HARDWARE/SOFTWARE INTERACTION IN GRAPHICAL DISPLAY SYSTEMS

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ABSTRACT

A review of the principles and applications of
display systems is given.   A state-of-the-art survey
is made of the various types of display devices and
their disadvantages.   A study is made of the problems
associated with two particular display devices and
solutions found by the use of hardware and software
techniques.

A communications line is occupied for an excessive
amount of time when drawing graphs on a standard
incremental plotter from a remote computer.   This time
was significantly reduced for low cost by using a
satellite computer and trying various alternative coding
techniques.

A low cost interactive raster scan graphics system
was developed that used a magnetic disc to refresh
television monitors.   This system was used to determine
the best method for overcoming the crossing vector
erasure problem.

A system using the improvements to both the
display devices is proposed as a further development.

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ILLUSTRATIONS.

chapter 1

INTRODUCTION

1.1 DISPLAY SYSTEM OBJECTIVES.

An appreciation of display aims and criteria is essential to a correct evaluation of display systems. However, there are usually no quantitative measures of effectiveness for display systems, and often no clear qualitative criteria (1). Display systems are almost always part of a larger system, and display criteria expressed in terms of the whole system is an additional complication in evaluating display alternatives e.g. a computer aided design system for electronic circuits would display a representation of the circuit under consideration but it is also required to calculate currents, voltages, component values etc. Thus, without a single all inclusive objective several subjective display aims and criteria have to be considered (2).

The most general objective of display systems is to improve human decision making. This is difficult to measure because it must be appraised subjectively and it is difficult to separate the influence of the displays from the intellect of the decision maker. Decisions might range from the military commanders' strategic decisions to a radar operator deciding whether signals are an aircraft or noise.

The quality of decision making is based on insight and understanding of the problem. Thus a primary display system objective is to allow the user to assimilate, perceive, comprehend, and apprehend the information available from the main system. The display

system thus needs to present complex situations in such a manner that significant relationships, conflicts, correlations, and extrapolations can be correctly comprehended. It should be possible to display separate categories of information in a manner that optimizes the users ability to detect these relationships. The display system should allow details to be understood in context with the whole situation, and conversely, should allow the whole situation to be examined in detail. For instance a display system could show the interrelations between units in a whole industrial plant and allow one particular unit to be examined to show its inner workings.

The ability to make good decisions quickly is an important objective that requires the appropriate information in an effective form. Decision makers need speed in direct presentation of input data less than they need speed in the interpretation, evaluation and recommendations based on such input data, in order to hasten their decisions. It would be far more useful for, say a marketing manager to have a display showing increase in sales, popularity of various products, success in reaching targets rather than a mass of sales figures.

Another important objective of display systems is to provide effective man-machine communications as display systems are generally closely related to data entry. A display system should augment data entry capabilities by providing supporting information and aid

data entry by displaying indices, formats, and data being entered.

When each user or working group has different data from different sources, contradiction, conflicts, and misunderstandings may arise. Thus improved co-ordination within diverse operations is a further objective of display systems. Each individual or group should have current, identical data available.

Any display system involving data storage and retrieval has a classification and indexing problem. Users must be able to quickly and conveniently identify and request various data categories or combinations of information characteristics. Quick, accurate means which allow the user to obtain the exact information he needs are an important objective.

Display systems should provide thorough, accurate, dependable data which will minimize human errors and improve the effectiveness of human judgement. This requires reliability in data and equipment, and confidence in the operation and the data presented. Similarly simplicity of operation is an important objective in display systems. If equipment is difficult or inconvenient to operate it will not be used effectively.

Display requirements often change drastically with time due to changes in the operating environment or in the tasks performed. If a display system cannot adapt to changing requirements it loses operational value and may have to be replaced early. If a system incorporates excess capability to meet any unforseen requirements its

initial expense may be unwarranted.   Thus flexibility
to adapt to necessary changes quickly and effectively
is a primary objective of display systems.

1.2   MAN-MACHINE COMMUNICATION.

Most display systems are subsystems of larger
data processing systems which divide the data processing
and decision-making activities between man and machine.
Information must thus be communicated between men and
machines. This can be greatly improved by proper
co-ordination of display with data entry.

Computers are relied on for fast, accurate
processing of data while human operators specify criteria
and environment and guide and interpret the results of
data processing. A joint allocation of tasks to men
and machines must take into account their disparate
abilities in establishing their particular information
requirements. Similarly ensuring effective interaction
between man and computer needs careful consideration
of the means of information transfer (3).

A diagram of the basic process in man-machine
communication is shown in Fig. 1. This represents a
computer which generates a display appropriate to human
perceptual abilities and accepts human responses via
input devices. The user controls the display produced
by modifying the computer programming and editing the
data by accessing the computer memory. (This diagram
takes no account of the purpose of the information
system, the tasks it must perform or its relations to
the external environment, all which would be critical
factors.)

Common human methods for conveying information
include talking, writing, sketching, printing and other

MACHINE

MAN

HUMAN
PERCEPTION

DISPLAY

DISPLAY
GENERATION

DISPLAY
INTERPRETATION

DATA
PROCESSING

INFORMATION
PROCESSING

PROGRAM

DATA

DECISION
MAKING

INPUT
DEVICES

HUMAN
RESPONSES
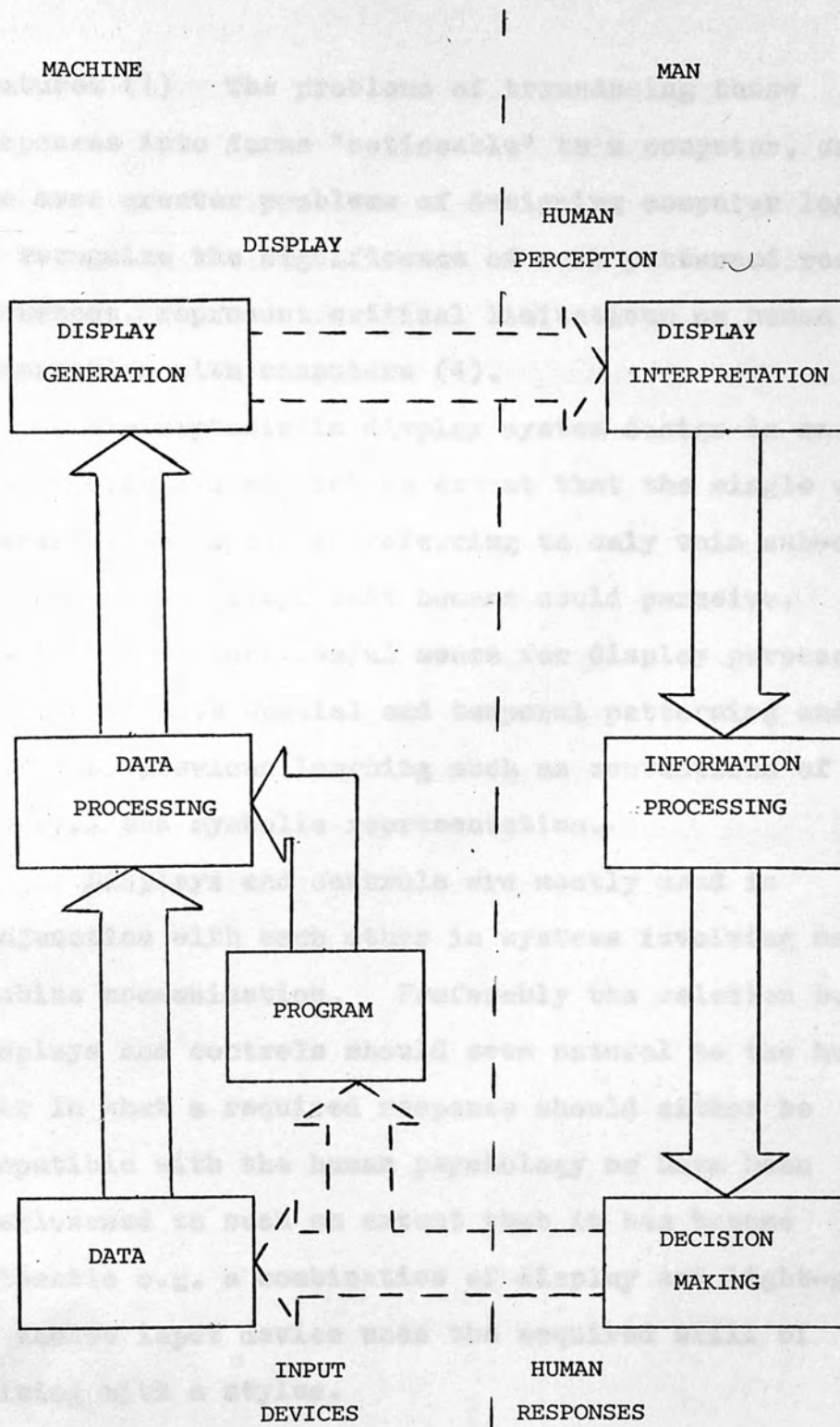
FIG 1. - A DIAGRAMATIC VIEW OF THE MAN - MACHINE
COMMUNICATION PROCESS

gestures (!) The problems of transducing these responses into forms "noticeable" to a computer, and the even greater problems of designing computer logic to recognize the significance of such patterned response sequences, represent critical limitations on human interaction with computers (4).

The emphasis in display system design is on visual displays to such an extent that the single word display is accepted as referring to only this sub-class of possible displays that humans could perceive. Vision is the most useful sense for display purposes as it permits both spatial and temporal patterning and relies on previous learning such as conventions of pictoral and symbolic representation.

Displays and controls are mostly used in conjunction with each other in systems involving man-machine communication. Preferably the relation between displays and controls should seem natural to the human user in that a required response should either be compatible with the human psychology or have been overlearned to such an extent that it has become automatic e.g. a combination of display and light-pen or tablet input device uses the acquired skill of writing with a stylus.

Often "data" and "information" are confused; data is the raw material that the information to make decisions is extracted from. The data can be processed before being displayed and this processing will determine how effectively a user can extract the information he

requires. Attempting to increase the amount of data
displayed when more information is required is likely
to complicate the situation rather than to clarify it.
An air-traffic controller, for instance, would find a
pictorial display showing the relative positions and
velocities of the aircraft in his care far more helpful
than tabulated statistics giving the speed, height,
direction, etc. of each plane.

Two way communication between man and machine
allows the computer to display questions, answers,
formats, checklists, alternatives, instructions, and the
next operation to be performed. The user in return
enters data (as alphanumerics, graphics or both),
decisions, instructions, display requests, co-ordinates,
corrections, and initiates searches.

1.3   HUMAN FACTORS.

The primary reason for using a display is to provide visual information to a human operator. Thus the physiological and psychological factors influencing the reception of information by the operator are of utmost importance, but in practice are often overlooked in the design stage.

The resolution of a display surface is an important factor in display systems as it defines the amount of detail a display can present. However, even though a human eye is a very sensitive receptor it has its limits and thus may not be able to detect fine detail on high resolution displays.

Visual acuity is the ability of the eye to see fine detail and there are several different types of acuity. Stereoscopic acuity is the binocular ability of the eyes to determine which of two objects is the closer, but is of little use for two dimensional displays. Minimum detectable acuity refers to the minimum size that an object must have to be seen at all, and would thus be expected to have a size equal to the minimum resolvable spot size in the eye, about 1 minute of arc. Bright spots against a dark background can be smaller than this as the bright object will be seen if it has enough energy to trigger one of the cones in the eye. Conversely dark objects against a bright back-ground seem smaller and thus more difficult to see, as it is the background that triggers the eyes' cones in this case.

Minimum separable acuity is the ability of the eye to determine if there is one spot or two spots at a particular position on a display, or alternatively the ability of the eye to detect a space between two spots. This is of importance for the display of detail e.g. in character recognition to distinguish between E and B the eye must be able to resolve lines as short as one fifth of the character height, or to distinguish between C and O a gap as small as one third of the character height may have to be distinguished. The minimum separable acuity can be taken to be about 1 minute of arc, the diameter of the cones in the eye. Getting displays to resolve objects much finer than this is thus of no use for characters and for detailed pictures (5).

Vernier acuity, which covers such tasks as aligning a pointer with a dial mark, is appreciably better than minimum separable acuity. This is due to the random placement of the cones in the eye as in Fig. 2. In the position shown the image is illuminating part of cone "B" which will generate a nerve impulse. As can be seen only a small lateral movement of the object to the right, smaller than a cone width, will illuminate part of cone "A" and generate a nerve pulse. The exact improvement in alignment accuracy depends on the length of the line, brightness and contrast ratio of the image. A vernier acuity of 10 arc seconds can be used when extreme placement accuracy of crosshairs or dial marks is required (5).

Brightness and contrast are closely related to

A

CONES

B
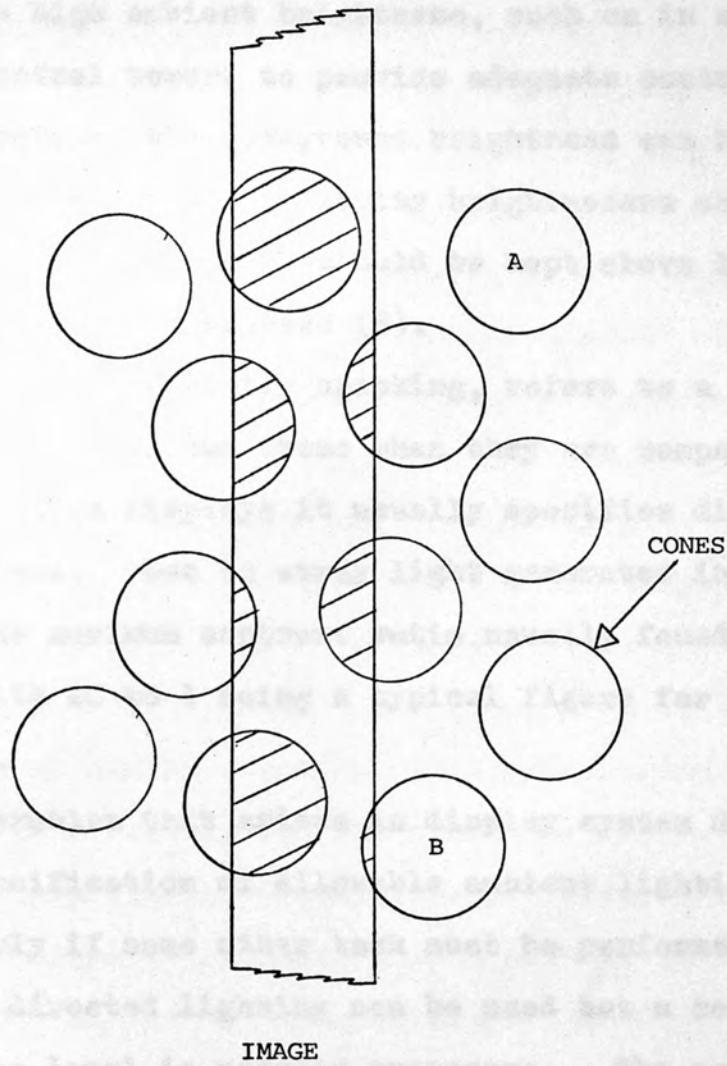
IMAGE

FIG 2 - VERNIER ACUITY FOR IMAGE FOCUSED ON VISUAL CONES

each other and to visual acuity. The desired brightness
levels for most complex displays are in the range from
20 to 70 foot lamberts, if sufficient contrast is
available. More display brightness is necessary where
there is a high ambient brightness, such as in an air
traffic control tower, to provide adequate contrast.
Alternatively if the background brightness can be
reduced sufficiently low display brightnesses can be
used, although brightness should be kept above 1 foot
lambert for acuity purposes (5).

Contrast, strictly speaking, refers to a
difference between two items when they are compared side
by side, but in displays it usually specifies differences
in brightness. Due to stray light generated in a
display the maximum contrast ratio usually found is
50 to 1 with 20 to 1 being a typical figure for cathode
ray tubes.

A problem that arises in display system design
is the specification of allowable ambient lighting levels
particularly if some other task must be performed.
Hoods and directed lighting can be used but a compromise
in lighting level is usually necessary. The optimum
level of ambient brightness for using self luminous
and illuminated displays, e.g. a cathode ray tube and
reference chart can be determined using the relative
time taken to perceive data on each display, as the
criterion. Colour contrast may be used in a situation
where the ambient lighting level necessary, prevents
having sufficient brightness contrast. For example

radar rooms require very low ambient levels of illumination but when the displays use orange phosphors, blue light can be used to provide sufficient working illumination without interfering with the radar display.

Minimum separable acuity, which is used to distinguish between characters, is customarily taken as 1 minute of arc. Characters such as E must therefore subtend a minimum of 5 minutes of arc to be resolved. This is a minimum based upon clearly printed characters, with good contrast, brightness and eyesight. In fact displays rarely produce sharply focused characters and often produce characters at the edge of the screen which are poorer than in the centre. Observers may have poor eyesight and be fatigued from viewing the display for a long period of time. Taking human factors into consideration, a character needs to subtend at least 10 minutes of arc in practice, twice the minimum, for observers to be likely to recognise characters. Thus for a standard viewing distance of 18 inches a minimum character height of at least 0.05 inches is needed.(see 1.4)

Most cathode ray tube displays present their information at a recurring rate as, apart from storage tubes, the characteristics of cathode ray tube phosphors cause the display on the tube to last only for milli-seconds. It must then be rewritten or "refreshed", at a sufficiently high rate to present a steady picture to the viewer without annoying screen flicker. For a given brightness flicker is more noticeable for large objects, short wavelengths and young operators. At

lower intensities flicker is also more noticeable for
peripheral vision and for dark and light periods of
equal duration.   Flicker is less noticeable at lower
brightness levels and for smaller variations in
brightness.   Fig. 3 (5) shows the average critical
flicker frequency (the lowest repetition frequency at
which flicker can not be perceived) for different values
of display brightness.   Thus displays operated at
refresh rates above this frequency have no flicker.
For displays with refresh rates under the critical
frequency longer persistence phosphors can be used to
reduce flicker.   Methods based on the physiology of
the eye (6) can also be used to decrease flicker.

Commercial television uses an interlace method
of eliminating flicker to give a repetition rate of
50 fields per second.   As can be seen from Fig. 3
this gives a flicker-free display for brightness levels
up to 30 foot lamberts, the average display brightness.
Displays driven at a repetition rate below this may be
acceptable for many applications even though not
flicker-free but cause operators visual fatigue (7).
Displays become completely unviewable at repetition
rates under 20 cycles per second.

