# Communications Research Centre

## COMPUTER GRAPHIC TERMINAL USING A STORAGE CRT

by

W.W. Nelson



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**COMMUNICATIONS RESEARCH CENTRE**

DEPARTMENT OF COMMUNICATIONS
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ABSTRACT

This technical note describes a computer graphics terminal developed at the Communications Research Centre (CRC). The terminal uses a Tektronix 611 Bistable storage oscilloscope and is used with a Honeywell DDP-516 computer. The character generator uses hardware character generation to form characters made of 5 x 7 dot matrices. A two-speed clock is used, where the clock normally runs fast but is slowed down when dots are written, which greatly increases the writing rate. This feature gives the terminal an average writing rate of 620 μsec per character. The terminal is capable of displaying in three modes: non-store, store, and write-through. The write-through-mode has the capability of writing over previously stored information without affecting the stored information. Eight programmable character sizes are available with the smallest character able to store 72 characters x 72 lines or 5184 characters. The design and development of the character generator, control circuit and computer interface is discussed in detail and the operating information is covered briefly.

## 1. INTRODUCTION

A graphic terminal using a Cathode Ray Tube (CRT) capable of displaying alpha-numeric and graphical information can be a very useful addition to a computer installation. There are two basic approaches to the design of low-cost CRT computer displays; one utilizes the conventional CRT without built-in memory and the other uses a storage CRT.

With the conventional CRT the picture must be refreshed at least 30 times a second to appear flicker-free. This method requires some external memory in the form of ferrite cores or a magnetic disc to store the data to be displayed and a high-speed controller and CRT driver capable of reading the stored data and refreshing the display. The extra circuits required make this method more expensive than the method using a storage CRT. However, it does have the advantage that the display appears very bright, and can be updated rapidly.

With the storage CRT, the displayed information need only be written once, eliminating the requirement for a separate refresh memory. In addition, the writing rate can be greatly reduced compared with the conventional CRT, thus simplifying the control and drive circuitry. An improvement over the normal storage CRT is the Bistable Storage CRT on which information can be written in a non-store mode without destroying any previously stored information. Bistable storage CRTs are now available with high resolution, capable of displaying 4000 characters of a quality and information density comparable to that found on an 8½" x 11" typewritten page. Although the storage CRT does not flicker, it does not have as good a contrast or brightness as a normal refresh CRT. Another disadvantage is: storage CRTs do not have selective erase so that the entire screen must be rewritten if it is desired to alter any part of it. This disadvantage can be partially overcome using the Bistable Storage CRT and a technique of partial refresh through computer programming. Here each line is written initially in the write-through mode and is only stored after verification by the operator.

This TN describes a computer display developed at CRC to be used with a DDP-516 Honeywell computer and uses a 16 cm x 21 cm Tektronix 611 Bistable Storage CRT. The TN will cover the design and development of the character generator, control and computer interface. The character generator uses hardware generated characters and uses two clock speeds when writing the characters; a fast speed when scanning the character matrix, and a slow speed when a dot has to be written. This greatly increases the overall writing rate.

## 2. DESIGN

The design consists essentially of two parts, the initial design formulating ideas and methods, and the development showing the actual methods and circuits used, in block diagram form.

### 2.1 INITIAL DESIGN

Any piece of equipment developed which is to be interfaced with a computer has to communicate with the computer through Input/Output buses and control lines.

The first consideration is how the computer word is to be organized.

#### 2.1.1 Computer Word Development

The Honeywell DDP-516 computer has a 16-bit word length so that information presented to the CRT display terminal should also have 16 bits or some multiple of it. For the character generator it was decided to use two 16-bit computer words for every character to be written. These two words will select the character and specify the X and Y positions on the CRT, the size, and the writing mode.

It was decided to specify the X and Y positions using two 10-bit words, which gives 1024 increments on each axis. This leaves 12 remaining bits. Since standard ASCII code has 64 characters it was convenient to use 6 bits for character selection. Of the remaining 6 bits, 3 bits were used for size, giving 8 possible sizes, and 3 bits were used for mode selection. Three bits for mode selection are more than are needed since the only modes of operation are non-store, store and write-through, but they leave room for later additions. The words were divided up as shown in Table 1 below.

TABLE 1

Word Format

| | Bits | Fields |
|---|---|---|
| Word 1 | 1 … 6,7 … 15 | Character (1–6) \| X Position (7–15) |
| Word 2 | 1 … 3,4 … 6 | Size (1–3) \| Mode (4–6) \| Y Position |

The first word contains the character and the X-axis position and the second word contains the size, mode and the Y-axis position.

2.1.2 Character Font and Repertoire

The next major design decision was to choose the makeup of the letters. When using a storage CRT, it is easiest to use letters made up of dots since this type of CRT stores information only after it has been present for a specific time. A character matrix of 5 x 7 dots was chosen since it is fairly standard and produces quite legible characters.

The standard ASCII code of 64 characters was chosen with the exception of some characters which were changed to make provision for drawing graph axes and to provide cursors for using a joystick.

2.1.3 Character Generator Timing

Another important phase of the design is the character generator timing which sets maximum writing speeds, etc. The timing must be designed around the limitations of the CRT used. First thoughts indicate that the maximum writing rate is specified by the slew rate of the CRT. This would include the time it would take for a dot to travel diagonally across the CRT plus the dot settling time. For the Tektronix 611 with a slew rate of 3.5 μsec/cm and a diagonal of 27 cm this would be 94.5 μsec plus a dot settling time of 5 μsec or a total time of approximately 100 μsec. This gives a dot writing rate of 10 kHz, so if a 5 x 7 matrix was to be written it would take 3.5 msec per character. The time would become lengthy for writing a full screen of characters.

If it is assumed that the slew time is only of concern in the initial positioning of a character and not in writing the character (due to the short distances involved) a much faster clock may be used. To allow for the initial slew time, the start of each letter is delayed 100 μsec for positioning.

In addition to this positioning time, the specification for the CRT requires a 20 μsec writing time for each dot. To speed up the writing it was decided to stop for 20 μsec at a dot only when there is a dot to be written. This is accomplished with the use of a two-speed clock that operates normally at a fast rate, and at a slow rate only when dots are to be written. The maximum time to write a dot, including settling time, is 20 + 5 + 3.5 μsec = 28.5μsec.

Two μsec were allowed to scan unwritten dots and 16 times as many, or 32 μsec, to write a dot, which is within the limits of the CRT used.

If it is now assumed that each character is made up of an average of 15 dots, with a fast clock rate of 500 kHz and a slow clock rate of 31.3 kHz, we can calculate the time taken to fill the screen with characters. The total time to write a character after it is positioned will be (32 μsec x 15 dots) + (2 μsec x 20 dots) = 520 μsec/char.

Allowing a fixed 100 μsec to position a character, this makes 620 μsec/character.

For a probable maximum of 2500 characters it would take 1.55 seconds to completely fill the screen, which is hardly noticeable.

### 2.1.4 Computer Interface

Three different types of interface were available to the computer. The Direct Multiplex Control Method, which was chosen, permits high-speed Input/Output data transfers to be performed between the computer memory and Input/Output devices with a minimum of program control. When a device using DMC is ready for a data transfer, it requests service by the DMC on a priority basis. Upon receipt of a request, the DMC breaks into the computer program sequence at the end of the current instruction and performs the data transfer between the memory and the device.

This lends itself very well to a character generator where individual characters are written at different speeds. It allows the character generator to set up the data transfer rate.

## 2.2 CHARACTER GENERATOR DESIGN

This section contains detailed character blocks of the character generator design. Figure 1 shows a block diagram of the complete display terminal.

### 2.2.1 Diode Matrices

In a hardware character generator the nucleus of the system is the circuitry for producing characters. Commercially available 6 x 8 diode matrices which are packaged in 14-lead flat-pack integrated circuits were chosen to generate characters. In these matrices, diodes can be selectively burned out forming essentially a read-only memory with one letter in each matrix.

