2101-2 KEYWORD GRAPHICS LIBRARY

REFERENCE MANUAL

FOR MTU-130 COMPUTERS

WITH BASIC 1.0

DECEMBER, 1981 Rev. A

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TABLE OF CONTENTS

TITLE - PAGE

1. Overview - 1
2. Loading the Keyword Graphics Library - 3
3. Running the Demonstration Programs - 4
4. Fundamental Graphics Commands - 6
5. Advanced Graphics Commands - 10
6. User Defined Characters and Figures - 16
7. Additional Usage Information - 22
8. Error Messages - 23
9. Listing of KGLDEMO Demonstration Program - 24
10. Appendix A, Command Summary - 27

1. OVERVIEW

The Keyword Graphics Library, or KGL for short, is a 6502 machine language program that extends the command repertoire of MTU BASIC 1.0 to include 48 graphics commands. This greatly simplifies creating graphics images in the bit-mapped pixel display in the MTU-130 Computer. The manipulation of the 122,800 picture elements in the display is fast since it is done with machine language.

For example, if a solid vector between the coordinates 35,21 and 117,73 is desired, the BASIC statement:

```
130 LINE 35,21,117,73
```

would be inserted into the user's program (or by omitting the line number, the vector would be drawn as soon as the command was typed in). The caption "MARKET INDEX" beginning at X=220 and Y=123 could be generated simply by coding:

```
710 MOVE 220,123
720 CHAR "MARKET INDEX"
```

In addition the package provides some powerful advanced functions not found in other graphics packages such as automatic coordinate transformation (both translation and scaling), solid or dotted lines, keeping track of up to 4 different "display windows", subimage definition, and even a "scroll" command to facilitate the programming of animated displays.

1.1 GRAPHIC DISPLAY CHARACTERISTICS

The Keyword Graphics Library uses the bit-mapped display in the MTU-130 to ceate the graphics images. The display itself is very simple in concept consisting of 122,800 dots arranged in a rectangular array 480 dots wide by 256 dots high. Each of these dots may either be white (or green as the case may be), in which case it shows as a small point of light; or black, in which case it does not show up. Graphic figures are typically drawn by turning dots on to approximate the figure's outline which means that the figure is white against a black background. A simple command is provided for "drawing" black dots on a white background instead if the user prefers that mode of display.

1.2 PLOTTING FEATURES

The most common use for graphics is plotting graphs and other images from mathematical functions or measured data. When the system is initialized, the origin of the plotting grid (the 0,0 point) is set to the lower left corner of the screen. X coordinates in the range of 0 through 479 and Y coordinates in the range of 0 through 255 are acceptable. For greater flexibility, a coordinate offset can be specified which has the effect of moving the origin. Independent X and Y scale factors can also be specified which will shrink or expand the image in either or both dimensions.

When plotting, a virtual grid having X and Y ranges of -16384 to +16384 is actually available. If a figure larger than the visible limits of the screen is being drawn, the visible part is still drawn correctly. Different parts of the overall image may be seen by resetting the X and Y offsets and then redrawing the entire image.

As an added convenience, storage and automatic handling of 4 display windows is provided. This allows the implementation of split-screen and other multiple display techniques with much of the housekeeping associated with switching among windows to be done at machine language speed.

Two different kinds of subimage capability are built-in. Subimages are useful for cases where shapes from a library of shapes are to appear in an image several times at different locations. Examples include various types of schematic diagrams and even ordinary text characters. The "vector-byte" type of subimage features compact storage of the shape definition (one byte per line segment) in exchange for restricted shape size and line angles. A default ASCII character set encoded in vector-byte form is a standard feature of the package. The "relative coordinate" type of subimage allows shapes nearly as large as the screen with lines at any angle to be defined at the expense of doubled storage requirements.

1.3 ANIMATION FEATURES

While any type of microprocessor driven stored image display is limited in its animation capability, two features of this package combine to provide animation from BASIC nearly as good as dedicated machine language programming. One of these, the vector-byte and relative coordinate subimage feature, means that entire images can be redrawn in different locations at machine language speed merely by specifying the new location of the subimage. The other is a "scroll" function which will move entire portions of the screen from one location to another without the need to erase and redraw them in the new location.

1.4 HOW TO USE THIS MANUAL

The first part of this manual is devoted to getting the customer started in the use of this package. In addition to the KGL.Z file containing the KGL program, there is a demonstration program called GDEMO.B on the distribution disk. It is strongly suggested that this demo should be run to convince yourself that all is working properly.

The user's manual itself is basically divided into two parts. The first part, which is sections 4 and 5, is written as a tutorial which not only describes the graphics commands in detail but also teaches the reader many fundamental concepts of computer graphics in general. It should be read carefully by customers relatively inexperienced in graphics and at least skimmed by more experienced customers. The second part, which is sections 6-10, can be referred to directly by experienced users for concise descriptions of the commands and other system characteristics. The entire manual is written assuming a good knowledge of MTU BASIC. If the reader is inexperienced with BASIC, the MTU BASIC Reference Manual should be studied in conjunction with this manual. In addition, machine language concepts and terms will be used occasionally. This should not be much of a problem for the inexperienced user as only the more advanced functions are involved.

2. LOADING THE KEYWORD GRAPHICS LIBRARY

If you are using the KGL for the first time, it is important to first make working copies of the KGL.Z and GDEMO.B files. Refer to section 2.2 for instructions on how to copy the files from the distribution diskette to a work diskette.

2.1 LOADING INSTRUCTIONS

To load the KGL Library, simply include the name "KGL" as a file name in a LIB command. For example, the following command would load just the KGL Library.

```
LIB "KGL"
```

If there is an occasion when the KGL and IGL Libraries are to be loaded at the same time, you should should place the "KGL" name prior to the "IGL" in the LIB command. The following example shows the proper order.

```
LIB "KGL","IGL"
```

If the IGL Library is already loaded, it will be necessary to execute a FRELIB command before executing the LIB command above.

The specified order is necessary if you wish to use all the commands in both libraries. If they are loaded in the reverse order, some of the commands in the IGL Library will give SYNTAX ERRORs when executed. These IGL commands will be the ones which have a matching command in the KGL, only without the "S" prefix. An example would be the SMOVE command which has a matching MOVE command in the KGL Library.

If you wish to use the KGL and the VGL at the same time, you should note that some of the commands have identical names. These are the MOVE, DRAW, and WINDOW commands. The library which gets to execute such commands is the one that came after the other in the LIB command. If the LIB command was:

```
LIB "KGL","VGL"
```

then the VGL will be the one to execute the matching commands. In this case, you should also note that the SCFLIP command in the KGL contains the characters "FLIP" which matches a command in the VGL. The result is that an SCFLIP command will give a SYNTAX ERROR when executed. For the reason why, refer to the TOKENS AND KEYWORDS section in chapter 4 of the SETUP AND INSTALLATION section of the MTU-130 MANUAL.

2.2 MAKING A WORK COPY OF THE KGL

Before using the Keyword Graphics Library, you should first copy the KGL.Z and GDEMO.B files over to your work disk. On a 1 drive system, use COPYF1DRIVE to copy the two files over to your work disk. On a 2 drive system, place your work disk in drive 0 and the distribution disk in drive 1. Then OPEN drives 0 and 1, and execute the following two commands:

```
COPYF KGL.Z:1

COPYF GDEMO.B:1
```

Once your work copies are made, you should store your distribution disk away in a safe place.

3. RUNNING THE DEMONSTRATION PROGRAMS

A demonstration program has been included on the distribution diskette. Its purpose is two-fold. First it allows the first time user to see the KGL in operation with a minimum of effort. Second, the listing of the demonstration program serves as an example of how to use the KGL to perform a variety of graphics functions. While not every possible command or graphic technique is exploited in the demo programs, an effort was made to include as many as possible. In the descriptions, specific KGL commands are sometimes referred to. Consult sections 4 and 5 for detailed description of these and other commands.

3.1 RUNNING THE GDEMO PROGRAM

To load and run the GDEMO BASIC program, execute the following two commands from the CODOS Monitor.

```
BASIC

RUN "GDEMO"
```

These commands assume that the disk in drive 0 contains the BASIC, KGL.Z, and GDEMO.B files.

3.2 DESCRIPTION OF GDEMO

The first program illustrates point plotting by drawing a circle (depending on adjustment of the display monitor, it probably will not be perfectly round) with 250 individual dots. The parametric equations: X=COS(A) and Y=SIN(A) are used to generate X,Y pairs as a function of the variable A, which varies from zero to 2*Pi. The MOVE command is used to put the "cursor" at the desired X,Y position while the WRPIX command actually plots the point. Note that offsetting and scaling of X and Y, which vary between -1 and +1, is necessary to produce the appropriate X and Y values for plotting. KGP can also be instructed to do the offsetting and scaling (with restrictions) automatically if desired.

The second program illustrates vector plotting by creating a 31 point star. Since the string of lines is connected, the DRAW command can be used to draw from the current cursor position to the next endpoint. However the first endpoint is a special case. To handle the first point, a variable called FP is initially set to 1. As each new endpoint is computed, the value of FP is interrogated. If it is found to be non-zero (which will only occur for the first point), a MOVE is done instead to position the cursor without drawing. After the first point is plotted, FP is set to zero thus allowing vectors to be drawn between all successive points.

The 31 point star is actually drawn 4 times in different graphics modes (GMODE) to illustrate their effect. It is first drawn in mode 1 which gives normal line plotting. Next it is "drawn" in mode 2 which is actually an erase mode since it draws black lines. Note that when two lines cross and one of them is erased that a small gap is left in the other line. This is a fundamental problem of all stored image (as opposed to refresh vector) graphic displays. The last two times the star is drawn in mode 0 which is "flip mode". In flip mode, the state of each point plotted is made the opposite of what it already is. Thus on a black background it produces lines as in mode 1. However when lines cross, the point of intersection is flipped twice resulting in a gap. Note that drawing the star the fourth time in mode 0 erases it (flips white back to black) but that erasing "repairs" the gaps at line intersections! This is a very powerful property of flip mode which will be explained later.

