THE DIGIGRAPHIC DISPLAY PROGRAM

FOR THE DX-1 COMPUTER SYSTEM

adams associates

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by

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ABSTRACT

The Digigraphic Display Program for the DX-1 computer system utilizes a buffered display scope, light pen and push-button panel to provide the console user with the basic ability to draw charts, diagrams, curves, etc. on the face of the display scope. The drawings may contain graphic and alphanumeric information, which is reduced to a condensed digital format called an Entity Table. The Table can be operated on by special-purpose software routines either during the drawing action or after it is completed.

Certain man-machine programming techniques have been designed to accelerate the manual task of drawing (or drafting). The console user may draw points, lines, circles, arcs, and freehand or third-degree curves. Distances and angles may but need not be specified. Subdrawings or copies of them may be moved about, rotated or reflected; angles and distances may be queried, and drawn dimensions can be generated on the drawing itself.

DX-1 CONSOLE CONFIGURATION
FOR DIGIGRAPHIC DISPLAY PROGRAM

CONTENTS

Figures

I. PROGRAM AND SYSTEM

Function of Program

The Digigraphic Display Program (DDP) was designed to enable a console user to introduce to a computer graphic and alphanumeric information which can be displayed without flicker and stored in memory in condensed digital form. The program itself facilitates the preparation and digitation of all types of charts and drawings. However, the digital description of the graphical data can be used by other software routines either during or subsequent to the actual drawing process. DDP is an improved version of a program written by Charles W. Adams Associates as part of a joint project with the Itek Corporation.

System Components

The DX-1 system consists of a standard 4K PDP-1 computer, a display scope and four magnetic-tape units with type 52 control (all developed and manufactured by Digital Equipment Corporation); a Bryant magnetic drum; a flicker-free display processor and a fiber optics cable light pen (both developed by Itek Corporation and now being produced by Control Data Corporation); and a push-button control panel with two foot pedals (suggested by Adams Associates and Itek Corporation and produced by the DX-1 engineering staff).

The computer has an information exchange buffer which permits communication with another 4K PDP-1, the latter having a color display scope and light pen. An additional 4K core bank as well as the tape units and controls can be attached to either computer. While only the first computer can presently use the magnetic drum and flicker-free display processor, equipment now on order will provide the second computer with access to the drum and a flicker-free display processor for the color display scope. DDP currently restricts itself to the first computer (see Figure 1 on page 2), but the program will be modified for use by the second computer and its color scope.

As shown in the figure, the 15 spring-loaded buttons on the control panel, the push button mounted on the light pen, and the two foot pedals are connected in parallel to the 18-toggle-switch test word of the first computer.

