| 119-120 | VDB | 17 | 2 |
|  | PSC | 4 | 1 |
| 120-122 | PSD | 52 | 2 |
|  | VC | 4 | 1 |
| 122-123 | VDB | 17 | 2 |
|  | PSC | 4 | 1 |
| 123-125 | PSD | 52 | 2 |
|  | VC | 4 | 1 |
| 125-126 | VDB | 17 | 2 |
|  | PSC | 4 | 1 |
| 126-128 | PSD | 56 | 2 |
|  | VC | 4 | 1 |
| 128-129 | VDB | 17 | 2 |
|  | PSC | 4 | 1 |
| 129-133 | PSD | 164 | 4 |
|  | VC | 4 | 1 |
| 133-134 | VDB | 17 | 2 |
| 134-135 | VD | 50 | 2 |

TOTALS
TIME/FRAME: 4242 USEC
WORDS/FRAME: 268

B.   QUALITY - Several factors affect the image quality.  Some of these factors may also affect data content, as indicated in the following discussion:

## Accuracy (Linearity)

Accuracy describes how the programmed position of the beam corresponds to some external reference.  For example, if a grid were scribed in the face of the CRT and the beam were programmed with a digital instruction which should cause the beam to fall at a grid line intersection, the variance between the beam position and the intersection is the accuracy.  Commercially available systems have accuracies ranging from 1% to 5% of full scale.  Generally, pictures drawn with this accuracy are quite acceptable to the observer provided there is no attempt to superimpose the electronic image with a mechanical reference.  The presence of the mechanical reference will emphasize the nonlinearity or inaccuracy of the display. For comparison, the nonlinearity of a well-adjusted home television set is about 10% to 15%.

## Short-time Stability

Short-time stability of the image will affect the observers reaction to it.  Small movement of the graphic element, called jitter, can be quite objectionable when it occurs at low frequencies (less than 10 cps).  Jitter results mainly from a beat between the frame rate and the power line frequency (or submultiple frequency).  In an adequately shielded terminal, the jitter is about 0.5 to 1 spot - but even this value can be disturbing to the user.

Two methods are used to reduce or eliminate the apparent jitter. One is to maintain the frame rate at such a value that the beat frequency is relatively high...typically 20 cps.  Although jitter still may be present, the graphic element is moving so fast that, to the observer, the line or dot simply thickens a bit.  Hence, the resolution is affected, but the image appears stationary.  This technique is especially successful when used with longer persistent phosphors.

Alternately, since the jitter most frequently comes from stray magnetic fields, the display frame rate can be locked to the line frequency and the jitter essentially eliminated.

## Repeatability

When the beam is programmed to the same location from various places on the screen, the successive dots will probably not be

superimposed. The spread, called repeatability, may range from 1 spot size to 10 spot sizes. In commercially available equipment this effect may be particularly disturbing when various line segments are programmed to start from the same point, but, because of repeatability, they do not.

## Brightness and Contrast

If the display is to be used in a normally lighted room, it is important that the presentation be bright or have a high contrast ratio. Typical terminals produce 20 foot-candle to 50 foot-candle presentations. Shorter persistent phosphors, such as the P4 and P31 do produce bright, easily read displays, but these phosphors require relatively high frame rates to reduce flicker. Longer persistent phosphors such as P19, P23, and L3 reduce the frame rate requirements at the expense of brightness. Therefore, displays using longer persistent phosphors may require subdued room illumination. Contrast can be enhanced with neutral density filters. Although these filters reduce total brightness, they do increase contrast and enhance to the readability of the display.

## Phosphor Color

Phosphors are available which produce white, green, yellow, blue, and red outputs (and shades inbetween). The shorter persistent phosphors are generally in the white, green and blue range; while the longer persistent phosphors are in the orange, yellow range.

The eye is most sensitive in the green region, so that with equal light output, displays with a green image appear brighter. This is one reason why the P31 phosphor is used in many terminals.

## Graphic Symbol Construction

Graphic elements can be constructed in a variety of ways... some of which enhance the quality of the display and others which tend to detract from it. For example, characters formed from a 5 x 7 dot format may be readable but not aesthetically satisfying. Other graphic elements constructed from a series of dots may be readable, but not pleasing.

Stroke characters usually produce acceptable quality formats. The beam forming and monscope techniques permit a wide range of character formats, with few limits on character style. Higher resolution dot formats, typically 16 x 16, are also capable of producing excellent quality symbols.

C.    EASE OF USE – There are two categories discussed in this section; those which are based on human factor considerations and those which are based on programming considerations.

## Human Factors

Screen angles range from approximately 10° from the vertical, to horizontal.  Generally this is fixed although at least one commercially available unit has a tiltable head.

A variety of light pen configurations are available ranging from a simple penholder type to a gun type.  Some pens are relatively heavy while others are light weight.  Some use a very flexible cable and others use a rather stiff cable or coil cord. Aiming circles are provided with some light pens so that the operator knows where the sensitive area of the pen is pointed. Activating switches for the light pen range from mechanical shutters on the pen, electrical switches on the pen, knee swtiches and foot pedal switches.

Other operator input devices are available on various consoles. Alphanumeric keyboards and function keys are used.  Some function keys use plastic overlays for additional coding.  Track balls and joy sticks are preferred by some users.  The Rand tablet, which provides an easy method for graphic input, is available as an accessory in several systems.  Some displays eliminate all mechanical input devices and allow the operator to get a response by simply pointing with his finger at something on the screen.

Operator controls on commercially available terminals range from having only an on-off power switch to providing manual adjustments for various display parameters.

Servicing facilities incorporated in terminals range from a logic card extender to elaborate maintenance panels, which include register lights and test pattern generators.

Terminal packaging ranges from multiple cabinet configurations, with the display console separated from the display generator, to relatively large integrated units which occupy 10-15 square feet of floor space, and are 4-5 feet high.

## Systems Programming

The display command structure influences system programming. Two common types of command structures are shown in Figure 5.  In one approach, illustrated by Figure 5A, each data word is completely self-contained and has a mode instruction and all other information required to define a graphic element.  In contrast,

the word organization currently favored (Figure 5B) establishes
a mode of operation with one word and then uses a series of
succeeding data words to program identical kinds of graphic
elements.  Figure 5B also illustrates a word organization which
includes computer-type instructions such as JUMP and JUMP AND
SAVE.  Some graphic terminals are designed so that more than one
display console can be driven from a common display generator.
These other consoles may be slaved (and have identical informa-
tion) or they may have different information.  Such displays may
be photographed or used to produce wall size pictures or immediate
hardcopy.

SUMMARY

This section has discussed the characteristics of commercially
available terminals from an equipment viewpoint - not from an
applications viewpoint.  One can list a number of current and
potential applications for CRT graphic terminals, but the data which
describes terminal requirements in terms of these applications is
scarce.  For example, the line drawing needs of a terminal used by
civil engineers for cut-and-fill analysis, may be quite different
from those of an engineer using the terminal to design integrated
circuit masks.  Adams Associates, in their "Computer Display
Review" formulated several typical presentations - schematic
diagram, floor plan, and weather may - and using terminal manu-
facturer's supplied performance specifications, analyzed how long
each terminal would take to write the display.

Generally, though the terminal user considers his data
(applications) content requirements proprietary, and seldom
publishes his findings.

4.    TYPICAL TRADE-OFF DECISIONS - At this point, you should have
a pretty good idea of how a graphic terminal works, and what factors
affect its performance.  From time-to-time in the discussion, I
have inferred that the terminal designer needed to make various
trade-offs - hardware vs. software, type of character generator,
etc.

As a user, you too will have various trade-off decisions to
make, also - because often your budget, or your operating require-
ments cannot be matched by a single piece of equipment.

Such a decision making process will come as no surprise.
After all, you are faced with it every day.   Take the simple case
of buying a package of cigarettes - what happens when you go into
the corner cigar store and say:

"A package of cigarettes, please."

Does the fellow behind the counter just lay a package down in
front of you?   No indeed!   You'll be led through a series of trade-
off decisions which go something like this:

"What brand?"

"Filter or plain tip?"

"Hardpack or softpack?"

"Regular or menthol?"

"70 mm, 85 mm, or 100 mm long?"

By this time, you may decide to give up smoking!

In this section, I will discuss some of the choices you will
have to make in configuring a terminal.   These will be technically
based decisions.   Other trade offs, such as the reputation of the
manufacturer, the personality of the salesman, the availability of
lease vs. purchase and the availability of software, will enter
into your final decision...but these considerations are "beyond the
scope of these lectures".*

Here are some of the trade-off decisions with which you will
be faced in choosing a terminal for your application.   The "your
application" is intentionally underlined - because it is unlikely
that any one terminal will be the best for all applications.   Many
questions will be raised and few answers will be found in the
following discussion.   My intent is to raise some caution flags!


A.    COST VS. PERFORMANCE - Earlier, it was emphasized that per-
formance and capability are generally (but not always) related to
cost.   Higher performance units...more data capacity, better
quality characters, greater versatility...generally cost more.
Therefore, where the budget is limited, it is important to care-
fully consider what performance your application actually requires...
and then choose a terminal which provides enough (with some safety
factory and provision for growth), but not significantly more than
you need.

---

*This phrase is commonly used to allow the author to avoid highly
 controversial areas!

Notice that most of the other trade-off discussed in this section carries some cost implication.

B.   HARDWARE VS. SOFTWARE – "Hardware vs. software" trade-off is not an easy one to make.  The kind of application, the capability of the driving computer, the number of identical systems in related facilities, display data content, are all factors which enter into the decision.  Where hardware funds are limited, where display data content is low, when the capability of the driving computer is not being pushed, where there are many identical systems in related areas, the tendency is to use more software and less hardware.

Dr. H. McDonald of Bell Labs. has favored the software approach... his displays are simply digitally controlled point plotting systems, with virtually no special function generators or mode controls.  In contrast are the MAC graphic consoles developed by John Ward at MIT. Here, functions usually assigned to driving computer software, such as coordinate transformation, are accomplished by hardware in the display console.

C.   RASTER VS. RANDOM – One of the high cost items in CRT Graphic Terminal Systems is the display itself.  This is especially true where several displays are driven from a common display generator. Generally, the display used in a raster system is significantly less expensive than one needed in a random system.  This difference occurs because raster displays can use TV like techniques which are (1) inherently less expensive technically, and (2) adaptable to commercial TV monitors which are produced in substantial quantities, and therefore are less expensive.