The third program illustrates how a fully labeled and captioned graph can be produced. First the Y axis labels are produced with a FOR loop, number conversion into a string variable, and the CHAR command to print the labels in the desired positions along the Y axis. Note that if the FOR loop had been written: FOR Y=-1 to 1 STEP .2 that after 10 iterations Y would not be precisely 0 because of round-off error in decimal fraction to binary floating point conversion. Thus rather than 0 being printed, something like -1.16415322E-10 would be printed instead. The captions are printed next by positioning the cursor with MOVE commands and then printing text with the CHAR command. Then the axes themselves are plotted with calibration marks for the Y axis. Finally the Fourier synthesis of the sound waveform of a particular organ pipe is plotted.

The fourth program illustrates the capability of KGP to keep track of and display multiple windows of text and graphics. Four windows of varying size and position are set up on the screen. Three of the windows act as miniature scrolling text displays and simply display a continuous stream of characters. The fourth window displays a portion of a somewhat larger graphic image. The program to generate this display services each window in round-robbin fashion but the KGP takes care of saving and restoring the "state" of each window while another is being serviced.

The last program illustrates advanced graphics functions and rudimentary animation. First the screen is filled with a checkerboard pattern. Use of the SCFLIP command is used to generate the white squares at high speed. Next a single letter "X" is set roaming about the screen. The movement will continue until a function key is pressed, at which point the demo ends. Basically this program works by drawing the character twice in "flip" mode which will cause it to first appear and then disappear. The cursor coordinates are then updated according to the wander direction and the character is drawn and after a delay, erased again. Since machine language in the KGP draws the individual lines making up the character, the entire process is performed fast enough to give an illusion of continuous motion.

4. FUNDAMENTAL GRAPHICS COMMANDS

Because of the large number of commands in the KGL and their wide range of sophistication, they will be described in two groups: fundamental commands and advanced commands. In addition, they will be described in their probable order of need rather than grouped by function. The appendix has a long and short form summary of the commands grouped by function.

4.1 FUNDAMENTAL SETUP COMMANDS

Before executing plotting functions in your program, it is necessary set the operating mode of the KGL. In many cases defaults are provided to simplify usage.

4.1.1 Display Mode Commands

Three commands are provided for selecting either a black background with white plotting or a white background with black plotting. The NRMDSP command selects a black background which is considered "normal" for CRT displays. The RVSDSP command selects a white background. FLPDSP changes to the opposite background color. Typically the background color is specified once at the beginning of the program and then left alone. If it is changed in the middle of the program, the new background color will only apply to subsequent plotting commands; it will not change the background color of what is already on the screen. Thus one would normally clear the screen following a background color change. The default is a normal display (black background) which is easier on the eyes and on the picture tube.

4.1.2 Screen Clearing Commands

Two high speed screen clear commands are provided. A simple CLR will set the entire Visible Memory screen to the current background color in about 1/10 of a second. SCLR can be used to clear rectangular portions of the screen if desired. Following the SCLEAR command should be four numbers (or BASIC variables) which define the X and Y coordinates of the upper left and lower right (or lower left and upper right) corner of the rectangle to be cleared.

The order of the arguments is Xul,Yul,Xlr,Ylr (or Xll,Yll,Xur,Yur) The X coordinates are expected to be in the range of 0 to 479 and the Y coordinates are expected to be between 0 and 255. If either Y has a fractional part, it will be truncated to an integer. X is a bit more complicated however. The first X, which defines the left edge of the cleared area, is reduced by the KGL until it is divisible by 8. The second X, which defines the right edge, is increased until it is one less than a value divisible by 8. Thus if the X coordinates were 66 (left) and 163 (right), the 66 would be reduced to 64 (the closest lower value divisible by 8) and the 163 would be increased to 167 (one less than 168 which is divisible by 8). This action will be referred to as "rounding to a multiple of 8" in the description of other commands that act this way. To avoid unexpected results it is a good idea to always make the left X coordinate a multiple of 8 and the right X coordinate always 1 less than a multiple of 8 in commands that do such rounding.

4.1.3 Plotting Mode Commands

Even with only two colors possible on the screen, there are three ways that points, lines, and characters can be plotted. The command GMODE followed by a single integer or variable selects one of these three modes. Mode 1 is used for most normal plotting. In mode 1, all plotted points are set to the opposite color of the background. Thus for a black background, white points, lines, and characters are plotted. In mode 2, all plotted points are the same color as the background, i.e., nothing shows up. However if an image previously plotted in mode 1 is replotted in mode 2, it is erased. The replotting must be exact for the erasure to be complete.

Mode 0 is a special case. In mode 0, the points plotted are made the opposite of their previous color rather than opposite the background color. The effect is the same as mode 1 if an isolated point or line is drawn on an unblemished background. However if a line crosses a previously plotted line, their point of intersection will revert back to the background color. If two identical lines are drawn in mode 0, the second line will effectively cancel out the first one and leave nothing but the background! The drawings below illustrate the effect of different drawing modes on a figure:

Figure A was drawn in mode 1 which gives a "perfect" image within the display's resolution limitations. Figure B shows the figure A image after two of the lines have been erased by drawing them in mode 2. Note the gaps where previous lines had crossed the remaining line. Figure C shows the same 3 lines drawn in mode 0. The gaps where the lines cross are due to the "flipping" action of mode 0. Figure D however reveals that when two lines are erased by redrawing them in mode 0 that the gaps have been "repaired" leaving a perfect remaining line! Thus mode 0 is most useful where extensive editing of an image is expected. The default mode is 0.

4.2 PLOTTING COMMANDS

The KGL is capable of directly plotting points and drawing straight lines. The location of the points and lines on the screen are defined by X and Y coordinates. X has a legal range of 0 to 479 inclusive and Y has a range of 0 to 255 inclusive. If mixed numbers are given for coordinates, they are truncated before use (same effect as the BASIC INT function). The handling of out of range coordinates is described in the individual commands.

4.2.1 Positioning the Drawing Cursor

In many of the plotting commands the location of a "drawing cursor" is important. The MOVE command followed by X,Y coordinates is used to set the position of this cursor. The drawing cursor is simply a pair of numbers kept internally to the KGL, no real cursor shows up on the VM screen. Coordinates in the range of -32767 to +32767 are acceptable to the MOVE command. If they are outside of that range, an "ILLEGAL QUANTITY ERROR" will occur.

4.2.2 Plotting Points

To plot a point at the current location of the drawing cursor, simply enter the command, WRPIX. The command name is mnemonic for "WRite PIXel". The actual effect of writing the pixel is dependent on the current background color (see sect. 4.1.1) and the current graphics mode (see sect. 4.1.3). With a normal black background and the graphics mode set to 1, WRPIX will unconditionally plot a white point. If the drawing cursor specifies a point location outside the 0-479,0-255 screen area, point plotting is skipped.

4.2.3 Plotting Lines

Two commands are provided for plotting lines between points. The LINE command will plot a line between any pair of endpoints without having to set the drawing cursor first. The format of the command is: LINE X_1,Y_1,X_2,Y_2 where X_1,Y_1 defines the location of the initial endpoint, and X_2,Y_2 defines the final endpoint. Note that when the command is completed, the drawing cursor will be set to X_2,Y_2. If part of the line is outside of the 0-479,0-255 screen area, only the visible part will be plotted. Note that the invisible part still requires plotting time even though no plotting is done. Thus a command like LINE -10000,-10000,10000,10000 will require a few seconds to plot even though only 256 of the 20000 points are actually visible. When drawing lines larger than the visible screen, the maximum line length must be kept in consideration. Because the KGL uses signed 16-bit arithmetic, the maximum line length is 32767 points. This means that even though the LINE command will accept coordinates in the range ±32767, the line will not draw properly if the line is longer than 32767 points.

The DRAW command works somewhat differently. It is followed by a single pair of coordinates, X_2,Y_2, and will draw a line from the drawing cursor position to the X_2,Y_2 point. When the drawing is complete, the drawing cursor is repositioned at the X_2,Y_2 point. This command is useful for drawing figures made of end-to-end connected lines. It is particularly useful for graphs where the plotted points are to be connected by straight lines for improved appearance. Again, only the visible portion of the line will be plotted. The DRAW command also has the same coordinate range and maximum line length as the LINE command.

The commands discussed up to this point are sufficient for plotting any kind of graphic image. However it is often desirable to caption and label the image with text characters. Only the simplest form of character plotting will be discussed here, i.e., normal character size and left-to-right reading. The standard character set contains definitions for all of the upper and lower case letters, the digits, and standard ASCII special characters. Since they are drawn in a 5 dot by 7 dot matrix, up to 80 characters can fit on a line.

The CHAR command is used for displaying short pieces (one line or less) of text. It may be followed by a single numerical argument or variable in which case it will interpret the number as an ASCII code and draw the corresponding single character. The character is located such that the leftmost point of its baseline coincides with the current drawing cursor position. The character extends 7 coordinate units above the baseline and 5 units to the right of the X cursor position. Note that lower case characters with descenders (g,j,p,q,y) draw up to three units below their baselines. After the character is drawn, the X coordinate of the drawing cursor is incremented by 6 in preparation for another character. Thus the statement: CHAR 64 will plot a capital A at the cursor position and then increment the cursor position by 6 in the +X direction.

CHAR may also be followed by a BASIC string variable in which case the entire string will be printed. Movement from one character to the next is as described above. When the string has been drawn, the drawing cursor is positioned to the next available character space. One may also use multiple arguments with the CHAR command. Each argument is separated from the preceeding one by a semicolon (;) just as in BASIC print statements. (The comma (,) separator for tabbing to the next field is not available.) You may also mix numeric arguments and string variable arguments. Note that if the line of text becomes too long, it will simply run off the screen and the excess characters will not be seen.