If it is required to display an image that is
changing in time, e.g. a vehicle moving across some
terrain, separate and distinct images have to be
generated.   These have to be displayed rapidly enough
for the eye to be unable to detect the individual
images and them to appear to be continuous motion.
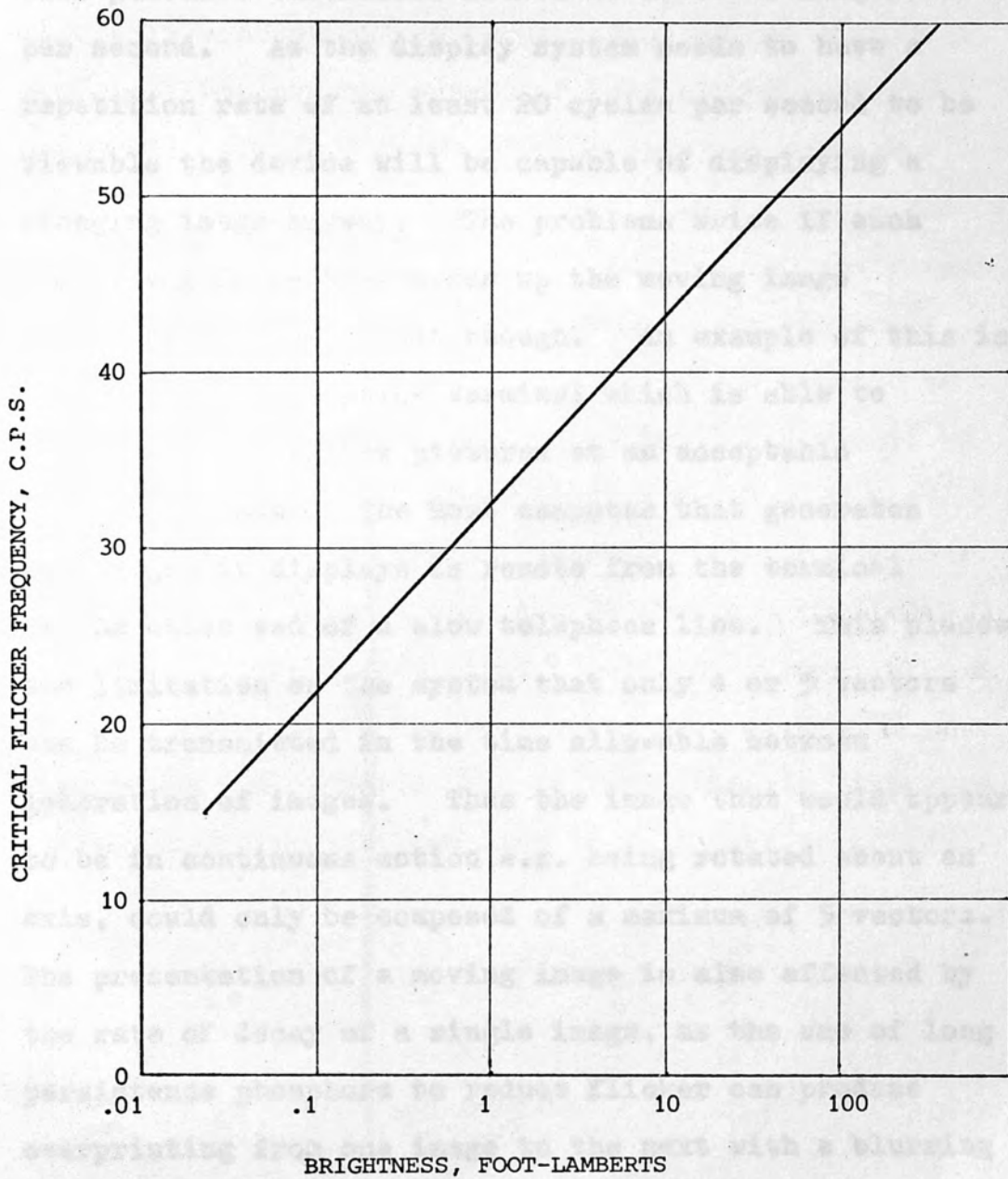
FIG 3 - CRITICAL FLICKER FREQUENCY (5)

Images changing too slowly would have the jerky
movement that characterised silent films and the eye
will perceive continuous motion at about 20 images
per second.   As the display system needs to have a
repetition rate of at least 20 cycles per second to be
viewable the device will be capable of displaying a
changing image anyway.   The problems arise if each
individual image that makes up the moving image
cannot be generated fast enough.   An example of this is
an intelligent graphics terminal which is able to
display quite complex pictures at an acceptable
repetition rate.   The host computer that generates
the images it displays is remote from the terminal
at the other end of a slow telephone line.   This places
the limitation on the system that only 4 or 5 vectors
can be transmitted in the time allowable between
generation of images.   Thus the image that would appear
to be in continuous motion e.g. being rotated about an
axis, could only be composed of a maximum of 5 vectors.
The presentation of a moving image is also affected by
the rate of decay of a single image, as the use of long
persistence phosphors to reduce flicker can produce
overprinting from one image to the next with a blurring
effect as the image moved.

Another human factor to consider in the use of
display systems is the low storage capability of people.
If an operator requests a necessary image and the time
till its appearance on the screen takes longer than a
few seconds, the probability is about 50 per cent that

he will remember what was originally requested. After
18 seconds even in a simple case the probability drops
to about 10 per cent. The storage capability of
people is related to the organisation of the data they
are receiving and the amount of interfering activity
going on. These factors require that the request
response time (see 1.4) is no more than 3 seconds and
preferably as low as possible. If long request response
times are unavoidable the situation can be made more
tolerable for the user (8). Some form of message as
to what task the operator has just initiated should be
provided e.g. a few lines of text in a reserved area
at the bottom of the display screen. Feedback on the
state of the display system can be provided by a method
such as the "count-down light clock" which is displayed
on the screen during the processing of the next image.
This tells the operator that (a) something is happening,
and (b) approximately how long it will take to happen.

1.4 DATA PRESENTATION.

Written language is not necessarily the simplest or most efficient means of representing information as the number of different symbols is limited. However displays of data composed of alphanumeric characters in tabular or text form are the most common type of presentation for human interpretation.

It is more effective to use special symbols to facilitate visual communication, particularly where the information represented has a characteristic pictorial shape that is easy to remember e.g. it would be better to represent an aircraft by its shape than by the word "aircraft". Symbols provide a good medium for other coding modes such as colour size, orientation, blink rate, and intensity.

Certain types of data such as contours, vehicle routes, and mathematical functions cannot be presented alphanumerically or symbolically in an effective form for human comprehension. Line drawings are a better means of presenting such information and are capable of being easily produced by the display systems.

Displays of areas are occasionally necessary to define special hazard areas on maps or areas on graphs or histographs. Areas can best be represented by colouring or shading, but as, this is more difficult to produce, line drawings, symbol arrays or cross-hatching usually prove adequate.

Formats used for displaying information can range from text, tables, graphs and diagrams to actual scenes or pictorial simulations in three dimensions.

Combinations of formats and coding allow superposition
of different types of information, and relationships
can be clearly presented.

Reference backgrounds of a relatively permanent
nature which are not frequently updated are often used
in display systems. Permanent formats such as tabular,
row and column, headings and lines can reduce the amount
of data storage and display generation to only the
variable data. Windshield displays and other optical
mixing methods allow actual scenes to be used as
background for displays. Black and white outline
drawings are usually adequate for displaying simple
political and geographical maps. Such data can easily
be handled in the same form as other display data.

The rate of comprehension is a major factor in
determining how much information should be displayed.
With enough time a complex and detailed display can be
absorbed and understood. Conversely highly summarised
information assists the making of rapid decisions. In
some cases it may be necessary to present more data than
can be comprehended. Several persons can derive
different types of information from a common display,
and a particular user may only need to glance at a
display and gain an impression of the general degree or
location of activity.

The amount of information that can be perceived
is certainly much greater than that which can be quickly
comprehended. However, visual perception does limit
the amount that can be made available for quick access

by shifting the attention. Visual perception also
involves such factors as rates of change of information,
colour and gray scale discrimination, and blink rate.
The large amounts of information that can be presented in
a single display depends primarily on the solid angle
subtended and the resolution of the eye. Fig. 4 (2)
shows the relationships between size of display,
acceptable viewing distance and the number of characters
which can be displayed. This shows the popular concept
that one must have a big display i.e. Television, to see
large amounts of information, to be false.

When the information required by an individual
exceeds the capacity of one display, access to other
information must be provided. Display access time is
defined as the time lapse between a users request and
the display of the requested information. Access can
be achieved by the information on a single display
being changed at the command of the user. Alternatively
all the information is simultaneously presented and the
user gains access to different information by focusing
his attention on the particular information desired.

The time between the input of new data into a
display system and the resulting data having been
displayed is the update response time. In systems
which display different information, this time depends
on the priority given new data, and the processing of
queues, as well as the data input rate and the response
time of the display equipment itself. The request
response time is defined (9) as the time duration from

25,000

20,000

15,000

NUMBER OF CHARACTERS, N

10,000

5,000

O   2   4   6   8   10

$$\frac{\text{VIEWING DISTANCE}}{\text{DISPLAY SIZE}} = \frac{D}{S}$$

.75H

1.5H   H

.65H

CHARACTER SLOT

$H = .003D$
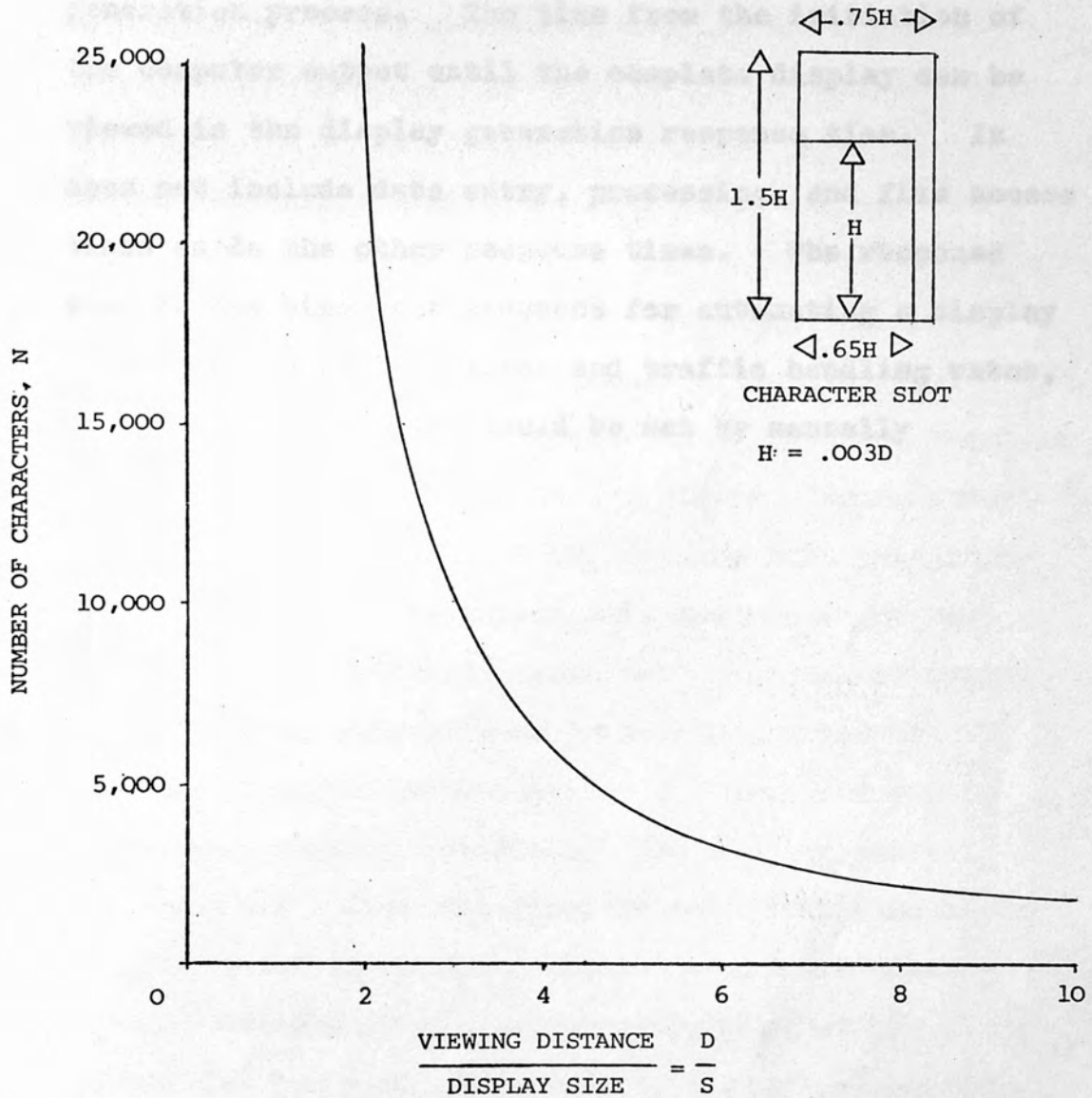
Character height, H, subtends 10 minutes of arc at viewing
distance, D, which is greater than 13 inches.

FIG. 4 - RELATIONSHIP BETWEEN DISPLAY DETAIL(N), DISPLAY
SIZE(S), AND VIEWING DISTANCE(D). (2)

request until the image appears. This is a function
of the display data access as well as the display
generation process. The time from the initiation of
the computer output until the complete display can be
viewed is the display generation response time. It
does not include data entry, processing, and file access
times as do the other response times. The response
time is the strongest argument for automating a display
system, as apart from error and traffic handling rates,
all other requirements could be met by manually
generated displays.

1.5   PROGRAMING CONSIDERATIONS.

A large part of a display system is concerned
with organising and processing display information.
This task and that of controlling one or more displays
would usually be performed by software.   The display
control functions handle the routing of display
information to display units.   This task requires the
routing control routines to know the data categories
currently displayed at a particular display, for
updating purposes, and data categories that are required
by a display unit at any time.   The routing routines
would also take account of the display unit priorities
and security restrictions on data categories by such
means as jobnumbers and passwords.   Special attention
criteria would also have to be handled, where the
presence of specified conditions are detected and the
appropriate user(s) notified.   The display control
functions may update the displays on a real time basis
or after a set interval.   Alternatively the displays
may be updated each time a certain amount of new
information has arrived or only when display requests
are made.

Some display systems can display all their
information in a single presentation e.g. radar systems,
while in other types it may not be either possible or
desirable to present all their information at once.   The
latter type of display systems require the information
to be divided into categories for updating and display
by methods involving file organisation, indexing, data

entry and processing, and the information requirements
of the users. The organisation of information into
predetermined categories limits flexibility by hampering
the displays ability to request data. However,
elaborate display requests are avoided, and with
thorough analysis predetermined categories can be
specifically designed to meet the requirements of a
particular application. An index is required for the
user and it is most useful in the form that it is
convenient for the user to call the data e.g.
geographical areas, shapes, sizes etc. Some systems
may have 100 or more predetermined display categories
and preparation of individual programs for each
category would be expensive and inflexible due to the
changes that would be required in display categories.

An alternative approach is to develop basic
programs for each type of display format e.g. alpha-
numerics, labels, symbols, line drawings etc., which
in turn generate new programs each time a new display
is requested. The request message supplies the needed
parameters and control information to generate and mix
different types of display formats. This approach
reduces the analysis of operational requirements needed
and provides versatility and adaptability by providing
the users with the capability of defining their own
display formats and contents.

A large portion of display software consists of
file organisation, and one of the primary considerations
is to decide whether basic data files are to be

organised by display records or not. If data is
preprocessed, the display records are generated and
updated before an actual request to display one of them,
so an individual input message may have to update many
different display files. This increases input
processing and files tend to be larger but searching,
assembly of information, and display generation are
simplified. Preprocessing thus reduces the user access
time and in general updating response time is traded for
request response time (see 1.4).

The function of graphics software is to transfer
data between an applications program and the display
hardware. The applications program may output data
by issuing commands or by creating some sort of data
structure. In either case the output relates to the
application rather than the final picture on the display.
For example a control-system program may use graphics
 to display the system to be analysed, composed of
connected symbols. The applications program is
concerned only with the connections between, and the
properties of, the components, whereas the graphics
software is concerned mainly with the position of the
symbols on the screen and their size shape and
orientation. The applications dependent part of the
graphics software accepts commands from the applications
program or scans a data structure produced by the
applications program and generates a description in
two-dimensional space. The display-dependent part of
the graphics software has to manipulate the two

dimensional field to a form suitable for the display
hardware.

The applications program specifies what is to
be displayed.   The degree of structuring used by the
applications program to describe the picture depends
on the particular application itself.   The picture
may have no particular structure e.g. contour lines and
graphs, so would be best described in terms of point
co-ordinates.   Most pictures however have a definite
structure.   Points which represent a separate object
for example are more closely associated than other
points in the picture.   The disposition of the
separate objects may also be structured, e.g. when
characters are grouped into words or electronic symbols
are linked into a more complex component.

For such structuring the applications program
usually deals with units of the structure and will
describe the display in the same terms.   The most
common way of structuring points and lines in a display
is to associate them into sets.   When a transformation,
such as a shift or rotation, is applied to a set it is
applied to all the points and lines which make up the set.
At a higher level the sets may be associated to produce
subpictures and frames, e.g. for circuits and maps,
depending on the particular application.

Thus a picture is caused to be displayed by
executing the procedures which define it (10).   As
higher-order procedures activate lower-order ones nested
inside them the structure is unravelled into a linear

```
DEFINE FILTA
        CAPACITOR AT (0,120)
        CAPACITOR AT (120,120)
        RESISTOR ROTATED (Pi/2) AT (120,0)
        LINE FROM (0,0) TO (240,0)
        CIRCLE SCALE (0.1) AT (0,120)
        CIRCLE SCALE (0.1) AT (0,0)
        CIRCLE SCALE (0.1) AT (240,120)
        CIRCLE SCALE (0.1) AT (240,0)
END FILTA

DEFINE RESISTOR
        LINE FROM (0,0) TO (20,0) TO (30,-10) TO (50,10) TO
            (70,-10) TO (90,10) TO (100,0) TO (120,0)
END RESISTOR

DEFINE CAPACITOR
        LINE FROM (0,0) TO (50,0)
        LINE FROM (50,20) TO (50,-20)
        LINE FROM (70,20) TO (70,-20)
        LINE FROM (70,0) TO (120,0)
END CAPACITOR
```
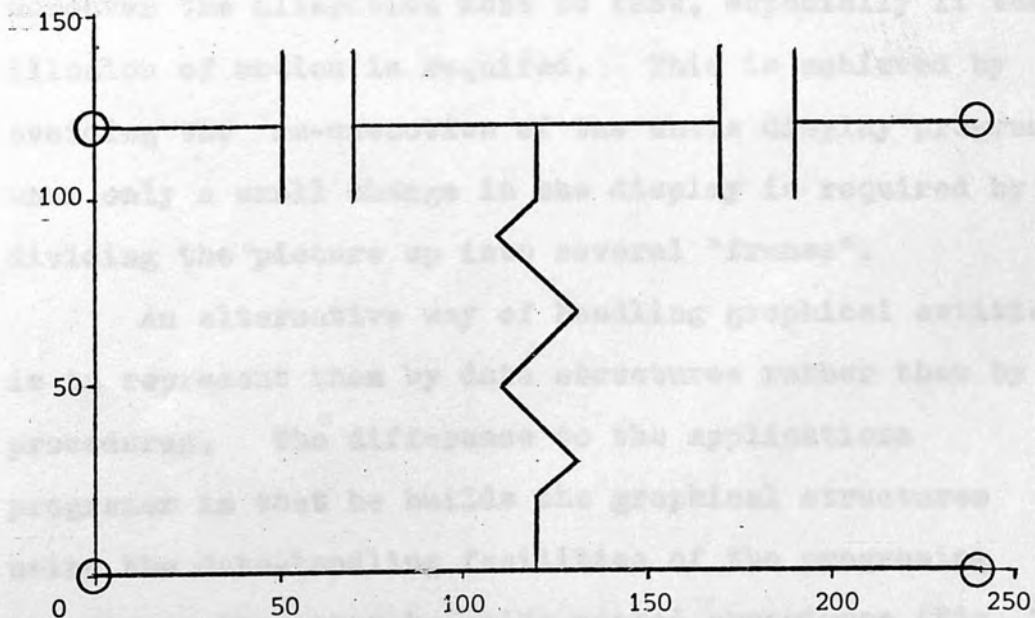

FIG. 5 - DISPLAY PROCEEDURES   (15)

list of co-ordinates.   For instance, displaying a
picture of a circuit diagram would involve activating
procedures for displaying filters, and these in their
turn would activate procedures for displaying capacitors
and resistors (see Fig. 5).