However, the use of a raster system may have several other drawbacks.  The user may not find the appearance of a raster display as pleasing as one made from continuous lines.  Programming a raster system imposes burdens.  Primary data is generally defined by specific locations on the screen.  For example, a line may be defined by two end points, $X_1Y_1$ and $X_2Y_2$.  In a random positioning system, the beam is simply programmed to move between these points. In a raster system, the end point definition must be converted into a different (time-dependent) coordinate system...and the conversion must generally be done in the central computer (another aspect of the hardware vs. software trade-off).  Communication from the display to the computer via light pen is also complicated in a raster system.

D.  REFRESH FROM CENTRAL COMPUTER VS. DISPLAY BUFFER - Including a buffer in the display increases the cost of the terminal.  In some applications - (for example where the terminal is located more than 2000 feet from the central computer, it is not practical to use a high data rate communication line)---the display must have a buffer.  However, in many cases, the display could be refreshed directly from the central computer.  Generally, central computers with data break, direct memory access, or overlap control facilities, are better suited to refresh the display.  If the application does not require a substantial amount of processing time in the central computer, it may be practical to also refresh the display from the computer.

Availability of truly low cost general purpose computers (where the computer cost is not greatly different than a wired core memory) further complicates (or increases) the choice.  Enough advantage may be obtained by allocating certain housekeeping functions (display refresh, light pen tracking, editing, coordinate transformation) to the small computer-used-as-display-buffer, to favor the use of the small computer where an ordinary buffer would not generally be used.

E.  HIGH REFRESH RATE VS. PHOSPHOR STORAGE - If storage phosphors are available, why use a high refresh rate at all?  Several reasons.  Generally, the storage phosphors are not as bright, or as efficient.  Also, most storage phosphors are "soft" in the sense that they can be burned easily.  It is virtually impossible to protect a storage phosphor against some condition which may damage it.

When rapidly moving data is presented, the storage phosphors will tend to show a smeared picture.  Time-dependent communication between the display and the computer may be impaired because of the stored image.  For example, it may not be possible to use a light pen with a storage phosphor.

F.  MECHANICAL KEYBOARDS VS. LIGHT PEN - Some kind of keyboard is needed with most graphic terminals in order to transmit the operator's command to the computer.  These commands may call up new information, change data, or put the system in a different mode.

The light pen in conjunction with displayed information, can be used for this type of communication.  Why, then, add any mechanical keyboards?  Many users find that total light pen command is not efficient...for example, when the system is being used for computer-aided design.  Here, the operator would be required to continuously move the pen between the command keyboard and the drawing area.  By having a mechanical function keyboard, the operator can work the buttons with one hand and the light pen with the other.

Message composition is somewhat easier using an alphanumeric keyboard rather than a light pen in conjunction with a displayed alphabet.

G.    MONOCHROMATIC VS. COLOR - Color television is here...why not color CRT Graphic Terminals?

Why not, indeed?  There are some applications where color would be most helpful.  Using the display to design integrated circuit masks, or multilevel printed circuit boards, for example. There are many other applications where color probably would not offer enough to justify the cost or lower performance.

Generally, the manufacturer must use a commercially available color CRT - the same one being used in home color TV sets.  Tube construction limits the resolution.  The smallest character size, for example, would be about 1/4" high (compare to 3/32" in a readily available conventional monochromatic CRT).  Technical problems with the convergence circuits (the circuits which allow the three primary colors to be combined to produce any other color including white) drastically increase line drawing time in random position systems (from typically 1 USEC/inch to 100 USEC/inch).

H.    ABSOLUTE VS. INCREMENTAL - In an absolute positioning system, the screen locations are given in specific numbers.  For example, if the screen is divided into 1024 addressable locations, and the extreme left is 0, the center will be 512; three quarters across will be 768, etc.  Graphic element location data must be specified in terms of these absolute locations.  For example, in Figure 7, the three input diodes (between points 1-10, 11-20, and 21-30) are identical and drawn with the same sequence of commands.  But because the diodes are in three different locations on the screen, the data describing each is different, i.e., the absolute location of point 2 is different from the absolute location of point 12, which in turn, is different from the absolute location of point 22. The same consideration applies to other groups of common figurations.

However, if it were possible to command the display with information describing the relative position of successive points; i.e., the change from a prior position, common graphic elements need be stored only once and simply called out as a subroutine as needed.  Referring again to the three input diodes in Figure 7, the change between points 1 and 2, is the same as the change between 11 and 12, and is the same as the change between 21 and 22. Similarly, the changes in the succeeding beam positions needed to trace out the diode in each of the three locations are identical. Hence, one sequence of computer words could be used to trace out

the three diodes if the data were relative instead of absolute.

As listed in Table 1, the sequence between terminals 1 and 10 requires 20 data words. By using the identical group between 11 and 20 and 21 and 30, approximately 40 data words could be saved per frame. (Not exactly 40 because an extra Program Control Word, Figure 5B would be needed to call the subroutine from memory each time). Similarly, the sequence between 31-38 and 74-81 could be stored as a subroutine, saving about 14 data words per frame; and the route between 40-47 and 48-55, saving about 14 data words per frame.

In this specific example, the storage requirement per frame could be reduced about 25% by using an incremental rather than absolute positioning system.

Note that the time per frame does not change significantly – only enough to process the necessary Program Control Words. In this example, 7 Program Control Words, each requiring about 4 USEC would be needed, increasing the frame time by less than 0.7%.

The incremental system is available, at higher cost, in some terminals. Notice that the incremental system could also be implemented by computer software.


I.   LIGHT PENS VS. JOY STICK VS. RAND TABLET – This trade-off decision follows the same kind of consideration as Mechanical Keyboard vs. Light Pen. That is, the choice depends on application – and in many cases it's desirable to use all three. In practice, the light pen is almost always used, supplemented in some cases with the other devices.


J.   GRAPHIC TERMINAL VS. SOMETHING ELSE – I suppose it is a little late to raise this one – because this is probably the first decision you will be called upon to make. After all, there are other computer input-output devices...many much less expensive than a CRT Graphic Terminal!

Keyboards, printers, plotters, CRT alphanumeric inquiry stations are available. Generally, the CRT Graphic Terminal can be justified

1.   Where "quick-look" fast graphic output is needed, as in some types of pattern recognition problems.

2.   Where rapid dynamic graphic man-machine communication is needed, as in computer aided design, on-line problem solving and simulation.

3.   Where the user's understanding is enhanced and response time decreased by a graphic presentation, as in management information and

command and control systems.

4.    Where you're not sure, but you have a budget which will let
you find out!

5.    SYSTEM SPECIFICATION - You have studied your application...
you have decided what performance you need...you have some idea
about what range of equipment characteristics are practical.  How
do you get the system you want?

      Basically, you have two choices.  Either buy by a manufacturer's
part number...or write your own specifications and invite manu-
facturers to submit proposals.  In either case, it will be a good
idea for you to know what and how to specify a CRT Graphic Terminal.

      This section will develop a typical terminal specification to
illustrate what might be specified and how it might be specified.
The underlined areas are phrases and terms that might appear in
your specification.

      The section closes with a representative specification which
might be submitted by the manufacturer in response to your inquiry.

   1.    PURPOSE - It will be helpful to the manufacturer to
         know how the display will be used.  Perhaps it will
         allow him to propose trade-offs that will improve
         performance or lower cost.

   2.    DISPLAY CONSOLE -

         2.1   Cathode Ray Tube - Specify any special CRT or
               phosphor here, if you wish.  Note whether you
               especially want a bonded face plate, perhaps a
               filter to enhance contrast, and/or an etched
               face plate to reduce reflection.

         2.2   Display Area - Specify how much working area you
               want.  The rest of your performance specs should
               be based on this area.

         2.3   Resolution - Specify what resolution you need,
               typically in terms of spot size.

         2.4   Deflection - Specify how fast the deflection should
               be, and if you care, what kind (electrostatic or
               electromagnetic or a combination).  Alternately,
               you might describe a typical problem and leave it
               to the manufacturer to decide what deflection times

(and other times) are needed.

2.5 Accuracy

2.6 Jitter

2.7 Repeatability

2.8 Stability - Specify number for these items (2.5 - 2.8).

2.9 Input Devices - Specify desired input devices; keyboard, light pen, etc. Describe any special characteristics desired, such as an aiming circle for the light pen.

2.10 Construction - Specify any limitations on physical configuration, such as size, weight, air conditioning, etc.

2.11 Environment - Specify available power, the range of room temperature, and any other special factors such as shock or vibration.

3. DISPLAY GENERATOR

3.1 Function Generators - List what function generators are wanted. Typical are:

3.1.1 Character Generator - Specify type (if concerned), writing time, number and type of symbols, any special code requirements.

3.1.2 Vector Generator - Specify type (if concerned), absolute or incremental, time to draw vectors of defined length, linearity tolerable brightness variation.

3.1.3 Position Generator - Specify addressability.

3.1.4 Dot Generator - Specify dot writing time.

3.1.5 Other - Specify any function modifying program controlled features desired such as size control, intensity control, etc.

3.2 Computer - Specify which computer the display is to be used with. Describe any special features in the computer which might affect the display. State through which channel(s) the display is to communicate with the computer.

3.3 <u>Mode Control</u> - Specify any special Mode Control features desired such as strung or random characters, strung vectors, program registers, etc.

3.4 <u>Construction</u> - Same as Paragraph 2.9 for Console. In addition, specify maximum desired separation between Console and Display Generator.

3.5 <u>Environment</u> - Same as Paragraph 2.10 for Console.

As a result of your specification, the manufacturer might respond with a document like that following. Although he has responded to all your requirements there is still one major gray area...the meaning of some of the specified values. Time spent with the manufacturer ascertaining his understanding of such things as "spot size", "jitter", "repeatability", "settling time", and the like, will give you a better insight into exactly what has been offered.

From then on, it's simply a matter of settling on price and delivery!

(TYPICAL MANUFACTURERS RESPONSE)

SPECIFICATION FOR

COMPUTER CONTROLLED DISPLAY

TYPE CM10118

1.  PURPOSE

The Type CM10118 Computer Controlled Display, designed to operate with an XYZ Computer, facilitates new concepts of man-machine communications for computer-aided design.  Using a 21" CRT, the CM10118 provides completely flexible graphical and alphanumeric formats and includes light pen capability.  Two cabinets comprise the CM10118.