Characters are actually drawn with line segments rather than by moving a 5x10 dot matrix into the display area. This means that the characters are plotted according to the same rules as lines with respect to the background color and the plotting mode. In particular, drawing a new character on top of an old one will not erase the old character, instead the two characters will be superimposed. This also applies to the space (code 32) character which in effect simply moves the cursor without erasing. The old character must be erased first by drawing it again with the graphics mode set to 2 or 0. Alternatively, a delete (code 20) may be printed which will erase the character cell (including descender) but it will be relatively slow. Note that the delete code does not move the cursor. A text type-in and display program therefore should detect blanks and replace them with a delete-blank sequence.

5. ADVANCED GRAPHICS COMMANDS

While the previously discussed commands are sufficient for most any kind of graphics application, many additional commands and modes are available to simplify the more complex applications. These were not discussed in the previous section to avoid confusing first time users.

5.1 SCALING AND OFFSETS

In most plotting applications the X and Y coordinates will not "naturally" be in the 0-479,0-255 range of the display. Of course the user program can always transform whatever coordinate representation is desired into the proper range but then plotting is slowed substantially by the additional BASIC language programming. To alleviate this, the KGL has the ability to transform all of the coordinates it receives at machine language speed.

5.1.1 Offset Command

Normally the origin of the coordinate system for plotting (i.e., the 0,0 point) is at the lower left corner of the screen. By using the offset command, the origin may be set anywhere desired. OFFSET followed by two numbers or variables separated by a comma will establish a value that will be added to all X coordinates and a value that will be added to all Y coordinates before they are used. Thus if the statement: OFFSET 160,100 is executed and offsetting is enabled (see below), then the origin of the coordinate system will be at the center of the Visible Memory screen. Offsets may be anything in the range of -32767 to +32767 however any fractional part is truncated off. The default offsets are 0,0. Note that the drawing cursor position will become undefined immediately after execution of the OFFSET command.

5.1.2 Scaling Command

In addition to moving the origin, it is useful to be able to shrink or expand the image, that is, scale it. For maximum speed and to simplify the machine language coding in the KGL, scaling can be only by positive or negative powers of 2. In fact the scaling command expects the actual power of 2 to be specified rather than a multiplying factor. Thus for scaling up by a factor of 8 (i.e., coordinates are multiplied by 8), the scaling parameter would be 3 since $2^3=8$. For scaling down, the scaling parameter would be negative; to shrink by a factor of 8 -3 would be specified since $2^{-3}=1/8$. The SCALE command is used to establish the X and Y scale factors as a pair of scale factors separated by a comma following the command. As an example, the statement: 130 SCALE 2,-1 will expand the image by a factor of 4 in the X dimension and shrink the image by a factor of 2 in the Y dimension. The default value for both scale factors is 0 which gives no scaling ($2^0=1$). Note that the drawing cursor position will become undefined immediately after execution of the SCALE command.

When studying the effect of combined scaling and offsetting, it is important to realize that scaling is done before offsetting. In addition, all arithmetic is integer arithmetic. Thus the equations that are actually evaluated by the KGL when coordinate transformation is enabled are as follows:

```
Xdrawn=INT(Xoffset)+INT(INT(Xspecified)*2↑INT(Xscale))

Ydrawn=INT(Yoffset)+INT(INT(Yspecified)*2↑INT(Yscale))
```

5.1.3 Enabling Coordinate Transformation

After setting the offset and scaling parameters, it is necessary to enable coordinate transformation. The command XFFLG followed by a single number establishes the transformation mode. Mode 0 is no transformation and is the default. Mode 1 enables transformation. Note that transformation only applies to subsequent drawing; the current content of the screen is not transformed. Also note that the drawing cursor position becomes undefined when the coordinate transformation mode is changed.

The maximum line length described for the LINE and DRAW commands (section 4.2.3) still applies. However, the limit of 32767 points should be applied to the length of the line after its coordinates have been transformed.

5.1.4 Character Scaling and Rotation

Characters can also be scaled and rotated independently of graphic scaling. The CHSCALE command followed by a single number sets the scale factor for characters. The scaling parameter is interpreted in the same way as the graphics scaling parameter, that is, it is an integer power of 2. Generally only positive values are useful since so much of the detail of the character will be lost when negative values are used that text becomes unreadable. The automatic cursor movement associated with the CHAR command is also affected by the character scale factor so that proper character and line spacing is maintained. The default character scale parameter is 0 which gives normal sized characters.

Characters may also be rotated in 90 degree increments by use of the CHROT command. The single following argument must be in the range of 0 to 3. The amount of counter-clockwise rotation is equal to 90 degrees times the rotation parameter. Note that CHAR will update the cursor position correctly for rotations other than 0. The default rotation parameter is 0 which gives normal upright, right-reading characters.

Note that character scaling and rotation is always in effect, it need not be enabled before use.

5.2 DISPLAY WINDOWS AND BOUNDARY CHECKING

The KGL has the capability of maintaining up to 4 independent "viewing windows" which is useful for implementing "split screen" functions in application programs. Again, appropriate BASIC programming could perform the same function but the KGL is able to switch among the windows much faster; fast enough in fact to give the illusion of simultaneous action in each window. (Note: what is described here as a "window" is called a "viewport" in the VGL Library. A KGL window is not the same thing as a VGL window.

A "window" is really nothing more than a set of 6 numbers stored in memory. Associated with each window is its current boundaries (4 numbers) and the position of its drawing cursor (2 numbers). When a different window is selected as the "current window", these 6 numbers are saved in the old window's memory and the 6 numbers for the new window are made current. Thus a user program can freely switch among the 4 windows without having to save or restore any data. (Note however that character scaling and rotation parameters are global and not saved with the windows.)

5.2.1 Window Definition

When the KGL is first loaded and enabled, all 4 windows are initialized with boundaries set to the screen boundaries (0,0,479,255) and the cursor position undefined. In addition, window 0 is selected for use. The WINDOW command followed by a single argument is used to select a window and make it current. Data about the previously selected window is saved. The argument must be in the range of 0 to 3 since memory space for only 4 windows is available.

Window boundaries may be set with the SETWIN command. SETWIN is followed by 5 numbers which specify the window number (0 to 3), the left boundary, the bottom boundary, the right boundary, and the top boundary respectively. Note that the boundary values are with respect to the untransformed screen coordinates, i.e., the left and right boundaries must be between 0 and 479 and the bottom and top boundaries must be between 0 and 255. If the specified boundaries are out of range or scrambled up, they will be forced to something that makes sense but the final result will be undefined. Note that if SETWIN refers to the currently active window that the new boundaries will become the current boundaries. This allows software simulation of more than 4 windows if needed. Setting the boundaries of a window makes the cursor position for that window undefined.

Some operations on windows will "round" the left and right boundary values to a multiple of 8 as described in section 4.1.2. Thus it is a good idea to always specify a left boundary that is a multiple of 8 and a right boundary that is one less than a multiple of 8.

5.2.2 Boundary Checking

The BNDCHK command causes the KGP to check the coordinates of every point plotted against the boundaries of the current window before actually plotting. If the point would be outside the boundaries, the point is not plotted. This applies to points plotted by the WRPIX command, the line drawing commands, and the character drawing commands. Obviously this constant checking slows down plotting substantially, even though it is done in machine language. Plotting speed may be increased by giving the NOCHK command to turn off boundary checking.

When boundary checking is turned off, points, lines, and characters being plotted are not specifically checked against the window boundaries. They are checked sufficiently so that memory addresses outside of the visible area of the Visible Memory are not written into, thus protecting memory. The actual visible effect of plotting outside of the screen area when boundary checking is off is undefined.

5.3 CURSOR DISPLAY COMMANDS

Although a cursor is used internally to define the location of points, line endpoints, and characters, it does not show up on the screen. For interactive graphics programs, it is useful to have a display of the current cursor position. The GRACSR command can be used to display a crosshair cursor at the current drawing cursor position. The cursor is always drawn in "flip" mode so that it will show up regardless of the type of image, if any, it covers. Subsequent movement of the drawing cursor will not cause the displayed cursor to move however. Instead, the visible cursor must first be erased by executing the GRACSR command again with the old cursor coordinates, updating the drawing cursor coordinates, and then issuing another GRACSR to display the crosshairs at the new location.

For text entry applications, an underline cursor would be preferred over the crosshair cursor. The TEXCSR command will display an underline cursor at the drawing cursor position. It is also draw in "flip" mode so that it will always become visible when displayed the first time, and erased when displayed again at the same position. With no character scaling, the underline cursor will appear as a line starting one dot below the drawing cursor position, and will be 5 dots long. Like the graphic crosshair cursor, updating the position of the text cursor is done by first redisplaying the text cursor to erase it. Then moving the drawing cursor position, possibly by displaying a character with the CHAR or AUTEXT commands. Finally, the text cursor is displayed again at its new position.

During debugging or simulating more than 4 windows, it may be helpful to be able to read what the current drawing cursor position is. The RDCSR command followed by two variable names will read the X and Y coordinates of the cursor position into those variables. Thus the statement: 235 RDCSR EX,WY will set the value of EX to the X coordinate of the cursor and set WY to the Y coordinate of the cursor. Note that the values returned have already been transformed if transformation is enabled.

5.4 ADVANCED TEXT DISPLAY FUNCTIONS

While the CHAR command is useful for printing short labels and captions on figures, it is awkward to use when multiple lines of formatted text are to be displayed. The AUTEXT command is similar to CHAR except that it handles end-of-line and end-of-page conditions. Thus after plotting a character and moving the drawing cursor, a check is made to determine if the next character will go beyond the current right boundary. If so, the X coordinate of the cursor is set to the left boundary (plus 2 units for spacing) and the Y coordinate is decremented by 10 so that a new line of text is started. If when Y was decremented it comes within 3 units of the bottom boundary, the entire content of the current window, text, graphics and all, is moved up 10 coordinate units instead, that is, scrolled. These actions effectively make the Visible Memory into a scrolling text display with a screen capacity of 20 lines of 53 characters each. If the current character scale factor is other than zero, the numerical values listed above are suitably altered.