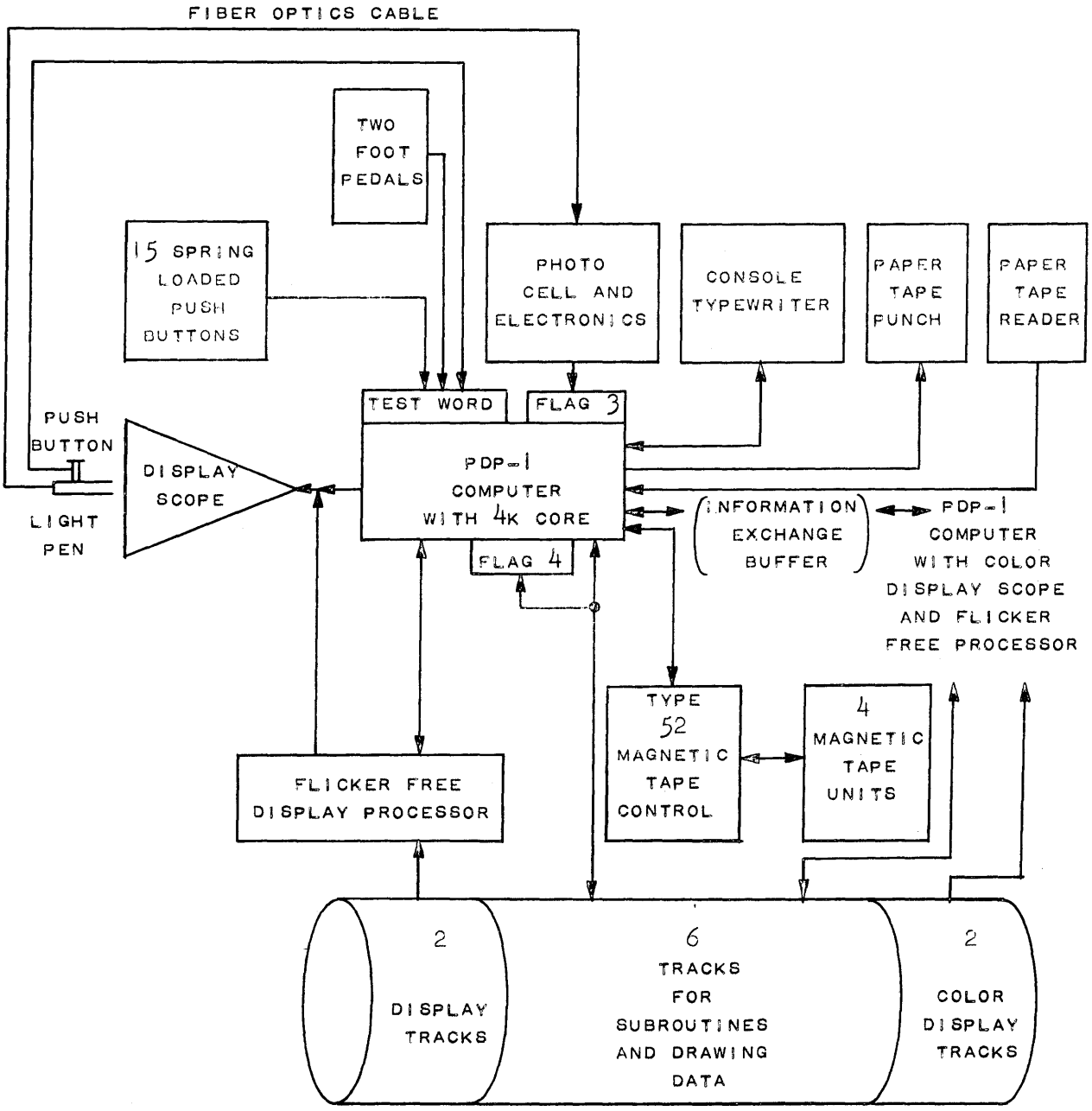


Figure 1

DX-1 EQUIPMENT USED BY
THE DIGIGRAPHIC DISPLAY PROGRAM

The flicker-free display processor was described in a paper by Earle W. Pughe, Jr. at the 1962 DECUS meeting. However, to those not present at that meeting the following abstract of Mr. Pughe's paper may be of interest:

> The Itek Flicker Free Display displays line drawings on a 10" x 10" scope 30 times a second with a maximum total line length of 600 inches. The Display is controlled from a Texex disc through logic which controls the beam. There are about 20 instructions used to control the display. When the display is to be changed, new instructions are put on the disc by a block transfer from the PDP, otherwise the computer is not needed for the display.

It should be noted that the Telex disc is a Bryant drum in the DX-1 system, and that the four-bit byte instructions referred to by Mr. Pughe are now six-bit bytes stored on the 20,000-byte display track. The change from four- to six-bit byte logic and the longer drum display track have increased the drawing capacity to approximately 2,000 linear inches. However, to accomodate extremely crowded drawings, a new six-bit byte instruction has been added to permit the use of two display buffer tracks rather than one whenever necessary. While the reduction of the repetitive cycle in this case to 15 times a second produces a flickering effect, it was done to avoid losing any display information.

The drum consists of ten tracks, each containing twenty sectors with 1,000 bytes in every sector. (A byte is composed of six bits of data and a drum parity bit.) While reading or writing is begun at the start of a sector, the length of the block of information transmitted is variable.

The display scope has a useable area of 10" x 10", the bottom 2" of which are used to provide numerical display registers and a series of displayed points utilized as control buttons (called light buttons). A plastic template is used to label the points and registers. The original preference for light buttons over an additional set of push buttons was influenced by the versatility of the former in changing the number and configuration of control buttons. The light buttons will be replaced by hardware, however, as soon as DX-1 users have had sufficient experience to finalize the design.

Geometric Digital Description of Drawing

Drawings are made of different figures combined to effect the desired representation. DDP can produce standard figures and manipulate them in various ways. To do so, each item of the drawing, referred to as an entity, is stored internally in digital form and oriented on a 2^{18} grid, the smallest increment of which represents $2^{-5} \times 10^{-2}$ or .0003125 paper inches, and the maximum spread of which is $2^{13} \times 10^{-2}$ or 81.92 paper inches. Since actions are performed in terms of entities, the functions will be described in these terms.

The types of entities that can be produced are:

Point	Used for reference, centers of circles, etc.
Line	Used as part of the drawing, guide lines, etc. (Note: DDP distinguishes between horizontal, vertical and slanting lines, but the user need not concern himself with this capability.)
Circle	Used in various ways.
Curve	Third-degree curve or curves defined by a series of points. (Note: a freehand poly-string of lines can be replaced by a series of third-degree curves to produce a smoother representation.)
Arc	Parts of circles.
Polygon	Regular polygon of three to fifteen sides. (Note: A polygon entity need not close in the DX-1 system. In fact, this entity is used in freehand drawing to represent a series of points connected by straight lines, commonly called a freehand poly-string of lines.)
Dimensions	Lines, arrow heads and numbers used to show dimensions.

Remarks	Text attached to a drawing as a note or explanation, composed of letters, numbers, punctuation and special characters.
Grid	A matrix of points whose location, density, number, individual values and maximum time are specified.

As a drawing is prepared, each entity is assigned an identifying subdrawing number, called a group number. This number can apply to one entity or to a number of entities which are to be treated in a similar manner. While each entity may have only one group number assigned to it, the entity may be reassigned if required or desired. The numbers 0 to 63 may be used for group numbers.