2.  DISPLAY CONSOLE

2.1  Cathode Ray Tube: 21EM10P31*.  Bonded safety glass.  Neutral Density Filter.  Etched face plate.

2.2  Display Area:  Manually adjustable to either 12" x 16" rectangle, or 15" diameter circle, or 13" square.

2.3  Resolution:  CRT spot size typically 0.010" in center and less than 0.015" at edges.

2.4  Deflection:  Magnetic deflection for large angle positioning, and electrostatic deflection for character writing.

2.5  Magnetic Deflection Channel Random Positioning Time: 14 USEC, maximum

2.6  Magnetic Deflection Channel Small Angle Positioning Time: 3 USEC, typical.

2.7  Electrostatic Channel Bandwidth:  DC to 5 MC

2.8  Accuracy:  $\pm$3% of full scale.

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*Other phosphors are available at no increase in cost.

2.9   Jitter:  Less than ±0.01".  Can be further improved by line lock.

2.10  Repeatability:  Less than ±0.04".

2.11  Stability:  ±0.5% of full scale, after 1/4 hour warm up over eight hour period.

2.12  Keyboard:

    2.12.1  Photoelectric, INVAC Series PK200, or equal.

2.13  Light Pen:

    2.13.1  Type:  Fibre optics light pipe with photo-multiplier, Aiming Circle, Enable button.

    2.13.2  Modes:  Program controlled TRACK and REFERENCE Mode.

    2.13.3  Signal Output:

        TRACK MODE:      Logic "1" each time excited by illuminated point on CRT.  Level persists typically for 1-10 USEC.

        REFERENCE MODE:  Logic "1" when excited by illuminated point on CRT.  Level holds until computer responds. Note that display program stops until either (a) computer responds or (b) enable button released.

2.14  Housing:  Attractive desk console, 30"W x 54-7/16"H x 36"D. The desk extends approximately 16".

2.15  Weight:  750 pounds, estimated.

2.16  Power Supply:  120 VAC ±10%, 60 CPS ±3 CPS, 1000 watts, single phase.

2.17  Construction:  Fully solid-state (except for CRT), built to best commercial standards.  Modular chassis and plug-in circuit boards.

2.18  Operating Temperature:  25°F to 100°F.

3. DISPLAY GENERATOR

## 3.1 Function Generators

### 3.1.1 Character Generator:

a. Type: CURVILINE Character Generator. Stroke writing, combining straight and curved lines.

b. Character Writing Time: 10 USEC, maximum.

c. Character Vocabulary: 128 Symbols available. Code compatible with ASCII.

### 3.1.2 Vector Generator:

a. Type: Continuous line generation. Absolute or incremental, under program control.

b. Writing time: 50 USEC, full screen vector.

c. Intensity Compensation: Intensity compensated for vector length, resulting in substantially equal brightness for vectors of any length.

d. Linearity: $^{+}_{-}1\%$, exclusive of display linearity.

### 3.1.3 Position Generator:

a. Type: Digital-to-Analog Converters.

b. Resolution: Up to 10-bit X (1024 positions) and 10-bit Y (1024 positions).

### 3.1.4 Dot Generator:

a. Writing Time: 1 USEC, typical.

### 3.1.5 Other Functions:

a. Size Control: Four character sizes under program control, plus superscript and subscript.

b. Intensity Control: Four character, vector, and dot intensities (in addition to OFF) under program control.

     c.   Blink Control:  Character, vector, and dot can be blinked under program control.

     d.   Line Structure:  Four vector line structures available under program control; solid, dash, dash-dot, dot.

3.2  Computer Interface

    3.2.1 Computer:  XYZ

    3.2.2 Communications:  Compatible with the XYZ DMA channel.

3.3  Mode Control:  Strung character, dot, vector.  See Figure 9 for Word Organization.

3.4  Auxiliary Line Drivers:  Drive H character, V character, H position, V position and Intensity up to 1000 feet, into 100 cable.

3.5  Housing:  Cabinet, 72"H x 36"D x 30"W.

3.6  Weight:  500 pounds, estimated.

3.7  Power Supply:  120 VAC $\pm$10%, 60 CPS $\pm$3 CPS, 500 watts, single phase.

3.8  Construction:  Fully solid-state, built to best commercial standards.  Modular chassis and plug-in circuit boards.

3.9  Operating Temperature:  25°F to 100°F.

Figure I

Basic Deflection Schemes
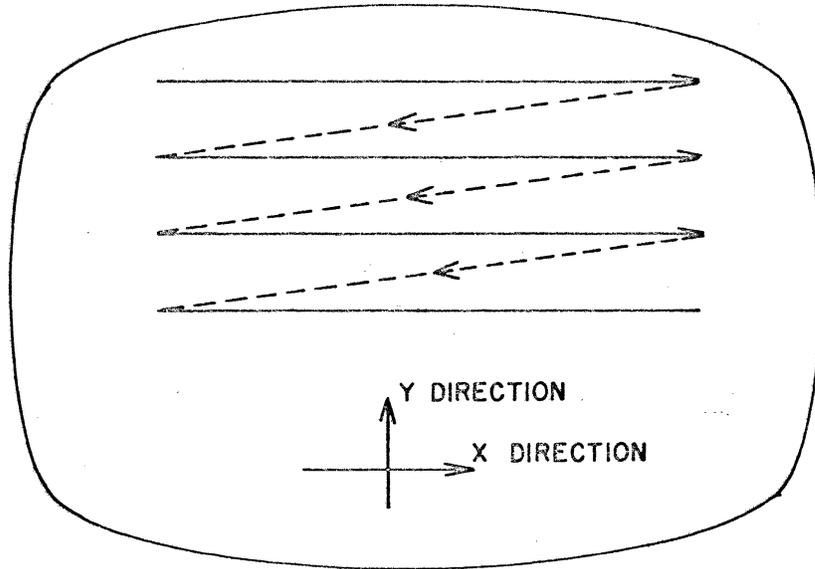


A. Raster Scan



B. Random Position

DIGITAL TO ANALOG CONVERTER

COMPUTER —DIGITAL— INTERFACE —DIGITAL— DISPLAY GENERATOR —ANALOG— CRT DISPLAY

INPUT DEVICE(S)
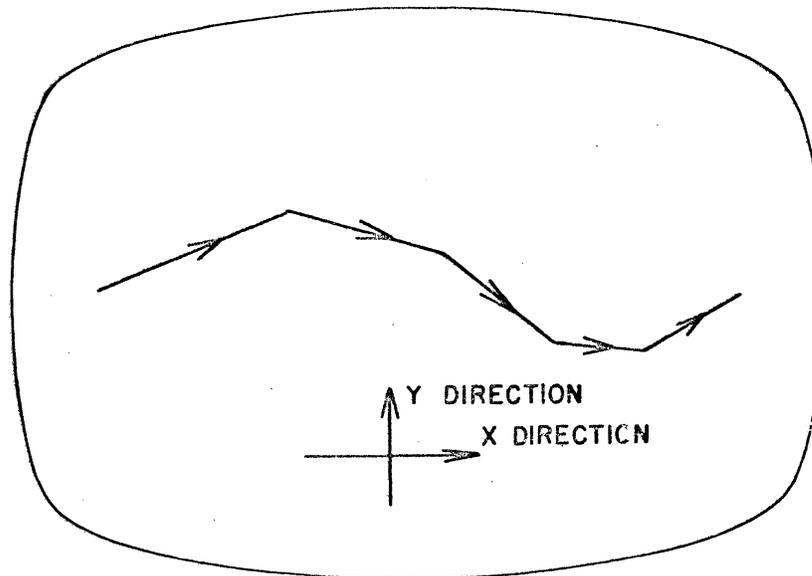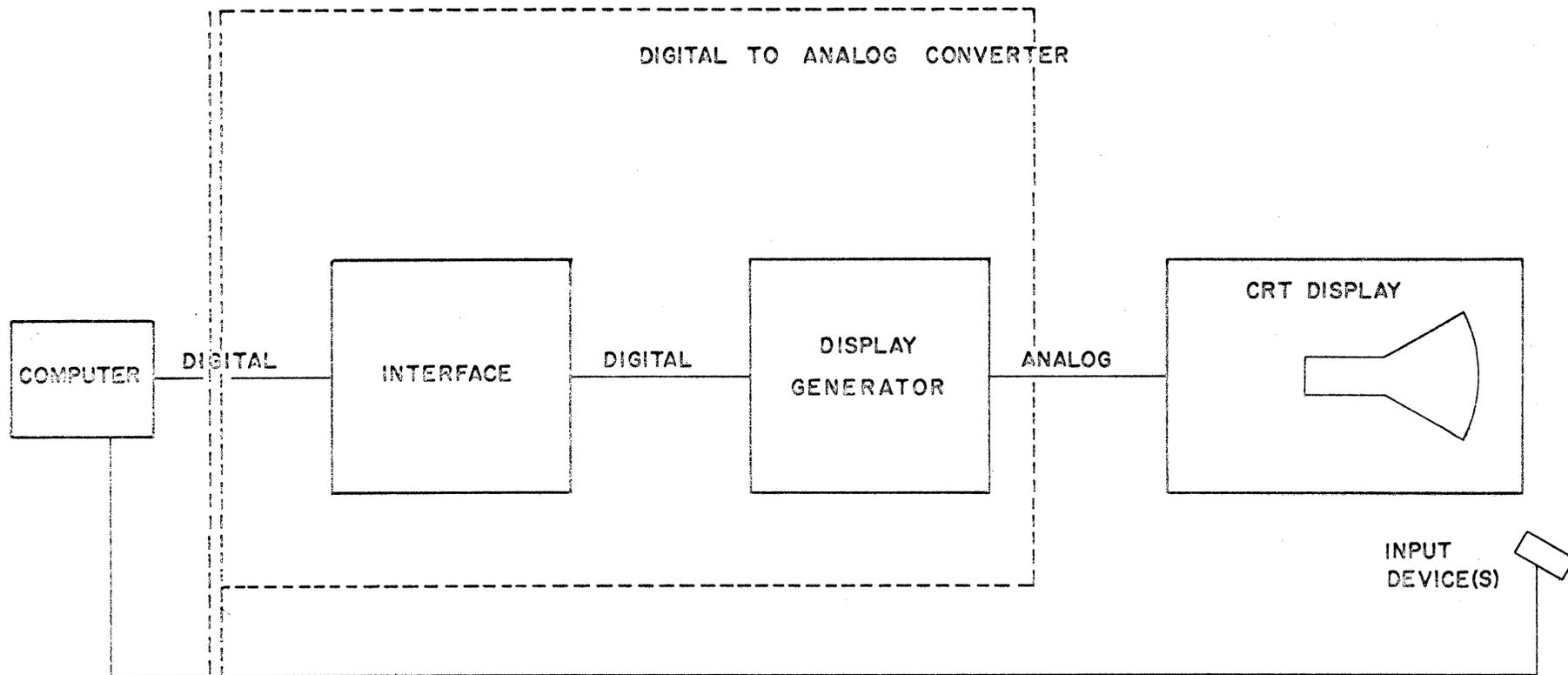
FIGURE 2
CRT GRAPHIC TERMINAL
BASIC BLOCK DIAGRAM
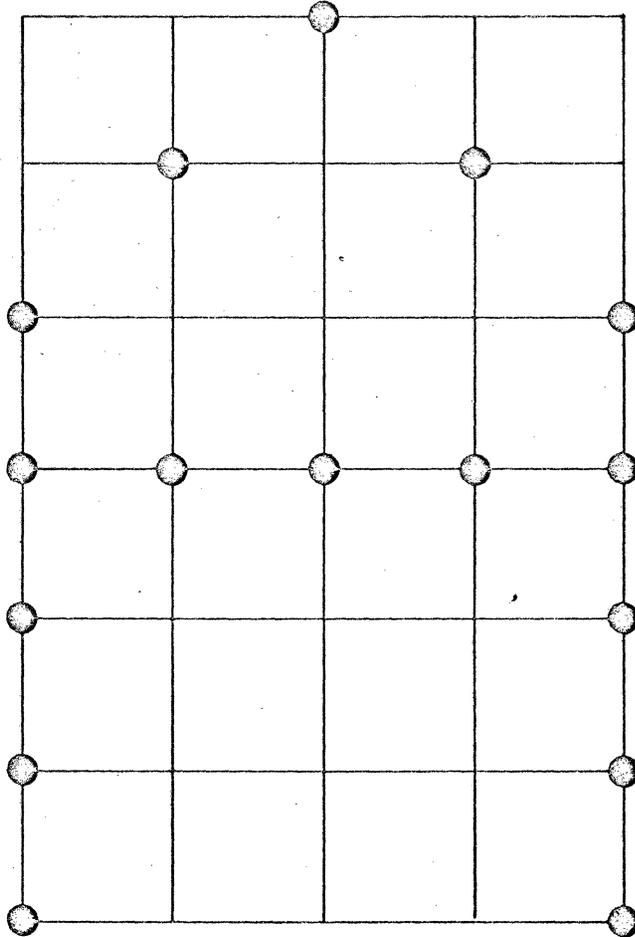
Figure 3