Figure 2 shows a 6 x 8 diode matrix set up with the letter B in it. The letter itself is contained in Row 1-7 and Columns 1-5. By scanning the columns 1-5 with a logical 1 and the rows 1-7 with a logical 0 each diode can be

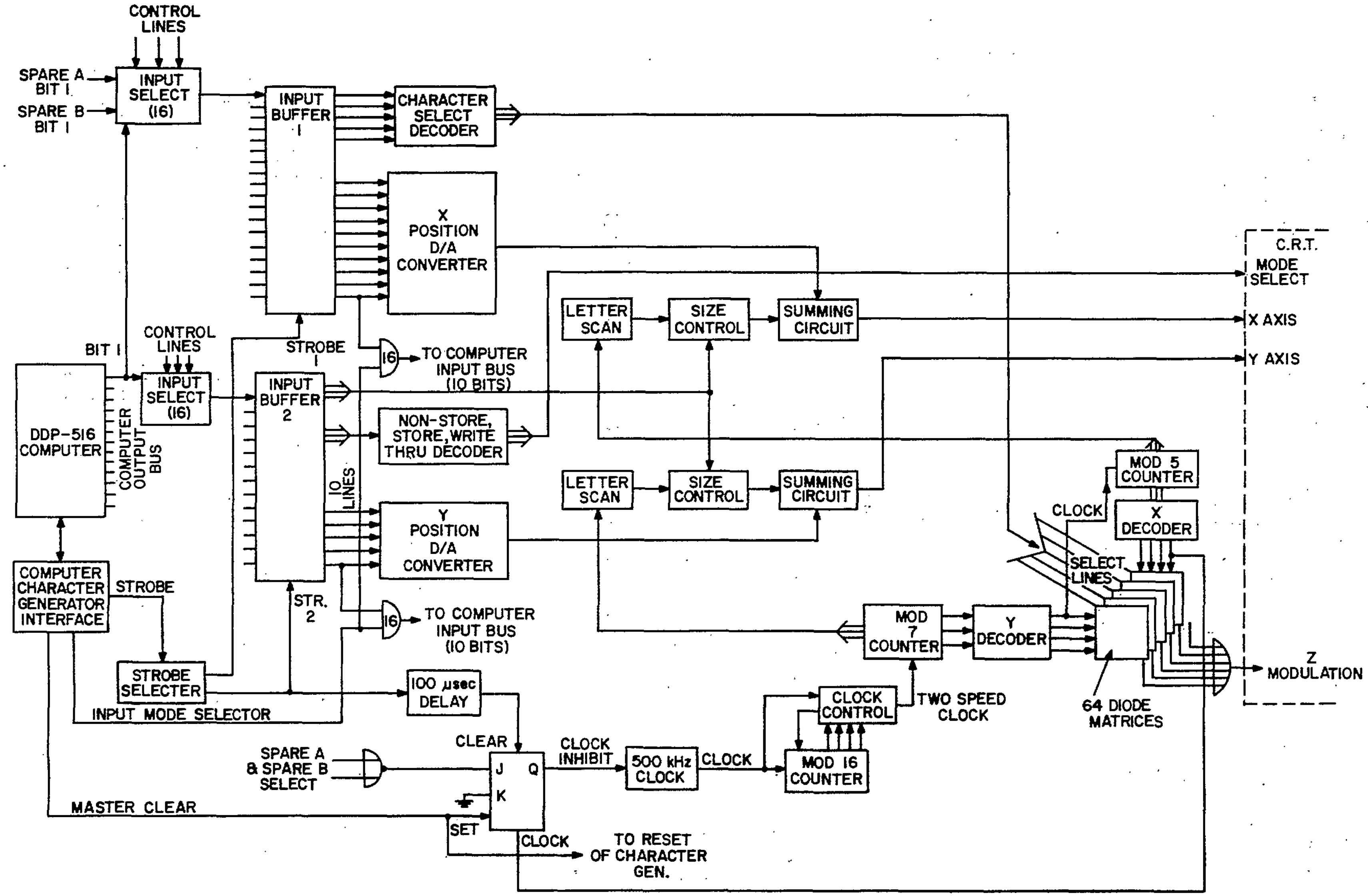


*Fig. 1. Computer graphic terminal.*

selected individually. If a diode is present when its position is selected, the output on Row 8 will go to a logical 0; if no diode is present the output will stay at a logical 1. Column 6 is used as a selection line; if Column 6 has a logical 0 on it, the diode of Column 6 and Row 8 will be back-biased allowing Row 8 to operate as an "OR" gate. If Column 6 has a logical 1 in it, the output of Row 8 will always be high and will not allow any output modulation. The output of the selected matrix is fed to a transistor "OR" gate which supplies Z modulation to the oscilloscope.

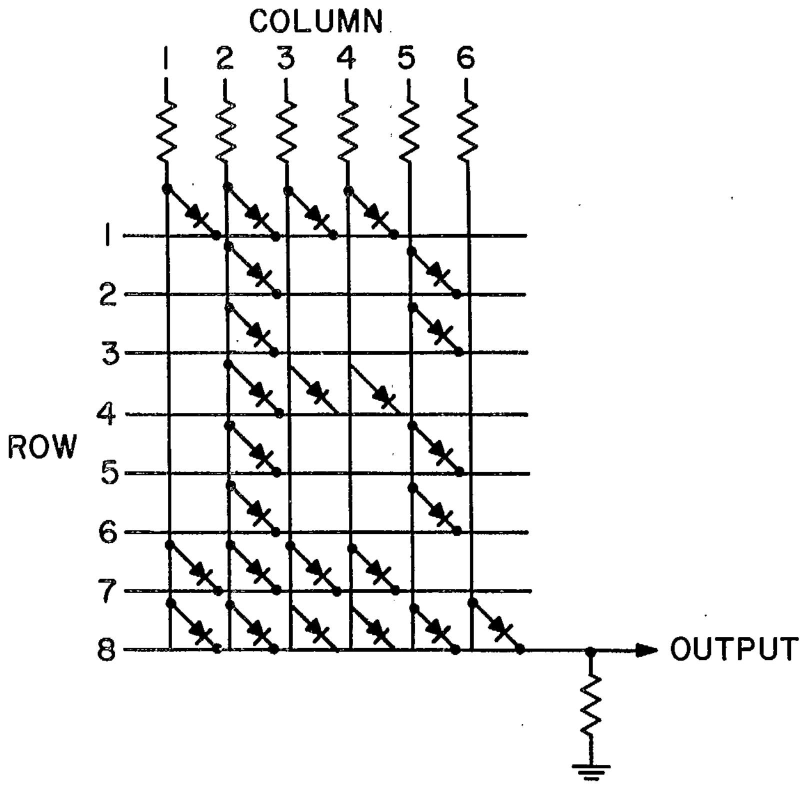


*Fig. 2. Diode matrices containing Letter B.*

### 2.2.2 Matrix Scan and CRT Character Sweep

The simplest way to form a matrix scan and to provide CRT character sweep is to use counters. To scan the matrix, a modulo 7 counter and a modulo 5 counter are used. The modulo 7 counter is decoded to act as a ring counter which propagates a 0, and the modulo 5 counter is decoded to act as a ring counter which propagates a 1. The decoded modulo 7 counter scans the rows and the decoded modulo 5 counter scans the columns as shown in Figure 3. The counters scan all 64 matrices in parallel.

As shown in Figure 3, the 7th output of the decoded row counter-clocks the column counters, with both counters being trailing-edge-clocked counters. The effect is a sawtooth scan starting at Column 1, Row 1. After Row 7 is complete, the column scan goes to Column 2 and the row scan goes back to Row 1 and scans the next column row by row.

The binary-coded outputs of the row and column counters are summed in two operational amplifiers making D/A converters which provide the analogue sweep for the CRT.