Transformation commands are collected separately
from the positioned data.   Both are sent to trans-
formational routines where the required scaling,
shifting, rotating or clipping is done.   The transformed
co-ordinates are then compiled into instructions which
can drive the display and placed in the display file.
A generalised data flow in a display system is shown in
Fig. 6.   In an interactive environment the user will
manipulate the display by moving small objects about and
altering the picture gradually.   When a change is made,
most of the displayed image will remain unchanged.
moreover the alteration must be fast, especially if the
illusion of motion is required.   This is achieved by
avoiding the re-execution of the whole display program
when only a small change in the display is required by
dividing the picture up into several "frames".

An alternative way of handling graphical entities
is to represent them by data structures rather than by
procedures.   The difference to the applications
programer is that he builds the graphical structures
using the data-handling facilities of the programing
language rather than by using nested procedures (Fig. 7).
Once such a structure is established it acts as a
description of the displayed material and can be
interrogated and manipulated by the applications
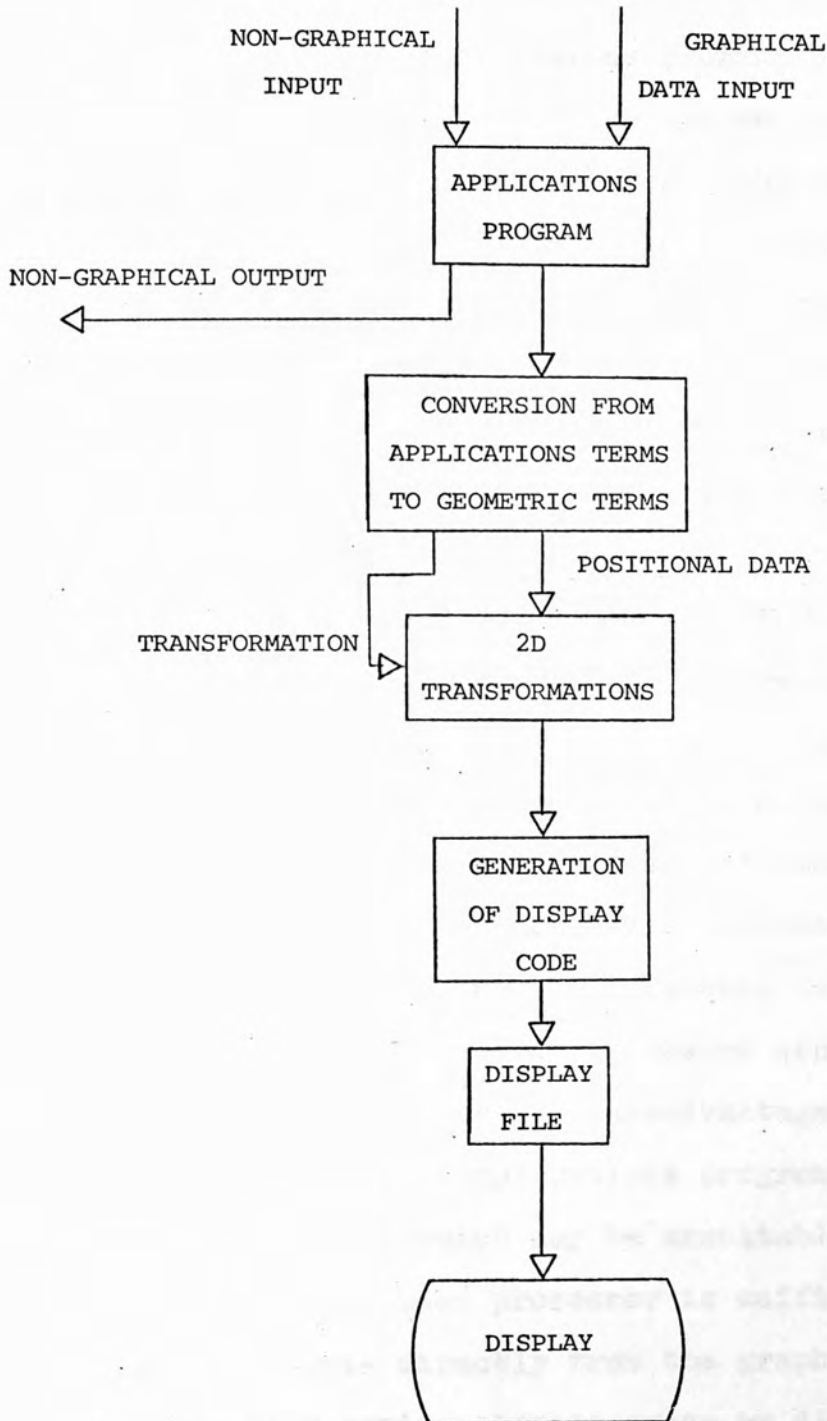
FIG. 6 - DATA FLOW IN A GRAPHICS SYSTEM

program (11).   The applications program displays the
graphical structure by calling a system-display routine
which scans the structure.   Usually the start point
of the scan can be specified so that a picture can be
generated from part of the complete structure.   The
scanning routine traces its way through the graphical
structure, expanding the sub-picture and definitions
into their constituents and finally into a linear list of
display co-ordinates.   Transformations and the
generation of the display file are performed in the same
way as for display procedures.   The graphical structure
can have areas never encountered by the scanning routine
and so may be used to carry all sorts of non-graphical
information, for example, the value of each component,
its cost, and what other components connect with it.
Such structure acts both as a data-base for the
applications program and as the source structure for the
display-scanning routine.   A disadvantage of this
approach is that the applications program must be a
graphical structure which may be unsuitable for the
problem.   If a display processor is sufficiently power-
ful it can operate directly from the graphical data
structure, thus saving storage space by dispensing with
the display file.   This however makes the task of the
applications program more difficult as it will have to
perform all transformations and convert all co-ordinates
from the display processors low-precision fixed point
format display commands into the high-precision floating
point format.

```
┌─────────────────────┐
│        FILTA        │
├─────────────────────┤
│ AT 0,120            │
│ SUBPICTURE  PTR.    │──┐     ┌──────────────────────┐
│ AT 120, 120         │  │     │      CAPACITOR       │
│ SUBPICTURE PTR.     │──┤     ├──────────────────────┤
│ RO. Pi/2            │  │     │ LINE 0,0:50,0        │
│ AT 120,0            │  └────▷│ LINE 50,20:50,-20    │
│ SUBPICTURE PTR.     │──┐     │ LINE 70,20:70,-20    │
│ LINE 0,0:240,0      │  │     │ LINE 70,0:120,0      │
│ SC. 0.1             │  │     │         END          │
│ AT 0,0              │  │     └──────────────────────┘
│ SUBPICTURE PTR.     │  └────▷┌──────────────────────┐
│ SC. 0.1             │        │       RESISTOR       │
│ AT 240,120          │        ├──────────────────────┤
│ SUBPICTURE PTR.     │        │ LINE 0,0:20,0        │
│ SC. 0.1             │        │ LINE 20,0:30,-10     │
│ AT 240,0            │        │ LINE 30,-10:50,10    │
│ SUBPICTURE PTR.     │        │ LINE 50,10:70,-10    │
│ SC. 0.1             │        │ LINE 70,-10:90,10    │
│ AT 0,120            │        │ LINE 90,10:100,0     │
│ SUBPICTURE PTR.     │──┐     │ LINE 100,0:120,0     │
│         END         │  │     │         END          │
└─────────────────────┘  │     └──────────────────────┘
                         └────▷┌──────────────────────┐
                               │        CIRCLE        │
                               ├──────────────────────┤
                               │ SUBPICTURE PTR.      │──┐   ┌────────────────┐
                               │ RO. Pi/2             │  │   │    QUADRANT    │
                               │ SUBPICTURE PTR.      │  └──▷├────────────────┤
                               │ RO. Pi               │      │ POINT 50,0     │
                               │ SUBPICTURE PTR.      │      │ POINT 49,8     │
                               │ RO. 3Pi/2            │      │ POINT 47,17    │
                               │ SUBPICTURE PTR.      │      │ POINT 43,25    │
                               │         END          │      │ POINT 38,32    │
                               └──────────────────────┘      │ POINT 32,38    │
                                                             │ POINT 25,43    │
                                                             │ POINT 17,47    │
                                                             │ POINT 8,49     │
                                                             │      END       │
                                                             └────────────────┘
```

AT = SHIFTING TRANSFORMATION

SC.= SCALING TRANSFORMATION

RO.= ROTATION TRANSFORMATION

END = END OF BLOCK

PTR.= POINTER TO SUBPICTURE

FIG. 7 - DISPLAY DATA STRUCTURE (15)

The pictures a graphics program is mostly
required to generate are composed of continuous straight
and curved lines. Most displays are only capable of
generating discrete pointson a fixed grid, so points
have to be chosen to represent a continuous line. There
may be a noticeable difference between the proper line
position, and the nearest grid point, so that the grid
points must be chosen to give the best approximation
to the line (see Fig. 8). A similar problem occurs
with digital plotters, which have to represent a
continuous line by a series of short lines in eight
possible directions. Operating the plotter stepper
motor in single phase mode enables short lines to be
drawn in 16 possible directions (12). Some displays
have the facility to generate lines but usually the
problem has to be handled by software. In the best
possible situation the smallest increment of the display
is comparable to the spot size and a large number of
spots can be displayed side by side to create the
impression of continuity, but this is usually not
possible. A method of generating straight lines that
does not take an unacceptable amount of time is a soft-
ware implementation of the digital differential
analyser (13), or from information on grid cell crossings
(14). Curved lines can also be generated by the
digital analyser method (15) or by the intrinsic method
(16) which also gives analytical information.

The four basic transformations are applied to an
object in two dimensions. "Shifting", where an object
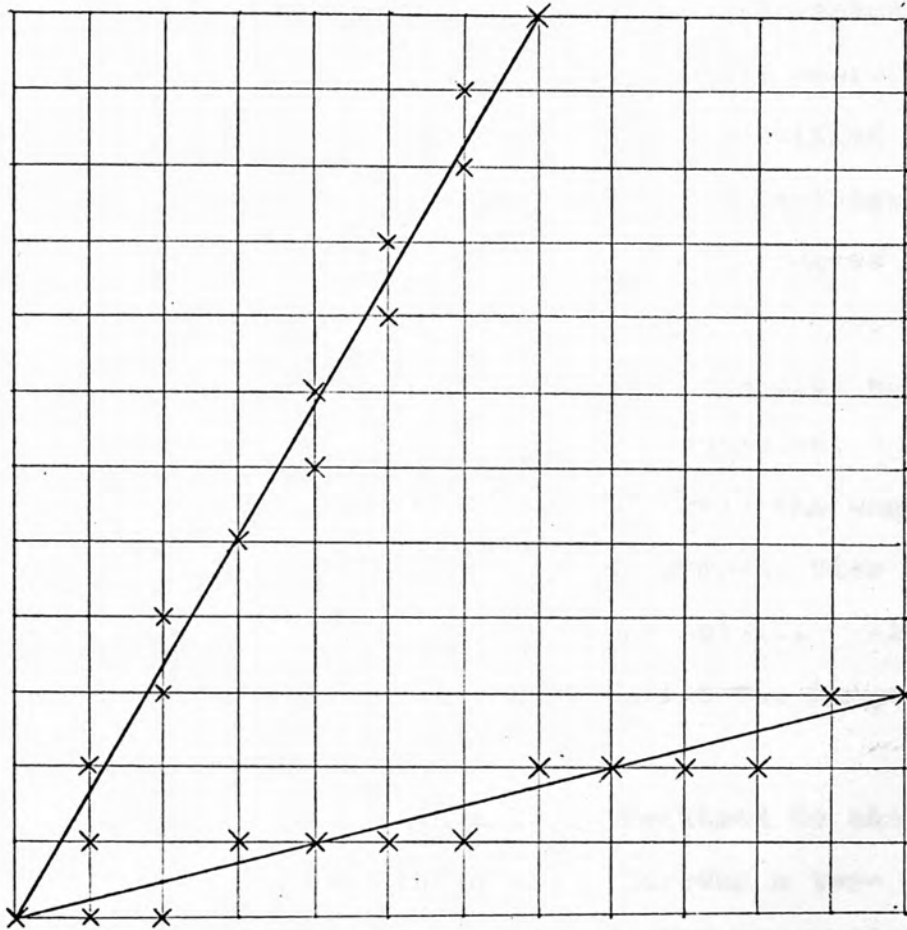
FIG. 8 - POINTS ON A FIXED GRID CHOSEN TO GIVE THE
BEST APPROXIMATION TO A STRAIGHT LINE

is displaced along one or both axes relative to the origin. "Scaling", where an object is magnified or reduced in size, it is possible to apply unequal scaling along each axis resulting in compression or attenuation of the object. "Rotation", where an object is rotated clockwise through a specified angle about the origin. "Clipping", where a rectangular area is applied to a set of points and produces from it only those points which lie within the area. "Windowing", is a more complex transformation which may use clipping, scaling, shifting and rotation. The window is a rectangular area which moves the whole picture, being enlarged to give an overall view or being made smaller in order to zoom in on detail. Also the window can be rotated in order to tilt the image seen (see Fig. 9).

Many of the objects it is required to show on a display are three-dimensional. However a two-dimensional picture of the object will generally be inadequate unless depth information is also provided. Curved surfaces are difficult to display and are usually treated as plane surface polyhedra (17). The simplest technique for forming images of three-dimensional objects involves displaying orthogonal views (Fig. 10 d), a plan, two elevations and sections if necessary. This technique depends on the viewer being able to comprehend the object represented and most people have difficulty in quickly perceiving a complicated object from orthogonal views.

41
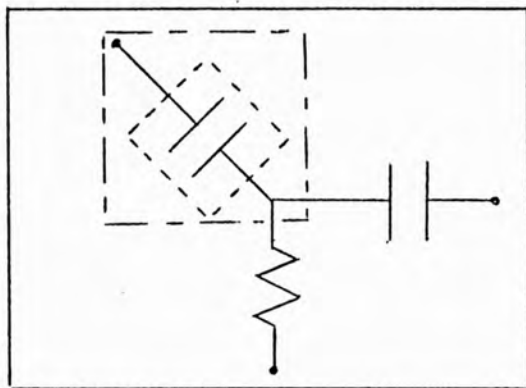
ORIGINAL VIEW

WINDOW REQUIRED - - - - -

INITIAL CLIPPING _ _ . _
   RECTANGLE
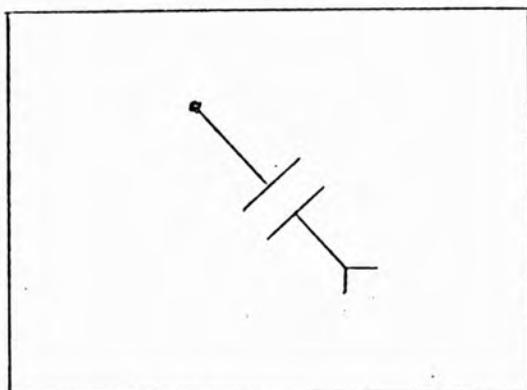
AFTER INITIAL CLIPPING
   AND SHIFTING
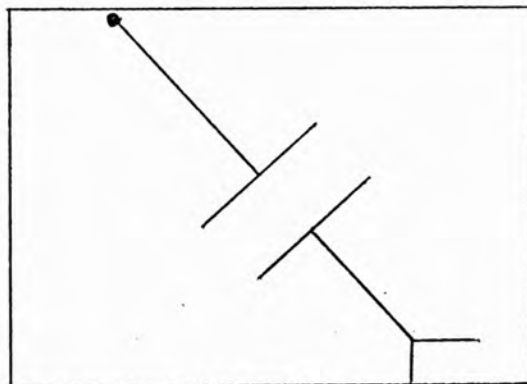
AFTER SCALING
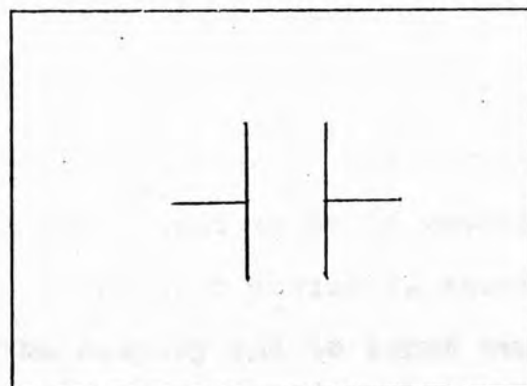
AFTER ROTATION AND
CLIPPING TO WINDOW
   REQUIRED

FIG. 9 - WINDOWING

A better image is displayed by showing a
perspective view of an object by one of three methods.
In the "wire frame drawing" of a solid object (Fig. 10 a)
the view is a perspective projection of the object viewed
from an arbitary position.   The perspective effect of
depth is a reasonably simple technique to implement and
helps to create the illusion of depth though it is not
sufficient to eliminate possible ambiguities.   The
"outline drawing" (Fig. 10 b) is also a perspective
projection from an arbitary viewing position.   However
lines or portions of lines hidden behind surfaces of the
objects are not shown.   This technique (18) requires
considerably more computation but produces a more
recognisable picture of an object.   In "shaded pictures"
(Fig. 10 c) hidden surfaces are omitted (19, 20, 21) and
shading of a particular surface is related to its
position relative to a hypothetical light source.   This
technique generates spots of varying intensities which
requires more complex display hardware but produces the
most realistic pictures (22, 23).   The two dimensional
transformations of objects can be extended to three
dimensional data e.g. three-dimensional rotations require
the specification of the direction and location of the
axis the object is to be rotated round (24).

