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A Data Display Subsystem

Abstract: A cathode ray tube device is described in which up to 4000 flicker-free characters are displayed dynamically. The developmental system is designed to permit monitoring the display while data are inserted, deleted or corrected by means of a keyboard. This system uses a novel positioning method which combines electrostatic and magnetic techniques.

Introduction

In certain computer applications the user needs a fast and easy way to monitor operation and modify data or instructions. Numerous devices designed to meet this need have been introduced in the past few years.[1,2,3] However, none of these provide the user with a flexible off-line tool for adding to, inserting, deleting, or correcting data presented by the computer while dynamically displaying the data and the effects of such editing operations. The Data Display Subsystem (DDS) is a developmental cathode ray tube display designed to provide these features, utilizing solid state circuitry.

A system which has some similarity to the DDS is the Electrada Datacom, a buffered display which can display two messages (one incoming, one outgoing) totaling up to 500 characters. Another, the Data Display Incorporated equipment, Model dd51, takes a quite different approach, employing two tubes to gain a 4100-character capability, and is an unbuffered output-only device. Another somewhat different man-machine communication console is the RCA Prototype Analyst Console (PAC),[4] which utilizes a storage tube to avoid regeneration and communicates with the computer via magnetic and paper tapes.

The DDS is capable of displaying on one tube a flicker-free page of 4000 characters. Line drawings can also be displayed with or without alphanumeric data. The data is presented as a dynamic display to permit real-time observation of data changes introduced by the operator with the extensive editing functions incorporated.

The basic elements of the subsystem include a character generator, which provides alphanumeric character display; a graphic generator, which provides line drawing display; a memory, which provides data storage and serves as the regeneration device; a cathode ray tube, the output medium; a control section; and a keyboard. A block diagram is shown in Fig. 1 and a photograph of the laboratory model in Fig. 2. In this paper each of these elements will be described with reference to the laboratory model which was constructed.

Character generation

The beam-pencil technique is used for the generation of characters for display. With this technique, an electron beam under control of the character generator traces out the character to be displayed, in much the same way as one prints with a pencil. The main features are attractive character shape, minimum demands on display tube resolution, and relatively low-speed digital circuitry for the majority of the character generation circuits. These features permit unambiguous display of numerous characters with reasonable electron optics and good reliability, and the over-all system compares favorably with other means of character generation.[5-8]

The essential feature of the character generator is the use of a read-only memory to control the generation of variable-slope voltage ramps in time, which are applied to the deflection plates of the cathode ray tube. These voltage ramps, serving as the horizontal and vertical components, generate each character. For purposes of economy and simplicity of operation, only three different slopes per axis are used: $0°$ and $\pm 45°$. When these three ramps in time are applied in all possible combinations to the