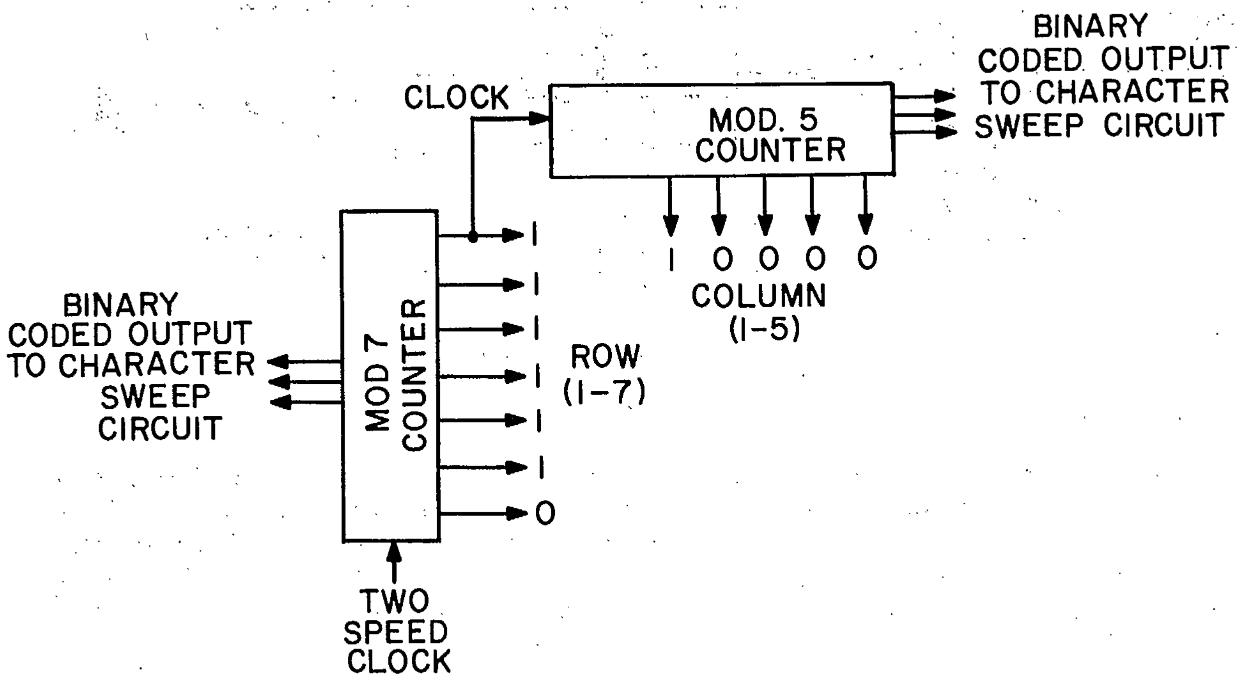


*Fig. 3. Matrix scan circuit.*

### 2.2.3 Character Position and Size Control

After devising a method for forming the characters, a method had to be developed for specifying their positions on the CRT and for varying the character sizes.

Due to the stability of position required, it was decided to use commercially available 10-bit D/A converters for character positioning.

The size of the characters has to be controlled digitally and the character position and the character sweep have to be summed together for each axis. To vary the character sizes, the amplitude of the character sweep signal has to be varied before it gets to this summing operational amplifier. The method used is shown in Figure 4. Operational amplifier 1 is the character scan D/A converter and operational amplifier 2 is used to sum the output of the position D/A converter with the output of the character D/A converters. The circuits for both axes are the same.

The three size bits from the computer word are fed through buffers directly to the field-effect transistor switches. The switches are used to alter the values of the input resistors which specify the gain of the output summing amplifier, and thus alter the size of the characters.

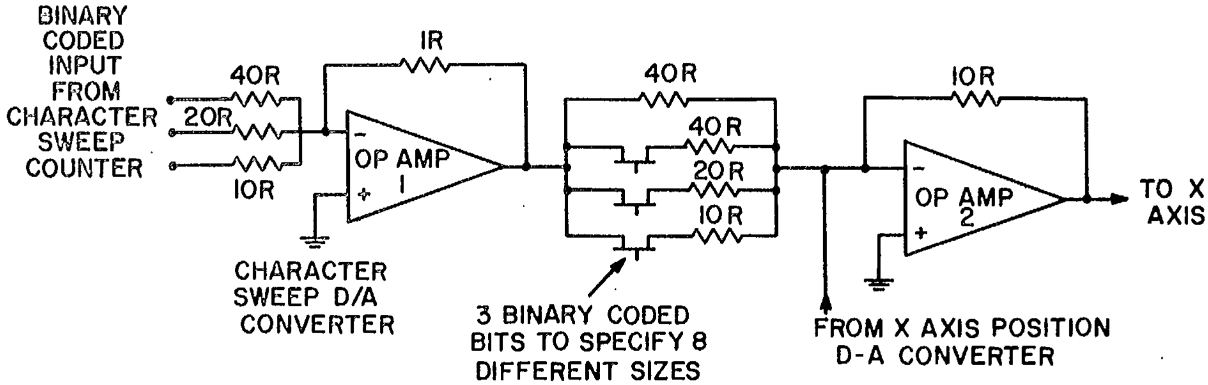


*Fig. 4. X-axis character size control.*

### 2.2.4 Input Buffers and Buffer Strobe

Since two computer words are needed for each character, two 16-bit buffers are needed to store these two words. It was decided that facilities should also be provided so that the character display unit could be controlled from external sources such as a joystick and a keyboard. A joystick provides the facility for interaction with the display. A cursor is displayed on the CRT and its X and Y positions are controlled by the movements of a joystick.

Figure 5 shows the first bit of input buffering. The input buffers are essentially 'D' type flip-flops with three selection gates combined in an "OR" gate at the input. At the input another selection gate is used at each buffer for entering data into the computer from the character generator. This is necessary for operation using a keyboard or a joystick.

The buffer strobe consists of two pulses from the computer DMC channel which are routed so that the first pulse strobes in the first sixteen bits and the second pulse strobes in the second sixteen bits.

### 2.2.5 Two-Speed Character Clock

The character clock consists of a pulse generator that must be able to be started and stopped, and a counter to divide the clock pulse down if a dot is to be intensified on the CRT.

The character clock is started by a pulse delayed by 100 μsec from the strobe pulse that strobes data into the second input buffer. The clock is stopped after the last diode is scanned in the character matrix.

The divide-down circuit has a sensing circuit which stops the main clock from getting through for 16 counts if a dot is to be intensified on the CRT.

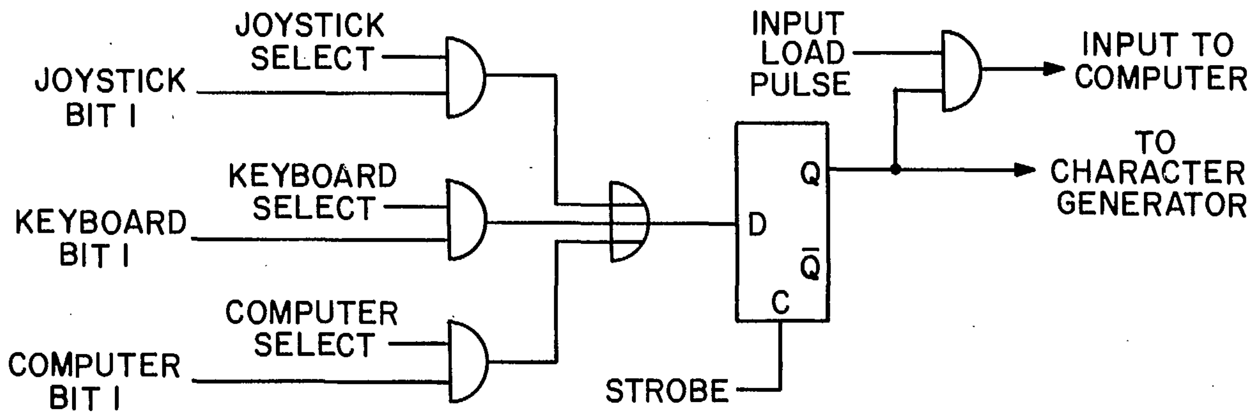


*Fig. 5. Input buffering (Bit 1).*

## 3. CIRCUIT DEVELOPMENT

It was decided to build the character generator and its associated circuitry in the computer cabinet making use of spare space available. Along with this decision was the decision to use Honeywell Series 335 Micro-Pack Integrated Circuit Modules wherever possible. These are the modules that were used in the construction of the computer and that made the circuits easier to implement. The Series 335 modules are made of DTL integrated circuits which work to at least 5 MHz and are constructed on 34 contact 2.9" x 2.7" double-sided printed circuit boards. All intermodule wiring was done using "Wire Wrap" wiring which is easy to implement and easy to correct. The complete character generator and associated circuitry was installed in the computer in an area of about 19" x 6". Figure 6 shows the computer drawer in which the character generator was mounted. It is made up of five 24-card blocks which are outlined with a dotted line.

Circuit modules which could not be purchased were constructed at CRC using the same type of printed circuit boards as are used by Honeywell. Figure 7 shows a typical module constructed at CRC which contains 8 diode matrices and their associated load resistors. Figure 8 shows one of the most dense boards used in the character generator; it contains 21 transistors, 10 dual diodes, and 43 resistors.

### 3.1 CIRCUIT CONSTRUCTION

Since much of the circuitry in the character generator is duplicated, such as the diode matrices and the input buffers, it is not necessary to show complete circuit diagrams. Instead, Figures 9 to 12 will show only one level of the circuitry used. Figure 9 shows the input buffers, the input selection circuit and the strobe circuitry. $\overline{\text{ENABLE}}$ and $\overline{\text{RRLIN}}$ are two signals from the computer DMC, which, when 'ANDed' together form the strobe. Since 'D' type flip-flops were not available on Honeywell modules, J-K flip-flops were used and were made into 'D' type flip-flops with the addition of a gate.