An input device is necessary to indicate objects
on the display and to input two-co-ordinate data not
necessarily corresponding to anything being displayed.
So a graphical input device has to select a point in
2-dimensional space, usually in the same co-ordinate
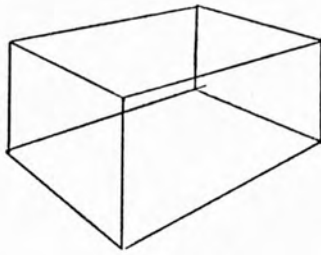
A - WIRE FRAME DRAWING
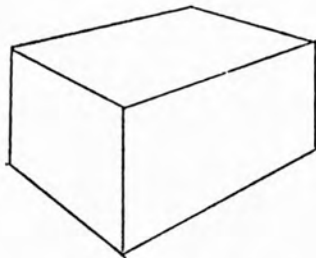
B - OUTLINE DRAWING
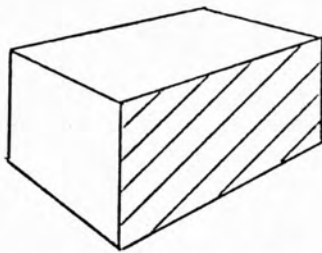
C - SHADED PICTURE
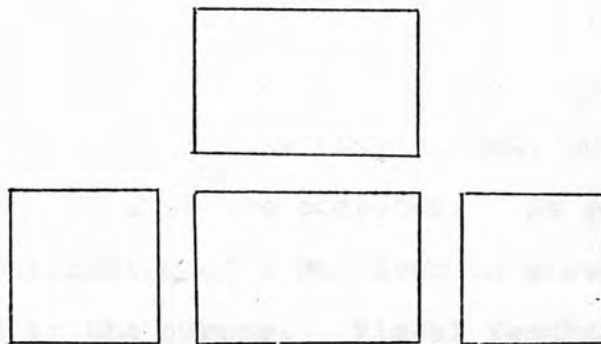
D - ORTHOGANAL VIEWS

FIG. 10 - 3-DIMENSIONAL IMAGES

system as the display.   A "light-pen" can be positioned
over an indicated point and interrupts the computer as
the point is generated.   However this method can only be
used when a point is being displayed, to indicate an
arbitary point the system software has to generate
something in the appropriate position first.   The most
common method is to use a tracking symbol, such as a
cross.   When the light-pen is placed on the periphery
of the symbol, sending information to the computer as to
its position, the program repositions the symbol so that
its centre lies under the light pen.   Thus the tracking
symbol will follow the movements of the light pen to any
desired position.   The tracking of the light pen is
usually done by a service routine and does not generate
interrupts.   Attention must be initially drawn to the
light pen by some device such as a keyboard, or by having
an "attention" region around the original position of the
tracking symbol.

The result of each input operation should be
repeated on the display so that the operator can appreciate
the effect of his input and take corrective action if
necessary.   The more immediate and complete this feed-
back, the easier the operator's task, but also the
greater the load on the computer.   An example of this
is the positioning of a resistor to a required position
indicated by the cursor.   Visual feedback is better if
the resistor symbol actually accompanies the cursor as it
moves about the screen.   Visual feedback may also be
improved by causing a particular object to stand out in

some way such as making it brighten or causing it to flash regularly.

As well as displaying symbols for positioning on the display it is also common to display a "menu" of small symbols known as 'light buttons". Each of the light buttons is connected with some input function which is indicated by the presence of the cursor inside the symbol. Numerical data can be input using a "potentiometer" displayed on the screen (8). The opposite ends of the potentiometer represent high and low values and the actual value to be input depends on the position of the cursor along the potentiometer.

The language in which the applications program is written must be able both to program the application and to handle the graphic devices. This requires that the language has good general-purpose facilities, so specially designed graphics handling language can be used (25, 26, 11). Alternatively high-level languages which are extended to handle graphics can be used (27). Readable and easily understood formats usually involve changes to the syntax and compiler of the language. Simpler implementations using subroutines or procedure calls defined within the existing language syntax e.g. FORTRAN (28, 29), do not have the clarity and conciseness of other methods.

1.6   DISPLAY DATA TRANSMISSION.

There are several likely reasons for having a
display at a distance from the machine that produces the
data.   In some cases the machine environment may be
unsuitable for human beings, in other cases data from
diverse locations may be required to be brought to a
central point to make co-ordinated decisions.   The use
of large centralised computing facilities by numerous
remote users in multi-access and time shared computer
systems has increased rapidly in recent years.   As well
as central computational facilities being used by
individual organisations, companies have been set up that
sell time on their computer to remote clients who have
hired terminal equipment.

The normal data channel between a computer and its
peripheral equipment allows the transfer of information
between them at a high rate.   The peripherals must be
close as it would be uneconomical to have this type of
data channel extended to equipment at any appreciable
distance from the computer.   If much slower forms of
communication such as the use of the postal service or
special couriers is inadequate, electrical communications
have to be used.

The limitations on the speed of information
reception is set by the devices themselves or the band-
width of the communications channel being used.   For
instance the normal switched voice grade line will, in
general, transmit up to 1200 serial data bits per second
(baud).   This allows an alphanumeric Cathode Ray Tube

(C.R.T.) terminal to display a message from the computer over 10 times faster than a teletype, which is limited by its mechanical speed of reception.

A large multi-access or time shared computer usually requires a smaller satellite computer to act as a communications controller (Fig. 11). It is programmed to control input to and output from the terminals, and in its turn is controlled by the supervisor program in the main machine. The satellite computer interrupts the main computer to feed in data and to run user programs. Both the terminals and the communications computer generate and receive parallel binary data, but for transmission across a single low bandwidth channel the data must be converted to serial form then changed back to parallel form at the receiving device. This is done by a data adaptor unit at the computer end of the line and usually within the terminal itself at the other end of the line. For transmission along the line itself a modulator/demodulator (or modem) is required at the end of each line. These act as interfaces to the line converting the binary data into frequency modulated signals suitable for transmission over telephone facilities. This is the same frequency as that of the human voice so chosen so that transmitted data will not interfere with other services, particularly the single-frequency signalling systems used to set up and take down connections.

The G.P.O. offer data transmission services at various line speed ratings. The Datel 600 service (30)
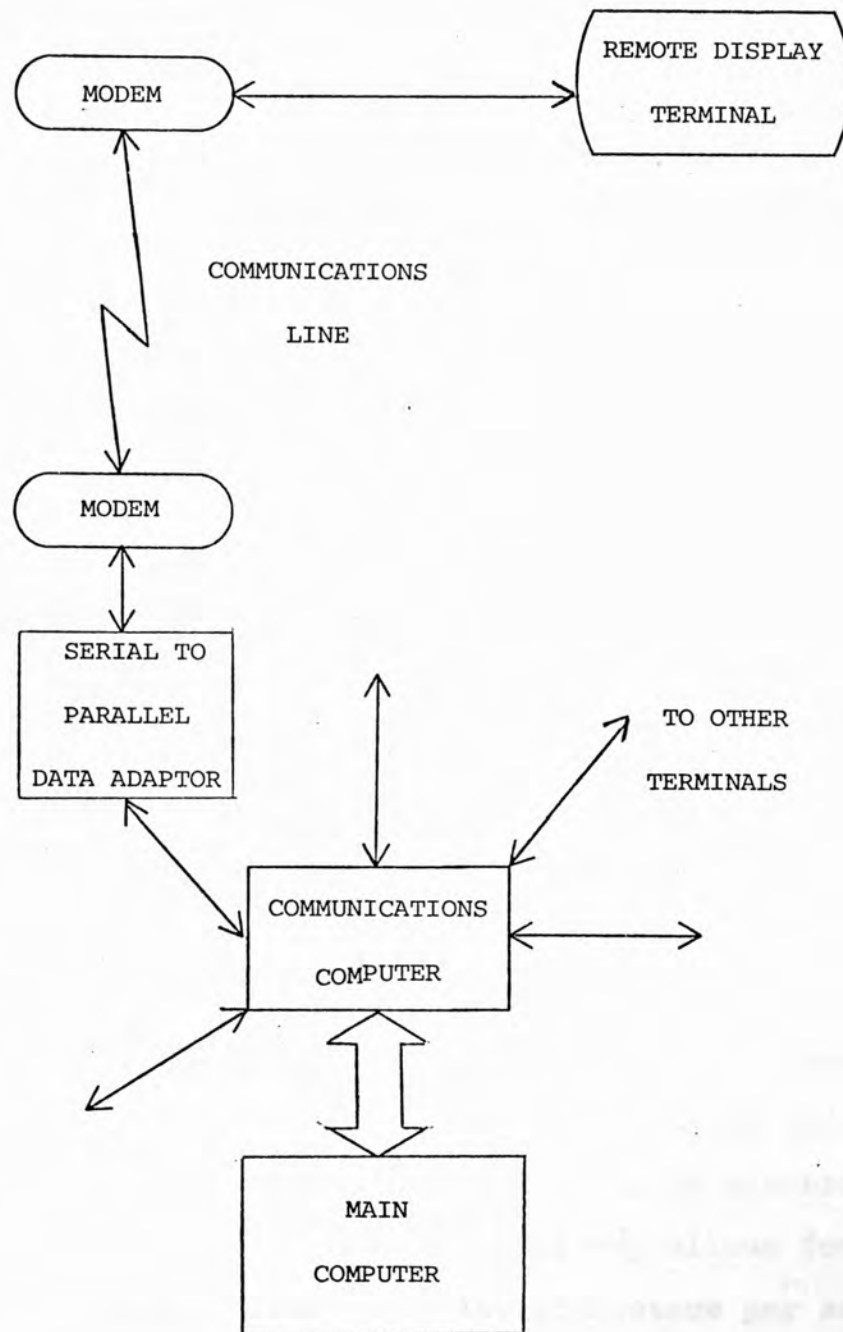
FIG. 11 — GENERALISED DIAGRAM OF A REMOTE TERMINAL
CONNECTED TO A MULTI-ACCESS COMPUTER

operates over the public switched telephone network and
offers a transmission rate of up to 1200 baud.   It is
operated in half duplex mode, i.e. 1200 baud transmission
in one direction with a simultaneous supervisory channel
of an interrupt signal at 75 baud in the other direction
on the same line.   All a user requires is to hire
normal telephone connections and modems from the G.P.O.
at the computer terminal locations.   Similar systems
are used in America and the service provided by Bell is
known as DATA-PHONE (31).   The G.P.O. also operates a
Datel 2400 service (30) which operates in full duplex
mode over hard wired dedicated lines.   These are laid
to order and their lease is fairly expensive.   The full
duplex mode uses four wires and offers transmission in
both directions simultaneously at 2400 baud.

Alphanumeric data is normally transmitted in
asynchronous mode using ASCII (American Standard Code
for Information Interchange).   Seven bits are used to
define the character and one is used as a parity check.
Each character is preceded and followed by start and
stop bits so the terminal does not need to be synchronised
to the communications controller.   If one allows for
these and other overheads about loo characters per second
can be transmitted across a 1200 baud line.   The data
could also be transmitted in synchronous mode, this is
more efficient than asynchronous mode as it does away
with start and stop bits with each character but requires
more sophisticated terminal equipment.

The network service has a substantial advantage

over the private line service in terms of reliability.
If a single private-line channel between two points
develops a fault, service is interrupted until the
trouble can be located and rectified. With a switched
network, if the trouble occurs at any place except the
end links of the circuit, automatic switching equipment
can switch the faulty circuit out of service and route
the information traffic over alternative facilities.

If the terminal is situated on the same site as
the computer and within a mile, it may be more economical
to connect it directly with a coaxial cable. This will
allow it to be operated with a data transmission rate
an order better than with a phone line.

In cases where speed is important, forward acting
error detection and correction codes can be used, the
drawback being the high cost of such schemes. Where
less expensive control is desired and sufficient time is
available the use of the "error detection and block
retransmission" method is used. The way this works is
that coded information is transmitted in blocks of a
suitable length. At the sending end each block has the
error detection digits added. When a block is received
in which an error is detected, the receiving end sends
back a signal to have the block retransmitted.

Techniques for transmitting graphic information
vary depending on the terminal device. A standard
incremental plotter describes pictures in terms of small
pen movements. Each increment is defined by a coded
character. As even a simple diagram could require the

transmission of some ten thousand increments, drawing rates are very slow.   This is not important for a slow device like a plotter which is governed by its mechanical speed of operation, but to be tolerable for a C.R.T. graphic display organisational means to minimise the exchange of data have to be devised (32).   As a C.R.T. display requires its picture regularly refreshed a local buffer can be used.   Input data can also be held in the store until a complete message is ready for transmission to the computer.   It is only then that an interrupt need be sent to the computer to receive the message.   Thus C.P.U. time spent servicing interrupts is reduced and time spent actually transmitting information over the telephone line is substantially reduced.   By this method one line can be used to service several independent displays each being polled in turn by the C.P.U.   Some C.R.T. terminals are designed for operation in cluster mode where a cluster of terminals share a local store, character generator, control unit etc.   The cost per terminal decreases as the number of terminals in the cluster increases.   When more than about four terminals are required on one site they are usually more economical as a cluster than as individual terminals.

1.7 DISPLAY SYSTEM DESIGN.

Usually hardware devices and software programing are pieced together to produce a display system for one or more particular applications. As a system appropriate for one application is usually not suitable for another the display system has to be specially designed for the particular application required (33).

Techniques are only one of the considerations in display system design. The process (Fig. 12) should start with operational analysis, system analysis, system configuration, then design of special devices and interfaces and conclude with the evaluation of the system's performance.

The operations analysis study determines what the users actual requirements are and what future requirements can be expected. Once the operational analysis is completed a functional analysis is necessary to determine the functions required to satisfy the particular operational requirements.

The next step is to perform a system analysis to determine the optimum system approach as a number of approaches usually present themselves. The system analysis is concerned with factors that are technique-oriented, such as reliability, cost, brightness, communication between man and machine (34) etc., rather than application oriented.

The system configuration which will meet the requirements of the operations analysis must then be determined. This would probably include choosing between
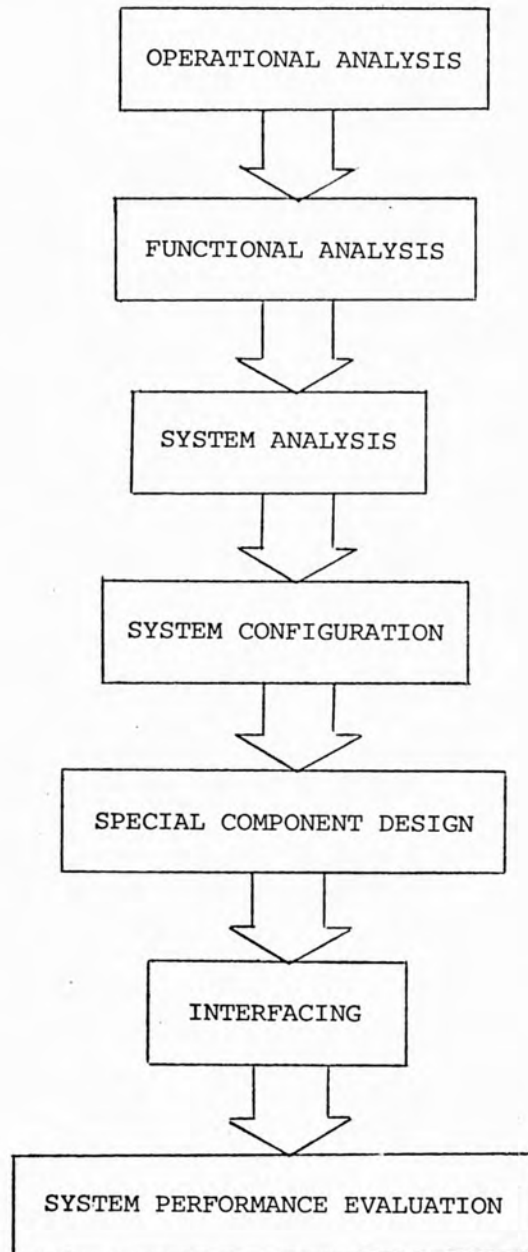
FIG. 12 - THE DISPLAY SYSTEM DESIGN PROCESS

alternative hardware and software components and making
an investigation of the trade offs possible. With linear
relationships it is usually easy to pick a satisfactory
operating point, for instance in television systems at a
given bandwidth the minimum picture repetitions frequency
is related linearly to the total number of resolvable
elements in the picture (5). When cost (usually an
important parameter) is considered against performance
it is usually found that increases in performance can be
obtained for small price increases up to a certain
performance level. At this point further increases in
performance require a change in equipment configuration
and may require a large increase in cost. The best
operating point would be just before a steep cost increase.

Many of the components chosen during the system
configuration will be readily obtainable items, however
there may be a need to design and build special devices
for specific tasks. Similarly some software will have
to be specially produced even if "device independent"
graphics software (33) is used.

The various devices have to be physically inter-
connected to each other and their electrical connections
are usually not immediately compatible with one another.
An example of this would be the need for a Digital to
Analog converter (D. to A.) to convert the digital values
output by a central processor into analog signals
suitable for driving the input to an X - Y display unit.

The last phase of the design process is the
evaluation of the system performance. The proposed

system must be able to meet its requirements or one or more of the design steps will have to be repeated. Both hardware and software must perform satisfactorily within the constraints imposed on the system, particularly with regard to costs and time taken in completing the specified tasks.

1.8 APPLICATIONS.

This section will cover the use of display systems for various applications. For many applications the type of display system used is often independent of its specific task. Due to rapidly falling equipment costs and progress in techniques, display systems are being constantly updated and used in increasingly diverse areas.

COMPUTER AIDED DESIGN.

Computers have been utilised as part of the technical design process for many years, mainly for analytical work rather than design itself. Increasingly inter-active man-machine systems, typically Cathode Ray Tube (C.R.T.) displays and light-pens, are being used to speed the process of developing a human idea to solve a design problem. Computer aided design (C.A.D.) is used in areas such as control systems (35), industrial plant (36), architecture (37), civil engineering (38), electronics (39), and mechanical engineering (40). A large number of programs for specific design problems exist (41) and there are general purpose graphics packages such as GINO-F (42) available to enable C.A.D. programs to be purpose written.

TELEVISION.

One of the commonest display applications now found in so many homes it is often taken for granted is television. A television system may be defined (43) as a system which transmits by scanning a scene or other picture from one location to another through a combination of a sensor, a communications link and a display.

In commercial television the signal from a camera is
transmitted at radio frequency and received by the
domestic T.V. set.   Closed circuit television systems
usually transmit their signals along cable, and limit the
distribution of the picture to a small number of
monitors.   Closed circuit television systems usually do
not have colour or sound facilities and are used for
industrial and military security and monitoring, remote
observation of hazardous environments and communications.
MEDICAL.