II. MAN-MACHINE CONTROL

Push Button Keyboard

There are basically two modes of light-pen operation: using the pen as a pointer, and using it as a pencil. If the user wants to point at an existing figure on the display scope, there is no need for tracking the pen. Rather, the light-pen flip-flop is monitored and, when a light response occurs, the position of the drum display track is queried. DDP is capable of determining from the track position which graphic entity has been touched by the pen.

If the user wishes to point at a position on the scope where there is no data, he must guide DDP to the position by using a light-pen tracking cross (developed, as far as the author knows, by Roland Silver). The tracking cross is also used for continuous pointing, i.e., using the pen as a writing pencil, and also for showing the movement of a subdrawing.

One of the two foot pedals is used to indicate whether the pen is to be used as a passive pointer or tracked for writing or moving. The two routines that control these actions are called Pick and Sketch, respectively.

The spring-loaded push buttons are used to further describe the light-pen action. Since there are only 15 buttons, an upper- and a lower-case function assignment was adopted. The Sketch functions are labeled on the top of the buttons and the Pick functions on the bottom. Each button has a red and a blue light behind it which indicate the function in use. A diagram of the push-button keyboard is shown in Figure 2 at the top of page 7.

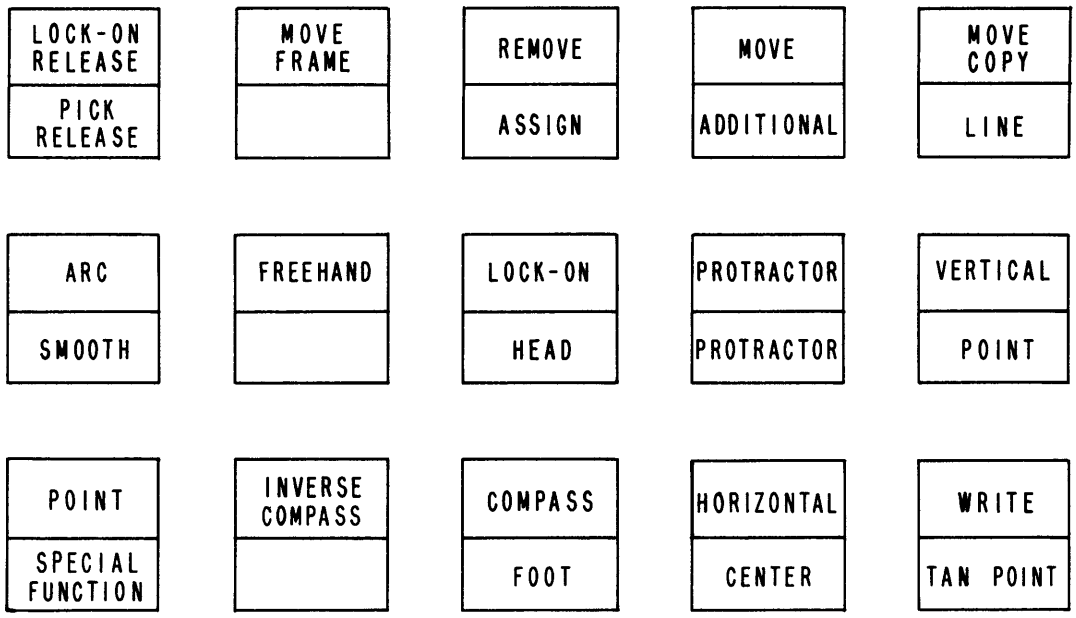


Figure 2

PUSH BUTTON KEYBOARD

Pick Push Buttons

The following pointing capabilities are currently provided by the Pick routine:

Pick a point
Pick an additional point
Pick a center point
Pick an additional center point
Pick a tan point
Pick an additional tan point
Pick a line
Pick an additional line
Pick a center line
Pick an additional center line
Pick the head point of a protractor straight edge angle (This can be the point on any graphic entity.)

Pick the foot point of a protractor straight edge angle (When the head and foot have been selected, the protractor straight edge angle will be set according to the angle from the foot point to the head point.)

Pick the protractor straight edge angle of a line (This angle will be set according to the angle of the line and its direction when originally drawn.)

Pick an entity and assign to it the logical group number displayed in the Group Number Register.

The PICK RELEASE push button is used to cancel or change a picking operation. The SMOOTH and SPECIAL FUNCTION push buttons are not associated with Pick.

Before proceeding, it should be made clear that the push button on the light pen sets a bit in the test word of the computer which, in effect, provides a logical shutter to the pen. The opening and closing of the shutter is achieved by depressing and releasing the light-pen push button.