The letter "A" formed by 16 dots

## DISPLAY GENERATOR

COMPUTER — INTERFACE — STORAGE — MODE CONTROL

KEYBOARD

DOT GENERATOR — INTENSITY CONTROL — BLINK CONTROL — INTENSITY

CHARACTER GENERATOR — SIZE CONTROL — MINOR DEFLECTION

CRT DISPLAY

CIRCLE GENERATOR — MAJOR DEFLECTION

VECTOR GENERATOR — LINE STRUCTURE CONTROL

POSITION GENERATOR

AUXILIARY LINE DRIVER — INTENSITY — MINOR DEFLECTION — MAJOR DEFLECTION

LIGHT PEN

GRAPHIC TERMINAL

FIGURE 4

| FUNCTION | 0 1 | 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 |
|----------|-----|---------------------------------------------------------------|
| POSITION | Mode 00 | X Position / Y Position |
| DOT | Mode 01 | X Position / Y Position |
| CHAR. | Mode 10 | / CHAR.1 CHAR.2 CHAR.3 |
| VECTOR | Mode 11 | X Position / Y Position |

FIGURE  5A

SELF CONTAINED WORD ORGANIZATION

FIGURE  5

TYPICAL WORD ORGANIZATION

## FIGURE 5B

### CONTROL WORD AND DATA WORD ORGANIZATION

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|----|----|

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | I | P | ADDRESS | | | | | Program Control Word |

| 1 | 1 | 1 | 1 | 0 | LP | F | TYPE | INT | BL* | Vector Mode Control Word |
|---|---|---|---|---|----|---|------|-----|-----|

| 0 | X Coord | | | | | | | | Z | Vector Data Word Pair |
| | Y Coord | | | | | | | | BL |

| 1 | 1 | 1 | 0 | 0 | LP | ⨉ | ⨉ | ⨉ | INT | BL* | Dot Increment Mode Control Word |
| 0 | ΔX | | ΔY | | Repeat | | | | | Z | Dot Increment Data Word |

| 1 | 1 | 1 | 0 | 1 | LP | ⨉ | MAR | INT* | BL* | Symbol Mode Control Word |
| 0 | CHAR | | | | | ∅S | INT | BL | | Symbol Data Word |

| 1 | 1 | 1 | 1 | 1 | LP | ⨉ | ∅S | INT | BL | Packed Symbol Mode Control Word |
| CHAR 1 | | | | CHAR 2 | | | | | | Packed Symbol Data Word (77₈ = escape) |

```
LP  = disable light pen
BL  = enable blink
Z   = blank
F   = frame sync

INT = 00 - normal
      01 - dim
      10 - bright
      11 - off

TYPE = 00 - Position
       01 - Position, Write Dot
       10 - dash
       11 - solid
```

$\Delta X, \Delta Y$ = 001 +1
 010 +2
 111 -1
 110 -2
 Others - no increment

```
∅S = 00 - normal, no offset
     01 - small, superscript
     10 - small, subscript
     11 - small, no offset

MAR = 00 - N∅P
      01 - set margin
      10 - return to margin
      11 - return to margin and
           line feed
```

*These bits do not actually control the Display, but are included to provide programming mode compatibility.

FIGURE 6

TYPICAL CRT PRESENTATION
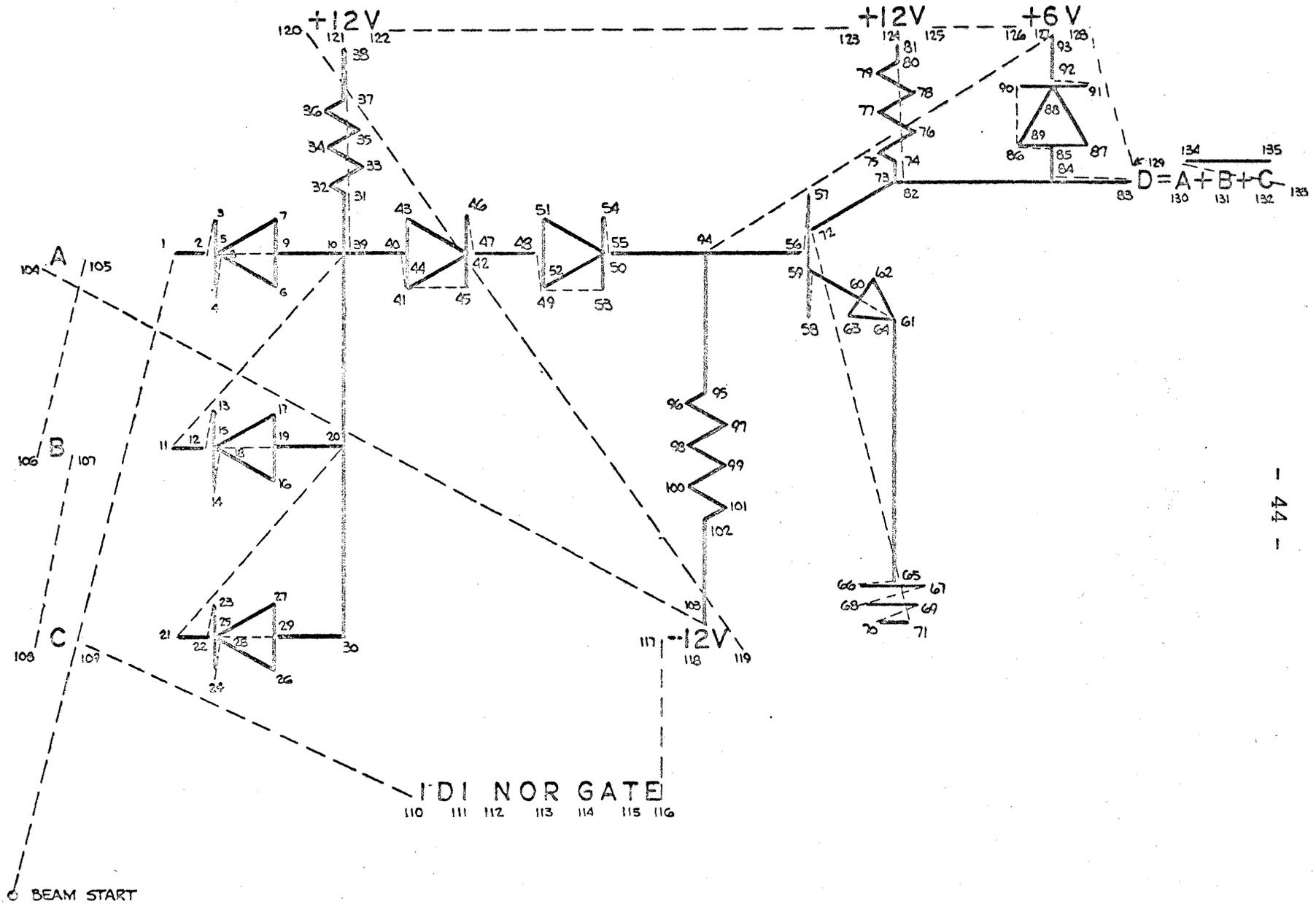
FIG. 7
CODING SEQUENCE

GRAPHIC

ALPHANUMERIC

POINT-PLOTTING

|         | LOW     | MEDIUM  | HIGH    |
|---------|---------|---------|---------|
| $2K     |         | $10K    | 60K     | $300K |