There is an increasing use of displays in the
medical world both in administrative and research areas.
Medical information systems (44) are used to provide
patient records, bed occupancy etc. for hospital personnel
using colour C.R.T. display terminals located in key
areas of a hospital.   Some examples of the use of
displays in medical research are the pictures of the head
produced from a tomographic X-ray scanner (45) to search
for tumours, blood clots etc. and the inter-active
analysis and display in an easily comprehensible form
of electroencephalogram (E.E.G.) data (46).
METEOROLOGY.

The atmospheric sciences have always extensively
used graphics, for example the weather map has been a
basic tool of the meteorologist for decades.   Display
systems that have been devised include computer driven
microfilm plotters, from which movies or hard copies of
contoured weather maps can be produced (47).   Systems
that display the satellite scans made in the infra red,

visible, and ultra violet frequencies are used for the
study of cloud formations.

POWER TRANSMISSION.

Inter-active graphics are used for the study and
planning of power transmission metworks to get rapid
load-flow information on present and planned systems (48).
Colour displays are being used to aid power control
operators in finding the necessary information and then
making decisions to switch power, energize transmission
lines or to drop some facilities for maintenance (49).

MANAGEMENT.

Displays are increasingly used in management to
display essential data in alphanumeric form (50), or show
more pictorial representations of the data by using
histograms, graphs, system diagrams, maps, pie charts etc.

INDUSTRIAL.

The industrial use of displays has been slow to
develop compared with their use by data processing
concerns like banks.   The flexibility of C.R.T. displays
in being able to display any signal the operator requests
has compensated for their cost compared with the old
panel meter dedicated to a single signal.   Examples of
the industrial use of displays are the control of a pulp
and paper mill, nuclear power plant operation, and
plastic extrusion monitoring (51).

MILITARY COMMAND.

Tactical display systems are used to aid field
army commanders and their staff co-ordinate the diverse
activities of an army and provide a focal point for

decisions concerning the immediate tactical situation.
The Army Tactical Operations Centre (52) is a mobile
system that processes information arriving by teletype,
telephone and courier to produce slides that are projected
onto a large screen or individual consoles.
SUBMARINE CONTROL.

Due to the need for dynamic control instrument-
ation in nuclear submarines, displays have been used to
relieve the operator of having to concentrate on several
indicators such as heading, depth, depth rate, etc., at
once. The CONALOG system (53) gives a picture showing
two-grids representing the ocean floor and ocean surface
with a "roadway" representing the required course that
the operator has to follow.
RADAR.

Basic radar systems are used for the detection of
distant objects via the reflection of a radio wave and its
display on a cathode ray tube usually in a Plan Position
Indicator (P.P.I.) scan. One of the earliest applications
of radar was for the detection of enemy targets in the
same way as Ballistic Missile Early Warning systems are
used today. A similar application is the tracking of
aircraft for operating anti-aircraft missiles. Radar is
also used for fire control, navigation and weather
prediction.
AIR TRAFFIC CONTROL.

One of the important applications of display
systems is in air traffic control. As well as the normal
P.P.I. radar displays computer processing of information is

used to aid rapid assimilation and decision making.
Updating of aircraft flight plans and conflicts between
them are displayed to operators (54).   The difficulty
of associating aircraft in the air with blips on the
radar screen has been overcome by the use of scan-
convertion so the picture can be displayed on a T.V.
monitor.   By the use of this approach it is a fairly
easy task for the computer to keep track of aircraft
returns and add alphanumeric tags to the blips dis-
played (55).

SPACE FLIGHT.

As television programs of the American space shots
have shown, display systems are extensively used in space
program control centres.   The sort of information
displayed relates to the status of each tracking station,
information on a satellite's position in orbit, status
of the satellite's systems and information on the progress
of the countdown checks (56).

AIRCRAFT SIMULATION.

Simulators are widely used for training personnel
so reducing the actual flight time required for training.
To be effective simulators must provide the trainees with
presentations that are realistic as possible so various
types of display system are used.   The first type of
systems projected an "out of the window" image that was
derived from the movement of a T.V. camera focused on a
three dimensional model of a runway, another plane etc.
(57).   The problems with this method are the limitations
in the motion of the camera and model and inaccuracies in

"response" of the simulated aircraft.   Computer graphics
has been used (58 and 59) to provide a more acceptable
simulation of the aircraft response and a more realistic
picture.

AIRCRAFT INSTRUMENTATION.

The effort to prevent aircraft accidents has
involved improving instrumentation which was judged to be
a contributory factor.   Examples of the improved dis-
plays (5) used are moving map displays which show the
position of the aircraft against an actual map background
of the terrain below the aircraft.   The contact analog
display shows the pilot an electronically generated
"roadway" in the sky which is the desired course.
"Head-up" displays usually utilize a cathode ray tube
to project essential information onto the aircraft wind-
screen.   Thus the pilot's head remains upright and he
does not have to periodically look down to the instrument
panel.

FILM ANALYSIS.

The extraction of information from movie film and
videotape has always been a very tedious process, yet is
essential in biomedical research, behavioural science,
industrial testing etc.   One system used in biological
research (60) projects the film for the user to indicate
features of interest with a digitizing pen.   The user
has constant computer generated feedback projected onto
the original image from a cathode ray tube.

REPRESENTATION OF STRUCTURES.

Systems have been developed that deal with general

data structures in the same way as is usual for text.
An inter-active system (61) based on a PDP-10 allows
tree-structures to be edited and a similar system (62)
has been written with the aim of allowing direct inter-
action whem optimizing networks.   One of the uses (63)
of the graphical representation of structures is in
automatically providing program flowcharts on a cathode
ray tube as an aid to programers.

HIGH ENERGY PHYSICS.

With the use of digital computers in high energy
physics to study the thousands of nuclear interactions
produced in a typical experiment, graphics is used for
the rapid assimilation of processed data.   Photographs
obtained from a special-purpose flying spot digitiser
(64) and a pattern recognition program sorts out interest-
ing particle tracks.   Further examination is required at
a display where an operator determines whether the
pattern recognition program was treating the tracks
correctly and takes appropriate action.

PSYCHOLOGY.

Display Systems have been devised (65) specifically
to simplify the automation of a general class of
psychological experiments involving presentation of
various patterns, recording multiple choice responses,
measuring of response latencies, etc.

EDUCATION.

Computer assisted instruction (C.A.I.) on an
individual level is a significant contribution to future
education.   The C.A.I. medium is capable of adjusting its

pace and material to a particular individual. A typical
system (66) would have a keyboard, graphics display and
light pen devices as the terminal for each student to
operate and be connected to a central computer.

ART.

As well as being the solution to a particular
problem or a graphical representation of data, the
pictures produced by display systems often have inherent
aesthetic properties. This has led to developments in
the use of computer graphics as a new medium for artistic
expression. One of the unique properties that computer
graphics provides is a real-time art form that interacts
with its creator or appreciator (67).

chapter 2

DISPLAY DEVICES

2.1   PLOTTERS.

There are two general types of data plotters
available, the time recording models and the X - Y
models.   Time-recording models (chart-recorders) have
been in use for many years to record events that vary
in time.   They usually contain a roll of paper which is
driven by a motor at a constant speed and have one or
more pens which swing up or down, depending on the
magnitude of the applied voltage, leaving a trace on the
surface of the paper.   The trace is usually made with
ink although other techniques such as thermally
sensitive paper are used.   If the pens traverse an arc
in their motion the paper has curved lines printed on it
to indicate the correct axis.   The speed of the drive
may be typically a few inches a minute, so an entire
test procedure can be recorded in real time and the data
studied at leisure.

X - Y plotters (graph plotters) move the recording
pen in both an X and Y direction relative to the paper to
trace out a desired graph or picture.   "Flatbed"
plotters use a fixed sheet of paper and the recording pen
moves in the X and Y directions under external command.
Typical sizes of the plotting surface are 31 x 34 in.
and 54 x 72 in. for CALCOMP plotters.   Flatbed plotters
are used where total visibility is a prime concern.   A
variety of methods (68) are used to hold graph-paper to
the surface of flat-bed plotter tables.   Magnetic holding
systems require specially prepared paper or the use of
iron strips which prove awkward to handle as do other

mechanical systems. Vacuum methods can be used but these become noisy and dust particles are continually attracted to the plotting surface. Electrostatic methods of holding the paper down have none of the disadvantages of the above methods and in addition allow the use of any size of paper smaller than the plotting surface. Chart alignment on the table is also important and one technique is to place two high intensity pin-point lights along the X-axis. These lights shine through the thickest of papers and allow fast alignment which is useful in comparative plotting.

"Drum" plotters use a roll of graph paper which enables a continuous trace up to 120 ft. in length to be drawn. The pen only moves across the width of the graph paper, the other drawing dimension is achieved by the backwards and forwards movement of the sprocket on the plotter drum which feeds and aligns the graph paper. CALCOMP produce drum plotters with 12 in. or 30 in. width graph paper, in which digital commands activate step motions to produce a short trace in the required direction. By issuing a command to step in two dimensions simul- taneously a diagonal increment is produced, thus the plotters produce traces by combinations of incremental vectors that can have 8 possible directions. More accuracy can be produced by running the stepper motors in combinations of single phase and double phase as this produces 16 possible vectors (69).

Digital plotters can be used off-line where plot data control commands are pre-recorded on magnetic tape.

For plotting purposes the tape is then played on a special magnetic tape unit which includes the control logic circuits that supply the X and Y axis drive signals to the plotter and decode commands to the pen. Normally the plot data and control commands are either supplied directly by a plotter adapter or through the interface electronics.

The advantages of plotters are their accuracy, permanence of record and low cost (compared with cathode ray tube systems). Their disadvantages are the need to change paper regularly, maintenance of the pen and ink supply, obstruction of part of the graph while it is being plotted and very slow speed. When plotting graphs on-line computers need to be run in an "interrupt" mode to avoid wasting large amounts of processor time waiting for the plotter to complete each mechanical movement. Plotters operated from a remote computer will still require the use of a communications line for long periods.

Several methods have been used to produce faster and more efficient plotters, some systems even incorporating a dedicated minicomputer for sophisticated plotting and limited processing tasks. To overcome the basic slowness of "one command - one increment" operation incremental plotters have been used that incorporate a delta-mode generator. This allows the plotter to produce drawings and annotating from a minimum of input data. Up to 256 directional commands for either axis can be contained in each X and Y word accepted by the generator. The generator then outputs a series of

pulses in the correct sequence to produce, say, a best-fit straight line.

The penless plotter provides another method to increase plotting speed. An ultraviolet beam is used to write on sensitized paper at speeds as high as 50,000 inches per second. The Honeywell Visicorder (5) is capable of writing up to 36 separate tracks simultaneously and the system does not require the use of inks, pens, electrical charge deposition or chemicals. Only a latent image is produced and an operation known as latensification which usually requires additional ultra-violet exposure is required to convert the image to a visible one.

Details of the DP-3 Calcomp Digital Plotter are given in 3.2. There are other Complot plotters of this family available. The DP-1 has a paper width of 11 inches as does the DP-5, but the DP-5 has a much faster plotting speed than the others - 1200 increments per second. The DP-1 and DP-5 are otherwise similar in operation to the DP-3. Calcomp also produce a large flatbed plotter known as the 700 High Performance Drafting System that is capable of speeds of up to 42 inches per second with a resolution of 0.0002 inch. The area of the plotting table is 48 x 82 in. and four pens with pressure inking are used to provide consistent line quality. The paper is held to the plotting surface by a vacuum system and strippable film can be used instead of paper.

2.2   CATHODE RAY TUBES.

The cathode ray tube (C.R.T.) is the basis for a
large number of display devices, and is so called
because the electron beams produced by electrical dis-
charge in gases were not at first understood.   The
basic cathode ray tube is illustrated in Fig. 13.   It
consists of three sections, an electron gun, a deflection
system and a phosphor screen.

The electron gun comprises a heater, cathode grid,
accelerator electrode and focussing system.   Thermionic
emission of electrons due to heat is the method used to
generate the electron beam.   A direct or indirect
electrical heater is used to raise the temperature of the
cathode to a point at which it emits electrons.   The
average velocity of the emitted electrons depends on the
temperature of the cathode and so a voltage is applied
between the cathode and the anode to accelerate the
electrons further.   Higher velocity electrons are desired
as they produce a denser, and thus brighter beam.   The
electron beam is then focused to produce a small beam
size on the screen which will give a high resolution
display.   Focussing is achieved by a second anode in
electrostatic tubes, and by electromagnets or permanent
magnets in electromagnetic tubes.

After the beam has been focused it must be
deflected to the desired location on the cathode ray
screen.   This is accomplished by electrostatic or
electromagnetic means.   In electrostatic tubes the
electron beam passes between a set of deflection plates,

SCREEN

PATH TAKEN BY

ELECTRON BEAM

(ELECTROSTATIC)

DEFLECTION SYSTEM

ELECTRON GUN

ASSEMBLY
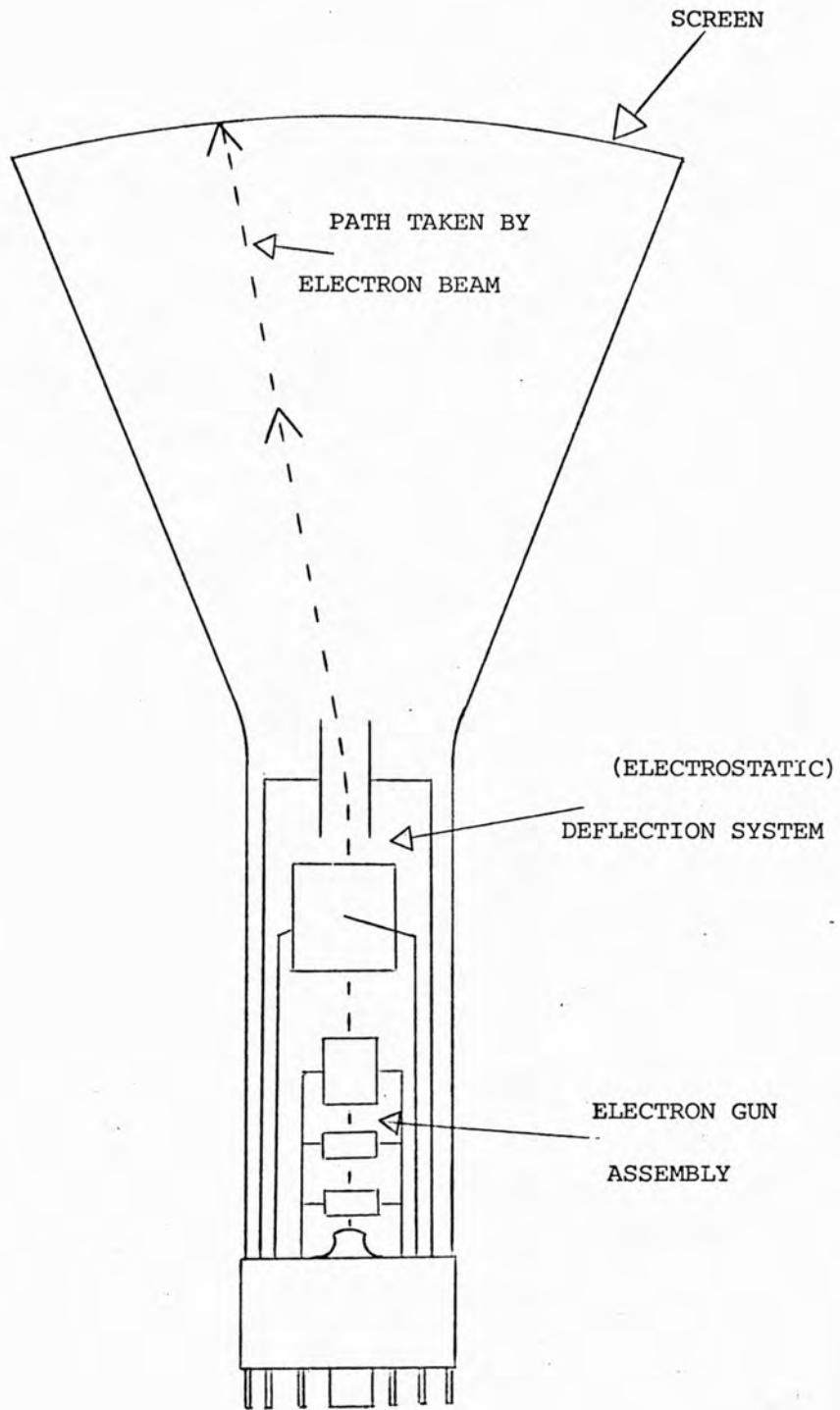
FIG. 13 - DIAGRAMATIC VIEW OF BASIC CATHODE RAY TUBE

and by applying an appropriate voltage across the plates
the electron beam is deflected to the required screen
position.   In electromagnetic tubes, coils are mounted
on the sides of the tube and deflect the electron beam
to the required position by generating an appropriate
electromagnetic field.

To produce a usable display, the beam energy must
be converted to radient energy.   This is accomplished by
transferring part of the incident electrons' energy to
electrons associated with the phosphor coating on the
screen.   The phosphor electrons are raised to an excited
level by this action and, when they return to their
initial state, release quanta of light energy (photons)
in a discrete burst.   The brightness of the display thus
depends not only on the energy of the beam but also on
the efficiency of the phosphor.   Other phosphor
characteristics of importance are saturation, decay time
and colour.

2.2.1 STORAGE TUBES.

The direct view storage tube (D.V.S.T.) was originally developed to study transient waveforms which being non-repetitive could not be received with an oscilloscope.   The D.V.S.T. is an electrostatic C.R.T. with a second electron gun, known as the flood gun, that provides a broad beam of low energy electrons.   A finely spaced grid electrode is placed very near the tube screen. In some cases, as for instance the Tektronix 4013 graphics terminal (70), the grid is actually deposited on the screen with the phosphor.

Immediately prior to writing on the display, voltages are applied to the grid electrode which leaves it negatively charged.   In this state the flood beam electrons are repelled and prevented from reaching the screen.   When the high energy writing beam bombards the grid secondary emission of electrons takes place.   The grid thus loses more electrons than it gains and becomes positively charged.   These positively charged areas of the grid accelerate the flood beam electrons onto the screen where they produce illumination corresponding to the stored charge pattern on the grid electrode.   Re-applying voltages to the grid electrode leaves it negatively charged and has the effect of erasing the image as well as preparing the tube for writing a new image.

The flood gun electrons have little effect on the charge pattern of the storage grid so that an image can be retained for many minutes without deterioration.

The storage tube is a low cost graphics device, its chief disadvantage is that although the image can be added to, part of the image cannot be individually deleted. This means that to make a small change in the picture being displayed necessitates redrawing the whole picture, which can be very time consuming. Another disadvantage is that a light-pen cannot be used with a storage tube as there is no periodic refresh of the image that a light-pen uses to identify a particular position on the screen.

By control of the write electron gun voltage, it is possible to produce a faint image on the viewing screen that is not stored in the grid charge pattern. This allows the use of a blinking cursor and data to be temporarily displayed until it is determined to be correct.