In all the Pick functions listed above, the Pick program initializes a picking operation if any push button or combination of buttons is depressed at the moment the pen shutter is opened. The monitoring of the light pen and the entity being touched continues as long as the button is depressed. To assure the user that he is pointing at the desired entity, Pick intensifies the entity by displaying it directly from the computer. If a point is being picked, the entity being pointed at will be intensified and Pick will choose the point on that entity which is closest to the center of the aperture of the pen. (The one exception is that if the point is within a fixed position from the end point of a line, the end point will be chosen instead.) If the pen shutter is closed, Pick will intensify only the current point. Reopening the shutter allows the user to choose a different point.

Once a selection has been made of the desired point or line (the latter in this case being a locus of points and either straight or curved), the push button (or buttons) is released and that point or line will be remembered by the program. In the case of HEAD, FOOT, PROTRACTOR, and ASSIGN, the actions indicated will be carried out.

To remind the user that a given point or line is currently being remembered by the program, a temporary symbol is displayed next to the point or line. Each kind of Pick action has its own symbol. These remembered points and lines are used by a set of Construct routines which are described later.

Sketch Push Buttons

Except for two situations, lock-on and remove, Sketch assumes that the light pen is to be tracked if its shutter is open. Whenever the shutter is opened, Sketch will display the last center point of the aperture of the pen. If the pen is no longer over the point, Sketch will monitor the shutter and continue to display the point brightly until the user positions the pen over the spot or closes the shutter.

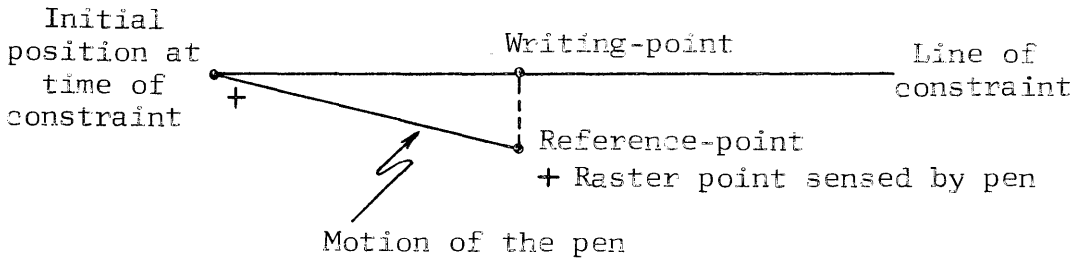
Once the pen has been positioned over the previous center point, a Roland Silver tracking cross is used to continually determine the new center position of the aperture. A pen position prediction routine was not used because, there being only one buffered scope, there is presently no need to use the computer for anything except tracking. The tracking cross, moreover, is displayed directly from the computer and cuts out the buffered display data; consequently a random interval between tracking crosses is required to allow all of the buffered display to appear on the scope (at the reduced rate of 25 times per second). Pen tracking currently uses about 15 percent of the computer time, the remainder being idle.

All Sketch tracking operations use a writing-point and a reference-point which are initially superimposed and displaced 1/4" above and to the left of the center of the tracking cross. The coordinates of the writing-point are those used to determine the end points and parameters of an entity. The reference-point is used as a guide under certain circumstances.

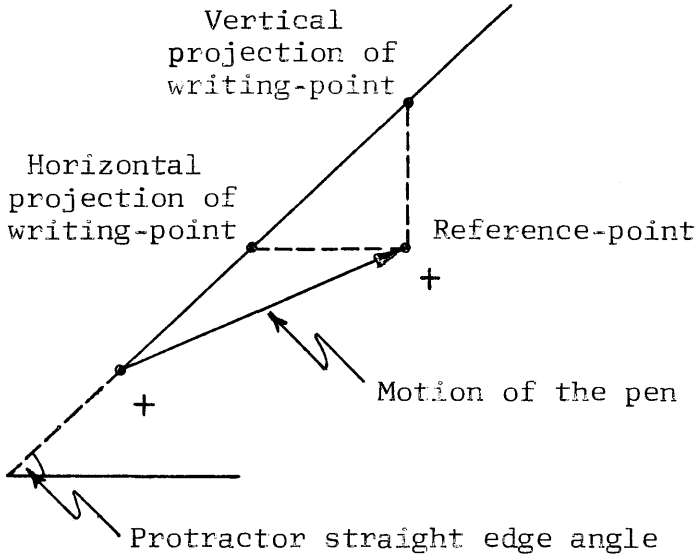
Since it is desirable to simulate a straight edge, there are three push buttons that provide constrained tracking horizontally, vertically, and according to a protractor straight edge setting. This means that the writing-point will be constrained whenever one of these

three constraint buttons is depressed. Thus the reference-point and the writing-point separate from each other, the reference-point remaining in the same relative position from the tracking cross while the writing-point is constrained to some angle of motion.

During horizontal tracking, as shown in the diagram below, the writing-point will continue to have the same y coordinate that it had at the time the HORIZONTAL push button was depressed. Its x coordinate will be the same as the x coordinate of the reference-point. The reverse is the case in vertical tracking.