COST   PERFORMANCE
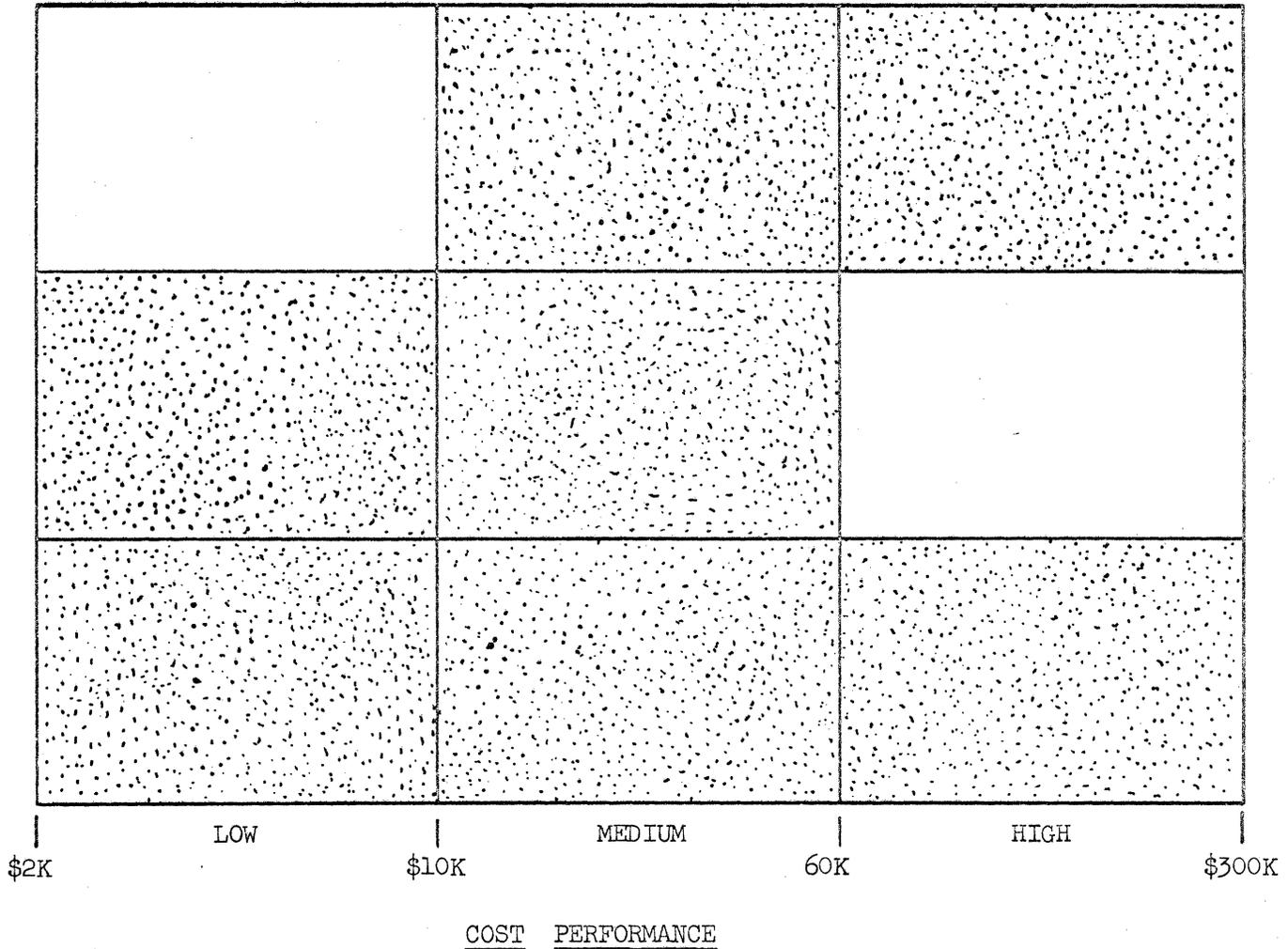
COMMERCIALLY AVAILABLE CRT DISPLAYS

FIGURE   8

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | 0 | 0 | Z | S | ╳ | | P | A | D | | L | | | I | | | F | | R | T | ╳ | | | |
| Vector | 0 | 1 | ± | X | | | | | | | | | | ± | Y | | | | | | | | | |
| Typewriter | 1 | 0 | 0 | Char. 1 | | | | | | Char. 2 | | | | | | | Char. 3 | | | | | | | |
| Strung Dot | 1 | 0 | 1 | ΔX$_1$ | | ΔY$_1$ | | ╳ | ΔX$_2$ | | ΔY$_2$ | | | ╳ | ΔX$_3$ | | | ΔY$_3$ | | | | | | |
| Instruction | 1 | 1 | OP | | ╳ | | | | Address (A) | | | | | | | | | | | | | | | |

Information Stored

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| A | | X Registers | | | | Y Registers | | |
| A + 1 | 0 | 0 | Control Word Contents | | | | | |
| A + 2 | 1 | 1 | 0 | 0 | 1 | ╳ | Command Location Register | |
| A + 3 | : | Control Transferred | | | | | | |

KEY

Z  =  Intensity
S  =  Size
P  =  Superscript, Subscript, or Normal
A  =  Absolute or Incremental Vector
D  =  Vector Type (line or dot)
L  =  Line Structure
I  =  Interrupt
F  =  Flag Set
OP =  Operations Code - 001   Jump
                        010   Jump and Save
                        011   Restore A
                        100   Not Used
                        000   Interrupt and Halt

R  =  Rotate
T  =  Track

FIGURE 9

WORD ORGANIZATION
CM10118 DISPLAY

APPENDIX

# converting data

## to human-interpretable form

### Carl Machover

A T LAST COUNT there were some 25-30 different manufacturers of Character Generators or Character Generating Systems. Other than the tendency of a company to "do-it-itself", why should there be such a variety of approaches to the relatively simple problem of putting letters and numbers on a cathode ray tube? One major reason is that particular applications differ and, therefore, some parameter of the Character Generator may be more important for that application than it might in another. What are some of these typical applications?

For one type of Computer Controlled Display, a number of low cost Inquiry Units may be needed so that the large number of operators can easily request data from the central store. Here, the cost of the Character Generator becomes important, particularly if one needs to be supplied with each Inquiry Unit. Quality of character can be sacrificed. At the other extreme are displays used for type setting. Pages of text are produced directly from a CRT Display. Under these circumstances, the quality of the characters can be extremely important outweighing any considerations of cost, size, or speed. For the generalized Computer Controlled application where the display is being used to plot curves, show graphs, or draw charts, the Character Generator may have evolved from conflicting requirements of cost, speed and character quality. In other CRT Displays, philosophically related but not necessarily directly related to Computer Controlled Displays, such as the bright displays used by the FAA, the Character Generators must be compatible with a TV raster. And, still other systems where Character Generators are used in Airborne Film Annotation Systems, ruggedness and small physical size are predominant factors. Speed and quality of character are somewhat less important. As in most real-life problems, a perfect solution is seldom possible and an optimum solution is sought. In the case of Character Generators, the design must be optimized, after considering problems of character rate, character quality, system bandwidth, physical size, cost, and ease of changing characters in the field. In view of the often conflicting requirements, it should not be surprising that a variety of design approaches evolved to solve a problem of electronic character generation.

## CLASSIFICATION OF CHARACTER GENERATORS

This discussion is limited to electronic Character Generators associated with cathode ray tubes. There are a variety of other digital indicators, such as projection indicators, the Nixie type tube, belts, illuminated dots, etc., that find application in computer systems. However, when there is a large amount of data that must be presented rapidly, where there is a need for communication between the display and the computer, electronic generation is indicated. There are primarily four parameters in the cathode ray tube which can be controlled in order to form characters. These are the $X$ deflection, the $Y$ deflection, the intensification, and the electron beam cross-section. It is convenient to organize the various types of character generation techniques into the organizational chart in Fig. 1.
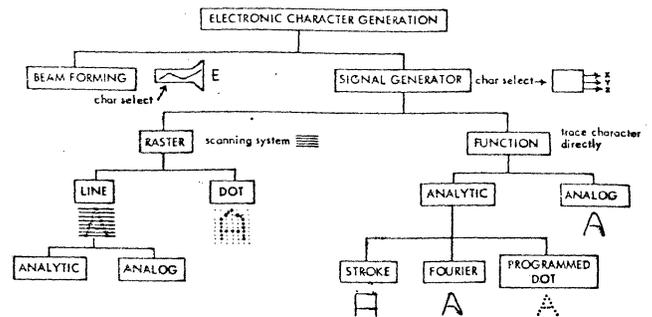


FIG. 1 Character generation techniques.

Beam Forming, the first of two basic techniques available, involves a modification of the cross-section of the CRT electron beam. In this system, a special CRT is used which has a stencil mask through which the electron beam is directed. The cross-section of the emerging beam has the shape of the particular stencil. Through further electron optics and deflection circuitry, the beam is directed to a particular location on the screen. Instead of forming the characteristic dot as it impinges on the screen, it forms the desired character. Typical systems utilizing the beam forming technique include the Charactron, manufactured by General Dynamics, and the Typotron, manufactured by Hughes.

Signal Generators, the second major classification for character generation techniques, simultaneously affect the three other parameters of a CRT. That is, they generate $X$ and $Y$ deflection voltages which force the beam to follow some particular pattern on the screen, and at the same time generate intensification voltages which turn the beam off and on at the correct times. The composite result is the desired figure or character.

With the Signal Generator category, there are primarily two techniques which are used in generating characters. One technique can be described as a raster technique. In this method, the beam is forced to follow a fixed scanning pattern, quite analogous to the scanning pattern one sees in the home television set. This pattern is not varied as a function of the character. However, the pattern is intensity modulated so that the composite pattern and the intensity modulation forms the desired character.

In the second system, the beam can be forced to follow some particular function or group of functions, and may not necessarily trace the same pattern for each character. This general group of Signal Generators can be designated as function types.