Figure 10 shows the method used for character selection decoding using radiation incorporated RM-31 diode matrices. This was much simpler than decoding

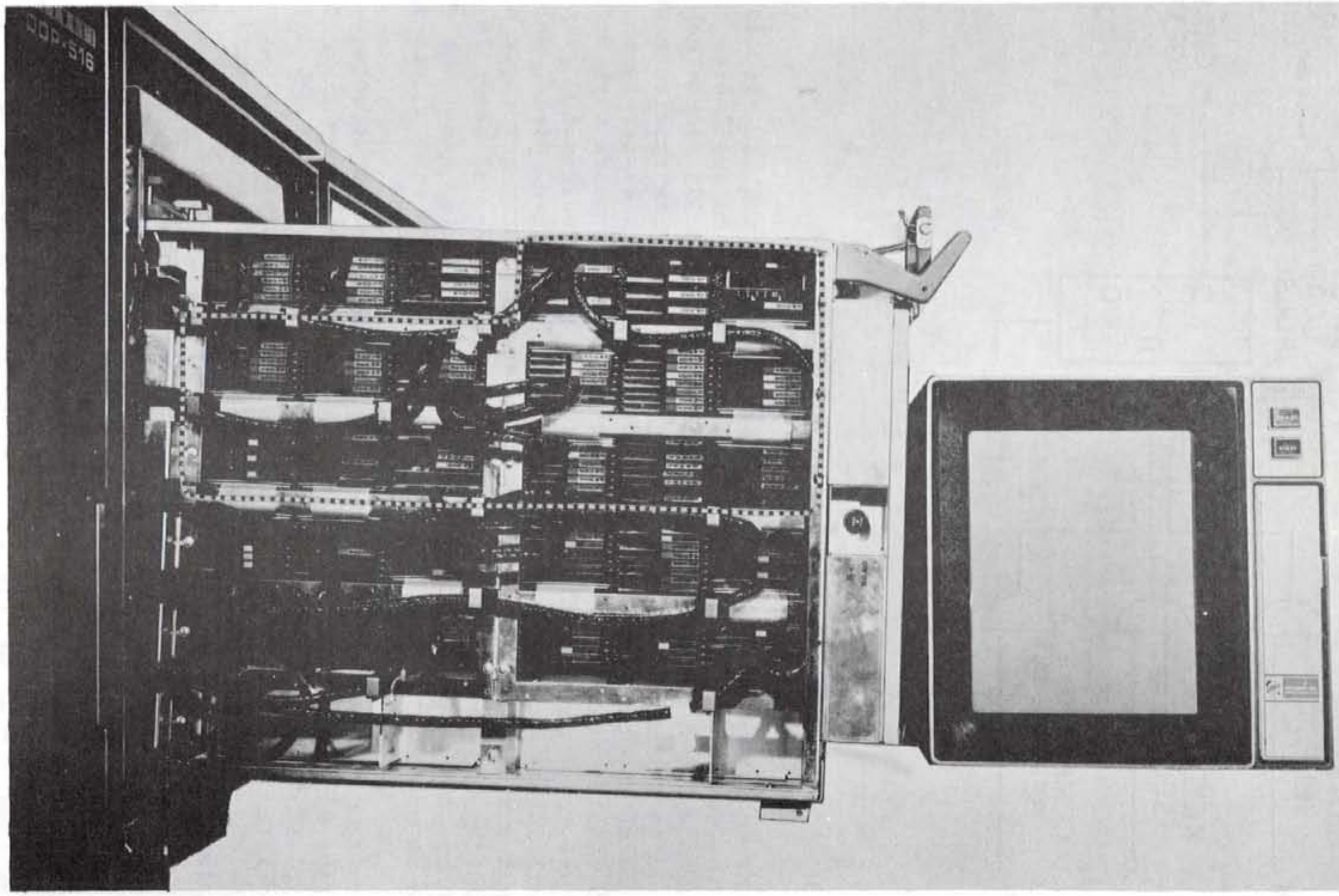


*Fig. 6. Display and drawer containing character generator.*

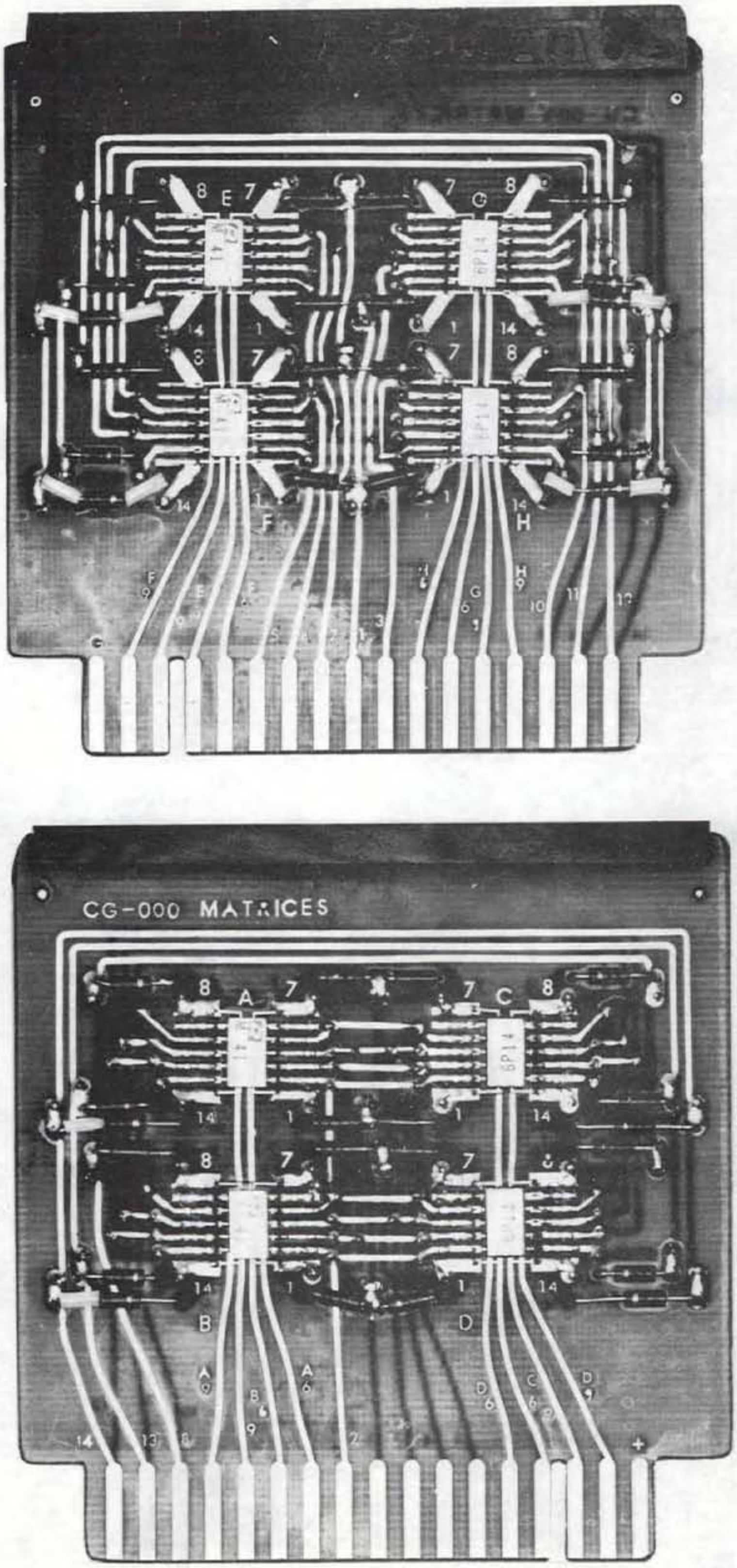


*Fig. 7. Circuit module containing 8 diode matrices and resistors.*

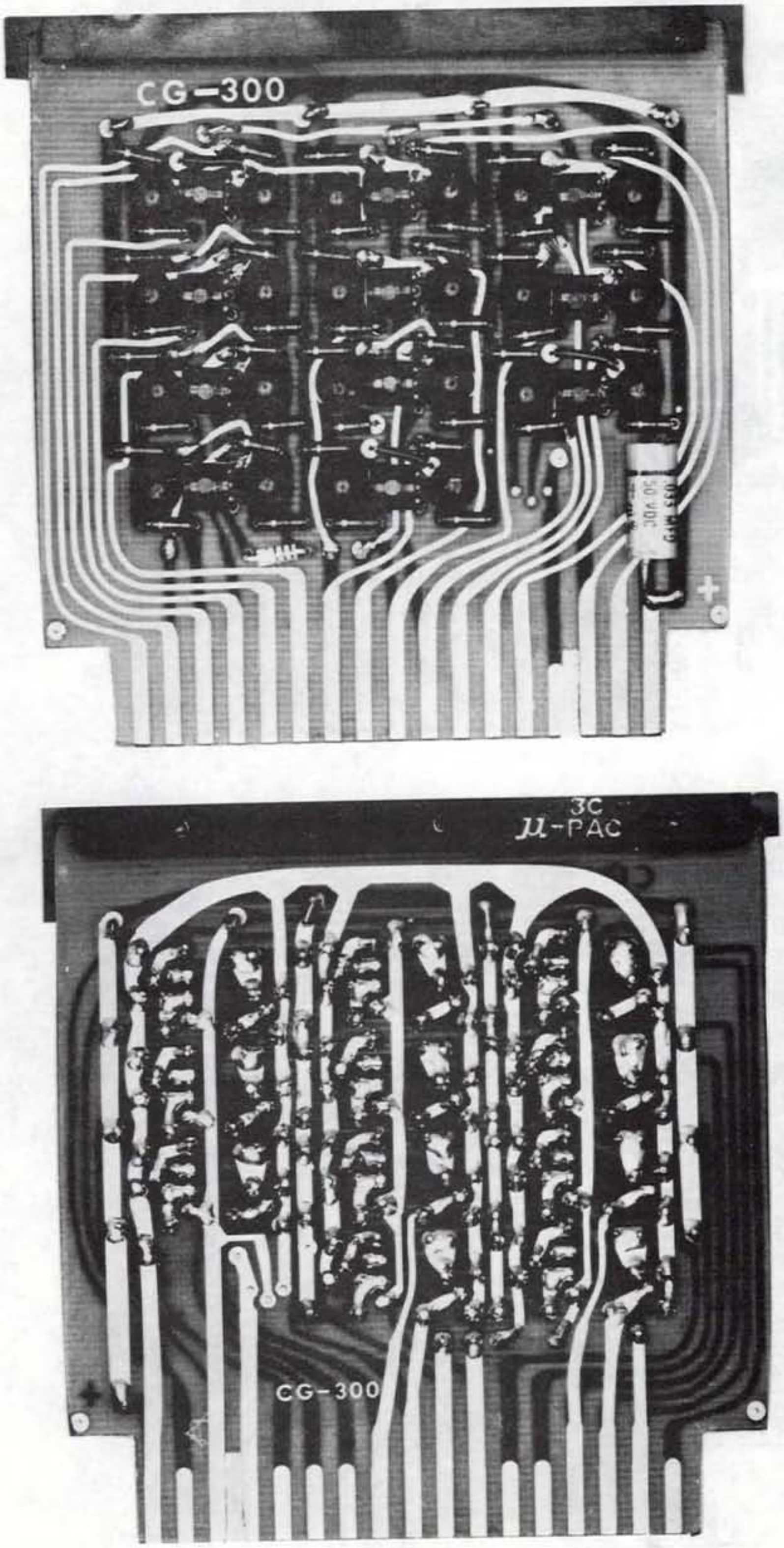


*Fig. 8. Matrices 'OR' circuit module.*

using DTL gates, and lends itself well to ASCII which is coded in octal and is the standard code used in computers.

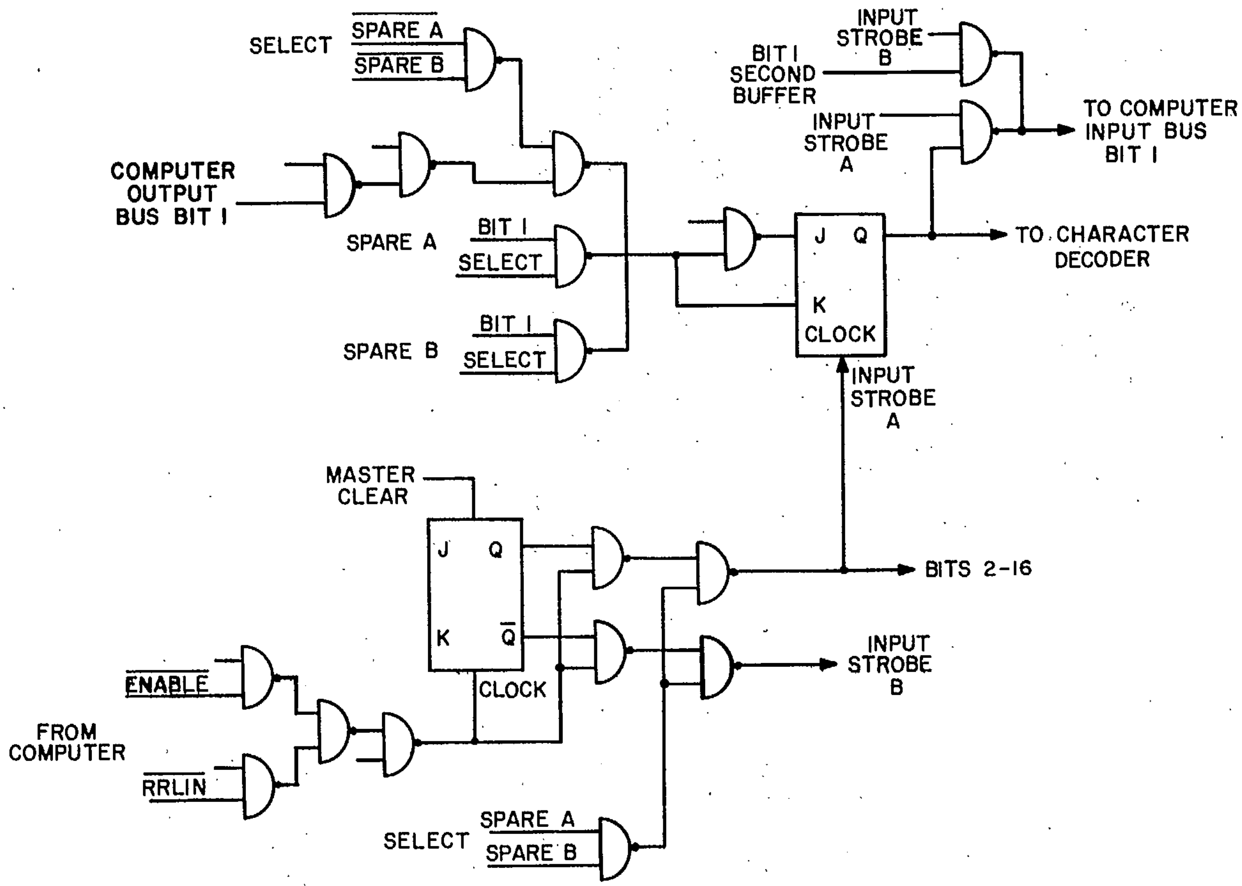


*Fig. 9. Character generator input buffers Bit 1, and strobe selector.*

Figure 11 shows the character D/A converter, position D/A converter and the size control circuit. Honeywell D/A converters and references were used because of their accuracy (+0.025 per cent full scale) and their good stability.

In size control, the field-effect transistors act as series switches which change the input impedance on one input of the position summing junction of an RCA-3010 operational amplifier. The resistors specify the sizes and can be changed easily for any size range desired. The feedback resistor of the operational amplifier is adjusted for about 10 times the voltage required at the CRT input, and the waveform is divided down at the CRT to reduce the noise pick-up. This is necessary since the amplitude of the staircase sweep for the letters on the CRT is as low as 20 mV.