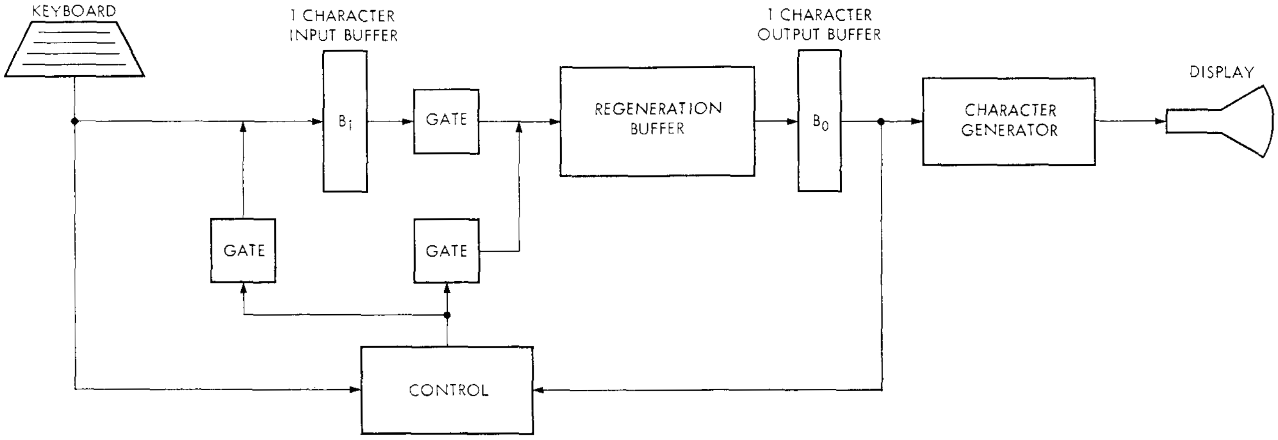


Figure 1 **Basic elements of the Data Display Subsystem.**

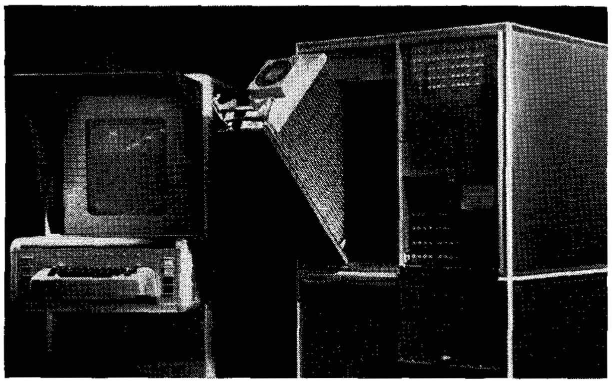
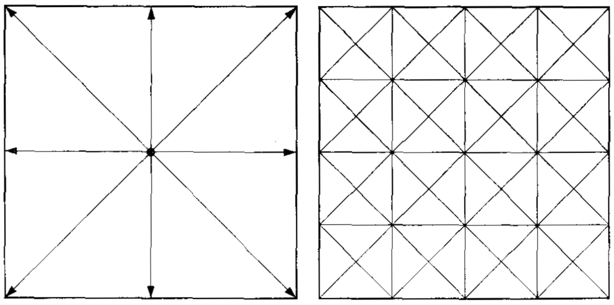


Figure 2 **Laboratory model of the Data Display Subsystem.**

Figure 3 **Vector matrices. (a) Vectors which can be formed with three possible combinations of x and y deflection. (b) Vector matrix for 72 possible characters formed with the vectors of (a), indicating the possible complexity and variety of characters that can be formed.**



x and to the y deflection the eight vectors designated in Fig. 3a can be produced. Characters are formed by sequencing an appropriate number of these vectors such that successive vectors begin where the previous vector ended.

In designing a character set from this inventory of vectors, the question arises as to how many vectors high and wide a character should be. A large fraction of alphanumeric characters have top-to-bottom and/or left-to-right symmetry, hence making it desirable to have an even number of vectors to describe the character height and width. A configuration that has the required symmetry and provides a compromise between complexity and appearance is illustrated by the 72-vector matrix of Fig. 3b. This matrix is used as the basis for the characters in the DDS and gives an indication of the complexity and variety of characters that can be formed but does not restrict character shape. For example, in the model some characters which are of exceptional height use vectors above and below this matrix (e.g., the parenthesis symbol).

Note that this matrix is not traced out in its entirety for each character, blanking at an appropriate time, as has sometimes been done. Rather, the beam moves in a continuous fashion over only those segments used to form the character, blanking where necessary. The maximum number of vectors that are traced for any character in the model is 16, considerably fewer than required to trace out the whole matrix. This is an important factor since we are required to regenerate the display on the face of the screen many times per second to preclude flicker.

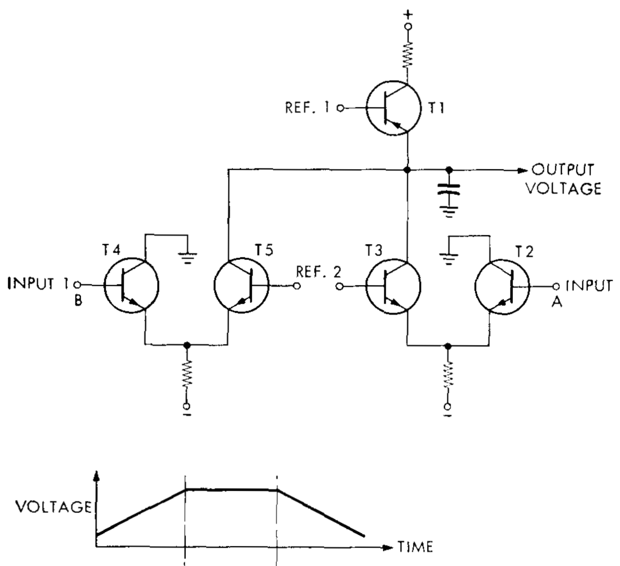
The actual character set for the model, using a maximum of sixteen line segments per character, is shown in Fig. 4. A lower-case character set with a maximum of 16 line segments is also shown in this Figure. The lower-case character set has not been implemented.

• *Slope generator circuit*

As previously mentioned, horizontal and vertical slope generators, which produce voltage ramps with slopes of 0° and ±45° per axis, are used to form the vectors. The horizontal and vertical slope generators are identical. The principle of operation is that of varying the voltage across a capacitor by varying the capacitor current. If a constant current is pumped into a capacitor, the voltage across it will increase linearly (Fig. 5). Similarly, if a constant current is pumped out of a capacitor, the voltage across it will decrease linearly. Finally, with no current in or out of the capacitor, its voltage will remain constant.