First, consider the raster technique. Within the raster technique, there are primarily two days of generating characters. In the first method, the character is formed from groups of dots. The raster is of a fixed configuration, typically five horizontal dots by seven vertical rows making up a total of 35 dots. The familiar equivalent to this electronic system is the typical basketball scoreboard. Although the typical dot raster consists of a 5 x 7 array, more elaborate structures of 7 x 9 and others have been used where it was desired to increase character quality. Dot raster character generators, as components, have been offered for sale by such companies as ITT, Digital Equipment Corporation, and IPC. This type of Character Generator has been included in display systems offered by LFE, Philco, Hazeltine, Ford, Teleregister and others.
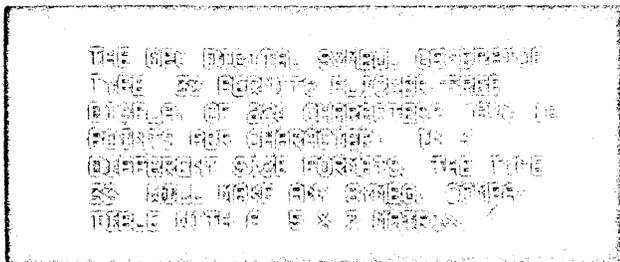


FIG. 2 Digital Equipment Corp.'s dot raster generator.

Instead of building the character from a dot matrix, the raster system can be used to build up the characters as a series of evenly spaced horizontal lines. As a particular horizontal line is scanned, it can be turned on at some arbitrary point and turned off again at another arbitrary point. Therefore, symbols are built up as a series of these illuminated horizontal lines. Two methods are used to develop the signals for the Line

Raster Character Generators. In the Analytic method, the data about the starting point and end point of the illumination for each line may be stored in some type of magnetic core memory. This approach is used in the CBS Vidiac and the Raytheon Character Gen-
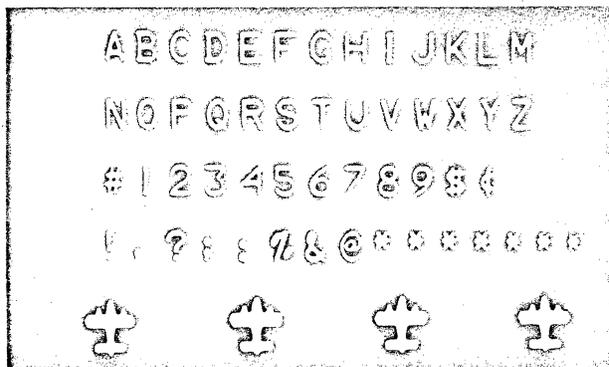


FIG. 3 CBS Vidiac line raster character generator, analytic type.

erators. Alternately, the character itself can be stored as an image. A class of cathode ray tubes called MONOSCOPES are functionally equivalent to a closed circuit television system, where the TV camera would be pointed at the desired character. The resultant video signals would be used to form that character on a remoted display. Companies offering Analog Line Raster (MONOSCOPE) Character Generators include A. B. Dick, Electrada and Avco.
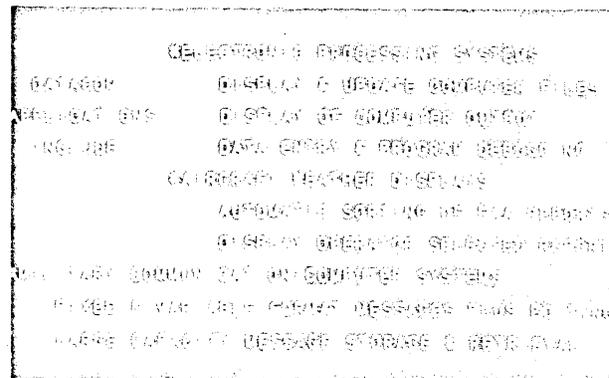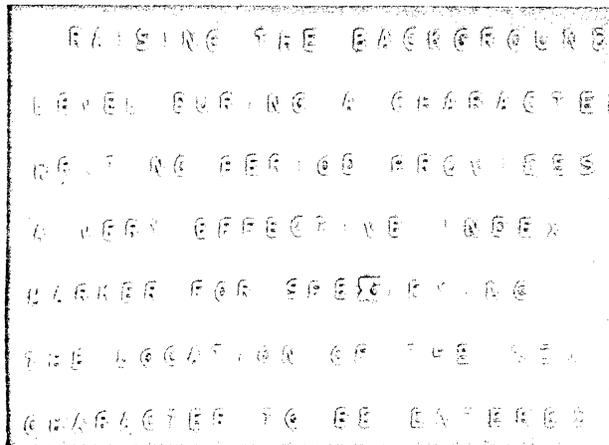




FIG. 4 Analog line raster character generators, A. B. Dick (above), and Electrada (below).

Within the group of Function type Signal Generators, there are two main subdivisions and these are related to the way in which the function signals are generated. You will remember that the Function Generator differs from the Raster Generator. Using the Function Generator, the beam of the cathode ray tube is forced to trace out the character directly rather than move through a fixed scanning pattern. Both Analytic and Analog techniques have been used in the design of Function type generators.

The Analog techniques, now generally obsolete, involve curve following or density modulation with cathode ray tubes. Either three cathode ray tubes are used to simultaneously generate X, Y and Z voltages, or one cathode ray tube is used and the beam is time-shared among three masks. In one typical system developed by Skiatron, opaque masks were drawn representing the X deflection, Y deflection and the Z intensification. Optical servos were used to force the beam of the generating cathode ray tube to follow the curves. The servo signals necessary to do this following were then the analog of the necessary deflection voltages and these were directed to a second cathode ray tube, upon which the character was formed. A somewhat similar system developed by Philco used variable density masks, rather than curve following techniques.

More commonly used Function Signal Generators involve analytic techniques in which the deflection voltages were generated by stored logic. This logic may be magnetic, resistive, or diode. Within the classification of analytic Function Signal Generators, there are three main categories.

The first category uses generalized Fourier techniques in a manner quite similar to the familiar Lissajous pattern, where two frequencies out of phase by 90° are applied to the X and Y deflection plates of the CRT to form a circle (provided the input signals are identical and the gain of two channels is identical). To build up a vocabulary of all letters, all digits, and many symbols, may require that the sines and cosines of fundamentals and up to the fifth harmonics of each of varying amplitudes be combined. Such a system was developed by MIT for some of their displays and was offered commercially by Wang Laboratories and Marconi. Apparently, the new Wyle Laboratories electronic desk calculator uses the Fourier type of Character Generator to form the digits that are displayed on their CRT.

A second type of Analytic Function Signal Generator involves programmed dots. In these systems there may be an array of 15 x 16 dots available of which some fixed number, perhaps 16, are used for forming each character. Instead of scanning through the entire matrix of 240 dots, the CRT beam is directed in sequence to those 16 which are needed to form the desired character. In some programmed dot systems, such as the Straza, the beam is intensified only as it reaches the programmed dot. In others, such as that used by DDI, the beam is left on during its excursions from one dot

to another so that the character has the appearance of being drawn with a continuous line. The Link Dotitron, which is no longer commercially available, was also of the programmed dot variety.
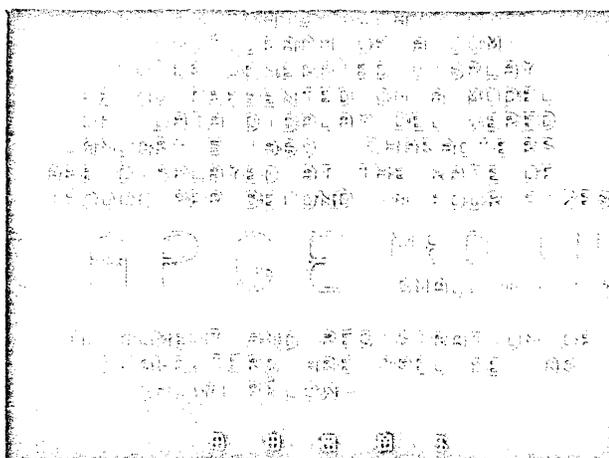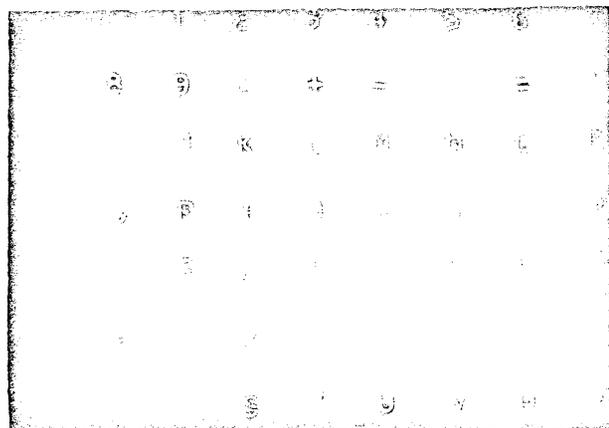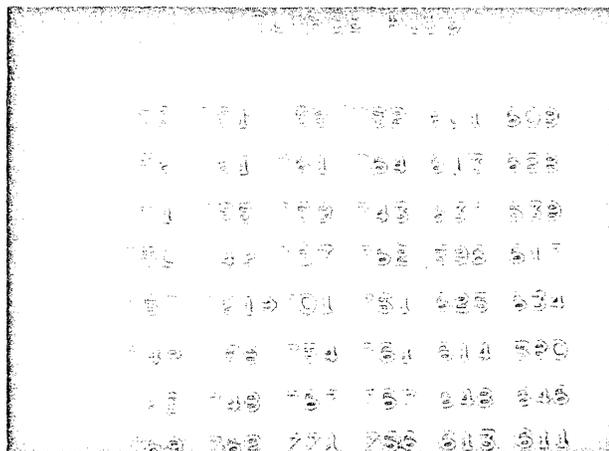


FIG. 5 Marconi (top) uses generalized Fourier techniques. Straza (middle) uses programmed dots as does DDI (bottom). Difference is that Straza intensifies beam as it reaches the dot, and DDI leaves beam on.

The final type of Analytic Function Signal Generator to be considered is the Stroke type. In this category, characters are formed from groups of continuous lines.