In protractor-constrained tracking, an illustration of which appears at the top of page 11, the writing-point will be constrained to move along a path whose slope is the same angle as the protractor straight edge angle and which passes through the original coordinates of the writing-point at the time the PROTRACTOR push button was depressed. The writing-point may be positioned on the protractor-constrained path either by a horizontal or vertical projection of the reference-point onto the path line. Since both situations are desired, the HORIZONTAL and VERTICAL push buttons have an auxiliary function of allowing the user to switch from one to the other projection while keeping the PROTRACTOR push button depressed.



The reference-point in the two illustrations above greatly reduces the need for guide lines. Furthermore, the ability to interrupt tracking long enough to use the pen as a pointer for the reference-point provides an effective drawing ability. This is done by depressing the LOCK-ON push button, which causes the Pick routine to be activated in choosing an existing point on the drawing.

As soon as the LOCK-ON push button is released, Sketch is reactivated, the reference-point is given the new coordinates of the picked point, and the writing-point is repositioned according, first, to the constraints (if any) imposed on it and, second, the coordinates of the reference point.

One final note on constrained tracking: when a constraint push button is released, the reference-point is repositioned to the coordinates of the writing-point, and the tracking cross is repositioned according to the new position of the reference-point. At times this snaps the tracking cross out from under the pen and forces the user to reposition his pen. This is done so that he will begin tracking again from the last mathematical point of the previous constraint.

Briefly, the functions of the remaining push buttons for Sketch are:

WRITE	To draw all straight lines
POINT	To draw points
COMPASS	To draw circles (The initial point is the center and the last point on the periphery.)
INVERSE COMPASS	To draw circles (The initial point is on the periphery and the last point on the center.)
ARC	To draw arcs (Two straight lines originating at the center are used, like the hands of a clock, to specify an arc.)
FREEHAND	To draw freehand curves (A string of connected points, the density of which is proportional to the tracking speed.) Note: Immediately after the curve has been drawn, it can be smoothed by releasing the Sketch foot pedal and then depressing the SMOOTH push button. The curve will then be replaced by a series of third-degree curves, thus producing a much smoother curve. The amount of smoothing required will depend upon the density of points defining the curve.
MOVE MOVE COPY	To move entities having a common group number or a copy of them
REMOVE	To remove an entity, the pen being used as a pointer
MOVE FRAME	To select a new view of the drawing in the frame, which can be moved about regardless of size (When this push button is released, the new view in the frame is recalculated and displayed.)

SKETCH DIMENSIONS	To permit the user, through the use of the second foot pedal, to see the length and angle of the lines being generated in the Sketch mode (If desirable to restrict the length of unhooked lines to a specific tolerance, say, 1/8", the tolerance is keyed in and the user will not draw an unhooked line whose fraction is other than a multiple of an eighth.)

Light Button Display Panel

If all push buttons and foot pedals are in the release position and the light-pen shutter is open, the light button display panel is turned on and displayed directly from the computer. The basic philosophy in light-pen operation in this case is that the last light-button point seen by the pen prior to the closing of the pen's shutter will be the button to be activated.

The functions of the registers and light buttons illustrated in Figure 3 on page 14 are described briefly below:

Left half of panel

MESSAGE Register	For passing comments to the user; for example, the word MORE is displayed if parameter data is insufficient.
PROTRACTOR STRAIGHT EDGE INDICATOR	Displays a small vector line in the circular cut-out of the template to indicate the angle of the protractor straight edge.
ANGLE Register LENGTH Register TOLERANCE Register X-COMPONENT Register Y-COMPONENT Register	These are display registers used to show numerical values. The light buttons to their left are used to prevent the contents of these registers from being cleared after an operation.