Figure 4 **Character set for square matrix with four line segments per side.**

Figure 5 **Slope generator circuit.**



Tx1 No.			
1	X	X	X
2	X		X
3		X	
4	X	X	
5			X

X INDICATES TRANSISTOR IS CONDUCTING

The actual circuit for the complete slope generator (horizontal or vertical) is shown in Fig. 5. Transistor 1 acts as a constant-current source of value *I*. Transistors 2 and 3 form a current-switching circuit with operating current *I*, and Transistors 4 and 5 form a current-switching circuit with operating current 2*I*. Transistors 3 and 5 serve as current sinks which are turned on or off according to the signals applied to the bases of the out-of-phase transistors (2 and 4) of the current-switching blocks. Only one of these sinks is ever on at the same time. When both sinks are off, the constant current from Transistor 1 is "pumped" into the capacitor *C*, and the capacitor voltage increases linearly. When the sink of current *I* is turned on (Transistor 2 off, 3 on), the constant current is diverted to it and the capacitor voltage remains constant. Finally, when the sink of current 2*I* is turned on, the constant current *I* is diverted to it; also, *I* additional units of current are drawn out of *C*, causing the capacitor voltage to decrease linearly. The voltage across the capacitor is, after appropriate amplification, applied to the deflection plates of the cathode ray tube. If both voltages are constant, the beam will remain fixed. As the various combinations are applied to the horizontal and vertical plates, the required line segments are generated on the face of the tube.

In order to generate a character, it is necessary to apply the appropriate horizontal and vertical deflection signals to the plates of the CRT in the proper sequence. A read-only memory determines which slopes are applied to the CRT for each character; the sequence of these slopes is governed by a ring. A block diagram of the character generator appears in Fig. 6. As seen from the diagram, the read-only memory combines information defining the character to be generated with information that defines the specific line segment to be formed and operates on the current sinks accordingly.

The read-only memory can be considered to consist of a matrix of diode AND circuits and five sets of transistor OR circuits. A schematic of the read-only memory is shown in Fig. 7. The matrix consists of a column of AND circuits for each character to be used. Each AND circuit has two legs, one brought up by the selection of the proper character and the other brought up by the proper time interval. The former line comes from the character decoder and the latter from the time-interval select ring.