Some typical systems, such as the Burroughs (formerly Strand unit), a vocabulary of unit length lines at fixed angular orientations are available, and these can be "strung" together with certain limits to form different characters. In other stroke systems, such as the Information Displays, Inc. CURVILINE®, characters are formed from a series of fixed formats. The beam always traces through the fixed formats, but only those sections required to form the character are illuminated. Stroke type generators are also commercially available from Marquardt, Contronics, Raytheon and Skiatron.
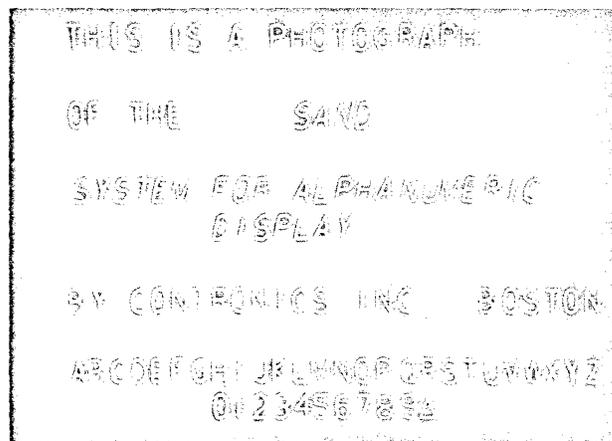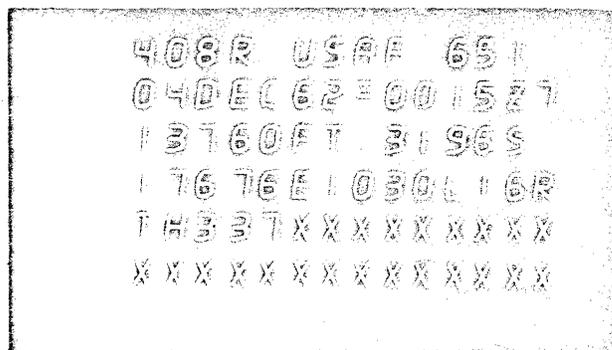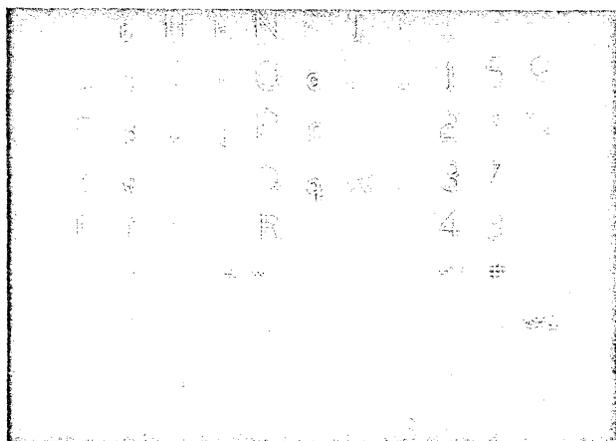


FIG. 6 Stroke type generators. Strand (left), Information Displays (top right), and Contronics (bottom right).

## COMPARATIVE PERFORMANCE

It is difficult to make completely meaningful comparisons among the various commercially available Character Generators, because in some cases the Character Generator is offered as a component which accepts a digital signal and develops a suitable deflection voltage to be used with an external cathode ray tube. In other cases, the Character Generator is simply part of an overall system and the supplier is interested in selling a system.

Typical of the commercially available Character Generators is the CURVILINE® which is in the category of Stroke Analytic Function Signal Generators. This unit was developed for applications where small size (only nine printed circuit boards are needed for full alphanumeric vocabulary) and low cost ($2400 for a typical unit) are important. Character speeds up to 100,000 per sec are available, but there are some constraints on the types of symbols which can be formed, since the unit operates primarily from a formatting technique and the number of strokes per character is limited to nine.

Where extremely high speed becomes an important factor, Character Generators offered by Raytheon and DDI feature rates in the order of 250,000 to 500,000 characters per sec. These rates become useful where the Character Generator is to be used in a multiplexing system driving a variety of cathode ray tube displays.

Extremely high character quality was a basic design parameter met by such units as the CBS Vidiac. Cost ($12,000-$15,000) was secondary to achieving extremely high quality. Typical Vidiac characters have resolutions in excess of 50 TV lines and there are no restrictions in character formats. The same type of character flexibility is characteristic of the MONOSCOPE type of Analog Line Raster Signal Generator, such as the A. B. Dick unit. The need to scan each character in a MONOSCOPE system occasionally places an upper limit on the character generation rate so that these systems typically operate at 30,000 characters per sec maximum.

The foregoing types of generators are basically black boxes. They can be purchased as any other type of Signal Generator and incorporated into a system. In some cases, where the manufacturer has taken a system approach, the Character Generator is not available as a separate entity. For example, in some of the LFE display systems, the Character Generator exists only as a look-up table on tracks of a magnetic disk memory already incorporated in the display for other purposes.

Perhaps the best known of the various character generation techniques are the beam forming systems. These play an important part in the early stage consoles and still find wide application. Character quality is excellent. However, in those applications where it be necessary to change characters in the field, the beam forming technique is less satisfactory since the entire tube needs to be replaced.

A Series M10000 High Speed DUALFLEC with an Option D, Light Pen,

plus a Display Generator which includes:

Option B:     High Speed CURVILINE Character Generator

Option C:     Vector Generator

Option E:     Mode Control

Option G1:    Size Control (2 sizes)

Option H2:    Intensity Control (3 levels plus off)

Option J:     Level Changers

Option N:     Line Structure

Option Q:     Blink

and

Power Supplies, and Computer Interface.

Cables are provided to connect between the Display and the Display Generator. Separation between the Display and the Display Generator can be up to 300 feet.

The CM10093 displays points, strung characters in two sizes plus subscripting the superscripting and vectors in two-line structures (dash, or solid). All may be displayed in any of three brightenesses, or blinked as selectively controlled by the digital input. Programmable line margin control is included.

Upon receipt of a light pen signal, the display will halt, will leave the contents of the Program Address Counter on-line to the computer, and will send an interrupt signal to the computer. When the computer accepts the address, it will send a restart signal to the display, which will then continue with its normal display routine.

In order to provide a more uniform intensity with different size display messages, the CM10093 contains a Repetition Rate Control to prevent refresh rates greater than a preselected amount (typical 40 frames/second).

Connection between the CM10093 and the PDP-8 are given in Table 1.

## 2. DATA ORGANIZATION

The CM10093 Display System operates from instructions in the form of consecutive 12-bit computer words. Basic operations are to: plot points, write characters, and draw straight lines between specified locations. Symbols, lines and dots can be positioned with a resolution of 1024 locations (10 bits) in both X and Y.

Characters may be written in two sizes; centered, or as small subscript or superscript; in three intensities. Characters are normally written in a typewriter mode with program controlled margin set, carriage return, and line feed - carriage return.

Dots may be randomly positioned, or incremented, at increments of 0, $\pm2^0$ or $\pm2^1$ in either or both X and Y. Under program control, any set of increment values can be repeated for up to fifteen dots, without using additional computer words.

A vector may be drawn from a current location to the X and Y location specified in a succeeding vector words with either of two line structures and three intensities.

Figure 1 shows the organization of the computer words. Three types of words are used: Program Control, Display Control, and Display Data.

Program Control words provide the PDP-8 JUMP instruction operation.

Display Control words generally establish the operation mode (such as dot increment, symbol, vector, and packed symbol), while the Display Data words contain the specific graphic element information, such as position, or symbol.

A description of the Word Organization follows.

Bit $\emptyset$ is logical "1" for all Control words and is logical "0" for all Data words (except the packed symbol data word).

Bit 1 is logical "1" for all Display Control words and is logical "0" for all program control words. In the Display Control words, bits 3-4 determine the mode.

- 3 -

Each Control word is 12 bits.  All Data words, are 12 bits.
Vector Data requires two 12 bit words.

In each Display Control word, bit 5 is used to enable the
light pen for succeeding Display Data words; bits 9-10 set in-
tensity for succeeding Display Data words; and bit 11 sets the
Blink for succeeding Display words.

PROGRAM   CONTROL

This word is used with the Jump (JMP Instruction
to provide essentially the same program control
operations as in the PDP-8). Program Control words
may be interspersed with Display Control and Display
Data words without disturbing the display operation.

With bit 3 a  logical "0", the address in bits 5-11
is the direct address (JMP) with bit 3 a  logical
"1", the location specified in bits 5-11 contains
the 12 bit address to be placed in the Program
Address Counter (JMP*).

With bit 4 a  logical "0", the address (bits 5-11)
is address specified of page zero.  With bit 4 a
logical "1", the address (bits 5-11) is address
specified of current page.

The memory addresses for the display words are
supplied to the computer Memory Address Input from
a Program Address Counter in the display.

The Program Address Counter will always start at
address 0007g.  The contents of this memory cell
are interpreted as an Indirect Address.  Upon re-
ceipt of an EOF message, the Program Address Counter
will go to the next address and wait for the start
of the next frame.  Recycling of the display is
accomplished by the use of a 5407 (JMP* 7) instruc-
tion.

Typical Operation Time:            JMP         1.0 USEC
                                   JMP *       3.0 USEC

- 4 -

( All typical Operation Times exclude computer access time;
total Operating Time is less than the sum of Display and
Computer Access time since most computer access occurs
during the Display operations.)

## VECTOR MODE (10)

This mode is used to either randomly position dots
or to position the beam for succeeding dot, vector
or symbol modes, or to string vectors (lines). Frame
sync is also accomplished in this Mode.

### CONTROL WORD

This word is used to set the conditions for inter-
preting the following pairs of Data words as either
beam position, random dot position, or end of vector,
depending on bits 7, 8 (until a new Control word is
encountered)

With bits 7, 8 = 00, the beam will be positioned only;
with bits 7, 8 = 01, the beam will write a dot after
positioning; with bits 7, 8 = 10, the beam will be
controlled by the vector generator and the line will
be dashed; and with bits 7, 8 = 11, the beam will be
controlled by the vector generator and the line will
be solid.

Bit 6 is for Frame sync.  Blink bit 11 is provided
for program compatibility but does not control the
display.

Typical Operation Time:                     4.0 USEC

### DATA WORD

Bits 1-10 of the first Data word determine the X
Position and Bits 1-10 of the second Data word deter-
mine the Y Position.  Bit 11 of the first Data word
is used to blank the beam irrespective of any control
bit settings in previous Control words.  Bit 11 of the
second Data word controls blink.

Typical Operation Time:  Beam position      17.0 USEC
                         Vector             50.0 USEC

## SYMBOL MODE (10)

This mode is used to string a series of characters, (one character per Data word) with each character individually controlled for size, offset, intensity and blink.

## CONTROL WORD

This word is used to set the conditions for interpreting the following Data words as strung characters until a new Control word is encountered.