The multimode tube is a development of the D.V.S.T. and has a second electron gun and deflection circuits as an erase gun. The grid in this type of tube can be charged negatively, so allowing selective erasure and negative writing (black traces on an illuminated screen) to be accomplished.

A varient of the C.R.T. storage tube is a direct viewing storage tube which uses targets excited by an A.C. current. Its principle of operation depends on the grid allowing A.C. current flow through the high potential, stored regions but not through the unstored regions. This allows the use of A.C. excited target materials such as A.C. electroluminescent compounds and
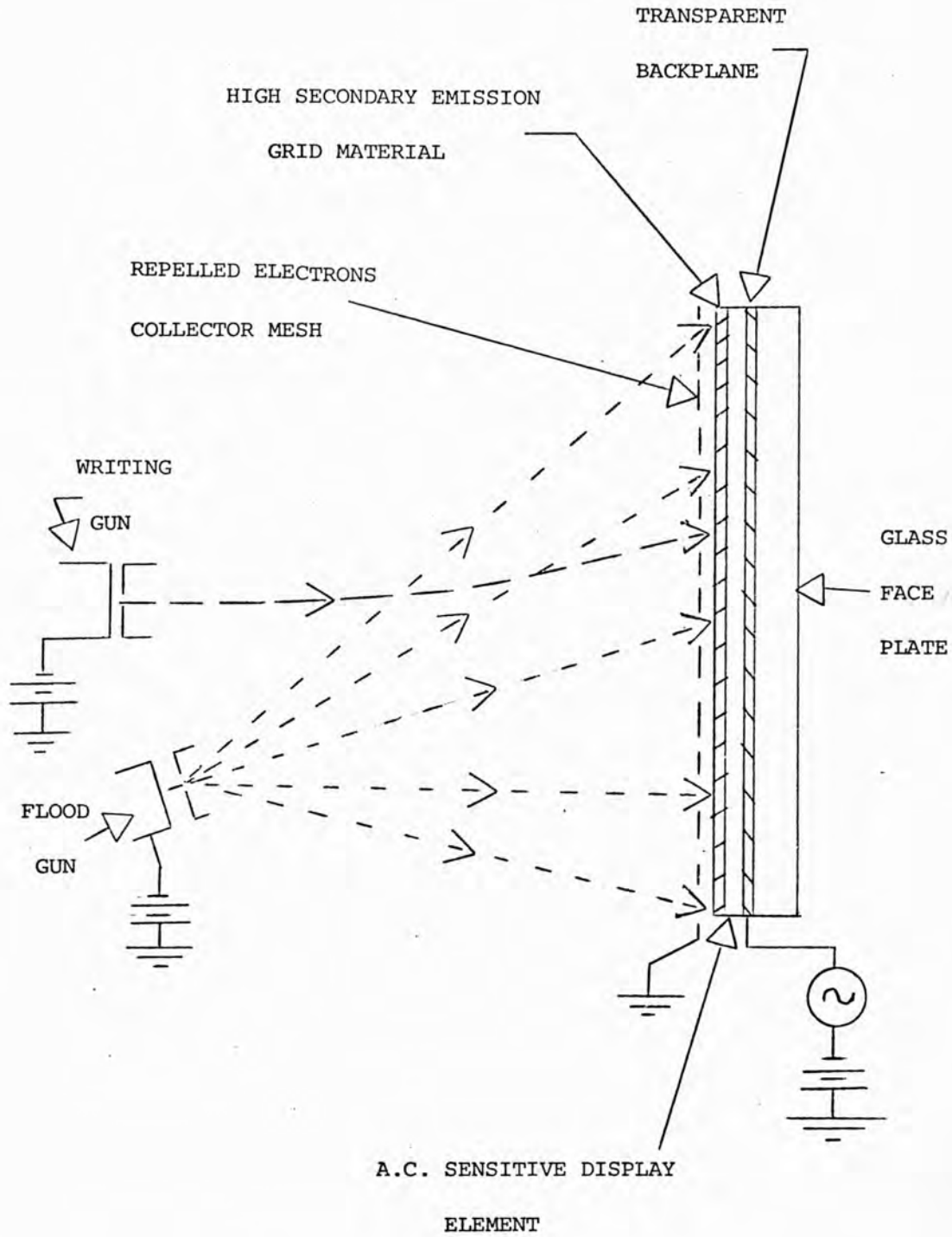
FIG. 14 - DIRECT VIEW STORAGE TUBE WITH A.C. SENSITIVE

DISPLAY ELEMENTS (71)

A.C. excited liquid crystals.   The basic elements of such
a tube are shown in Fig. 14.   From the results obtained
it is expected displays based on this technique will be
comparable with or better than those that use cathodo-
luminescent phosphor methods.

The Tektronix 4010-1 Computer Display Terminal
is a low cost storage tube display that allows hard
copies of displayed data to be obtained on a 4610 Hard
Copy Unit.   The terminal has a teletype style keyboard
with 63 printing characters and ASCII control characters.
Two thumb wheels allow a cursor to be positioned for
graphic input.   There are three modes of operation, two
alphanumeric modes that allow text to be displayed in one
or two columns and the Graphic Display Mode that produces
vectors in response to computer commands.   The display
area is 7.5 inches wide by 5.6 inches high.   2590
characters can be displayed in 35 lines each of 74
characters at a rate of 1200 characters per second.   The
4010-1 has 1024 x 780 receivable points in Graphic
Displa-y Mode and a drawing time of 2.6 ms per vector.

2.2.2 CATHODOCHROMIC DISPLAY TUBES.

Cathodochromic displays are C.R.Ts which make use
of special phosphors that change colour when bombarded
by electrons. The original colour of the phosphor can
be restored by light or heat, depending on the material
used. An advantage of this type of display is that it
can have an intense light focused on the C.R.T. face
and reflected to display the image on a rear projection
screen. This screen can be much larger than a C.R.T.
face and the reflected image gives good contrast in
high ambient light.

Erasure of the image is accomplished by brief
bursts of light from flash tubes focused on the screen.
Alternatively thermal erasure is possible by using an
electron beam to heat the phosphor at the point of
bombardment (72). This allows selective erasure,
which, combined with its low cost, could make cathodo-
chromic display tubes widely used as graphic display
devices.

2.2.3 X - Y DISPLAYS (CALLIGRAPHIC)

Interactive graphics in particular requires the
capability of selective erasure that the storage tube
cannot provide. The commonest type of interactive
graphics display device is a conventional C.R.T. where
the image is continuously redrawn at a speed fast
enough to present a steady picture to the eye (see 1.3).
To selectively erase a part of the picture, the partic-
ular item is simply left out the next time the picture
is redrawn.

The signal to continuously redraw the picture
on the C.R.T. is usually produced by a digital computer.
Digital computers however, are limited to producing out-
puts in a binary format that change by discrete amounts
at discrete intervals. The outputs from the digital
computer are converted into the appropriate voltages to
deflect the C.R.T. beam by means of a digital-to-analog
converter (D.A.C.). The controller (73) contains the
D.A.C.s, intensity controls and X and Y deflection
synchronizing circuitry that minimise inaccuracies.

The simplest form of output displayed on a C.R.T.
is a point, a series of points being used to outline a
graph or curve. Pictures of this kind are made by
issuing the co-ordinates of each point in turn to the
controller, which in each case sets the C.R.T. deflectio-n
signal accordingly and pulses the beam current. In
order to maintain the picture on the screen the process
is repeated at a high enough rate to avoid flicker. By
displaying points very close together they appear to merge

into a continuous line (see 1.3) and so geometric figures etc. can be displayed.

The co-ordinate systems used by displays are all Cartesian in that a point's position is specified by its X co-ordinate and Y co-ordinate. However there is a large variation in the precision that various displays offer, i.e. the number of different positions that may be specified along each axis. The limiting factor is the resolution of the C.R.T., the distance apart at which two displayed points become distinguishable from each other. The higher the precision the better, as this allows smoother curves to be drawn and makes text characters more legible. The C.R.T. used in the average graphical display has ten binary digits of precision giving an addressable area of 1024 x 1024 points (13).

Whenever a point is to be displayed the computer passes its two digital X and Y co-ordinates to the displa ying controller. The controller contains two co-ordinate registers in which the co-ordinate value is held during Digital to Analog Conversion. When the signal to display the point is received the beam current is pulsed to produce a spot on the screen. In some more elaborate displays a third register is provided for brightness control (or Z axis modulation). The value in this register is converted in the same fashion as for the X and Y registers and is used to control the beam current.

The simplest way for the computer to control the process of displaying points is by means of a separate

instruction to perform each operation. This reduces the complexity and cost of the controller but has the disadvantage that the computer can not be used for other tasks while points are being displayed. The computer can control a point plotting display by a single instruction that copies one half of the accumulator contents into the X-register, copies the other half into the Y-register, and intensifies the point. If the computer's accumulator is too small to hold both coordinates they are transmitted to the display registers by separate instructions and then the spot is intensified. To produce a simple pattern of dots on the C.R.T. screen the data to be presented is stored as X and Y coordinates in the computer memory. A program then works through this array of co-ordinates, loading them into the accumulator and transferring them to the display's X and Y registers. The program having reached the end of the array of co-ordinates would return to the beginning and start again, refreshing the picture so that it appears steady. The time taken to execute the program sets a limit on the maximum number of points that can be displayed without the refresh time falling below the critical flicker frequency (see 1.3).

By displaying dots in the appropriate pattern characters can be formed and text built up. The dot positions for a string of text may be held in a simple list as described above. A more efficient method is to define each character relative to one of its corners in a separate list. To display a character in a particular

position the co-ordinates are added to each of the character's relative co-ordinates in turn.   The main list only needs to contain pointers to the characters required, each of which are only held in store once no matter how many times they are used.

It is frequently required to produce straight lines on C.R.T. displays, and so special hardware vector generators can be used that draw lines very rapidly. Points on the straight line are calculated digitally and the line is drawn as a series of dots by a hardware implementation of the point plotting program.   Digital vector generators compute the location of points on the screen co-ordinate grid that lie nearest to the desired line and pass these points to the deflection circuitry for intensification.   The C.R.T. deflection is a sequence of discrete steps, each of which represents a new dot being displayed.   Analog vector generators (74) move the C.R.T. beam from the beginning to the end of the line in a continuous signal rather than in discrete steps.   As the deflection of the beam follows these signals, the beam current is left on, intensifying any phosphor struck by the moving beam whether it is on the co-ordinate grid or not.

A vector-drawing display is potentially several orders of magnitude faster than a point plotting display and a refresh program is much too slow.   An alternative device that can be used is the direct memory access (D.M.A.) channel that reads any number of sequential words from the computer memory and passes them one by one

to the display controller at a much faster rate. Once the transfer of a block of sequential words has been initiated it continues automatically leaving the processor free to perform other tasks. When the transfer is complete and the last word has been sent the processor is interrupted and may then reset the D.M.A. and start another transfer. The D.M.A. channel can thus read a list of point co-ordinates and send them to a point-plotting display as fast as the display can handle them. Alternatively it can pass a list of vector parameters to a vector drawing display. For a display system able to do both (75) the items in the list have to be marked with codes to distinguish points from vectors and logic has to be provided to decode the words received, so they are sent to the correct registers. Though text can be displayed by the use of software routines a more efficient method is the use of a hardware character generator. Another code is used to indicate the word in the display list is a character and the particular character required is represented by a code in the data part of the display list word. By the use of additional codes a variety of different hardware functions can be provided (76).

A further sophistication that can be made is to insert a word with a special code at the end of the display list containing co-ordinates and parameters. This contains the address of the start of a display list and the D.M.A. channel can reset itself to this address. The D.M.A. channel is thus capable of continuously
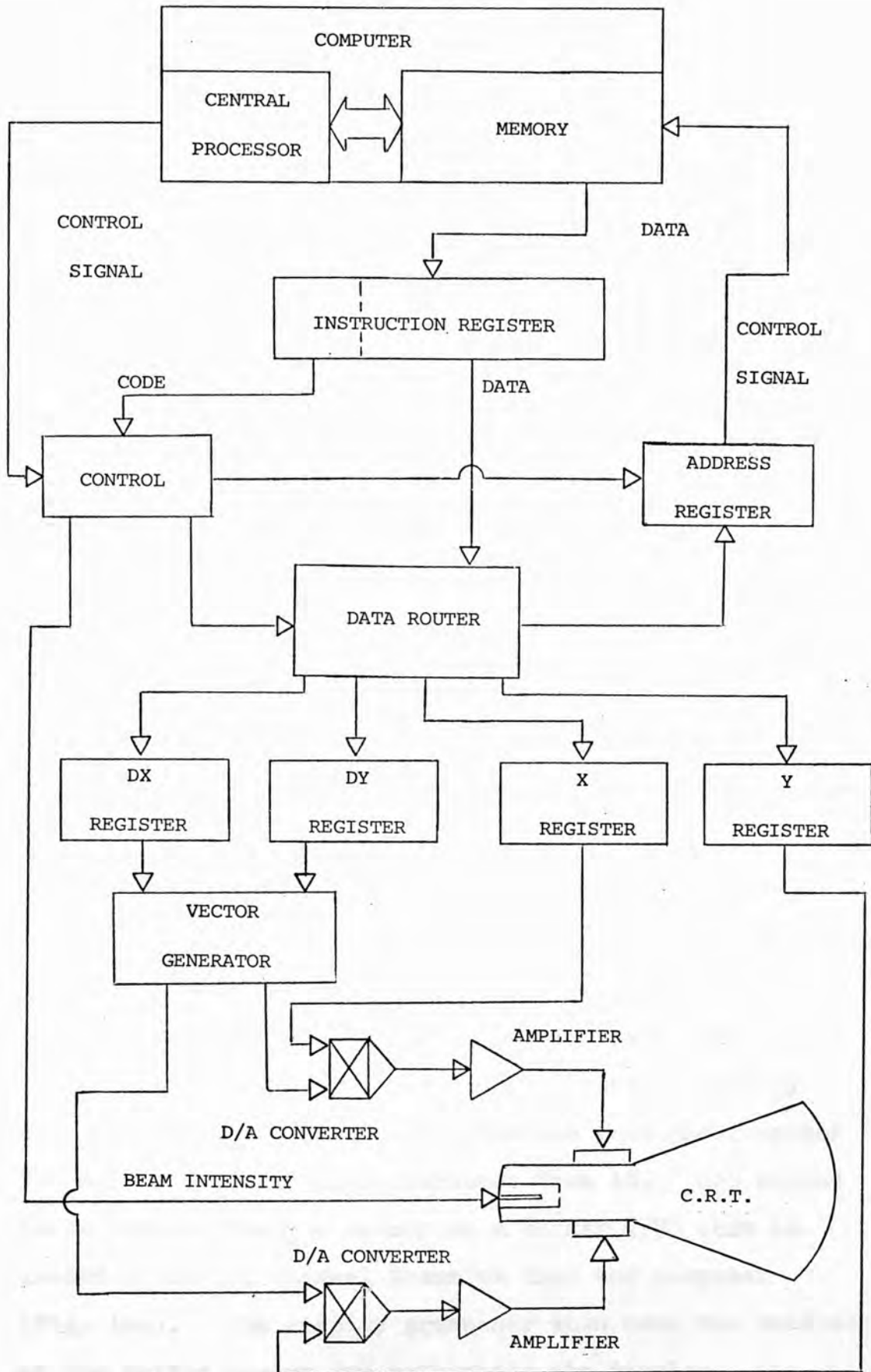
FIG. 15 - ARRANGEMENT OF SIMPLE DISPLAY PROCESSOR

refreshing the display by returning to the beginning of
the display list it has just finished processing.   The
D.M.A. channel is a display processor in its own right as
it operates independently of the central processor.   The
general arrangement of a display processor is shown in
Fig. 15.   Instructions are transferred via the D.M.A.
Channel from the computer memory into an instruction
register where they are decoded.   The data content of
the instruction is then loaded into the appropriate
register as determined by the operation code.   The
control path from the computer to the display processor
is also shown.   It is important that the computer can
maintain overall control over the display processor,
being able to reset the address register, stop and start
data transfers, examine register contents etc.

If a remote time-shared computer is used for the
graphics display it is not desirable to refresh the dis-
play directly from the computer memory as the computer's
performance may be affected by the numerous data transfers.
Problems also arise from the expense and likelihood of
errors of transmitting large amounts of data over long
distances.   This leads to the development of display
terminals that are physically separate from the computer
and may be a considerable distance from it.   One method
is to have a separate memory as a buffer (77) that is
loaded by D.M.A. channel transfer from the computer
(Fig. 16a).   The display processor then uses the contents
of the buffer memory for refreshing the display.   A
satellite display terminal such as the IMLAC PDS-4 is a
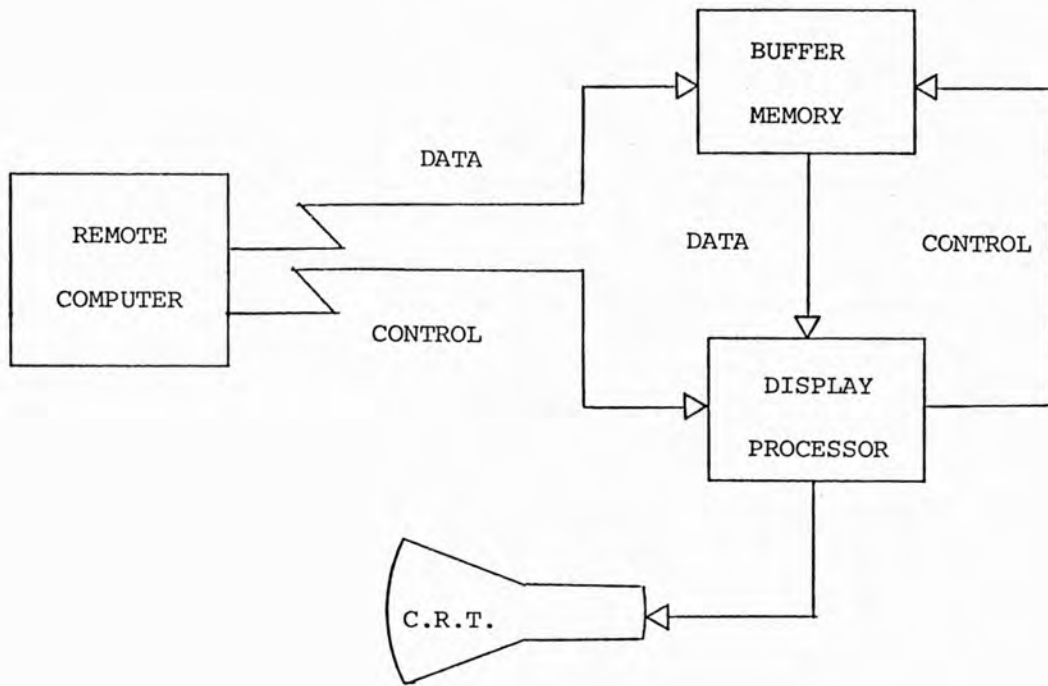
FIG. 16A - BUFFER DISPLAY TERMINAL
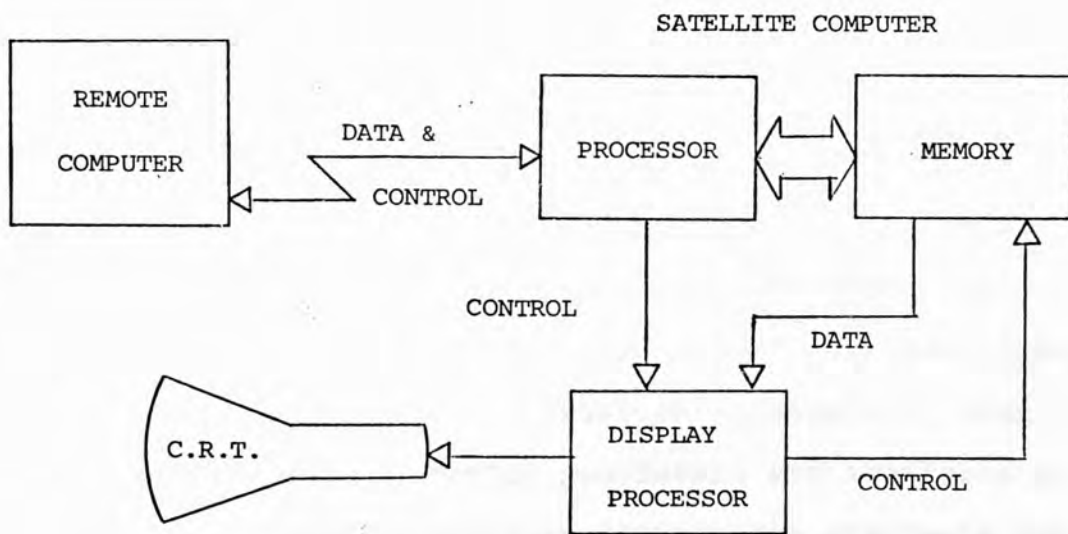
FIG. 16B - SATELLITE DISPLAY TERMINAL

more sophisticated approach (Fig. 16b) that uses a small
general purpose computer as the refresh memory (78).
This is a much more powerful arrangement as the satellite
computer not only handles the organisation of the memory
contents but can also execute user programs that require
rapid response.