• *Read-only memory operation*

The decoder defines a character to be generated; one

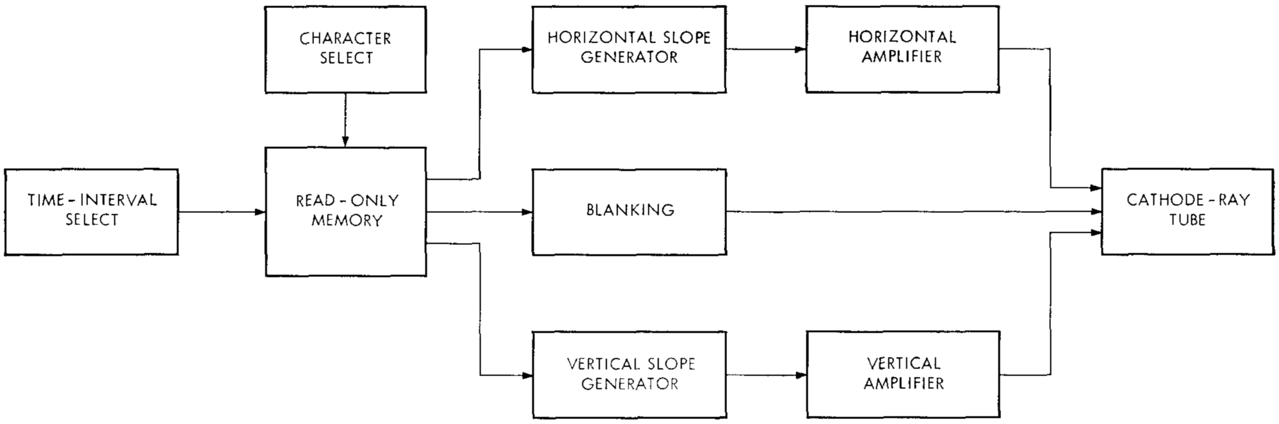


Figure 6 **Block diagram of character generator.**

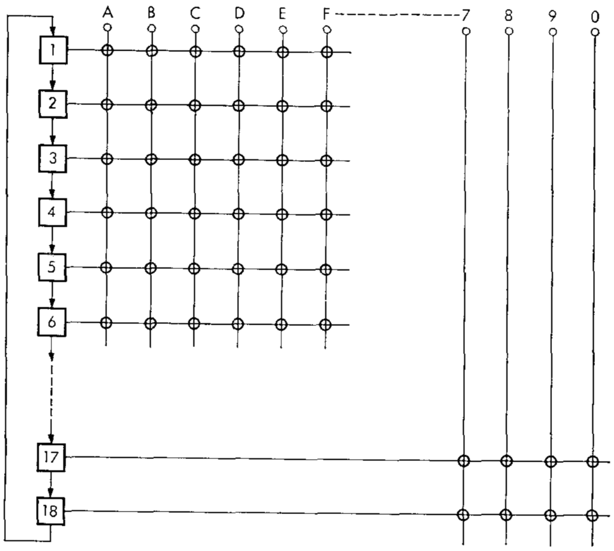


Figure 7 **Read-only memory.**

vertical line of the matrix is brought to a positive voltage while all others are at ground. Then Ring Stage 1 goes positive, causing the first AND gate to produce an output. Each ring stage subsequently emits a pulse, and the selected column of AND circuits emits a similar sequence of pulses. All other columns of AND circuits remain quiescent since one leg of each of them is at ground potential (unselected).

The output from any one AND circuit must perform three functions: define the vertical slope, the horizontal slope, and the on/off condition of the beam. There are two slope generators, each having two inputs. The AND output, therefore, can be connected to any of five circuits but a maximum of three at any one position. The time-interval select ring has 18 stages; the first 16 correspond to the 16 line segments used to generate a character (maximum), and the last two are used to provide time to select the next character to be written and to reposition the electron beam. For those characters which do not require all 16 line segments, the beam is blanked and not further restricted for those segments not required. When this is done, the beam moves upward and to the right across the screen; therefore, when the next character is to be written, the beam must be positioned to the proper place. During Ring Stages 17 and 18, the capacitor is shorted to ground, removing built-up charge and preparing it to be acted upon according to the direction of the read-only memory.

Character positioning

Thus far we have described the technique which is used to generate any single character on the face of the CRT. In order to display a full screen of text, it is necessary to reposition the beam to the proper location after each character is written. This repositioning must account for both horizontal and vertical spacing. The arrangement that we have incorporated allows for 64 character positions per line and 62.5 lines. The beam is originally positioned at a point near the upper left corner of the screen; it is maintained at this point for one character time. Then the beam is moved horizontally a distance equal to the width of a character plus the desired horizontal space. Note that all characters as defined for the system have the same height and width, thus simplifying the positioning problem. This operation is continued until 64 such character positions have been processed. The beam then is returned to the left margin and also deflected vertically down a distance equal to the height of a character plus the desired vertical spacing. After this operation has been completed for the entire screen, the beam is again returned to the upper left corner of the screen, and the operation is repeated. The display must be regenerated on the face of the tube at a rate sufficient to prevent a visible flicker.

This positioning technique defines 4000 specific points that serve as the home position for each character. Superimposed on the motion of the beam are the deflections required to actually generate the characters. The positioning is accomplished during Ring Stages 17 and 18, and the character writing is accomplished during Stages 1 through 16 inclusive. The screen is blanked during the repositioning operation.

It was desired to use solid-state circuitry throughout the model and, except for the obvious exception of the CRT itself, this was accomplished; however, this restriction eliminates the possibility of using electrostatic techniques for the positioning operation. Using a 20-inch tube and a nominal deflection requirement of 100 v/in., a full traversal of the screen would require a voltage differential in the order of 2000 v. Clearly, this is beyond the reasonable application of transistor circuitry; therefore, an electromagnetic-electrostatic positioning technique was devised and used in conjunction with the previously described electrostatic character generation technique.

The essential features of the positioning technique are illustrated in Fig. 8. A sawtooth current is applied to the deflection yoke, causing the beam to sweep the screen horizontally at a constant speed. With the screen unblanked, horizontal lines appear across the face of the tube. At the same time, a smaller, faster, sawtooth deflection of opposite polarity is applied electrostatically. The latter cancels the magnetic deflection during Ring Stages 1 through 16, producing zero deflection of the beam. During Ring Steps 17 and 18, the small electrostatic sawtooth returns to zero, producing a rapid beam deflection to the position defined by the yoke current.

If the screen is blanked during times 17 and 18, the resulting display on the screen is a horizontal line of dots equally spaced across the face of the tube. The points defined by these dots serve as the home position for each character.

This method provides considerable improvement over one which uses only magnetic deflection for positioning and only electrostatic deflection for character writing, because yoke problems must be contended with only once per line, rather than once per character. This allows an inexpensive yoke of modest quality to give excellent results. For example the DDS displays a 4000-character page of text in an 9″ × 11″ format with a flicker rate of 15 cps with normal components. With relatively minor circuit changes, 8000 characters in an 11″ × 14″ format at a regeneration rate of 30 cps could be displayed.