Figure 12 shows the two-speed clock circuit. The clock is started by the second input buffer strobe after a delay ofμ100 μsec. If there is intensity modulation on a dot, the divide down counter is cleared, thus stopping the clock to the Y sweep circuit. After the counter has counted up to 15, one Y sweep is allowed through; if there is no intensity modulation another pulse gets through and this continues until intensity modulation occurs again. The main

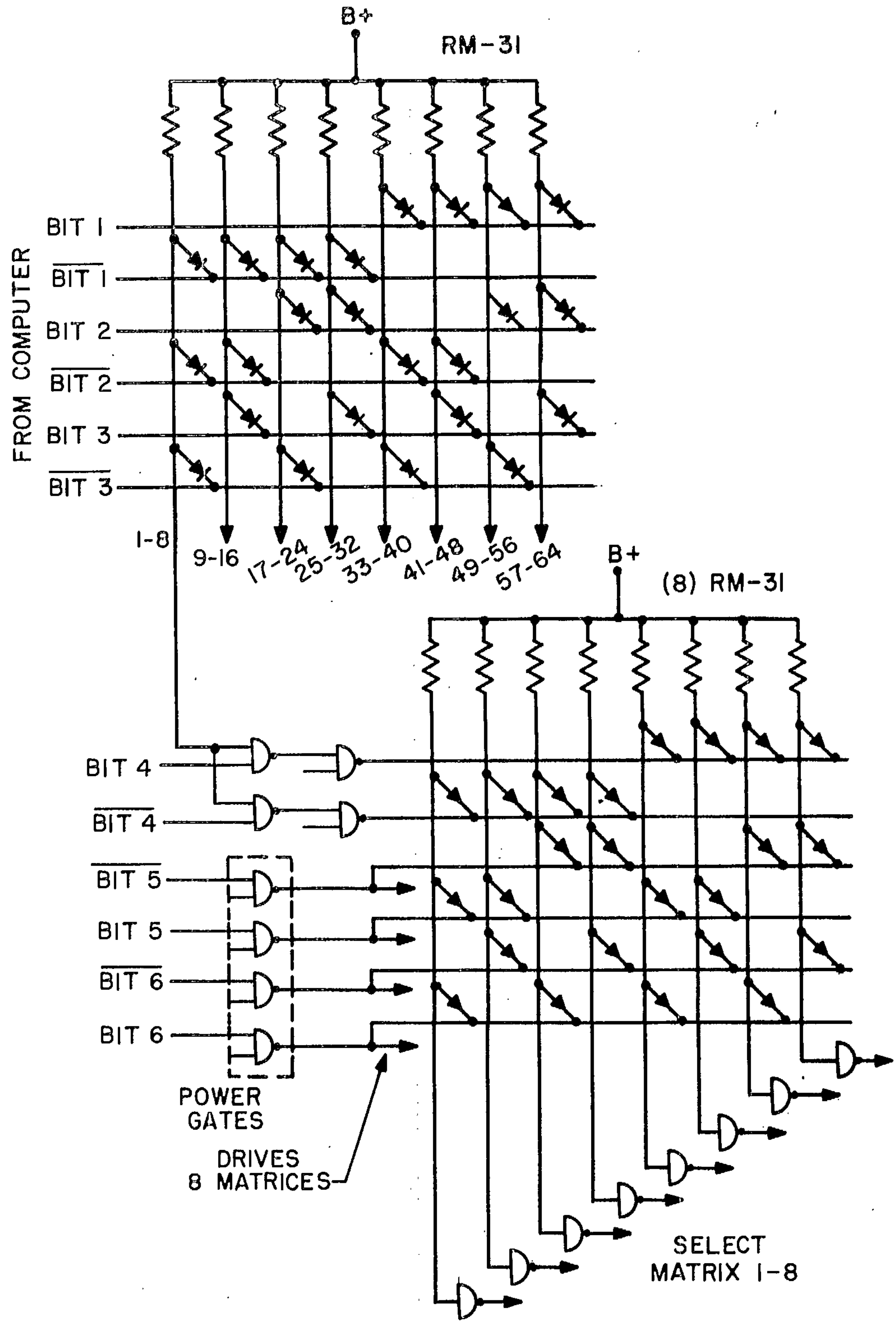


*Fig. 10. Character selection using diode matrices.*

clock is normally stopped after the last matrix position is scanned, except when a joystick is being used and it is necessary to scan the cursor repeatedly. In this case the J input of the clock control FF is held at 0 and the clock continues to run.

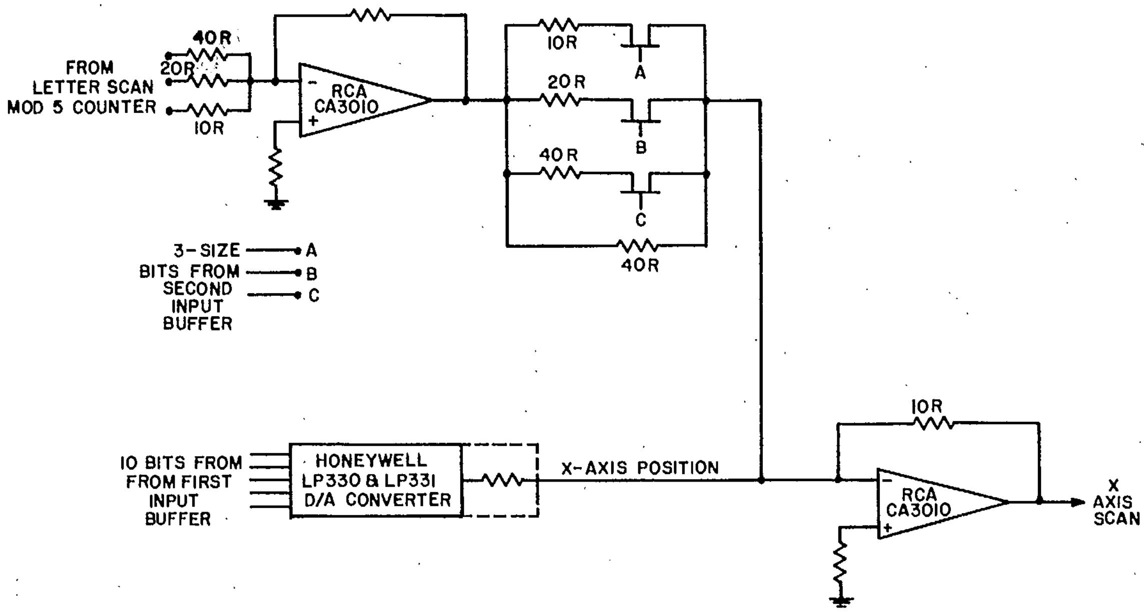


*Fig. 11. Character D/A, position D/A and size control circuit.*

Figure 13 shows the matrix circuits. The rows are decoded with power gates so that a 0 appears first on Row 7, with a '1' on all other rows, then after another clock pulse the '0' shifts to Row 6, etc. The outputs of the modulo 7 row counter are also fed through weighted input resistors to an operational amplifier D/A converter which feeds the y-axis size circuitry similar to Figure 11. When the '0' on the rows reaches Row 1 it is sent through an inverter to the clock column counter. Both the row and the column counters are made of trailing edge clocked flip-flops. Row counters are decoded in a RM-41 diode matrix and the outputs are fed to emitter-follower transistors which drive the column inputs of all 64 diode matrices. The signals fed to the column 1-5 are a '1' starting at Column 1, with all other columns being 0 and this '1' advances from column to column every clocking pulse from the row counter. The column counter outputs are fed through gates to an operational amplifier D/A converter.

All 64 diode matrices are scanned by row and column in parallel. Only the character matrix that is selected by putting a zero on the select line has an output. As the matrix is scanned, wherever a row and column is terminated by a diode, there is an output from the matrix. This output is fed to a transistor, then to a 64 diode 'OR' gate and then to a collecting transistor. This output and its inverse are used to control the two-speed clock as well as to provide the intensity modulation required for the CRT. The intensity modulation is inhibited when no matrix is being scanned. This is necessary since the row and column scan circuits rest on Row 7 and Column 1 and if there was a diode at this junction, a dot would be brightened on the CRT all the time.