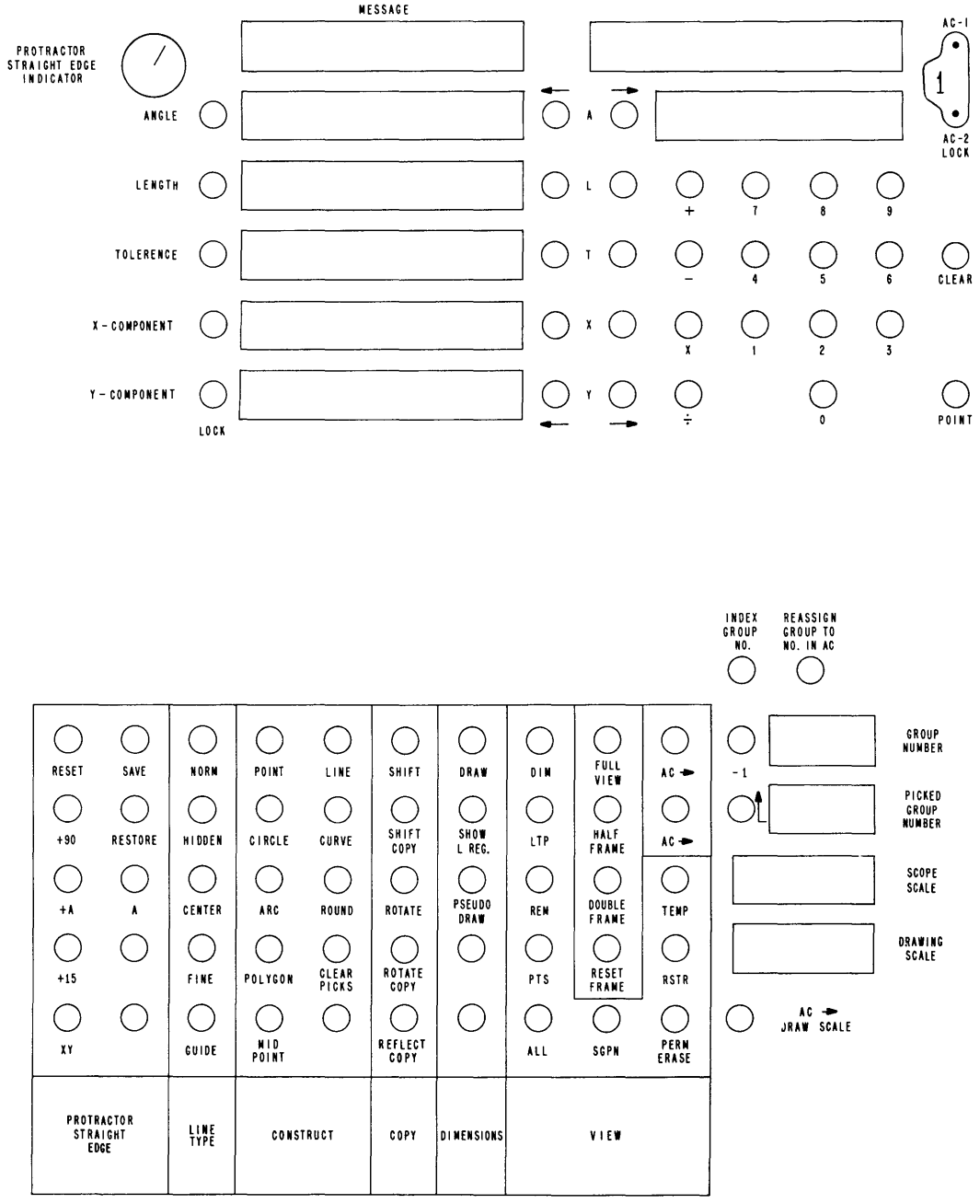
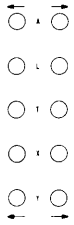


Figure 3

LIGHT BUTTON DISPLAY PANEL



These five light buttons, to the right of the numerical display registers, are used to transfer the contents of the registers to the selected accumulator, or the contents of the latter to the display registers.

AC-1 Register
AC-2 Register

These two light buttons, to the right of the two accumulators, are used to prevent the contents of the accumulators from being cleared after an operation. Between the buttons a small numeral 1 or 2 is displayed to show which accumulator is active. If one numeral is touched by the pen, the other accumulator is activated and its numeral will appear.

0 through 9

These ten light buttons are used as a regular numerical keyboard, the values being keyed into whichever accumulator is active.

+
-
x
÷

These four light buttons are used to add, subtract, multiply and divide between the two accumulators.

CLEAR

This light button clears the active accumulator.

POINT

This light button is used to indicate that any additional numerals keyed in will be placed in the fraction part of the active accumulator.

Right half of panel

PROTRACTOR STRAIGHT EDGE:

RESET	Resets the protractor straight edge angle to 0.
SAVE	Saves the current setting of the protractor straight edge angle.
RESTORE	Restores the previous setting of the protractor straight edge angle.
+90	Adds 90° to the protractor straight edge angle.
+A	Adds the angle in the Angle Register to the protractor straight edge angle.
+15	Adds 15° to the protractor straight edge angle.
XY	Sets the protractor straight edge angle according to the values in the X- and Y-Component registers.
A	Reads the protractor straight edge angle into the Angle Register.

LINE TYPE:

All entities (except Remarks and Dimensions) may be sketched or constructed with any of the following lines:

Normal

Fine

Hidden

Center

Guide

CONSTRUCT:

The general procedure in the Construct mode is to specify information required for the construction of an entity. This is done by introducing values into the numerical display registers and/or by using the pen as a pointer to indicate where the construction is to occur; and then by touching the appropriate Construct light button. If the data furnished is insufficient, the word MORE will (as previously stated) appear in the Message Register; if too much data has been specified, only that necessary will be used. Certain constructions produce ambiguous situations; for example, where three lines define a circle, one of the two possible figures is displayed. Touching the Construct CIRCLE light button a second time will produce the other figure.

The following constructions are currently available in the DX-1 system:

POINT LINE CIRCLE ARC POLYGON	The Digigraphic Display Program presently permits the expression of a point and a line in six ways, a circle in seven, an arc in two, and a polygon in three. However, since there are numerous ways of constructing geometric figures, it would be only a matter of developing specific subroutines to expand the program's construction capabilities.
ROUND	This light button is used to replace the intersection of two lines by an arc joining them. The arc will be drawn between the two lines in the quadrant specified by a point. The point and the ends of the line are removed.