Besides the normal printable characters, both CHAR and AUTEXT recognize and interpret a number of special control characters. These along with their function are listed below:

FUNCTION	ASCII CODE	DEFINITION
Erase	20	Erase the character at the current character position. (does not move the cursor)
Vert. Tab	11	Move cursor up one text line.
Line Feed	10	Move cursor down one text line.
Hor. Tab	9	Move cursor right one character position.
Backspace	8	Move cursor left one character position.
ASC("1")+128 through ASC("9")+128	177-185	Move one dot position in direction the digit is from 5 on a numeric keypad organized as follows: 7 8 9 / 4 5 6 / 1 2 3

5.5.2 Dotted Line Command

In some cases it may be desirable to make the lines connecting endpoints dotted rather than solid. The DOTL command can be used to accomplish this easily. DOTL is followed by two arguments separated by commas. The first argument specifies the number of coordinate units the line is to be "on" (the dash length) while the second argument specifies the number of coordinate units the line is to be off (the space length). If the second argument is zero, solid lines are produced. The default of course is solid lines. Lines making up characters are always solid.

5.5.3 Area Plotting Commands

Three commands are provided for rapid area plotting functions. WCLR will clear the area defined by the current window's boundaries to the background color. In addition, it moves the drawing cursor to a position appropriate for plotting a character in the upper left corner of the window. Also if boundary checking had been turned off previously with the NOCHK command, it will be turned back on. Note that the left and right boundaries are "rounded to a multiple of 8" for clearing purposes (see section 4.1.2).

SCFLIP is used to "flip" the state of all of the display dots in a specified area of the screen. Thus white dots become black and vice-versa. Following the SCFLIP command should be four numbers (or BASIC variables) which define the X and Y coordinates of the upper left and lower right corner of the rectangle to be cleared. The order of the arguments is Xul,Yul,Xlr,Ylr. The X coordinates are expected to be in the range of 0 to 479 and the Y coordinates are expected to be between 0 and 255. If either Y has a fractional part, it will be truncated to an integer. The X values will be "rounded to a multiple of 8" (see section 4.1.2).

The most powerful area command is SCROLL which can be used to move entire areas of the screen from one position on the screen to another. The entire command format is: SCROLL Xt,Yt,Xul,Yul,Xlr,Ylr where each of the 6 arguments may be either numbers or variables. The basic function is to move the rectangle defined by Xul,Yul,Xlr,Ylr (upper left and lower right corner coordinates) to an area of the same size whose upper left corner is at Xt,Yt. Please note that the three X coordinates are "rounded to a multiple of 8" (see section 4.1.2). The move is destructive, that is, the source rectangle is set to the background color as its content is moved to the destination rectangle. The source and destination rectangles can also overlap in any manner desired and SCROLL will still work as expected. Xt and Yt may specify part (or all) of the image to be moved off the screen and it will function as expected.

6. USER DEFINED CHARACTERS AND FIGURES

The Keyword Graphics Library has the ability to store up to 255 predefined "shapes" each of which may be recalled by giving its "ID" and drawn anywhere on the screen (according to the drawing cursor) at machine language speed. In fact the "characters" available through the CHAR and AUTEXT commands are nothing more than 94 of these stored shapes where the numeric value of each ASCII character addresses the appropriate stored shape. The advantages of using the shape table facility of the KGP to draw repetitive shapes are:

1. Compact storage of the shape data - as little as 1 byte per line segment.
2. All shape coordinates are relative meaning that the same shape can be drawn anywhere on the screen by specifying the location of the first point.
3. Intricate shapes are drawn at machine language speed, typically 10 to 100 times faster than doing the same thing in BASIC.

Normally, building up definitions for the stored shapes would be a complex process involving use of the machine language monitor but in the KGL several additional BASIC commands have been provided so that shape tables can be defined and redefined by a BASIC program.

6.1 SHAPE TABLE STRUCTURE

In order to understand how the shape table building commands are used, it is first necessary to become familiar with how the shape table itself is stored in memory. A shape table entry consists of a string of bytes beginning with its ID and ending with a zero byte as illustrated below:

```
            65,166,132,230,51,65,132,1,99,0
           ↗                               ↖
      ID byte                         Terminal 0
```

In most cases there will be many different shape entries in the shape table, each one following the previous one as shown below:

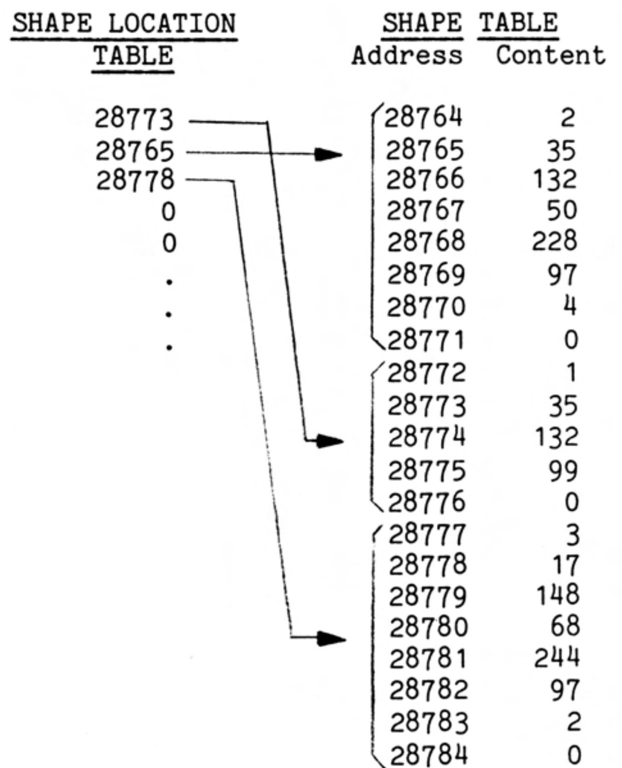
```
65,166,132,230,51,65,132,1,99,0,203,177,193,209,241,129,145,0,201,165,15,140,...

      Shape # 65                      Shape # 203                  Shape # 201
```

Since zero is not a legal drawing instruction byte in the shape table entry, it is easy to separate the entries simply by looking for zero instruction bytes.

When a shape is actually being drawn, the shape interpreter routine built into the KGL (i.e., the routine that executes CHAR and AUTEXT commands) receives the ID of the shape to be drawn and then "searches" the shape table for the matching ID. When a match is found, the drawing instruction bytes are interpreted one-by-one until the zero byte is found which terminates the shape. The drawing instruction bytes are described in section 6.2. If no match is found, nothing is drawn.

In reality it would be very slow even in machine language to search through hundreds of bytes of shape table entries looking for the requested ID. In order to speed up the search process, a separate shape location table is used. The shape location table consists of 256 pointers each of which points to a shape table entry. Since each pointer is two bytes long, the shape location table is always 512 bytes long. Now when a CHAR or AUTEXT command wants to draw a shape, it simply goes directly to the IDth entry in the shape location table and then follows the pointer directly to the first instruction byte in the corresponding shape table entry. If an ID is requested for which there is no corresponding shape table entry, the pointer in the shape location table will be zero and no drawing will be performed.

The diagram to the right shows a shape table with only three simple shapes defined and the corresponding shape location table. Using this as an example, let's assume that a CHAR 2 command was executed. KGL would look into the 2nd entry in the shape location table and find a pointer to address 28765. At 28765 is the first drawing instruction byte for a simple "+" shape. (Note that the ID byte for the shape is still in the shape table. This is "left over" from building the shape location table and is not used in shape drawing.) Each instruction byte would be executed in turn to draw the "+" until the zero byte was encountered. At this point the CHAR command would be complete and execution of the user's BASIC program would continue with the next line. If a CHAR 5 was executed, KGL would look at the 5th entry in the shape location table and find that the pointer was zero. Since a zero pointer means that no shape is defined for that ID, nothing is drawn and the CHAR command would be complete.



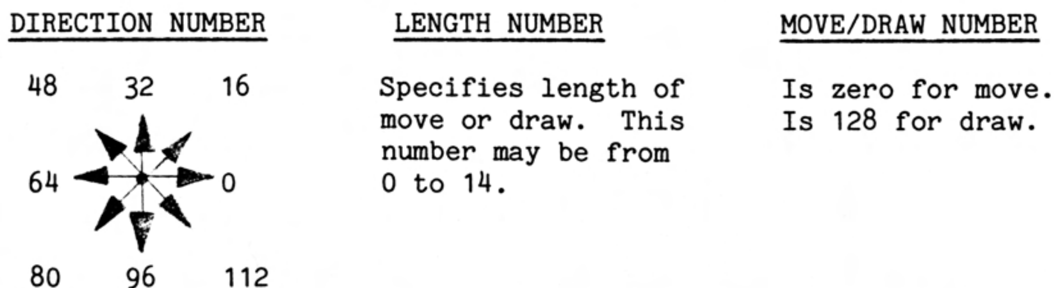
SHAPE LOCATION TABLE	SHAPE TABLE Address	Content
28773	28764	2
28765	28765	35
28778	28766	132
0	28767	50
0	28768	228
.	28769	97
.	28770	4
.	28771	0
	28772	1
	28773	35
	28774	132
	28775	99
	28776	0
	28777	3
	28778	17
	28779	148
	28780	68
	28781	244
	28782	97
	28783	2
	28784	0

6.2 SHAPE INSTRUCTION BYTES

The shape instruction bytes tell the shape table interpreter how to draw the shape. The drawing cursor, which specifies the location of the shape, is used and updated in all shape drawing.