Apart from being very expensive, X - Y display
terminals have the disadvantage that more and more memory
is required to cope with increasingly complex pictures.
Even if this can be provided the time taken for the
satellite computer to refresh the picture eventually be-
comes so long that the flicker produced makes the display
unviewable.

The IMLAC PDS-1G Interactive Graphic Display
Terminal is based on a 16 - bit 1.8 microsecond mini-
computer with 4K of store which is used to refresh a
C.R.T. X - Y display. With a 15 inch screen 1450 charac-
ters or upto 1200 inches of vectors can be refreshed at
40 frames per second. The PDS-1G has 1024 x 1024
addressable locations and a contrast ratio of 20 to 1.
An alphanumeric keyboard provides 96 ASCII upper and
lower case characters plus 6 user-defined function keys.
A short vector generator is provided as standard, long
vector and high speed vector generators are available as
options. Various interactive devices are available for
the PDS-1G including light pen, joystick, data tablet,
tackball and function keys. Software is provided so that
the PDS-1G can either operate as a satellite computer to
a larger host machine or in "stand-alone" mode.

2.2.4 CHARACTER DISPLAYS.

Several types of C.R.T. tube have been designed
for the inclusion of characters as a part of the tube.
The best known is the Charact-ron (79) which is a "shaped
beam" type of tube.   The electron beam is directed at a
stencil plate in which all the character shapes have been
etched out.   The beam is shaped by the particular
stencil is passed through into the required character.
The shaped beam is then deflected back to the axis and
positioned on the desired point on the C.R.T. screen as
in a conventional tube.   Charact-ron tubes are capable
of writing at high speeds, thus displaying a large number
of characters, but are expensive due to their complex
construction.

Most alphanumeric display terminals are based on
standard C.R.T.s and a large number of different makes are
available (80).   Character text is displayed sequentially
unlike graphical data so visual display units (V.D.U's)
use some type of scan technique.   The test is drawn and
regenerated by causing the electron beam to scan the
C.R.T. screen in a pattern of evenly spaced straight lines,
bright-up only being caused at the position an image is
required.   A recirculating store is used to hold the data,
usually M.O.S. shift registers.   These allow the store
circulation to be stopped and started to allow for line
and frame flyback times.   Data may be provided by a local
keyboard or from a remote source over a G.P.O. line.
This is loaded into the circulating store character by
character.

READ ONLY MEMORY

INTERNAL CONTENTS

REPRESENTING '5'

CHARACTER

CODE FOR '5'

0	1	1	1	0	0	1
1	0	0	0	1	0	1
1	0	0	0	1	0	1
1	0	0	0	1	0	1
0	1	0	0	1	1	1

ROW

CONTENTS

ROW SELECT (1-7)

ROWS

CHARACTER DISPLAYED
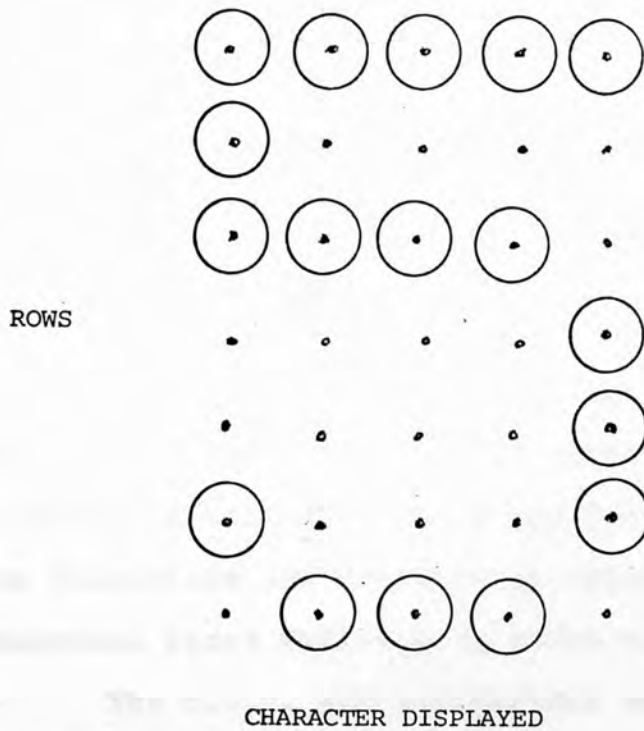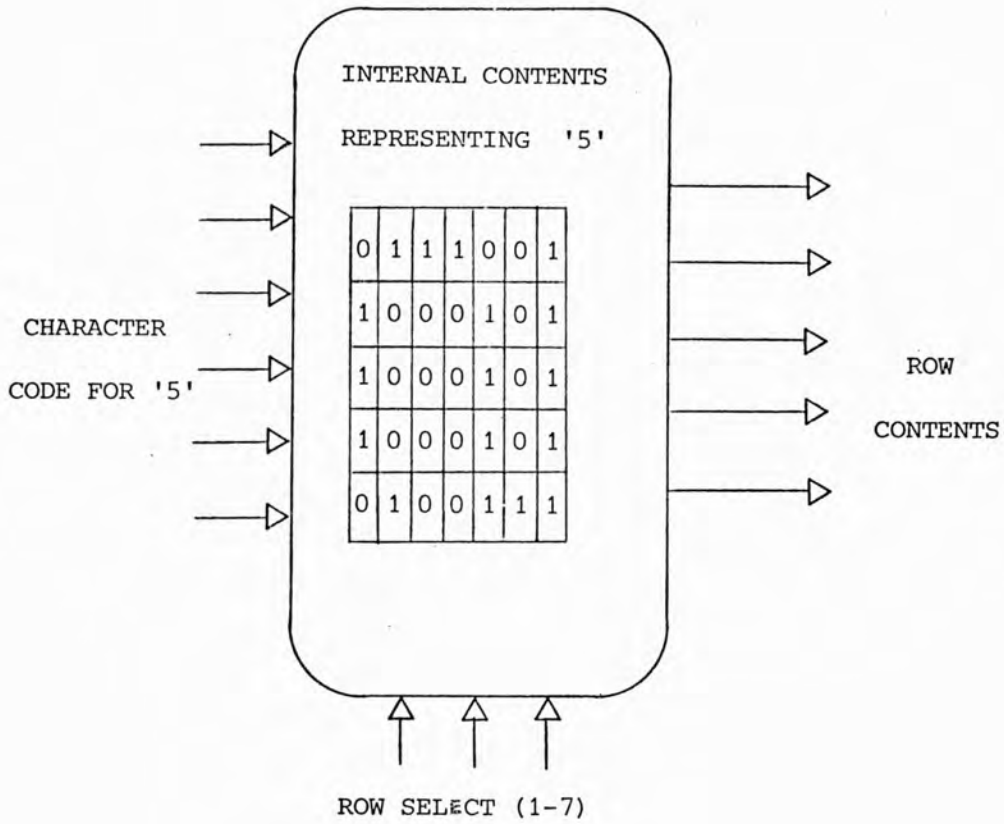
FIG. 17 - R.O.M. CHARACTER GENERATOR

Characters are generated by a read-only memory
(R.O.M.). A character-code byte from the circulating
store causes the R.O.M. to internally select a group of
registers that correspond to the rows or columns that
together form the coded character (Fig. 17). The re-
gisters are selected in turn depending on the position of
the electron beam in the scan and the contents of the
registers switch the beam current on in the correct
sequence.

The simplest V.D.U.s have 16 lines of text each
of 64 characters. Use of a small 7 x 5 character matrix
would require a 6 bit character-code byte and thus
6 1K M.O.S. static shift registers would be needed to
hold the data. A diagram of such a V.D.U. is shown in
Fig. 18. Better quality characters can be obtained by
using a larger character matrix size - 10 x 8 or 12 x 8.

Recently developed V.D.U.s employ T.V. monitors as
the display C.R.T. This takes advantage of the large
amount of effort that has been put into T.V. development
and the low cost of monitors due to mass production.
For T.V. raster scans, a complete line of characters is
written in several adjacent horizontal sweeps. The
binary character codes for the line are sent to the
generator in turn a number of times, depending on the
character matrix size. If the T.V. scan is interlaced
the characters are produced by writing lines with odd
addresses first followed by lines with even addresses.

The M.O.S. shift-registers are a cheap method of
providing a recirculating store, but problems arise due
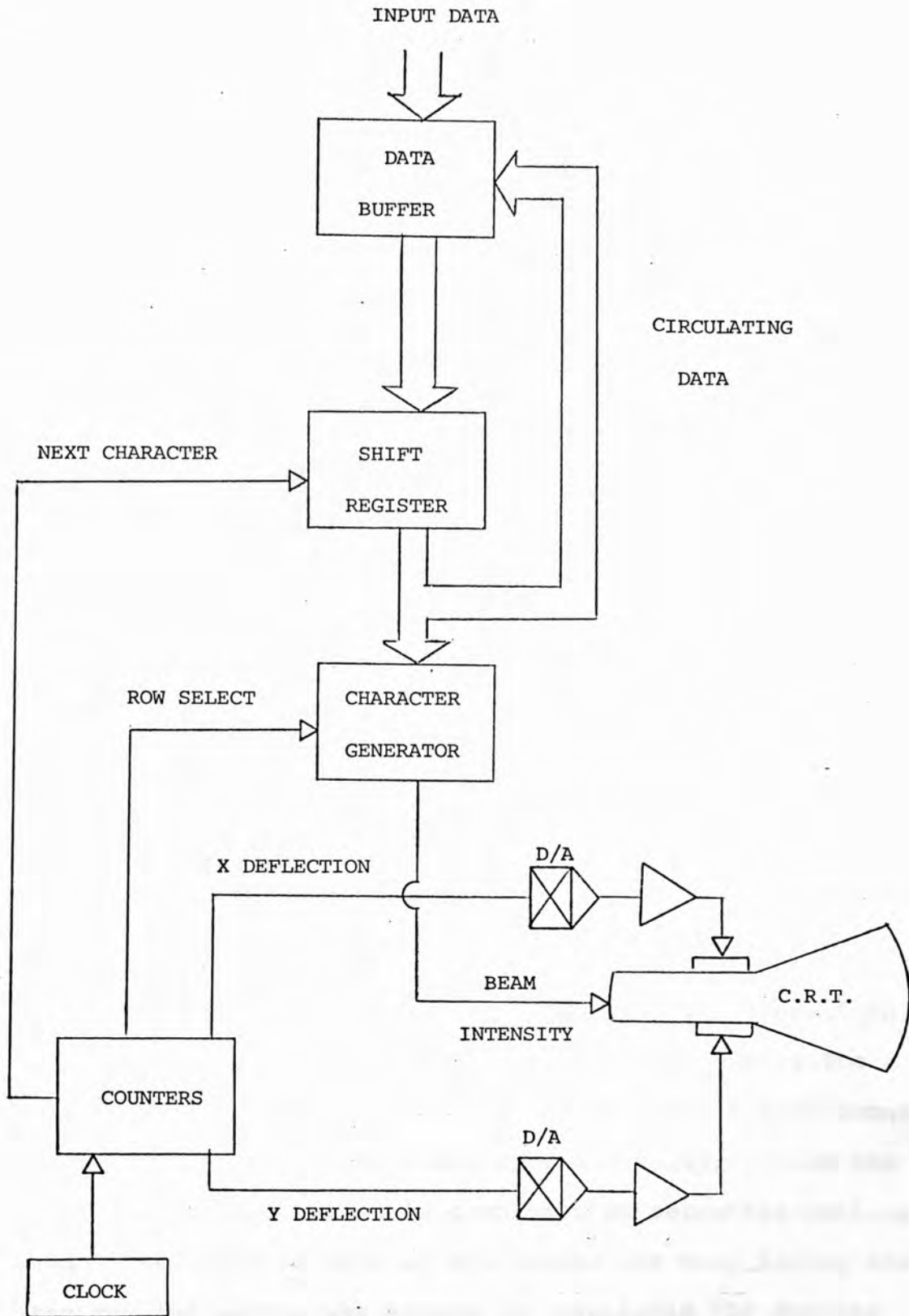
FIG. 18 - DIAGRAM OF A VISUAL DISPLAY UNIT

to its inflexibility.   Random Access Memory (R.A.M.) is
being used more so addresses can be manipulated rather
than data itself being moved.   This facilitates a
V.D.U. having a cursor that indicates where the next
character will be positioned and can be moved where
required.   Features such as back-space, erase, line
feed up or down and carriage return can also be
provided.

Some character displays have been designed to
include symbols that can form parts of diagrams and short
vector sections.   This enables continuous lines to be
built up and diagrams, graphs etc. to be drawn, although
the facilities are fairly limited.

The ITT 3210 Visual Display Unit has an 11 inch
screen and is capable of displaying 18 lines of text, each
consisting of 80 characters.   The characters are
generated in a 5 x 8 dot matrix with a height of 0.15 inch
and a width of 0.09 inch.   A standard alphanumeric key-
board produces 64 ASCII characters, and the cursor is
controlled by a separate function keyboard.   Characters
are stored in a buffer which allows editing before the
text is transmitted.   The 3210 incorporates a continuous
line denoting the lower limit of the display.   When the
last line of the screen is completed an automatic roll-up
causes the text to move up the screen one row, losing the
top row and making the bottom row available for further
characters.   The 3210 is compatible with a teletype so
can be used as a replacement without any modification.
The data transmission speeds possible range from
75 - 2400 baud.

2.2.5 SCAN GRAPHICS.

Many of the disadvantages of X - Y displays are overcome by using the C.R.T. in a raster scan mode. This is a similar mode to that used by character displays but allows graphical data to be displayed to the same precision as X - Y displays. T.V. monitors can then be used which are as little as one tenth the cost of comparable X - Y C.R.T. displays.

In the raster scan mode the picture is drawn by causing the electron beam to trace a constant pattern of lines across the display screen, as shown in Fig. 19A. The beam passes through each point on the display during one complete frame scan. An image is produced by turning the electron beam intensity on at the correct times during the scan, to bright up the required spots. Being able to set the beam intensity to several different values allows shaded pictures to be produced. A method of using two successive rasters, known as interlacing (Fig. 19B) is used to refresh the image at a high enough rate to avoid flicker and provide double the resolution that would be obtained by refreshing a simple raster.

The use of a T.V. monitor means that the data must be converted from X and Y co-ordinates into raster form with position along the scan as a co-ordinate. This scan conversion can be performed by software and stored in the core memory on a core bit per display element basis (81). The data is transferred from the core by direct memory access, in the same way as X - Y displays, to refresh the display. This system has a resolution of
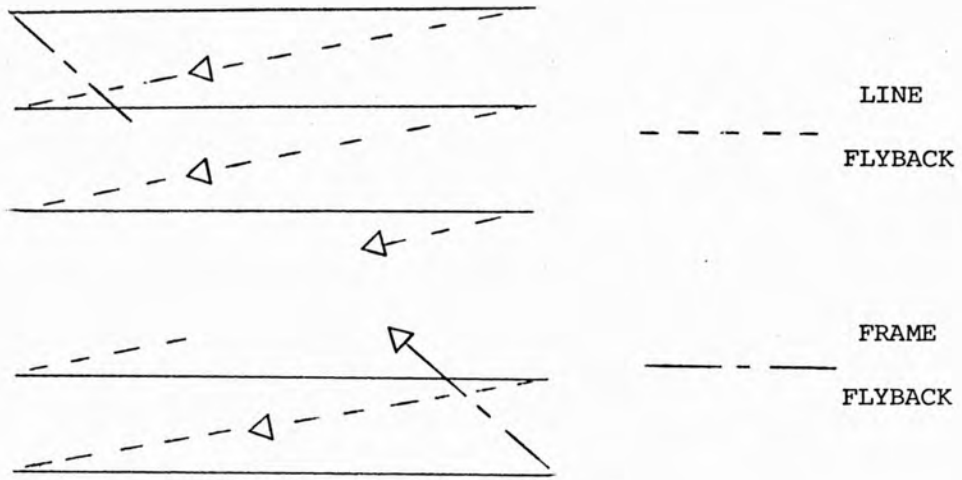
FIG. 19A - RASTER SCAN
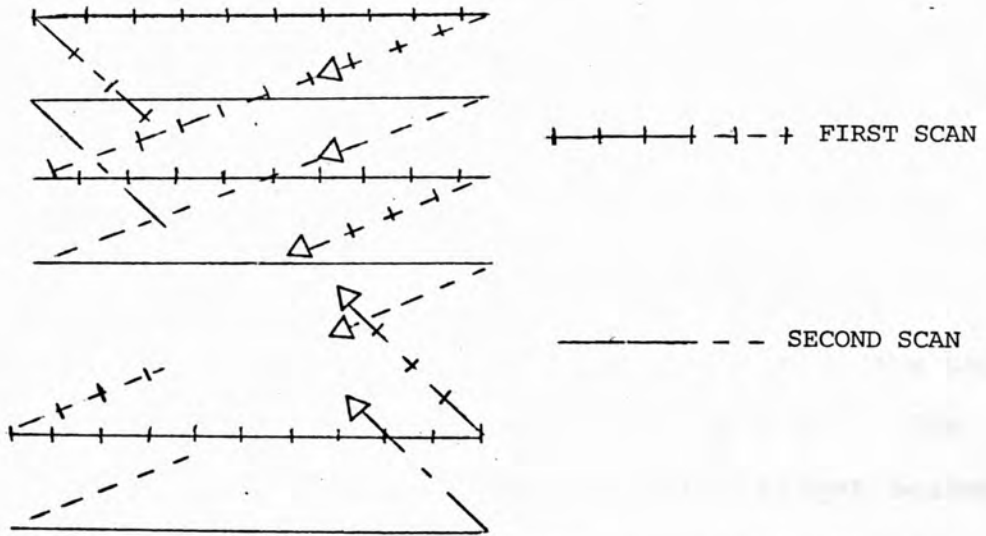
FIG. 19B - INTERLACED RASTER SCAN

240 x 254 points with no gray scale data, but the D.M.A.
speed is only sufficient to refresh the display at half
commercial rates. This means the T.V. monitors used to
have to be specially modified which defeats the object
of being able to use standard monitors.