The only special requirement on the CRT is that it contain provision for both electrostatic and electromagnetic deflection. Such tubes are readily available.

Figure 9 is a photograph of a typical display on the face of this tube.

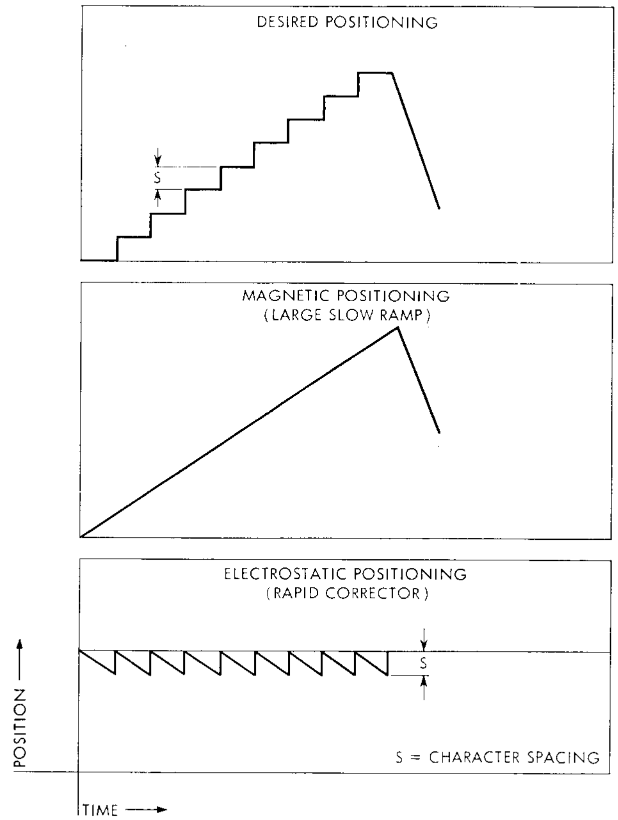


Figure 8 **Positioning technique.**

Regeneration memory

In order to regenerate the display on the face of the tube within the required period of time, a means must be provided to "remember" each character to be displayed and its position on the screen. A maximum of 4000 characters can be displayed on the screen at any one time; this determines the number of words of storage required. A total of 26 letters, 10 numbers, and up to 27 special characters are available for display; this determines the number of bits required per word as 6. Two additional bits are required: one to specify whether or not the character is a capital letter, and the other, a control bit, to be discussed later. The memory must, therefore, provide 4000 characters of storage at 8 bits/word.

With 4000 characters displayed at any one time and a phosphor decay to half brightness in 50 msec, a regeneration rate of at least 15 frames/sec is required. A standard IBM 12 microsec memory was chosen to provide this requirement in the model. This memory is available with 12 planes and 100 × 100 cores per plane. Either of two 4000-character blocks of the available 10,000 are used at one time in the model.

A version of the DDS incorporating magnetostrictive delay lines as the regeneration memory has been designed, providing a considerable reduction in cost and increased regeneration capability.