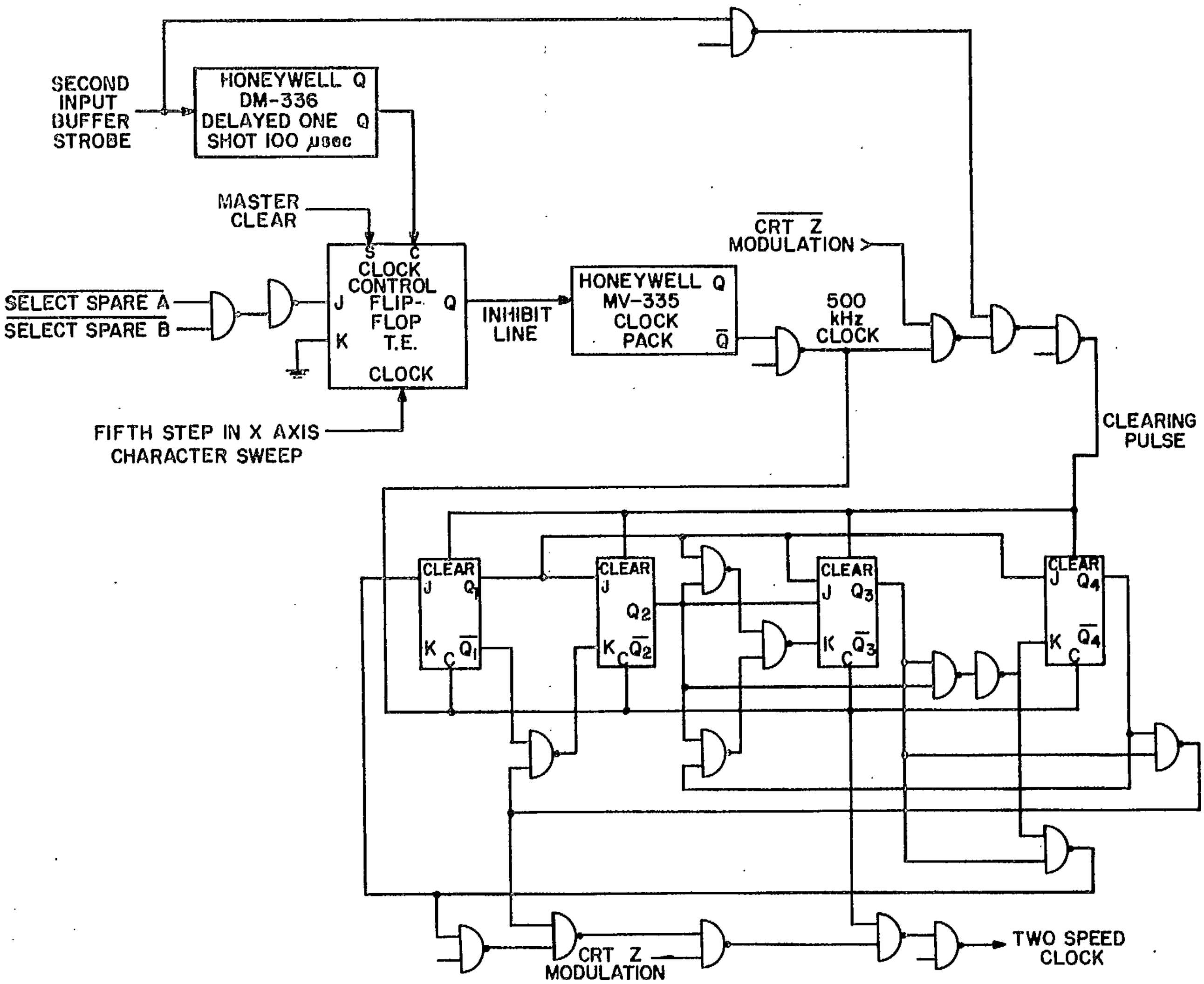


*Fig. 12. Two-speed clock.*

Figure 14 has been included to show the interface of the computer and the character generator. Since a good understanding by the reader of the DDP-516 computer would be necessary to make use of a complete diagram, a block diagram of the interface from the computer to the character generator only is included. There is also an interface circuit for entering data from the character generator to the computer when using a keyboard or joystick but since the principle is essentially the same it is not shown here.

When the computer wants to send information to the character generator, the first thing that happens in the interface is that the address appears on the computer address bus. The computer then checks the device busy line to see if the character generator is busy and if it is not the computer initiates an address decode pulse which sets the 'ENABLE' flip-flop. The output from the 'ENABLE' flip-flop is added with a ready signal from the character generator (which indicates character is finished) and the absence of an erase interval pulse (which indicates that the CRT is not in the middle of an erase cycle). The output from this gate requests service by the Direct Multiplex Control (DMC).

The DMC sends an acknowledgment pulse which is gated with a strobe from the computer to enter the data from the output bus into the character generator buffer. When using the character generator the DMC range must be in multiples of two, so that the user can enter as many characters as he wishes but must always enter two computer words for every character to be displayed. A master clear pulse or an end of DMC range causes the 'ENABLE' flip-flop to be cleared, allowing for another set of characters to be displayed.

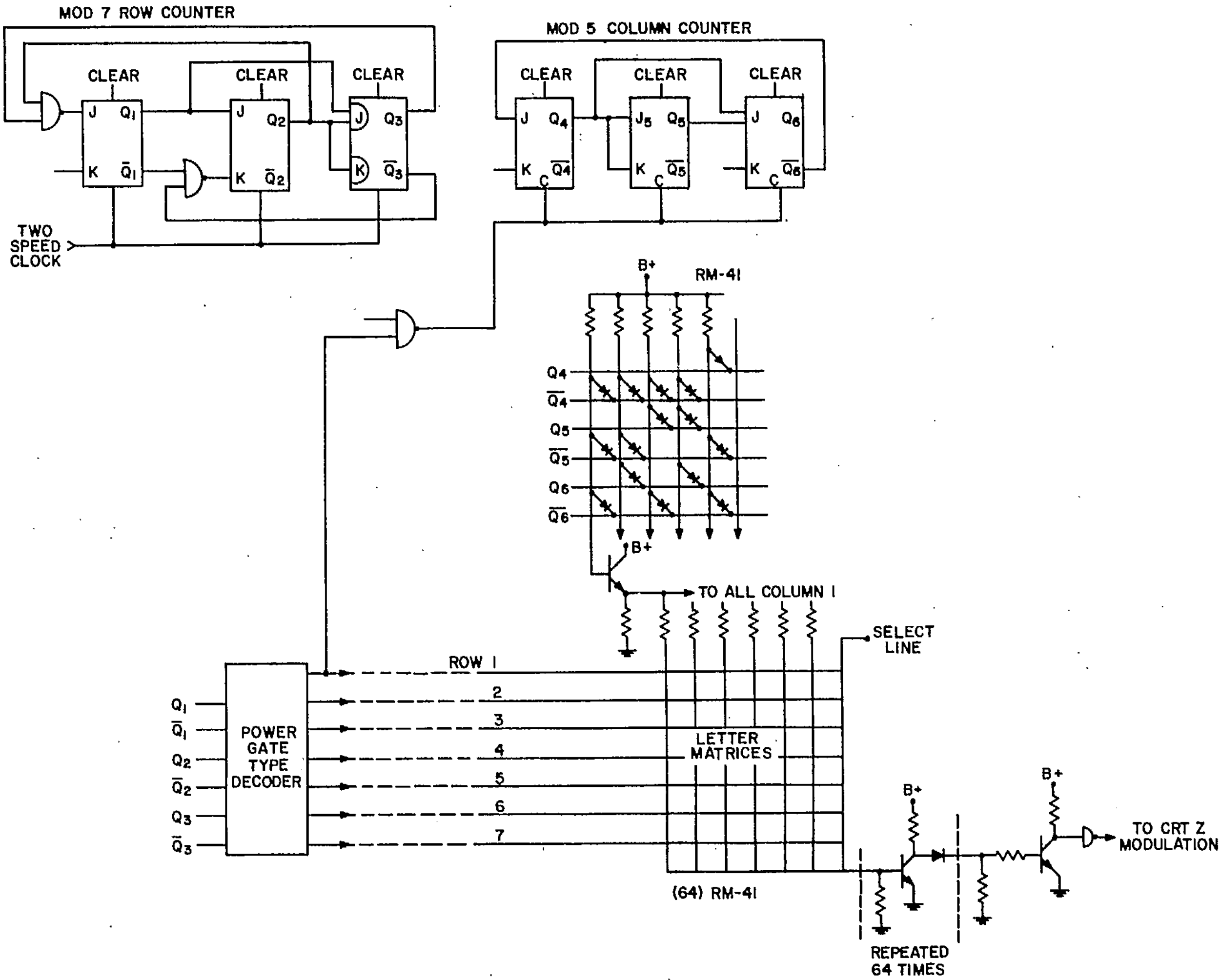


*Fig. 13. Letter matrix circuits.*

## 3.2 CHARACTERS USED

As was stated before, the characters are formed by scanning diode matrices which are essentially read only memories. Sixty-four RM-41 diode matrices were used and by selectively burning out diodes with a capacitor discharge set-up, any character or character style could be made. Figure 15 shows the character repertoire chosen and their respective ASCII codes. ASCII code usually has 8 binary levels but only 6 are needed for 64 characters. Any of these characters can be changed simply by changing the respective diode matrix. The RM-41 diode