6.2.1 Vector Byte Instruction

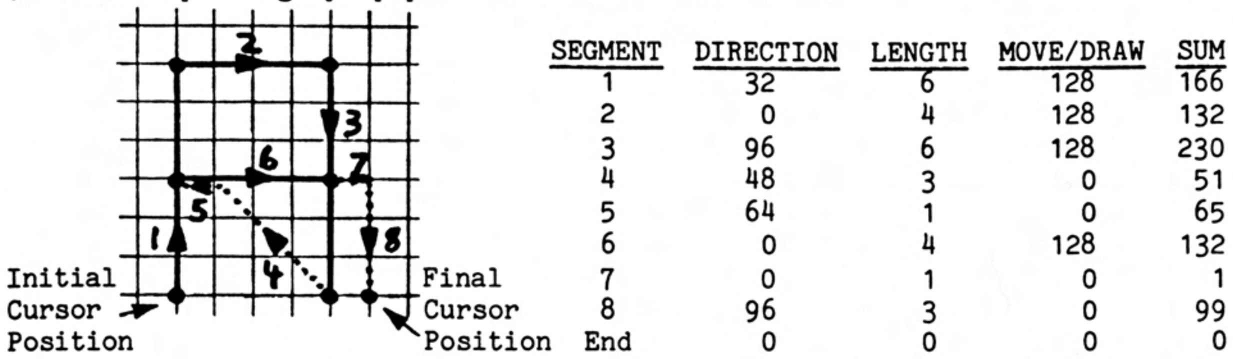
For small, relatively simple shapes such as characters, vector byte instructions are the most efficient. Within a single byte one can generate a line segment or perform a move without drawing in any of 8 directions a distance from 0 to 14 coordinate units. The drawing below illustrates how to compute the vector byte value given the direction, the segment length, and whether a draw or move without draw is desired.



The vector byte is simply the sum of the three numbers calculated above. Note that a move of zero distance to the right will be interpreted as an end-of-shape instruction.

As an example of how to code a shape definition using vector bytes let's try to code the shape definition for a squared-off letter "A". The first byte in the shape definition should be the ID number we wish to have refer to the "A". A logical choice would be the ASCII code for upper case A which is 65 in decimal.

Before trying to calculate the vector byte values, it is a good idea to draw out the shape on graph paper first as is done below:



SEGMENT	DIRECTION	LENGTH	MOVE/DRAW	SUM
1	32	6	128	166
2	0	4	128	132
3	96	6	128	230
4	48	3	0	51
5	64	1	0	65
6	0	4	128	132
7	0	1	0	1
8	96	3	0	99
End	0	0	0	0

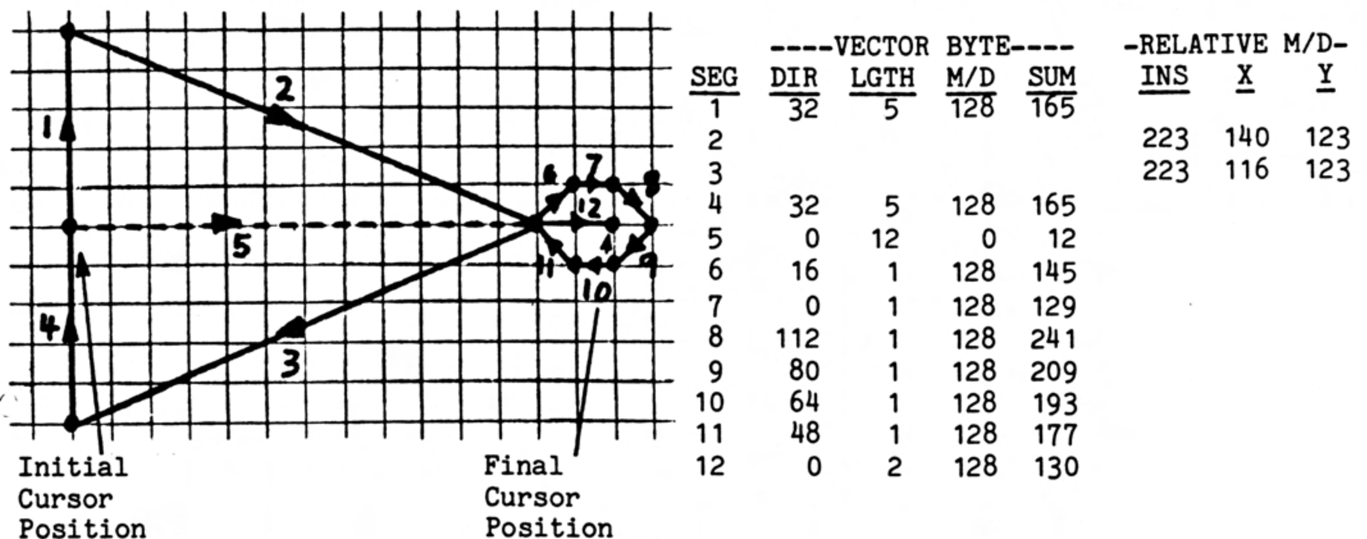
Note that an arrow is drawn over each line segment to indicate the direction of drawing and then each segment is given a number in order to avoid confusion. Next the direction number, length number, and move/draw number is computed for each segment. The actual sequence of vector bytes is the sum of the three numbers for each segment. Following the vector byte for the last segment is a zero byte to mark the end of the definition.

Note that a pair of moves is performed after the shape itself is drawn so that the cursor will be in position for the following character. If shapes are being defined for purposes other than text display, it probably will not matter where the cursor is left after drawing the shape. As an exercise, see if you can code the shape with fewer than 8 segments while maintaining the same final cursor position.

6.2.2 Relative Move and Draw Instruction Bytes

For larger shapes or shapes in which segments at odd angles are needed, relative move and relative draw instructions are available. Each of these are 3 bytes long. The first byte is a 223 for relative draw or 239 for relative move. The second byte is the X distance for the move/draw and the third byte is the Y distance. To allow moving or drawing in either direction, the number coded is the sum of the actual distance desired (within a range of -128 to +127) and 128. Thus if the cursor is to be moved 27 units to the left and 33 units upward, the entire instruction would be: 239,101,161 where the 239 is the relative move instruction code, the 101 is 128-27, and the 161 is 128+33.

Note that a shape table entry can be any mixture of vector byte instructions and relative move/draw instructions that may be appropriate. The example below shows how one might define a logic gate symbol with such a combination:



	----VECTOR	BYTE----			-RELATIVE	M/D-	
SEG	DIR	LGTH	M/D	SUM	INS	X	Y
1	32	5	128	165			
2					223	140	123
3					223	116	123
4	32	5	128	165			
5	0	12	0	12			
6	16	1	128	145			
7	0	1	128	129			
8	112	1	128	241			
9	80	1	128	209			
10	64	1	128	193			
11	48	1	128	177			
12	0	2	128	130			

6.2.3 Additional Instruction Byte Codes

Several additional instructions are recognized in a shape definition. Perhaps the most useful is the 47 instruction which allows the definition of another shape to be used as part of this shape definition. This is somewhat like a "graphics subroutine" and is most useful for shapes that have two or more identically shaped "appendages". Following the 47 instruction byte is the ID of the shape that is to be used as a "subshape". When using subshapes, the cursor position at the end of a subshape is crucial since the remainder of the "main" shape is influenced by it. A good convention to follow when defining shapes that will be used as subshapes is to make the final cursor position the same as the initial cursor position. Subshapes may be nested, that is, a subshape definition may itself call upon another subshape (which makes it a sub-subshape) ad infinitum. (The maximum nesting depth is determined by the length of the 6502 microprocessor's stack. A limit of 6 levels is reasonable.) The example shape definition below shows how subshapes can be used to shorten the definition of a logic OR-not gate symbol:

MAIN SHAPE DEFINITION

Seg	Vector Byte	Rel move/draw			Subshape	
	Sum	Ins	X	Y	Ins	ID
1					47	203
2	162					
3		223	127	131		
4					47	203
5		223	127	130		
6	136					
7		223	132	127		
8		223	131	127		
9		223	130	127		
10	241					
11		223	130	125		
12		223	126	125		
13	209					
14		223	126	127		
15		223	125	127		
16		223	124	127		
17	200					
18		223	129	130		
19					47	203
20		223	131	129		
21	162					
22		239	146	128		
		0				

INVERSION BUBBLE DEFINITION

203,177,193,209,241,129,145,0

A similar instruction is the 63 instruction. Following the 63 is a string of shape ID's terminated by a zero ID. This is most useful in saving space when defining a shape that is actually a sequence of shapes (such as the letters of a company logo). Don't forget the zero instruction byte to terminate the definition; the zero ID only terminates the 63 instruction.

There are three instructions that make it possible to change the character (shape) scaling, rotation, and the plotting mode. The 95 instruction will cause the next byte to be picked up, 128 subtracted from it, and the result added to the current character rotation parameter. The 175 instruction will cause the next byte to be picked up, 128 subtracted from it, and the result added to the current character scale parameter. And the 207 instruction will set the plotting mode to the value of the following byte if it is 0,1, or 2. If it is 255, then the plotting mode is flipped (mode 1 is changed to 2, 2 is changed to 1, and 0 remains 0).

The last two instructions are useful for debugging shape definitions or for maintaining "floating definitions" that are never really integrated into the KGL. The 79 instruction will cause the contents of a BASIC string variable to be used as a subshape definition. The two bytes following the 79 should be the ASCII code of the string variable's name. Remember that the subshape definition in the string variable must end with a zero byte. The 191 instruction is similar except that the actual memory address of the subshape definition (low byte first) follows the 191.

6.3 STORING SHAPE TABLE ENTRIES IN MEMORY

Now that we know what the byte values are for defining a shape, it is necessary to get them stored in a form that the KGL can use. In most cases the user will wish to add to the shape definitions already built into KGL so that the character plotting functions remain available. There are 593 bytes unused in the predefined KGL shape table that can be used for user shape definitions. This is enough for several dozen simple shapes or all of the examples given so far.