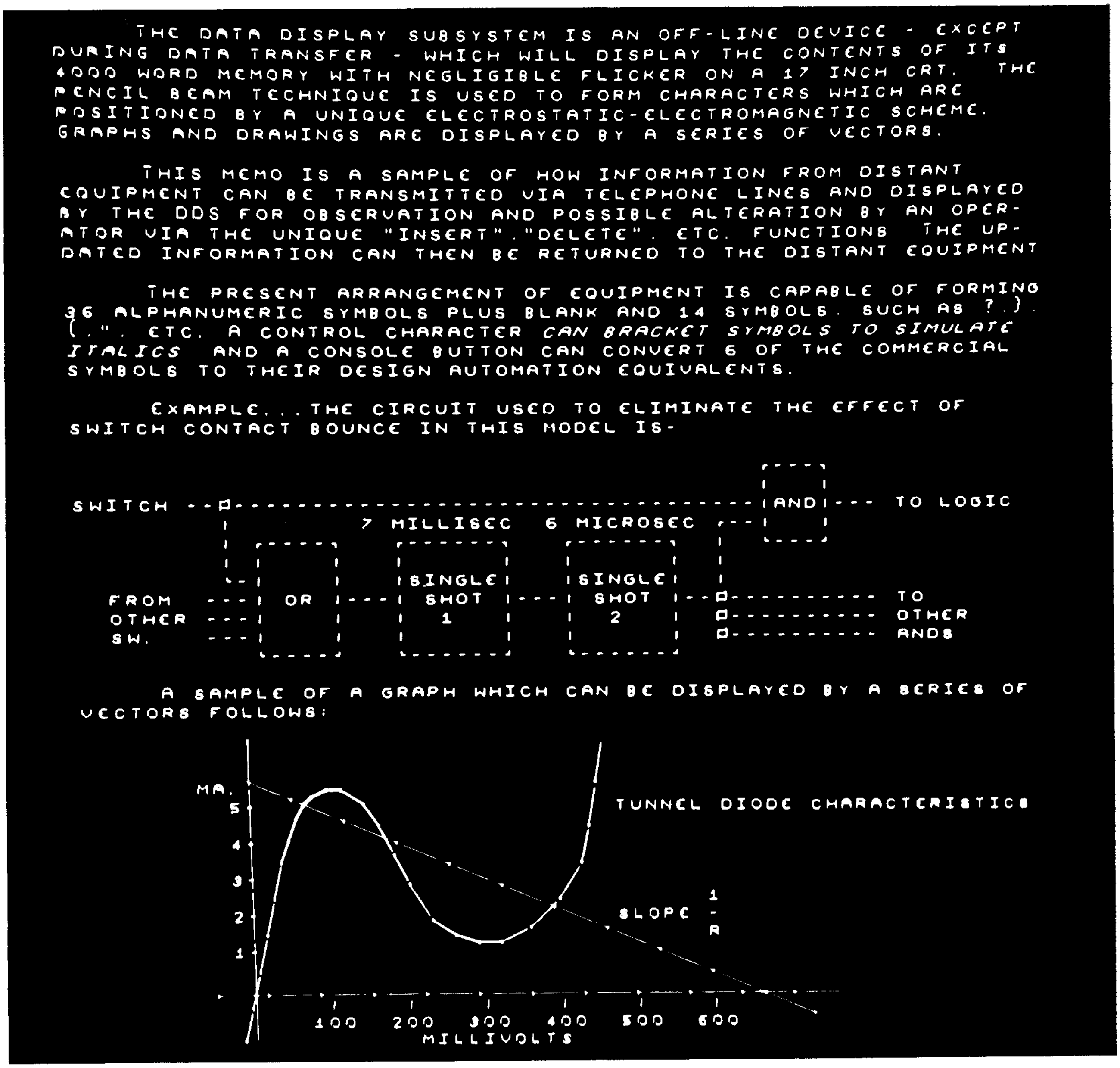
Control section

The operation basic to this subsystem is that of typing data into the memory and displaying this data on a cathode ray tube. In order to provide maximum flexibility it is necessary to allow the operator to specify the positioning of the entered data and also to be able to correct any errors or omissions. This section describes the various features provided and also discusses the logical implementation.

• *X-bit*

The basis of control of the entire subsystem is a single

Figure 9 **Typical display of the Data Display Subsystem.**



bit, hereafter called the X-bit, that is associated with each character of storage. As was stated in the section on the regeneration memory, each character of storage is comprised of 8 bits, one of which is the X-bit. Essentially, the X-bit is used to denote the next character position that will be filled if a character is entered; thus, in most cases, only one character position in the entire memory will have a logical 1 in the X-bit position at any one time. The X-bit is displayed on the CRT by a horizontal line, if that space is empty, or by increased intensity if that space contains a character. In this manner, the operator can always visually check where the next character will be typed.

The initial operation is normally that of generating the X-bit. This is accomplished by depressing the appropriate key on the keyboard which causes the X-bit to be written into the first location. The organization of the memory is such that each character position in memory corresponds to one and only one preset location on the CRT. The first memory position refers to the character position in the upper left corner of the CRT; each of the succeeding memory positions correspond to the next CRT position along the horizontal, with the 65th memory position starting the second horizontal line. The remainder of the screen is allotted in this manner; hence, the X-bit generation operation will place the X-bit in the first character position of memory.

- *Normal typing mode*

When a character is entered by means of the keyboard it is held in the buffer, B_i, until a character with the X-bit is read from the memory into the buffer, B_0. The time the information is held in buffer, B_i, is short compared to human reaction time, since the memory address register (MAR) cycles through all positions of the memory sequentially at a rate sufficiently great that flicker of the CRT image is negligible. When the X-bit appears in B_0, the character held in B_i is written into the regeneration memory in lieu of the contents of B_0. The X-bit is subsequently associated with the next character written into the regeneration memory, having the effect of moving the X-bit to the next character position.