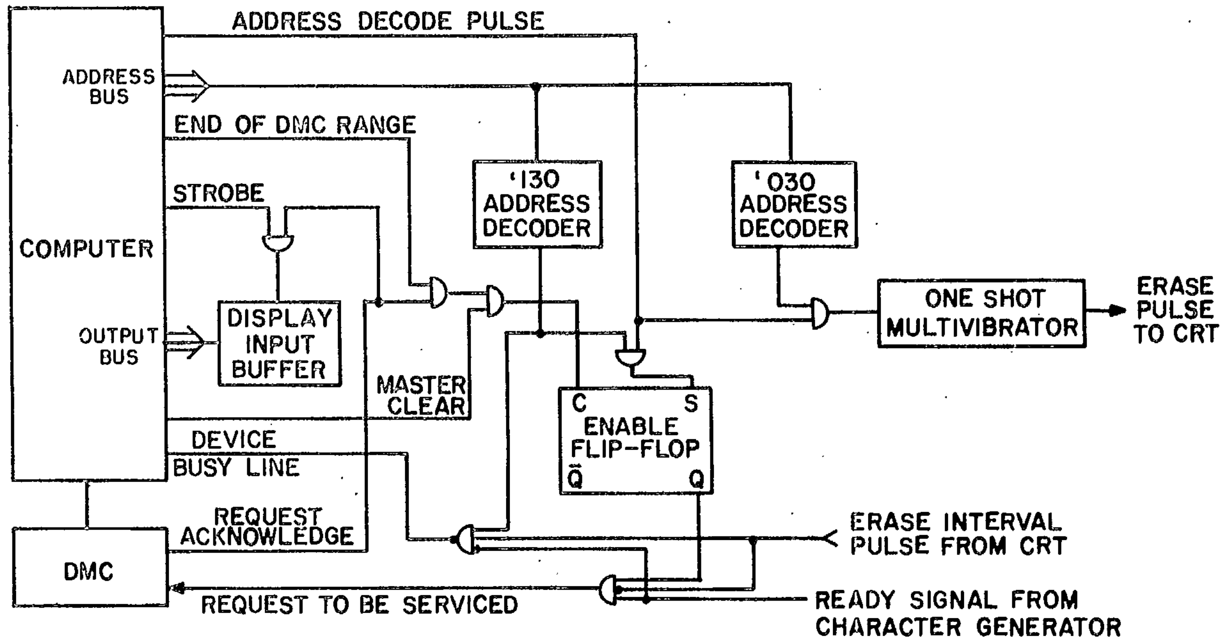


*Fig. 14. Character generator/computer output interface.*

matrices lend themselves very well to a 5 x 7 character matrix which gives a very recognizable character array. The character generator is able to form 64 characters which are the standard ASCII characters except for five exceptions; five characters were changed to form special characters: the @ symbol with ASCII code oo in octal was changed to a vertical line for drawing vertical graph axes, and the ; with ASCII code 73 was changed to a horizontal line for drawing the horizontal axis. The symbol & with code 46 was changed to two vertical lines to be used as a special cursor for a joystick. The symbol ( with code 50 was changed to a square for the same purpose, as well as the symbol ) with code 51 to form two horizontal lines. The other 59 characters were not altered. The characters chosen with the exception of the five changes lend themselves very well to computer teletype input.

## 4. OPERATING INFORMATION

From the beginning of the graphic display design an attempt was made to keep the character generator as simple to operate as possible, but at the same time keep it as general-purpose as possible. An analogy was made between the graphic display operation and that of a general-purpose computer line printer which gives the user complete flexibility. While this approach requires more computer programming it makes the terminal more general purpose. This approach differs from the one where all positioning, line feeding, etc., is done automatically in the terminal and consequently reduces the flexibility.

With the approach used it is just as simple to plot a graph as to write text and it allows for the simple addition of a joystick and a keyboard.

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

*Fig. 15. Characters available and their octal codes.*

## 4.1 PROGRAMMING INFORMATION

There are only three program commands for controlling the character generator. These are an OCP'030 command which remotely erases the CRT on SKS'130 command which is a skip-if-not-busy command, and an OCP'130 command which calls up the character generator and tells it to start requesting characters. When characters are to be written on the display, two computer words per character must be constructed and stored in the computer memory. The user must specify the starting and ending address of this area in memory and store these two addresses in location '22 and '23 in the computer memory to specify the range of character storage for use by the DMC.

The rest of the programming is similar to what would be required for a line printer, always remembering that each character to be printed is described by two computer words. The first 6 bits of the first word contains the character written in binary, the next ten bits contain the X position in binary. The first 3 bits of the second word contain the size, the next three bits the mode of operation (view, non-store, write-through) and the last 10 bits the Y address in binary. To specify mode, octal 0 is non-store, octal 2 is write-through and octal 3 is store.

Therefore, to write text, the writing would probably begin at the top left hand corner and every new letter would have to be started the correct number of increments from the left edge of the display so that the characters are spaced correctly. The X and Y positions specified by the computer input is the bottom left hand corner of a 5 x 7 matrix. Therefore when allowing for spacing between letters, the width of the letters must be included. To complicate this, the number of bits needed for spacing is, of course, different for different size characters. Table 2 below shows the actual height and width of the characters for the eight sizes available.

TABLE 2

Character Size

| Size | Width (cm) | Height (cm) |
|---|---|---|
| 0 | .14 | .19 |
| 1 | .23 | .32 |
| 2 | .31 | .43 |
| 3 | .38 | .54 |
| 4 | .47 | .65 |
| 5 | .55 | .77 |
| 6 | .62 | .88 |
| 7 | .71 | 1.0 |

Table 3 shows increments which can be used between characters for the eight different character sizes. These increments are only a guide but they make text quite legible. The same increment is used between characters and b between lines of text. When the X position and Y position are both 0, the location specified is the bottom left hand corner of the CRT. For writing text where the starting point is the top left of the CRT, the position specified would be X = 0 Y = 1023. For the second line to be written in Size 1 the starting position would be, X = 0 Y -0023 = 1000. This appears in the computer word written in binary. Since the X and Y positions must be specified for each character, carriage returns and line feeds are accomplished completely by software. The gain of the CRT has been changed to allow a 1 cm border on the top and right side of the display. This allows the maximum character size to be written giving the maximum address in the X and Y direction. This also improves the resolution on the remainder of the CRT.

TABLE 3

Letter Spacing

| Size | Number of Binary Bits |
|---|---|
| 0 | 14 |
| 1 | 23 |
| 2 | 31 |
| 3 | 39 |
| 4 | 48 |
| 5 | 57 |
| 6 | 64 |
| 7 | 73 |

With these general rules in mind, it can be seen that it is no harder to plot graphs than it is to write text. The axis can be drawn, labelled and the graph plotted using any characters desired.

It is also a simple matter to connect a joystick. All the joystick must do is to specify the X and Y positions, cursor, size and mode (usually write-through). If the write-through mode is chosen, the cursor can be moved through a graph or text and pick out any X and Y position and communicate through the character generator to the computer, which is a similar operation to that of a light pen.

## 5. RESULTS

Computer programs have been written to use the graphics terminal. The results have been very good with all the characters easy to read, even the smallest size. It also became evident that smaller characters could be used if this became necessary.

A computer program was written to use the computer teletype as an input to the graphic display for text editing as mentioned in the introduction. In this program each line of text is first written in the write-through mode and then it is stored when verified by the user, before going on to write the next line. In this way, mistakes can be corrected in lines before they are stored on the display. Using the smallest character size it was possible to write 72 characters per line and a total of 72 lines. Seventy-two characters per line is compatible with an IBM card so this editing program can be used to write computer programs that would normally be on IBM cards. This gives a possible character density of 72 x 72 = 5184 characters.

The writing speeds of the display seem to be quite adequate even though it is not quite as fast as a refresh type display.

## 6. CONCLUSION

The graphic terminal described has been interfaced with a DDP-516 Honeywell computer and is in operation now. The computer programming necessary to operate the display is not too difficult and for ordinary display of data the amount of computer memory used is not excessive. A keyboard and a joystick are going to be connected to it in the future. Complete circuit diagrams and an operating manual are available for more detailed information.

## 7. ACKNOWLEDGMENTS

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## APPENDIX

As described earlier in the report, the 3 mode bits in the second input word to the character generator are not completely used.

For expansion of the character generator, one of these bits could be used to expand the characters from 64 to 128. This still leaves two mode bits which specify only 3 modes. The fourth mode could be used in adding a stroke generator to the character generator. The third bit could also be used to rotate the character through 90°.

Commercially available displays have recently come on to the market which allow for a dot storage time of only 7.5 μsec. If this was incorporated in this system, we could get a further increase in writing rate of up to 2.4 to 1.