Three steps are necessary to add a shape definition to the shape table. The first step is to execute a CHINIT command followed by the number you wish to use as the ID of the new shape. The ID must be between 1 and 255 inclusive and should be an ID that is not already assigned to a character shape (if it is, that character shape will be effectively redefined). Currently unused ID's are: 1-10, 12, 14-16, 18, 21-28, 30-31, 124, 126-144, 146, 148-156, 158-159, 166-170, 172-176, 186-191, 200-239, 243-255. The second step is to enter a loop in which each byte in the shape definition is given as the argument of a CHDFC command. Thus if the shape requires 20 bytes (i.e., all vector bytes, relative move/draws, other instruction bytes, and the final zero) then the CHDFC command must be executed 20 times, once for each byte. The last step is to get the new definition added to the shape pointer table. This is accomplished by executing a CHBLD command which requires no arguments. Additional shapes may be added by following the preceeding three steps for each shape to be added.

As an example, lets add each of the 4 example shapes that have been discussed to the shape table. The BASIC program segment below will accomplish this:

```
100 DATA 166,132,230,51,65,132,1,99,0: REM FUNNY A
110 DATA 165,223,140,123,223,116,123,165: REM LOGIC INVERTER
111 DATA     12,145,129,241,209,193,177
112 DATA     130,0
120 DATA 47,203,162,223,127,131,47,203: REM OR-NOT GATE
121 DATA     223,127,130,136,223.132,127
122 DATA     223,131,127,223,130,127,241
123 DATA     223,130,125,223,126,125,209
124 DATA     223,126,127,223,125,127,223
125 DATA     124,127,200,223,129,130,47
126 DATA     203,223,129,131,162,239,146
127 DATA     128,0
130 DATA 177,193,209,241,129,145,0: REM INVERSION BUBBLE
200 CHINIT 200: REM DEFINE THE FUNNY A
210 FOR I=1 TO 9: READ A: CHDFC A: NEXT I
220 CHBLD
300 CHINIT 201: REM DEFINE THE LOGIC INVERTER
310 FOR I=1 TO 17: READ A: CHDFC A: NEXT I
320 CHBLD
400 CHINIT 202: REM DEFINE THE OR-NOT GATE
410 FOR I=1 TO 52: READ A: CHDFC A: NEXT I
420 CHBLD
500 CHINIT 203: REM DEFINE THE BUBBLE FOR THE OR-NOT GATE
510 FOR I=1 TO 7: READ A: CHDFC A: NEXT I
520 CHBLD
```

The following program segment will then use these definitions as part of a graphic image:

```
1000 CLR: GMODE 1: REM SETUP FOR DRAWING
1010 CHSCALE 1: REM DRAW LOGIC GATES TWICE NORMAL SIZE
1020 LINE 0,124,10,124: CHAR 201: DRAW 56,124: DRAW 56,154: DRAW 72,154
1030 LINE 56,199,56,174: DRAW 72,174
1040 LINE 0,164,10,164: CHAR 201: DRAW 74,164
1050 CHAR 202: DRAW 136,164: DRAW 136,140
1100 CHSCALE 0: REM DRAW LETTERS AT SMALLEST READABLE SIZE
1110 FOR I=156 TO 176 STEP 10
1120 MOVE 60,I: CHAR 200
1130 NEXT I
```

When debugging shape definitions it is important to realize that every time a definition is added to the shape table that an internal memory pointer is updated. Thus if a definition is added, checked, found to be in error, changed, and then added again, the old definition remains in memory taking up space. After enough iterations all of the memory available for shape table additions will be used up and error messages will begin to appear. To overcome this problem, execute a CSETUP and a CHINIT 0 command to reset the internal pointer and thus write over all of the previous user specified definitions.

6.3.1 Adding Shape Table Entries In the User's Own Memory

For some applications, the 593 bytes available in KGL memory may not be sufficient to hold all of the needed extra shape table entries. In this case it is possible to "steal" additional memory from BASIC to hold the definitions. The procedure below can be used to reserve the needed extra memory and then add definitions in that memory. This procedure should be done only after all necessary Libraries have been loaded in.

1. First execute the following statement to find the current top of memory:
   TB=PEEK(59)+PEEK(60)*256.

2. Next, compute what the new top of memory should be to reserve N bytes of memory for shape definitions. To do this, execute the following statement, replacing "N" with the number of bytes you wish to reserve: NT=TB-N-3. The extra 3 bytes specified is due to the fact that the CHDFC function writes three zero bytes in the shape table after each execution. Since the internal memory pointer isn't updated when these zero bytes are written, they will be overwritten if future CHDFC and CHINIT commands are executed. This is done to guarantee termination of your shape definition should you forget to include necessary zero bytes in the definition. This only guarantees termination of the definition, the shape will still not draw correctly if zero bytes are missing. The 593 bytes available in the KGL memory includes a subtraction for these three zero bytes.

3. Next, execute the following command to reserve the desired area of memory:
   POKE 60,INT(NT/256):POKE 59,NT-PEEK(60):CLEAR

4. Now, you tell the KGL that you wish to store future shape definitions in this reserved memory area by executing the command: CHDLOC NT

5. You may now add shape definitions in the same manner as in the previous section.

6. If you remember the value for TB above, you may determine the amount of memory you have left for shape definitions by executing the following statement:
   RDDLOC CL:PRINT TB-CL-3

7. ADDITIONAL USAGE INFORMATION

In this section will be found additional hints, usage information, and additional commands of use to advanced programmers.

7.1 HINTS FOR IMPROVING SPEED

The average user of the Keyword Graphics Package will quickly realize that the generally slow speed of interpreted BASIC really becomes noticable when hundreds or thousands of data points must be calculated to produce a single graph, family of curves, surface approximations of solid objects, etc. All of the techniques normally used for improving the speed of BASIC programs are equally applicable when KGP is being used.

If plotting time tends to dominate the program rather than computation (such as plotting from a list of precalculated values), plotting speed may be increased by turning boundary checking off with the NOCHK command. With boundary checking off, attempts to plot outside the window or screen boundaries may lead to strange-looking graphics on the screen. Enough residual checking is maintained however to prevent writing outside of the Visible Memory address range. Boundary checking may be restored with the BNDCHK command. See section 5.2 for additional information.

7.2 DEFAULTS

In order to simplify use by novices, the Keyword Graphics Library "comes up" in a usable state through the application of defaults. Thus every operating mode, parameter, etc. has an initial setting that is used in the absence of any commands to reset or change it. The theory behind defaults is that a novice user need not know or worry about a particular parameter until he has a need to use it. Below is listed the various KGL parameters and their default values:

1. Graphics scale factor is 2^0=1.0 which means that the graphic screen is 480 coordinate units wide by 256 coordinate units high.
2. Graphics X and Y offset values are both zero. This means that the origin is at the lower left corner of the screen and all X and Y values must be positive.
3. XFFLG set to 0 - coordinate transformation not done regardless of the graphics scale factor and offset settings.
4. Normal display mode - black background with white (green) plotting.
5. Plotting mode (i.e. GMODE) is set to 0 - Pixels are flipped when plotting, thus tiny gaps will appear where lines cross.
6. Boundary checking is disabled - plotting outside the boundaries may show on the screen.
7. Solid line mode is selected - all lines are shown as solid lines.
8. Window 0 is selected for use.
9. The boundaries of all windows are set for left=0, right=479, bottom=0, top=255.
10. CHROT is set to zero - all characters and shapes are right-side-up.

8. ERROR CODES AND MESSAGES

The KGL can detect when certain values are out of range, and in some cases, when parameters are missing. However, the majority of errors which occur during normal programming will be detected by the BASIC interpreter.

The error checking in the KGL is limited to checking if all the required parameters are present and if certain parameters are within the required range. If a parameter is missing, the KGL will give a SYNTAX ERROR message. If a parameter is out of range, the KGL will give an ILLEGAL QUANTITY ERROR message.

X and Y plotting coordinates outside of the current window boundaries is itself not an error. If boundary checking is on, points outside the window boundaries are simply not plotted. If boundary checking is off, such points will be transformed such that they _may_ be plotted but in an unexpected location. If an X or Y coordinate is beyond the two byte integer range of -32768 to +32767, then an ILLEGAL QUANTITY ERROR will be generated as described above. However, since the KGL uses signed integer arithmetic internally, line lengths must not exceed 16384 in either the x or y direction. Restricting coordinates to the range ±32767 avoids this problem.