When typing of a character in a nonsequential position is desired, it is necessary to move the X-bit. This is accomplished with keys which allow pseudo-analog positioning. These are: FORWARD SPACE, FORWARD LINE (as line feed on a typewriter), BACK SPACE, BACK LINE, CARRIAGE RETURN, RUNNING FORWARD SPACE (this operation results from a hard depression of the two-level forward space key and has the effect of rapidly striking the forward space key such that the X-bit appears to run from character to character), and RUNNING FORWARD LINE (similar to running forward space but on a line basis). With these keys the operator can rapidly access any character position on the screen.

It is desirable to be able to erase a single character. This operation is performed by positioning the X-bit to the character to be erased and then depressing the blank character key. Operation continues exactly as in the case of normal typing.

- *Insert mode*

Many conditions arise where a user wishes to insert additional information within a body of data where no space exists for the insertion. The DDS provides the ability to insert characters in the proper place without disturbing the rest of the message. This is performed in the following steps. First, the operator moves the X-bit to the position where the first omitted character is to be inserted. Second, the INSERT key is depressed. This key locks. Third, the operator keys in the first omitted character. This character appears where the X-bit was placed, and subsequent characters, including the X-bit, shift right one position. Each subsequent character enters in the same manner with the exception that only one blank will be transferred from the end of one line to the beginning of the next.

Data flow for the insert operation: First, the character from the keyboard is retained in B_i until the X-bit is written into B_0. Then the contents of B_i are written into the regeneration buffer instead of the contents of B_0, just as during the normal typing mode. However instead of the contents of B_0 being discarded they are written into B_i, where they are retained while the subsequent character is being read from the regeneration memory. The contents of B_i are again written into the regeneration memory in lieu of the contents of B_0, whose contents are again written into B_i prior to the next reading of the regeneration buffer, etc., until the last character of the page that is discarded and the READ rewrite cycle returns to normal. This manipulation has the effect of shifting all characters right and down the page to make room for the inserted character.

- *Delete mode*

Another editing condition which may arise is that the user needs to delete information from a body of data without leaving a blank area in the data. For this operation the DDS provides the delete and close feature. The X-bit is positioned one location to the right of the last character position to be deleted. Then an additional X-bit is entered and positioned to the character position immediately to the left of the position to be deleted. Finally, the DELETE key is pressed. This causes all the characters between the X-bits to be deleted, and all those characters to the right (down to a special character inserted by the operator) are shifted left to close the gap. The actual data flow is as follows. Depression of the DELETE key causes the MAR to count backwards. Each character, starting from the bottom character, is shifted one position exactly as in the insert operation. The only difference is that now the characters are being shifted left rather than right, since the MAR is counting backwards. This operation continues until the X-bit closest to the bottom of the page is reached. At this point, the operation is stopped and the result is that all the preceding characters have shifted left one position. The operation starts again when the MAR reaches the last memory position. This sequence continues until the two X-bits coincide. At this time, all the undesired characters have been deleted, and the gap has been completely closed. This condition resets the MAR to count forward again.

• *Recompose*

If words have been split at the ends of lines, as a result of the insert and delete operations, the operator can use the RECOMPOSE function to rectify the situation. This causes any word which is split to shift to the beginning of the next line; all subsequent characters will also shift. This operation starts at the top of the page and continues line by line until all lines have been corrected. It is accomplished by adding a blank under INSERT mode following the first blank character from the right of the page when a non-blank character has been detected in the last column of the page.

Line drawing mode

The versatility of the system can be greatly expanded if it is possible to display drawings, graphs, etc., by means of vectors whose length, position and direction are chosen by the data source (see bottom of Fig. 9). Drawing resolution is then limited by beam diameter and minimum vector length, and complexity is limited by a vector count equal to usable display storage.

The DDS includes provisions to trace drawings by a sequence of vectors. Each vector stems from the center of a matrix and extends to an intersection point of the matrix described by its corresponding computer word (Fig. 10a). The matrix for the succeeding word has its center located at the end point of the preceding vector (Fig. 10b).

The vectors can take two forms: *blanked*, to provide positioning, or *unblanked*, to display a line. Characters following vectors appear at the end of the preceding vector, and each succeeding character appears adjacent to the previous one as in the normal writing mode; hence, lines, labels of graphs, and comments on drawings can be placed at any location on a frame by preceding them with a sequence of blanked vectors for positioning.

The resolution obtainable by this system is limited by the size of the matrix subdivisions, while the size of the computer word and deflection amplifier power determines matrix size. The model uses a matrix of 14 × 14 subdivisions, each 1/70 of the total frame width. This matrix and subdivision size allows description of vectors with 8 bits, provides a reasonable resolution (about seven beam widths per minimum vector length), and limits the maximum vector length to a size suitable for a reasonable power deflection amplifier while requiring only 10 vectors to cross a frame.