CURVE	This light button is used to construct a continuous curve composed of a series of third-degree curves defined by two points. The curve is drawn by picking a series of points, tangent points, or a combination of both, which define the various segments of the curve.
CLEAR PICKS	This light button clears all picks (since entities, once picked, cannot be cleared individually) as well as the AC-1, AC-2, A, L, T, X and Y registers unless they have been locked. This button must also be used following ambiguous constructions because in such cases the picks are not automatically cleared.
MID POINT	This light button is used to construct a point in the middle of a picked line or midway between two picked points.

COPY:

The five light buttons described below are available for accurate manipulation of groups of entities. They provide for moving, rotating and reflecting entities and are similar to the corresponding functions in the Sketch mode.

SHIFT	Same as MOVE except angle and distance are specified by horizontal and vertical components or by two picked points.
SHIFT COPY	Same as MOVE COPY except as stipulated above.

ROTATE	Rotates a group, specified by the Picked Group Number Register, about a picked center point. The rotation is counter-clockwise and specified by the value in the A Register. The picks are not cleared and the function can be used repetitively.
ROTATE COPY	Operates in the same manner as ROTATE, but leaves the original group undisturbed. This function is used when drawing gears or other figures which are repetitive in a rotational sense. The copies are given the group number appearing in the Group Number Register. When the numbers in the Group Number and Picked Group Number registers are the same, the angle of rotation is doubled after each rotate operation. If the two registers differ, the value of the angle is accumulated after each rotation.
REFLECT COPY	Creates a mirror image of the group specified by the Picked Group Number Register. The copy is generated by reflecting the selected group about a picked center line. The copy is given the group number specified by the Group Number Register and the picks are cleared.

DIMENSIONS:

The three light buttons described below are used for showing dimensions on drawings. Actual or arbitrary dimensions may be drawn or dimension values may be shown in the Length Register.

DRAW	Used to draw a line dimension alongside the picked line or between two picked points.
SHOW L REG	Used to display, in the Length Register, the numerical value of the picked line or the distance between two picked points.
PSEUDO DRAW	Used to draw an arbitrary dimension alongside the picked line or between two picked points. The arbitrary length is entered in the Length Register prior to this operation.

VIEW:

DDP provides facilities for erasing, permanently or temporarily, specified portions of a drawing. When entities are temporarily erased they may be restored later; but when permanently erased they are not recoverable. To effect any of these operations, entities are specified by certain characteristics. In addition, it is possible to indicate that either all entities or only those within a specified group number may be affected. At least two specifications must be made: classification and type of action, the light buttons involved in each being:

Classification:

DIM	Only dimension entities will be affected.
LTP	Only entities with the line type currently selected will be affected.
REM	Only remark entities will be affected.
PTS	Only point entities will be affected.

ALL	All entities will be affected. This light button can be used alone or in conjunction with LTP; for example, all entities with guide lines.

Group Number:

SGPN	This light button provides further classification of entities in that only those belonging to the group whose number appears in the Picked Group Number Register are affected. Otherwise, entities in all groups will be affected by the action.

Action:

TEMP	The entities specified will be temporarily removed from the display but retained within the system.
RSTR	The entities of the type specified, which have been temporarily erased, will be restored to the display register. All other entities will be unaffected.
PERM ERASE	The entities specified will be permanently erased from the system. Extreme caution should be used in regard to this light button.

Scale

While some types of drawings (such as mechanical or architectural) have a direct dimensional relationship to the items they represent, many others (such as block and schematic diagrams) do not. To facilitate the preparation of dimensional drawings, DDP permits the use of a drawing scale which, as already mentioned,

represents the ratio of the drawing to reality. The light button and register involved in scaling are described below:

AC → DRAW SCALE

To set the drawing scale, the integer specifying the object/drawing is entered into either AC Register and the AC → DRAW SCALE light button is touched. The corresponding scale will be transferred to the Drawing Scale Register. Normally the drawing scale would be set before a drawing is begun and not changed. However, the scale may be changed at any time and the new value will affect the drawing only from that point on.

DRAWING SCALE Register

The scope scale is the ratio of the scope dimensions of the displayed information to the paper dimensions of the drawing (not reality). A scope scale of 1:4, for example, signifies that 1" on the 10" x 8" scope display area corresponds to 4" on a 40" x 32" drawing.

Magnification and Frame Control

The 10" x 8" drawing area of the scope is bounded by four displayed lines, called a frame. The buttons and register concerned with magnification and frame manipulation are as follows:

HALF FRAME

Any part of the drawing can be magnified by touching the HALF FRAME light button and positioning the frame, now reduced to half-size, over the desired area of the drawing by depressing the MOVE FRAME push button in the Sketch mode. Releasing this button will cause the frame to return to full scope size and correspondingly magnify everything within it.