9. LISTING OF KGPDM DEMONSTRATION PROGRAM

```
1 REM MTU GRAPHICS EXAMPLES
10 LIB "KGL"
200 REM DEMONSTRATION OF POINT PLOT
205 REM PLOT A CIRCLE IN CENTER OF THE SCREEN
210 CLR:REM CLEAR THE SCREEN
220 GMODE 1:REM PLOT ALL THE POINTS
230 FORI=0 TO 100
240 A=6.28318*I/100
250 MOVE 239*COS(A)+240.5,125*SIN(A)+126.5
270 WRPIX:REM PLOT THE POINT
280 NEXT I
290 GOSUB 9000
300 REM DEMONSTRATION OF VECTOR PLOT
310 REM SET MODES - ON,OFF,FLIP,FLIP
320 GM(1)=1:GM(2)=2:GM(3)=0:GM(4)=0
330 REM PLOT IN ALL 4 MODES
340 FOR MD=1 TO 4
345 REM CLEAR THE SCREEN BEFORE PLOTS 1 AND 3
350 IF MD=1 OR MD=3 THEN JE
360 TM=GM(MD):GMODE 1
365 AUTEXT 164;"GRAPHICS MODE";32;20;8;STR$(TM)
370 GMODE GM(MD)
380 FP=1:REM SET FIRST POINT FLAG
400 FOR I=0 TO 31
410 A=13*I*6.2831828/31
420 X=239*COS(A)+240.5
430 Y=125*SIN(A)+126.5
440 IF FP=1 THEN MOVE X,Y:FP=0:GOTO 470
450 DRAW X,Y
470 NEXT I
480 GOSUB 9000
490 NEXT MD
600 REM DEMONSTRATION OF AXIS PLOT AND LABEL
610 CLR:GMODE 1
620 REM INSERT Y AXIS LABELLING FIRST
630 DS=9:REM 9 DOTS BETWEEN LABELS
640 FOR Y=-10 TO 10 STEP 2
650 REM REPOSTION TEXT CURSOR
660 P=Y+10:REM P GOES FROM 0 TO 20
670 MOVE 0,P*DS+32
680 CHAR STR$(Y/10):REM PRINT THE LABEL
690 NEXT Y
700 REM PRINT X AXIS CAPTION
710 MOVE 49*6,90+32:CHAR "TIME"
730 REM PRINT Y AXIS CAPTION AND FIGURE CAPTION
740 MOVE 0,20:CHAR "AMPLITUDE      WAVEFORM OF "
750 CHAR "GREAT DIAPASON C4 16FT"
800 REM PLOT X AND Y AXES
820 LINE 20,125,284,125:REM HOR. ASIXIS
840 LINE 20,31,20,219:REM VERT. AXIS
900 REM PLOT TIC MARKS ON Y AXIS
910 FOR Y=-10 TO 10 STEP 2
920 P=Y+10:REM P GOES FROM 0 TO 20
930 Y1=P*DS+32+3
940 LINE 18,Y1,20,Y1
950 NEXT Y
1000 REM PLOT THE WAVEFORM USING VECTORS
1010 FP=1
```

```
1020 XF=270/(2*3.14159):REM X SCALE FACTOR
1030 YF=60:REM Y SCALE FACTOR
1040 FOR X=0 TO 2*3.14159 STEP 4*3.14159/270
1050 Y=SIN(X)+.49*SIN(2*X+3.9)+.3*SIN(3*X+5.81)
1060 Y=Y+.24*SIN(4*X+3.8)+.18*SIN(5*X+.97)
1070 Y=Y+.12*SIN(6*X+4.3)+.04*SIN(7*X+3.54)
1080 Y=Y+.07*SIN(8*X+.87)+.03*SIN(9*X+5.3)
1085 X1=20.5+XF*X:Y1=125.5+YF*Y
1090 IF FP=1 THEN MOVE X1,Y1:FP=0:GOTO 1130
1100 DRAW X1,Y1
1130 NEXT X
1140 GOSUB 9000
2000 REM EXAMPLE OF USING WINDOWS
2005 REM SETUP THE WINDOWS
2010 RVSDSP:CLR:NRMDSP
2020 W$="WINDOW":GMODE 1
2030 SETWIN 0,8,8,223,170
2035 WINDOW 0:WCLR:CHAR W$;STR$(0)
2040 SETWIN 1,240,9,311,90
2045 WINDOW 1:WCLR:CHAR W$;STR$(1)
2050 SETWIN 2,240,100,311,171
2055 WINDOW 2:WCLR:CHAR W$;STR$(2)
2060 SETWIN 3,24,180,295,195
2065 WINDOW 3:WCLR:CHAR W$;STR$(3)
2070 GOSUB 9000
2100 REM INITIALIZE ROUND-ROBBIN USE OF THE WINDOWS
2110 S0=1:S1=1:S2=1:S3=1:C1=0:C2=0:C3=0
2120 D3$="         THIS DISPLAY IS BROUGHT TO YOU BY"
2130 D3$=D3$+" THE MTU KEYWORD GRAPHICS LIBRARY "
2140 I3=6
2150 I2=65:WINDOW 2:WCLR:MOVE 309,108
2160 I1=32:WINDOW 1:WCLR
2170 I0=0
2180 WINDOW 0:MOVE 115,89:DS=0
2200 REM BEGIN ROUND-ROBBIN USE OF THE WINDOWS
3000 IF S0=0 GOTO 3100
3010 WINDOW 0:REM DRAW LINES
3020 GMODE 1
3030 RDXY X,Y
3040 DS=DS+1
3050 DR=DR+1:IF DR=4 THEN DR=0
3060 IF DR=0 THEN JD X+DS,Y:GOTO 3080
3065 IF DR=1 THEN JD X,Y+DS:GOTO 3080
3070 IF DR=2 THEN JD X-DS,Y:GOTO 3080
3075 IF DR=3 THEN JD X,Y-DS
3080 I0=I0+1:IF I0=100 THEN S0=0
3100 IF S1=0 GOTO 3200
3110 WINDOW 1:REM PRINT CHARACTER SET
3120 AUTEXT I1:I1=I1+1
3130 IF I1=127 THEN I1=32:C1=C1+1
3140 IF C1=2 THEN S1=0
3200 IF S2=0 GOTO 3400
3210 WINDOW 2:REM PRINT UPSIDE-DOWN
3220 CHROT 2:REM SET FOR UPSIDE-DOWN
3230 RDXY X,Y
3240 IF X<246 THEN GOSUB 3300
3250 CHAR I2:I2=I2+1
3260 IF I2=96 THEN I2=64:C2=C2+1
3270 IF C2=8 THEN S2=0
3280 CHROT 0:RESTORE
```

```
3290 GOTO 3400
3300 IF S0=0 GOTO 3100
3310 IF Y<171-12 GOTO 3330
3320 Y=Y-10:SCROLL 240,100,240,110,311,171
3330 MOVE 308,Y+10
3340 RETURN
3400 IF S3=0 GOTO 3480
3410 WINDOW 3:REM HORIZONTAL SCROLLING
3420 SCROLL 24,180,32,180,295,195
3430 MOVE 288,185
3440 CHAR MID$(D3$,I3,1)
3450 I3=I3+1
3460 IF I3=LEN(D3$)+1 THEN I3=1:C3=C3+1
3470 IF C3=2 THEN S3=0
3480 IF S0=1 OR S1=1 OR S2=1 OR S3=1 GOTO 3000
3490 GOSUB 9000
4000 REM DO CHECKERBOARD
4010 NRMDSP:CLR
4020 GMODE 1
4030 FOR I=0 TO 479 STEP 40
4040 FOR J=0 TO 249 STEP 25
4050 FLPDSP
4060 SCLR I,J,I+39,J+24
4070 NEXT J
4080 FLPDSP
4090 NEXT I
4100 REM DO THE ROAMING "X"
4110 NRMDSP:GMODE 0
4120 SETWIN 0,0,0,479,249:WINDOW 0
4130 MOVE 160,100
4140 MD=ASC("3")+128:REM MOVE DIRECTION
4150 C=ASC("X"):BS=8:REM BACKSPACE
4160 CHAR C
4170 REM MAIN LOOP
4180 CHAR BS:RDPIX PX
4185 IF PX=255 THEN GOSUB 4300
4190 CHAR C:CHAR BS:REM ERASE
4200 CHAR MD;MD;MD;MD;MD;MD:REM MOVE
4210 CHAR C:REM DRAW AGAIN
4240 FOR I=1TO10:NEXT I:IF KEY=0  GOTO 4180
4250 GOSUB 9000
4260 SETWIN 3,0,0,479,255:WINDOW 3:AUTEXT 164
4270 WINDOW 0
4280 LEGEND 1,"","","","","","","","":END
4290 REM END OF DEMO
4300 RDXY X,Y:REM AT BORDER, CHANGE DIRECTION
4310 IF X>=0 GOTO 4340
4320 IF MD<=183 THEN MD=MD+2:RETURN
4330 MD=182:RETURN
4340 IF X<480 GOTO 4370
4350 IF MD>=179 THEN MD=MD-2:RETURN
4360 MD=180:RETURN
4370 IF Y>=0 GOTO 4400
4380 IF MD<=179 THEN MD=MD+6:RETURN
4390 MD=184:RETURN
4400 IF Y<250 THEN RETURN
4410 IF MD>=183 THEN MD=MD-6:RETURN
4420 MD=178:RETURN
9000 FOR DL=0 TO 1000:NEXT DL:REM PAUSE
9010 RETURN
```

10.1.2 Screen Clearing Commands

SECTION	COMMAND FULL	COMMAND SHORT	PARAMETERS	DESCRIPTION
4.1.2	CLR	⊐E	none	Clears the Visible Memory contents, i.e., turns all the dots off (black) regardless of the current background color.
4.1.2	SCLR		X_1,Y_1,X_2,Y_2	Clears the specified region of the Visible Memory. When clearing, X_1 and X_2 are rounded to include the whole byte which the coordinate occupies. The coordinates X_1,Y_1,X_2,Y_2 must specify diagonal corners of the region. Also, if X_1 or X_2 is outside the range 0-479, it will be forced to the nearer limit. The same will occur for Y_1 and Y_2 for the range 0-255. After execution, the DRAWING CURSOR coordinates should be considered undefined.
5.5.3	WCLR		none	Performs a "home-clear" on the current window. As in the SCLEAR command, rounded values will be used for the left and right boundaries when the window is cleared. The WCLEAR command also turns boundary checking on.
5.5.3	SCFLIP		X_1,Y_1,X_2,Y_2	Flip the specified region of the Visible Memory. This command operates exactly the same as the SCLEAR except the region is flipped instead of cleared.

10.1.3 Boundary and Window Commands

SECTION	COMMAND FULL	COMMAND SHORT	PARAMETERS	DESCRIPTION
5.2.1	SETWIN		I,Xmin,Ymin, Xmax,Ymax (I=0,1,2,or 3)	Creates new window I boundary values in memory. These values will be forced to the range 0-479 for Xmin and Xmax, and 0-255 for Ymin and Ymax. If outside the valid range, the value will be set to the nearer limit. If I is the same as current window, the current window is updated. The command also turns boundary checking on. After execution, the DRAWING CURSOR for this window should be considered undefined.
5.2.1	WINDOW		I (0,1,2,or 3)	Makes window "I" the current window and turns on boundary checking. It saves the current DRAWING CURSOR coordinates for future recall of the previous window, and restores the DRAWING CURSOR coodinates to those previously saved for this window. The default window is 0, with default boundaries for all the windows of 0,0,479,255. The initial DRAWING CURSOR coordinates will be 0,0 for all windows.
5.2.2	BNDCHK		none	Turns boundary checking on.
5.2.2	NOCHK		none	Turns boundary checking off.