Bits 7,8 set the margin characteristic, according to the following table:

| | |
|---|---|
| 00 | NOP |
| 01 | Set Margin |
| 10 | Return to Margin |
| 11 | Return to Margin and Line Feed. |

The number of characters per line depends on the character size as set in the Data word. Sixty-four normal size characters or 128 small size characters fill a complete horizontal line. Line Feed is based on 64 lines of characters per page. Intensity bits 9,10 and Blink bit 11 are for program compatibility, only, and do not control the display.

Typical Operation Time: 4.0 USEC

## DATA WORD

The character determined by bits 1-6 (see table 2) will be written with the intensity determined by bits 9-10. Character size and offset will be determined by bits 7,8 according to the following table:

| | |
|---|---|
| 00 | – normal, no offset |
| 01 | – small, superscript |
| 10 | – small, subscript |
| 11 | – small, no offset |

Typical Operation Time: 13.0 USEC

## PACKED SYMBOL MODE (11)

This mode is used to string a series of characters (two characters per data word), with the character string as a group controlled for size, offset, intensity and blink.

### CONTROL WORD

This word is used to set the conditions for interpreting the following Data words as strung characters until an escape character is encountered.

Characters determined by the following packed Data word will be written in the size and offset determined by bits 7,8, with the intensity determined by bits 9,10, and will blink as determined by bit 11. Size and intensity codes are as given in the Symbol Mode 10.

Typical Operation Time:                                      4.0 USEC

### DATA WORD

Two characters are packed into each data word, with bits 0-5 determining character 1, and bits 6-11 determining character 2 (see table 2).  Because no control bit is available, one character code ($77_8$) is reserved as an escape code.

Typical Operation Time:                           26.0 USEC (for two characters)

## DOT INCREMENT MODE (00)

This mode is used to program a series of closely spaced dots.

### CONTROL WORD

This word is used to set the conditions for interpreting the following Data words as strung dots until a new Control word is encountered.  Bits 9,10 determine dot intensity; and bit 11 determines dot blink.

Typical Operation Time:                                      4.0 USEC

One dot increment ( X, bits 1-3:  Y, bits 4-6) is specified by each Data word according to the following table:

| | |
|---|---|
| 001 | $+2^0$ |
| 010 | $+2^1$ |
| 111 | $-2^0$ |
| 110 | $-2^1$ |

others - no increment

Bit 11 blanks the dot regardless of any control bit setting in the previous Control word.  The program dot increment will be automatically repeated the number of times determined by bits 7-10 (up to 15).

Typical Operation Time:                    5.0 USEC/DOT

## 3.0   OTHER

### 3.1   Character Vocabulary

The CM10093 uses the character vocabulary with associated codes shown in Figure 2.

### 3.2   Physical

Two cabinets comprise the CM10093.

The Display Generator is housed in standard 30" W rack cabinet 63-3/4" H x 24" D which weighs approximately 400 pounds, and the Display Console is housed in a cabinet 58-3/4" H x 36" D x 30" W which weighs approximately 750 pounds.  Power consumption from 120 VRMS, 60 Hz is approximately 2000 watts.  The Display Console is connected to the Display Generator through removable cables which can be up to 300 feet long, which connect to external connectors attached to the bottom rear connector panel on each unit.  Computer and power input connections to the Display Generator are connected to the same panel.

### 3.3   Price

The price of the CM10093 Display System is $51,750.

## 3.4 Variations

The CM10093 is only one of the many displays which can operate with the PDP-8 computer. Displays with core memory and keyboards are available, for example.

# FIGURE 1

## CM10093
## WORD ORGANIZATION

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|----|----|

| 1 | 0 | 1 | I | P | ADDRESS |  |  |  |  |  |  |

Program Control Word

I=indirect
P:∅=page zero; 1=current page

| 1 | 1 | 1 | 1 | 0 | LP | F | TYPE |  | INT |  | BL* |

Vector Mode Control Word

| 0 | X Coord |  |  |  |  |  |  |  |  |  | Z |
| | Y Coord |  |  |  |  |  |  |  |  |  | BL |

Vector Data Word Pair

| 1 | 1 | 1 | 0 | 0 | LP | ☒ | ☒ | ☒ | INT |  | BL |

Dot Increment Mode Control Word

| 0 | △X |  |  | △Y |  | Repeat |  |  |  |  | Z |

Dot Increment Data Word

| 1 | 1 | 1 | 0 | 1 | LP | ☒ | MAR |  | INT* |  | BL* |

Symbol Mode Control Word

| 0 | CHAR |  |  |  |  | ∅S |  | INT |  | BL |

Symbol Data Word

| 1 | 1 | 1 | 1 | 1 | LP | ☒ | ∅S |  | INT |  | BL |

Packed Symbol Mode Control Word

| CHAR 1 |  |  |  |  |  | CHAR 2 |  |  |  |  |  |

Packed Symbol Data Word
    (77₈ = escape)

LP = disable light pen
BL = enable blink
Z = blank
F = frame sync

INT = 00 - normal
      01 - dim
      10 - bright
      11 - off

TYPE = 00 - Position
       01 - Position, Write Dot
       10 - dash
       11 - solid

△X, △Y = 001 +1
         010 +2
         111 -1
         110 -2
    Others - no increment

∅S = 00 - normal, no offset
     01 - small, superscript
     10 - small, subscript
     11 - small, no offset

MAR = 00 - N∅P
      01 - set margin
      10 - return to margin
      11 - return to margin and
              line feed

*These bits do not actually control the Display, but are included to
provide programming mode compatibility.

| | | | | | |
|---|---|---|---|---|---|
| 00 | space | 25 | 5 | 52 | J |
| 01 | ! | 26 | 6 | 53 | K |
| 02 | " | 27 | 7 | 54 | L |
| 03 | # | 30 | 8 | 55 | M |
| 04 | $ | 31 | 9 | 56 | N |
| 05 | % | 32 | : | 57 | O |
| 06 | & | 33 | ; | 60 | P |
| 07 | ' | 34 | < | 61 | Q |
| 10 | ( | 35 | = | 62 | R |
| 11 | ) | 36 | > | 63 | S |
| 12 | * | 37 | ? | 64 | T |
| 13 | + | 40 | @ | 65 | U |
| 14 | , | 41 | A | 66 | V |
| 15 | – | 42 | B | 67 | W |
| 16 | . | 43 | C | 70 | X |
| 17 | / | 44 | D | 71 | Y |
| 20 | 0 | 45 | E | 72 | Z |
| 21 | 1 | 46 | F | 73 | [ |
| 22 | 2 | 47 | G | 74 | \ |
| 23 | 3 | 50 | H | 75 | ] |
| 24 | 4 | 51 | I | 76 | ↑ |
| | | | | 77 | ← |

Note:  Normally 77 is the indicated character.  When used in the
packed symbol mode, it is an escape symbol and will not
be displayed.

Alternate Symbols:
        Alternate 1 ↓
        Alternate 2 →
        Alternate 3 ↯
        Alternate 4 ▽
        Alternate 5 ▢
        Alternate 6 ∧ (up carat)
        Alternate 7 ∨ (down carat)
        Alternate 8 ÷

FIGURE 2

CM10093

CHARACTER VOCABULARY

# TABLE 1

## CM10093/PDP-8 CABLES (5 DEC TYPE W021C)

| Name | PDP-8 Connection Footnote 3 | Source Footnote 1 | Pulse-P Level-L | Logic Level Footnote 2 | Logic |
|---|---|---|---|---|---|
| MB 0 OUT | ME35D | P | L | Z | Memory Buffer Output (LOB |
| 1 | ME35E | P | L | Z | |
| 2 | ME35H | P | L | Z | |
| 3 | ME35M | P | L | Z | |
| 4 | ME35S | P | L | Z | |
| 5 | ME35V | P | L | Z | |
| 6 | MF35E | P | L | Z | |
| 7 | MF35K | P | L | Z | |
| 8 | MF35P | P | L | Z | |
| 9 | MF35S | P | L | Z | |
| 10 | MF35T | P | L | Z | |
| MB11 OUT | MF35V | P | L | Z | Memory Buffer Output (HOB |
| MA 0 IN | PE3D | D | L | Z | Memory Address Input (LOB |
| 1 | PE3E | D | L | Z | |
| 2 | PE3H | D | L | Z | |
| 3 | PE3K | D | L | Z | |
| 4 | PE3M | D | L | Z | |
| 5 | PE3P | D | L | Z | |
| 6 | PE3S | D | L | Z | |
| 7 | PE3T | D | L | Z | |
| 8 | PE3V | D | L | Z | |
| 9 | PF3D | D | L | Z | |
| 10 | PF3E | D | L | Z | |
| MA11 IN | PF3H | D | L | Z | Memory Address Input (HOB |
| Break Request | PF3K | D | L | Z | |
| Data In | PF3M | D | L | N | Data Direction (In= -3, Out=0) |
| B Break | PF3P | P | L | N | Break Cycle |
| Spare | SP1V | --- | --- | --- | --- |
| Address Accepted | PF3S | P | P | N | |
| Increment MB | PF3T | D | L | Z | Inhibit = -3 |
| Increment CA | SP1M (PF4M) | D | L | Z | Inhibit = -3 |
| Cycle Select | SP1K (PF4K) | D | L | --- | Single Cycle = -3 Three Cycle = 0 |
| Display Halt Flag | SP1H | D | L | N | True at Display Halt |

TABLE 1 Continued

| Name | PDP-8 Connection Footnote 3 | Source Footnote 1 | Pulse-P Level-L | Logic Level Footnote 2 | Logic |
|------|------|------|------|------|-------|
| Start Display | SP1D | P | P | N | Effective at Display Halt Only |
| Light Pen Switch | SP1S | D | L | N | Switch on Light Pen |
| Light Pen Flag | SP1P | D | L | N | Set True at Light Pen Match |
| Left/Right Half | SP1T | D | L | N | Which Char. on Light Pen Match |
| Reset Light Pen Flag | SP1E | P | P | N | Device has been serviced |
|  | SP1E | P | P | N | continue |

Note 1.    Signal Origin:

    D - Display
    P - Processor (PDP-8)

Note 2.    Logic Levels:

    Level:  Z  Logical "1"  =   0 Volts
            Z  Logical "∅"  =  -3 Volts
            N  Logical "1"  =  -3 Volts
            N  Logical "∅"  =   0 Volts

    Pulse:  P  Pulse  "1"  =  +2.5 Volts
            N  Pulse  "1"  =  -2.5 Volts

Note 3.    Connector SP1 is special for modified computer.