MOVE FRAME

The currently available scope scales are:

10" x 8" Display Area		Paper Drawing Area
1:8	=	80" x 64"
1:4	=	40" x 32"
1:2	=	20" x 16"
1:1	=	10" x 8"
2:1	=	5" x 4"
4:1	=	2-1/2" x 2"
8:1	=	1-1/4" x 1"
16:1	=	5/8" x 1/2"

As this table indicates, the scope scale operation can be used for preparing drawings smaller than 80" x 64" and magnifying portions of a drawing for examination or detail work. For the former purpose, all work is done at a magnified scale; for instance, a scope scale of 1:1 is used for 10" x 8" drawings. For the latter purpose, the frame is reduced by halving it as many times as desired, thus expanding the frame and its contents to full scope size. When the detail work is completed, the scope is set to the next desired scale.

FULL VIEW — To view the entire drawing and show the relative location and size of the frame on it, the FULL VIEW light button is touched.

RESET FRAME — To reset the frame to full scope size, the RESET FRAME light button is touched. The latter does not affect the scope scale but restores the frame to 10" x 8"

DOUBLE FRAME — Whenever the frame has been reduced in size by halving, it may be increased by touching the DOUBLE FRAME light button, which will double the size of the frame. This permits the user to move back up the scale, step by step, as well as zoom

SCOPE SCALE Register	down it. The Scope Scale Register will always display the scope scale of the current view. The frame may be doubled beyond the 10" x 8" scope area if the scope scale in use is less than 1:8, thereby allowing the user to see more of the paper drawing than he is actually viewing.

Group Number Control

When an entity is generated, it is assigned the group number appearing in the Group Number Register. The following registers and light buttons are available for assigning and changing group numbers:

GROUP NUMBER Register	This register contains the group number currently being assigned to entities. It is also used for other functions.
PICKED GROUP NUMBER Register	This register is used in the Construct mode to identify the entities to be used.
AC → GPN	This light button is used to transfer the integer in the selected accumulator to the Group Number Register.
INDEX GROUP NO.	This light button is used to increase the value of the Group Number Register by one.
-1	This light button is used to decrease the number in the Group Number Register by one.
AC → PGPN	This light button is used to transfer the integer in the selected accumulator to the Picked Group Number Register.

REASSIGN GROUP TO NO. IN AC	This light button permits the assignment of a new group number to an entire group of entities. The group to be changed is specified by the Picked Group Number Register and the new group number to be assigned is in the Group Number Register. The new group number will appear in the Group Number Register at the completion of the operation.

III. SPECIAL FUNCTIONS

DDP has a special-function selection feature which enables the user to extend his control to auxiliary functions. An auxiliary function is called by entering the function number as an integer into AC-1 and the desired mode number as an integer into AC-2. Then the SPECIAL FUNCTION push button is depressed and released.

Alphanumeric Input

Remarks may be added to the drawing by means of the SPECIAL FUNCTION push button. Since they are entities, remarks have group numbers, may be moved about, and possess all the other properties associated with entities. The basic size of the characters used is .12 x .08 inches at a scope scale of 1:1. The size of the characters will vary with scope scale and can also be changed by the user.

The procedure for entering remarks is to position the writing-point at the location of the first desired character, enter a 1 into AC-1, clear AC-2, then depress and release the SPECIAL FUNCTION push button. The typewriter will execute a carriage return to indicate a ready state for accepting alphanumeric information. The remark is entered through the keyboard and terminated by momentarily depressing the push button on the light pen. As each character is typed, it is displayed in its proper position on the scope.

The allowable characters are capital letters, digits 0 through 9, and the following symbols: quotation marks (single and double), brackets (right and left), comma, period, oblique, question mark and right arrow; and plus, minus, equal, square root and summation signs. Twenty-four spaces are reserved for future use. The typewriter keyboard symbol ↑ is used to specify a change in the size of the characters. Magnification is given relative to the base size of .12 x .08 inches. The number entered immediately following the ↑ symbol specifies the power of magnification; for example, ↑3 means that all future characters will be .36 x .24 inches at a scope scale of 1:1.

The symbol ∨ specifies a subscript mode and all the characters that follow will be entered as subscripts relative

to the last character before the ∨. Subscripts can be displayed at different levels by the successive use of ∨. The character ∧ specifies superscript mode relative to the last character before ∧. It is therefore possible to have subscripts and superscripts at different levels, to have subscript superscripts, and vice versa. To return to normal mode, the character ~ is entered.

Characters may be deleted by typing <. Each time this is done, the preceding character is erased from the display. The carriage return, space bar, back space and tab are used normally. Tabs are set by SPECIAL FUNCTION light button operation.

Concluding Remarks

The Digigraphic Display Program is a basic graphic drawing program. Except for a few control routines, it consists of a string of independent routines which can be supplemented by those of a special-purpose nature that are peculiar to the needs of individual users.

The Entity Table format has been designed for minimum storage space since detailed graphic drawings can be several thousand words long. Address pointers for common points, connected groups, etc., have not been included since their use is directed toward saving computer time for searching. With a completely buffered single display scope, however, there is abundant time for internal searches.

There are and will continue to be valid reasons advanced for expanding the entity format, and the DDP is so designed as to permit this to be done with very little program modification.