SECTION	COMMAND FULL	COMMAND SHORT	PARAMETERS	DESCRIPTION
4.2.2	WRPIX	]W	none	Write the pixel (dot), at the drawing cursor coordinates. What happens to the point is determined by the graphics mode (GMODE). The transformed drawing cursor location will be written if XFFLG =1.
5.5.1	RDPIX		var	Reads the state of the pixel (dot), at the drawing cursor coordinates. The variable "var" will be set to 1 if the point is white, to 2 if it is black, to 255 if it does not lie within the Visible Memory address, or within the current boundaries if boundary checking is on. The transformed drawing CURSOR location will be read if XFFLG = 1.
4.2.3	LINE	]L	X_1,Y_1,X_2,Y_2	Draw a line from X_1,Y_1 to X_2,Y_2. The coordinates will be transformed if XFFLG=1. After execution the drawing cursor will contain X_2,Y_2.
4.2.1	MOVE	]M	X,Y	Sets the drawing cursor to X,Y
4.2.3	DRAW	]D	X,Y	Draw a line from the drawing cursor coordinates to X,Y. The coordinates are transformed if XFFLG = 1. After execution the drawing cursor will contain X,Y
5.5.2	DOTL		$bval_1,bval_2$ (0 to 255)	Sets parameters for dotted lines. Lines will then be drawn with $bval_1$ dots drawn according to the graphics mode, followed by $bval_2$ dots drawn invisibly. If $bval_2$ is zero, lines will be solid. The default value for $bval_1$ is 0.
5.1.3	XFFLG	]F	I (0 or 1)	Enables and disables coordinate tranformations. 0 = transformations off; 1 = transformations on. The default value is 0. The transformation formulas are: X=Xshift+X*2↑Xscale Y=Yshift+Y*2↑Yscale After turning coordinate transformations on or off, the DRAWING CURSOR should be considered undefined.
5.1.1	OFFSET		X,Y	Sets Xshift to X and Yshift to Y.
5.1.2	SCALE		Xval,Yval (-128 to +127)	Sets Xscale to Xval and Yscale to Yval.

SECTION	COMMAND FULL	COMMAND SHORT	PARAMETERS	DESCRIPTION
4.3	CHAR	C	bval or str (0 to 255)	Displays character whose value is bval, or displays the characters in string "str". Drawing of the character, or characters, will begin at the drawing cursor position.
5.4	AUTEXT	A	bval or str (0 to 255)	Displays character whose value is bval, or displays the characters in string "str". This command is intended for horizontal printing of text. It also performs "CR-LF" and vertical scrolling as needed to keep the displayed characters within the current boundaries.
5.1.4	CHSCALE		val (-128 to +127)	Sets the character scaling parameter, chscale, to val. This parameter will also take effect when "CR-LFs" and scrolls are performed. Character size = normal size*2↑chscale. The default value is 0.
5.1.4	CHROT		val (-128 to +127)	Sets the base line orientation parameter, chrot, to val. Character rotation = chrot*90 degrees. The default value is 0.
5.5.3	SCROLL		Xt,Yt,X_1,Y_1,X_2,Y_2	Move the X_1,Y_1 corner of the region X_1,Y_1,X_2,Y_2 to Xt,Yt. The coordinates X_1,X_2, and Xt will be rounded to include the whole byte which the coordinate occupies. The coordinates X_1,Y_1,X_2,Y_2 must specify diagonal corners of the region. The X_1 and X_2 coordinates will be forced within the range 0-479, and Y_1 and Y_2 will be forced within the range 0-255. After execution, the DRAWING CURSOR should be considered undefined.

10.1.6 Cursor Commands

SECTION	COMMAND FULL	COMMAND SHORT	PARAMETERS	DESCRIPTION
5.3	GRACSR	]G	none	Draws the cross-hair graphics cursor at the DRAWING CURSOR coordinates. If XFFLG = 1, then the cursor will be displayed at the transformed coordinate position. The cursor will always be drawn in flip mode, so drawing it a second time makes it disappear.
5.3	TEXCSR	]T	none	Draws the underline text cursor at the DRAWING CURSOR coordinates. The cursor will always be drawn in flip mode, so drawing it a second time makes it disappear.
5.3	RDCSR		Xvar,Yvar	Reads the transformed values of the drawing cursor coordinates into variables "Xvar" and "Yvar", if XFFLG =1. If XFFLG = 0, then it reads untransformed values.
	RDXY		Xvar,Yvar	Reads the drawing cursor coordinates into variables Xvar and Yvar.

SECTION	COMMAND FULL	COMMAND SHORT	PARAMETERS	DESCRIPTION
6.3.1	CHDLOC		val	Sets the internal memory pointer to val. This determines where bytes entered with the CHINIT and CHDFC commands are stored.
	CHTLOC		val	Sets the beginning address of the shape pointer table. The table occupies 512 bytes and contains pointers to each character definition that has been built with CSETUP or CHBLD commands. The default value is the address of the default character table.
6.3.1	RDDLOC		var	Reads the current value of the internal memory pointer into variable "var".
	RDTLOC		var	Reads the beginning address of the current shape pointer table into the variable "var".
6.3	CHINIT		bval (0 to 255)	establishes "bval" as the character being defined. The byte "bval" is stored in the shape table and the memory pointer is incremented by 1. If bval is non-zero (1-255), then DEFINITION MODE is ENABLED. If bval=0 (CHINIT 0), then DEFINITION MODE is DISABLED. The command also stores 3 zero bytes after bval to guarantee the definition is terminated.
6.3	CHDFC		bval (0 to 255)	If the definition mode is enabled, bval is stored in the shape table and the memory pointer is incremented by 1. The successive values entered for bval may comprise one or more definitions. The command also store 3 zero bytes after bval to guarantee the definition is terminated.
6.3	CHBLD		none	If the definition mode is enabled, the definitions from the most recent CHINIT command are built into the current shape pointer table.
6.4	CSETUP		none	Clears the current shape pointer table, and builds the default set of definitions. After execution, the drawing cursor should be considered undefined. Also after execution the X coordinate read by RDCSR will give the starting location of the default shape definitions.
6.4	CHRESET		none	Clear the contents of the current shape pointer table by setting all the pointers to zero. This unbuilds, or resets all shape definitions. It leaves the actual shape definitions unchanged.

10.2 SPECIAL FUNCTION CHARACTERS

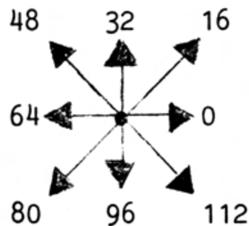
The following function characters are recognized in the character strings given to the CHAR command or the AUTEXT command:

CHAR CODE OR FUNCTION	ASCII CODE (DECIMAL)	DEFINITION
ERASE	20	Erase the character at the current character position.
Vert. Tab	11	Move cursor up one line.
Line Feed	10	Move cursor down one line.
Hor. Tab	9	Move cursor right one character position.
Backspace	8	Move cursor left one character position.
ASC("1")+128 to ASC("9")+128	177-185	Move one dot position in direction the digit is from 5 on a numeric pad. 7 8 9 / 4 5 6 / 1 2 3
ASC("D")+128	196	Add one to CHSCALE, i.e. double the current character size.
ASC("E")+128	197	Subtract one from CHSCALE, i.e. halve the current character size.
ASC("F")+128	198	Add one to CHROT, i.e. rotate orientation 45 degrees counterclockwise.
ASC("G")+128	199	Subtract one from CHROT, i.e. rotate orientation 45 degrees clockwise.
ASC("%")+128	165	Draw the contents of BASIC string variable GR$ as a definition, i.e. contains vector bytes, etc. The definition contained in GR$ MUST end in a zero byte!
Delete	127	Backspace and erase one normal size character. Will not erase scaled characters properly.
Up-arrow	160	Move cursor up one line.
Left-arrow	161	Move cursor left one character position.
Right-arrow	162	Move cursor right one character position.
Down-arrow	163	Move cursor down one line.
Form Feed	12	AUTEXT only. Clears the region specified by the current boundaries, and then homes the drawing cursor coordinates.
Home	164	AUTEXT only. Homes the drawing cursor coordinates.
RETURN	13	AUTEXT only. Performs a carriage return followed by a line feed.

10.3 CHARACTER DEFINITION INSTRUCTIONS

The following instructions are recognized inside of a shape definition:

SECTION	CODE	OPERANDS	DESCRIPTION
6.2.2	239	A,B	Add A-128 to X cursor position and add B-128 to Y cursor position
6.2.2	223	A,B	Draw a line from the current cursor position to A-128+Xcursor,B-128+Ycursor then update the cursor position.
6.2.3	47	ID	Draw the shape specified by the ID at the current cursor position. The shape itself may use a 47 instruction.
6.2.3	63	ID,ID,...,0	Draw the series of shapes specified by the ID's at the current cursor position. The shapes may themselves use a 63 or 47 instruction.
6.2.3	95	val	Add val-128 to the present value of CHROT. Result should lie in the range of 0-3.
6.2.3	175	val	Add val-128 to the present value of CHSCALE.
6.2.3	207	val	Set gmode to val, where val=0,1,2. If val=255, then flip gmode (1 becomes 2, 2 becomes 1, and gmode 0 remains gmode 0).
6.1	0		End of shape definition
6.2.1	Legal Vector Bytes		The vector byte is simply the sum of the three numbers calculated according to the chart below:

DIRECTION NUMBER	LENGTH NUMBER	MOVE/DRAW NUMBER
	Specifies length of move or draw. This number may be from 0 to 14.	Is 0 for move. Is 128 for draw.

10.4 COMMANDS WHICH LEAVE THE DRAWING CURSOR UNDEFINED

SCLR
SCFLIP
SETWIN
SCROLL
CSETUP
XFFLG
OFFSET if XFFLG is 1