The computer word is defined as illustrated in Fig. 11. Bits 1 to 4 indicate the length of the vector in the $\pm x$-direction and Bits 5 to 8, the vector length in the $\pm y$-

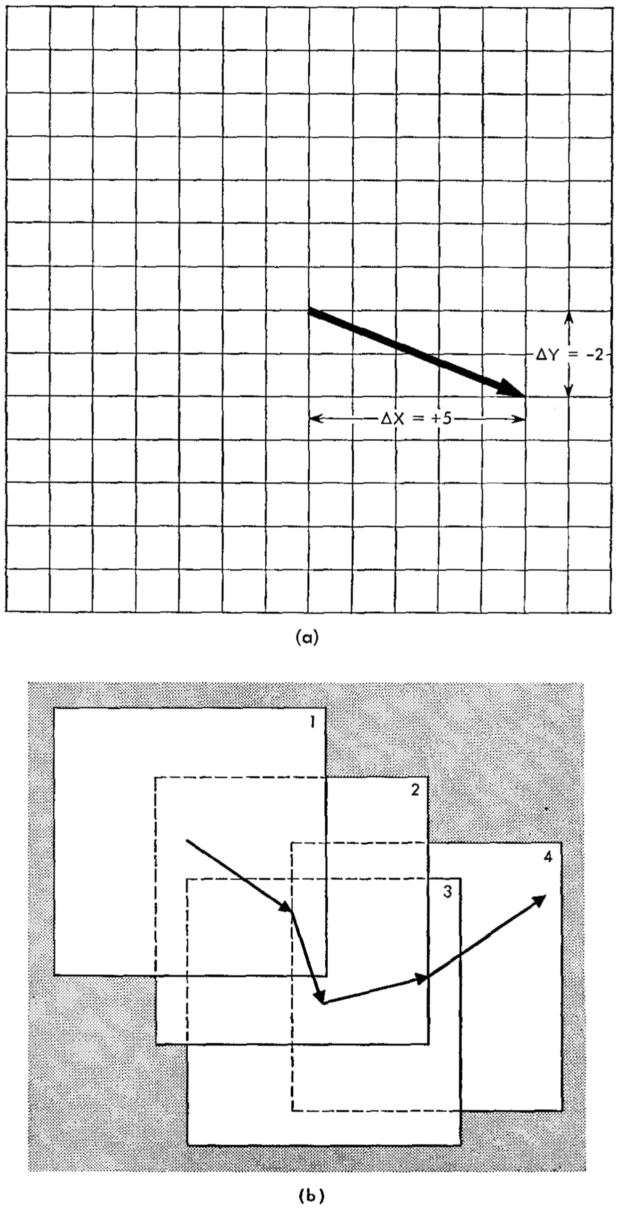


Figure 10 **(a) Vector matrix. (b) Sequence of vector matrices.**

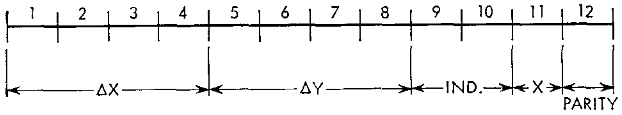


Figure 11 **Computer word.**

direction. Bits 9 and 10 are "indicator bits" which indicate a vector blanked for positioning and a vector unblanked for a line or a character. Bit 11 is the X-bit for designating the location of the next operation, as is done in the character mode.

This particular code is not necessarily the best, as it requires that indicator bits be carried along with each word when, in fact, many words frequently have an identical indicator and could be designated by fewer bits if the string of characters is preceded by a special control character to cause a shift operation. The X-bit is of use only for alphanumeric operation and thus could be considered part of the alphanumeric code.

The indicator bits are included in this experimental model because it was felt that programming and equipment debugging would be simpler if each word was tagged as to its function. The X-bit is kept separate from the alphanumeric code to eliminate the logic necessary to separate the alphanumeric with an X-bit from a vector, and because it allows the use of the normal functions TYPE, BACKSPACE, etc., with vectors so that line drawings can be hand encoded.

A starting point is provided by positioning the CRT beam to the upper-left-hand corner of each frame just prior to the start of each memory cycle.

• *Data transmission*

All operations thus far described are performed by the DDS as a free-standing unit. For information retrieval and computer monitoring applications, provisions have been built into the model to couple to any IBM equipment that utilizes the Synchronous Transmitter Receiver concept for transmission via phone lines (i.e., IBM 1009, IBM 1013, etc.). Two-way communication with an IBM 7080 computer located several miles away has been established and tested via this method. Standard telephone lines limited transmission to about 300 characters/sec. However transfer rates up to the memory limitation of 120,000 char/sec could be implemented with a different communications link or direct connection.

Acknowledgments

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