A faster method is the "real-time" raster display
which uses a coded display file similar to that used by
X - Y displays for refreshing the monitor (82, 83).
Vector, ellipse (84), polygon (83), character and circle
(85) codes are transmitted by D.M.A. to a hardware video
signal generator where they are converted to raster
format. The video signal generator must operate at a
high rate to prevent the refresh rate falling to a point
where flicker is seen. The problem with both methods is
the large amount of computer store required for the re-
fresh memory, as the computer's performance of other
tasks would be greatly impaired.

Transferring the task of image refreshing by off-
loading the data to a dedicated storage device allows the
raster system to become more efficient (Fig. 20). One
such device is the LITHOCON Electrical Storage Tube used
in the Princeton 801 Graphic Computer Terminal. The
LITHOCON is a C.R.T. with a silicon wafer target coated
with silicon dioxide. A pattern is written on the
target by a high energy electron beam. A lower energy
electron beam is then used to scan the target, the beam
current indicating the state of the charge pattern. A
picture of variable brightness can thus be written on the
target in X - Y mode and repeatedly read off in raster-

FUNCTION

PARAMETERS   BIT FORMAT DATA

VIDEO

SIGNAL

GENERATOR

INPUT

BUFFER

DATA   CIRCULATING

DATA

REFRESH

MEMORY

SYNCS

TIMING

COUNTERS

DATA

OUTPUT

BUFFER

VIDEO

SIGNAL

SYNCS   T.V.
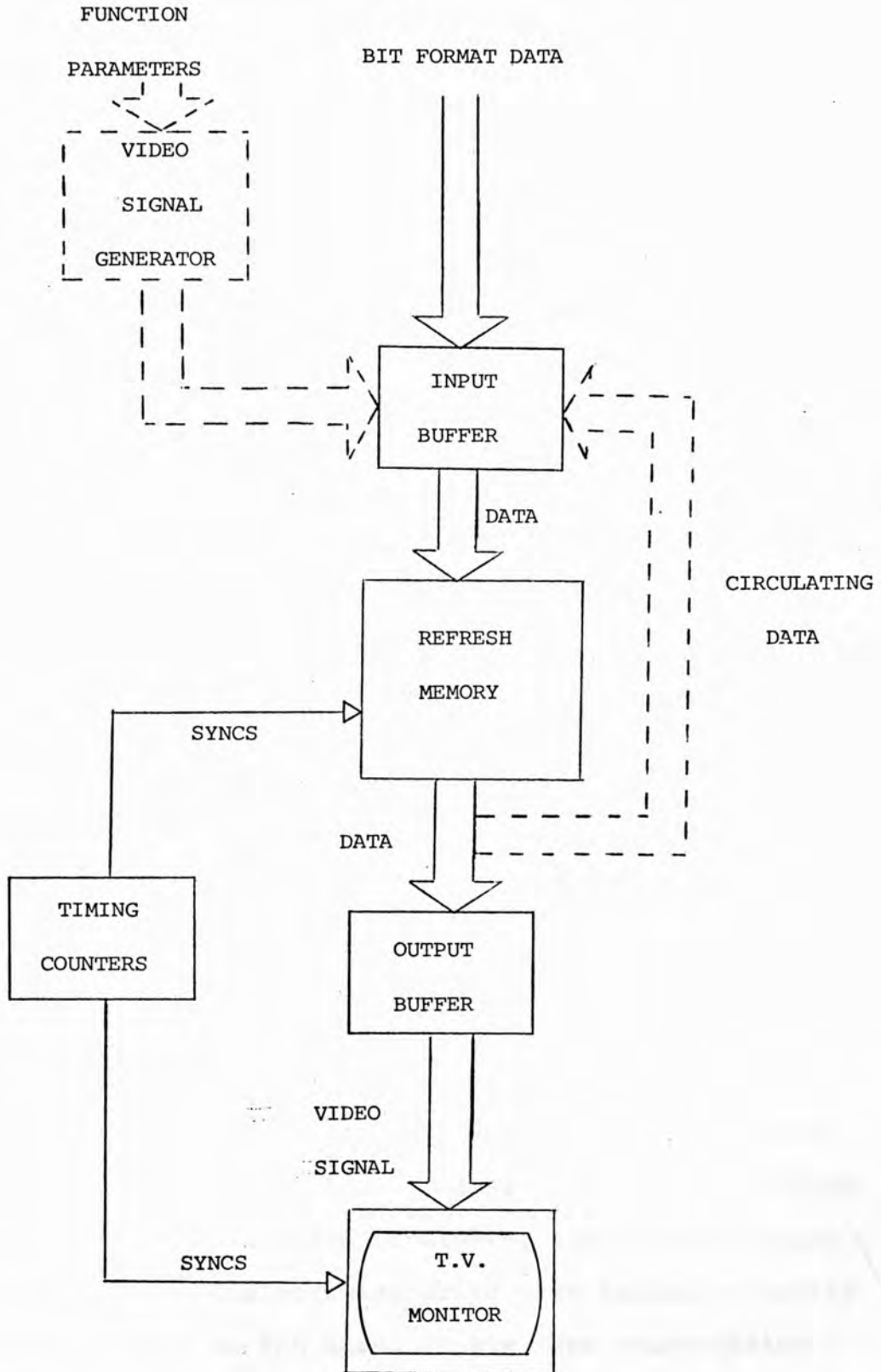
MONITOR

FIG. 20   -   A GENERALISED REFRESH STORE RASTER-SCAN SYSTEM

scan mode to refresh a monitor. A picture of good
quality and shaded tone can be generated and it is
possible to vary the scale of the picture (zoom in or
out). The problems with the LITHOCON are that the
picture quality gradually deteriorates when it is
scanned and erasure can only be achieved by retracing the
points to be blanked out. The main problem with its use
in interactive graphics is the LITHOCON not having
sufficient accuracy to hit a particular spot reliably due
to drift and noise limitations.

Magnetic discs or drums are particularly suited to
the serial mode of a raster scan and can easily handle
the large amount of data required to refresh a T.V.
monitor. Several raster systems have been developed
based on a disc refresh (86, 87, 88, 89) and manu-
facturers are now producing commercial systems such as
Process Peripherals Limited's Series 114 Multi-channel
Computer Graphics System. Disc refreshed raster scan
graphic systems are capable of high quality pictures but
the investment in a magnetic disc can only be justified
if it is used to refresh a number of different images.
The high cost of the disc is acceptable if it is shared
by a number of clustered terminals, though this limits
flexibility. Difficulties arise when trying to modify
the image held on the disc, as the area representing a
particular point on the display can only be accessed once
per revolution of the disc.

A solid state shift register refresh memory has
been provided for several systems (90, 91) and is used

commercially on the RAMTEK GX-100 graphics display system.
A shift register refresh system has the advantage that
a single T.V. monitor can be refreshed on its own at
reasonable cost, and the possibility of expensive mech-
anical failure is removed.   The method of operation is
similar to that of V.D.U.s, using M.O.S. shift registers
as a recirculating store to refresh the T.V. monitor.
The main difference is that the complete bit pattern to
be displayed on the screen is stored rather than symbol
display codes.   The availability of large, low cost
shift-registers enables good point resolution and
intensity control to be achieved.   There is still a time
delay when accessing a particular data bit in the circ-
ulating store however, as the shift register is serial in
nature.   The power consumed by such a memory may be con-
siderable with a corresponding problem with heat dissipat-
ion.

The RAMTEK FS-2000 is a colour raster graphic
display system based on a M.O.S. circulating shift register
refresh memory.   The FS-2000 produces a standard video
output enabling a wide range of T.V. monitors to be used.
The alphanumeric or graphic characters can be positioned
to any of 256 x 256 locations.   2000 alphanumeric charac-
ters can be held in the refresh memory additionally lines
of any thickness and length can be generated and are
specified by four bytes.   The FS-2000 has a 128 character
set and any character can be displayed in four sizes.
There are seven different colours available and two
intensity levels.   This makes it possible for the FS-2000

to blink any alphanumeric or graphic character from full
to half brightness to attract attention to important
items.

The use of random access memories (R.A.M.) over-
comes the problem of the access time of a circulating
store, but the use of dedicated core memory would be very
expensive.   As their costs have fallen drastically in
recent years it is now feasible to use M.O.S. dynamic
R.A.M. as the monitor refresh store (92, 93).   When not
being used for graphics the refresh store can be used as
an additional high speed memory to extend the computer's
main core memory.   The R.A.M. is scanned periodically in
synchronism with the T.V. raster, a word at a time being
read, then converted into a serial form to give the
necessary bit rate to refresh the monitor.   This also
allows the data in the R.A.M. to be accessible a large
proportion of the time.

In general the easiest way to provide colour
graphics is to use a raster scan system.   The monitors
developed for colour T.V. are much cheaper than any
alternative.   Provision of a video refresh memory only
requires an existing monochrome system to be reproduced
in triplicate e.g. three times as many magnetic disc
tracks would be used, or three R.A.M. modules.

While it is a straightforward process to generate,
or add to, a picture on a data refreshed raster display,
erasing or moving an item in an existing picture presents
difficulties.   The picture item cannot be removed from a
display file but has to be retraced and negated in the

refresh memory.   When objects overlap the erasure of one object removes points in common with the other objects leaving "holes" in them.   The present technique used to overcome this problem (13, 82) is to completely re-generate the modified picture which is a lengthy process, unsuitable for real-time and interactive use.

2.2.6 HARDCOPY DEVICES.

Besides interactive, direct view graphic consoles, C.R.T.s are also used as plotters to give a permanent record. The speed of the C.R.T. allows rapid outputs when transforming computer data into pictures. This is much faster than can be expected from mechanical plotters, though not as accurate.

Microfilm recorders are usually based on the Characteron C.R.T. (see 2.2.4) for the generation of alphanumeric and graphical pictures. Equipment such as the Stromberg SC4020 (94) use a 35mm automatic camera to photograph the image displayed on the 7 inch C.R.T. screen. Automatic reversal processors are used to develop the film output and paper copies are then produced on a Xerox printer.

Special C.R.T.s are used (5) where the phosphors are replaced by a matrix of fine wires, as dense as 250,000 per sq. in., that penetrate through the face of the tube. Electrons in a sharply focused beam strike the inner end of the wires and are conducted through the wires to produce a charge on their outer ends. The charge produced may then be deposited on the surface of a sheet of paper, or other dielectric such as a transparent film, held in close contact with the wires. The electrical charge pattern on the paper is developed by dusting powder over the paper surface and fixed by subsequent heating to produce a hard copy.

A number of C.R.T.s have been built that are otherwise conventional except for a fiber optics faceplate

attached to the screen. This is an array of "light
pipes" that convey the light directly from the phosphor,
eliminating light diffusion, parallax error and internal
reflections. In TEKTRONIX hardcopies (95) the fibre
optic faceplate is used to expose dry silver paper
directly without the use of lenses. A dry heat process-
ing device is used for developing the silver paper. A
version is available (95) that makes copies of video
images by scanning sequentially through vertical lines
of the T.V. picture.

2.2.7 COLOUR C.R.T.s

The colour C.R.T. used in commercial television is known as the shadow mask tube (5).   This has three separate electron guns with their beams arranged to converge upon a single spot on the shadow mask (see Fig. 21).   This mask is actually a perforated screen placed near the phosphor screen.   Each beam approaches the screen at a different angle and is only able to activate the phosphor of one of three colours.   The phosphors are deposited in a triad of red, green and blue phosphors in a position on the screen corresponding to each hole in the shadow mask.   Each of the three electron guns is only able to write on the phosphors of one particular colour.   Thus by utilizing the proper beam or combination of beams any desired colour may be produced.   Though the shadow mask colour C.R.T. is relatively cheap it suffers from poor resolution and brightness.   In normal use the colour T.V. is viewed from several feet and the images seen are of continuous tone.   When a colour T.V. tube is used in a display where the average viewing distance is 18 inches the dot structure formed by the phosphor triads produces objectional graininess in the image and a uniform colour is not available.

Some X - Y graphics displays use the beam penetration C.R.T. which has the high resolution and simple construction of monochromatic C.R.T.s.   The beam penetration (96), known as the Penetron, has a single electron gun and the face of the tube is coated with two
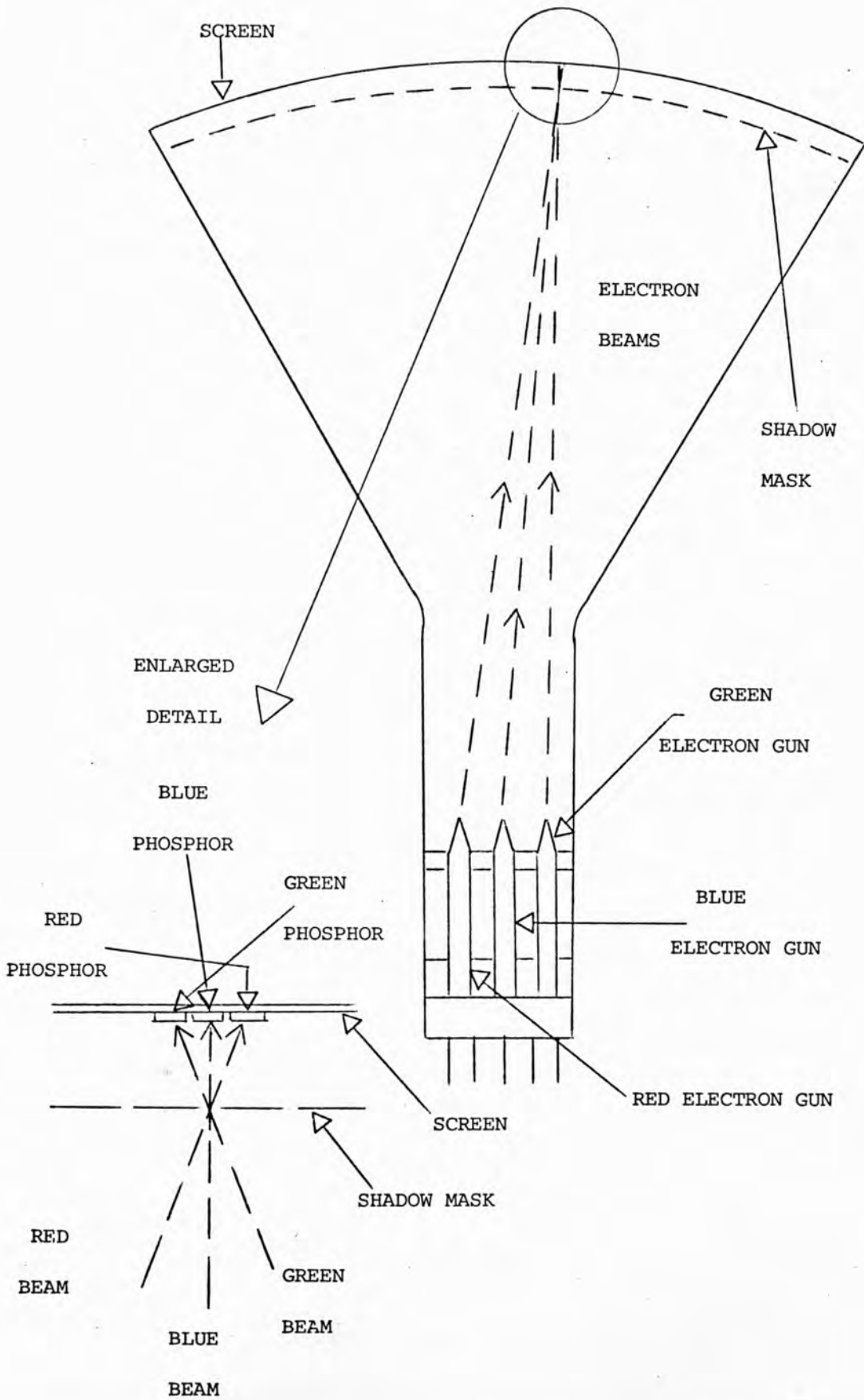
FIG. 21 - DIAGRAM OF SHADOW MASK CATHODE RAY TUBE

or three layers of transparent phosphor separated by a dielectric barrier. The dielectric barrier is needed so that an individual phosphor can be addressed to produce its particular colour. This is accomplished by varying the electron beam voltage and thus the velocity of the incident electrons. An alternative method is to use phosphors that respond to different current densities and vary the electron beam current to produce different colours. The disadvantages of the Penetron are that pure colours are difficult to obtain and switching between colours is too slow for the tube to be used for video signals.

2.3   PLASMA PANELS.

One small screen device now being developed is the plasma panel display, and this may eventually replace the C.R.T. in many graphic consoles.   The plasma panel has a simple physical construction with inherent memory and selective erase.   Visually it provides a bright, high contrast image with no flicker.

The basic display is made from a glass panel perforated with an array of holes.   This panel is laminated between two outer sheets of glass, the holes forming individual cells that are filled with a gas such as neon.   Each panel surface has a set of transparent electrode strips deposited on it, the two sets of electrodes being orthoganal to each other (Fig. 22).

When a suitable ignition voltage, depending on the cell size, gas mixture and pressure, is applied across the two electrodes on opposite sides of a cell an electrical discharge is created through the gas.   After initialization a sustaining voltage lower than the ignition voltage will maintain the discharge which causes an emission of visible light.   If the applied voltage falls below the sustaining voltage the cell will be extinguished.   Due to the voltage drop in the cell after ignition a corresponding impedance drop occurs, proportional to the number of cells fired.   This can cause voltage surges on the supply source resulting in unwanted cells firing, so extra circuitry to switch the high voltages is required.

A graphical display system based on a 512 x 512

TRANSPARENT
ELECTRODES

GLASS PLATE

CELL FILED
WITH NEON

PERFORATED
GLASS PANEL

GLASS PLATE

TRANSPARENT
ELECTRODES
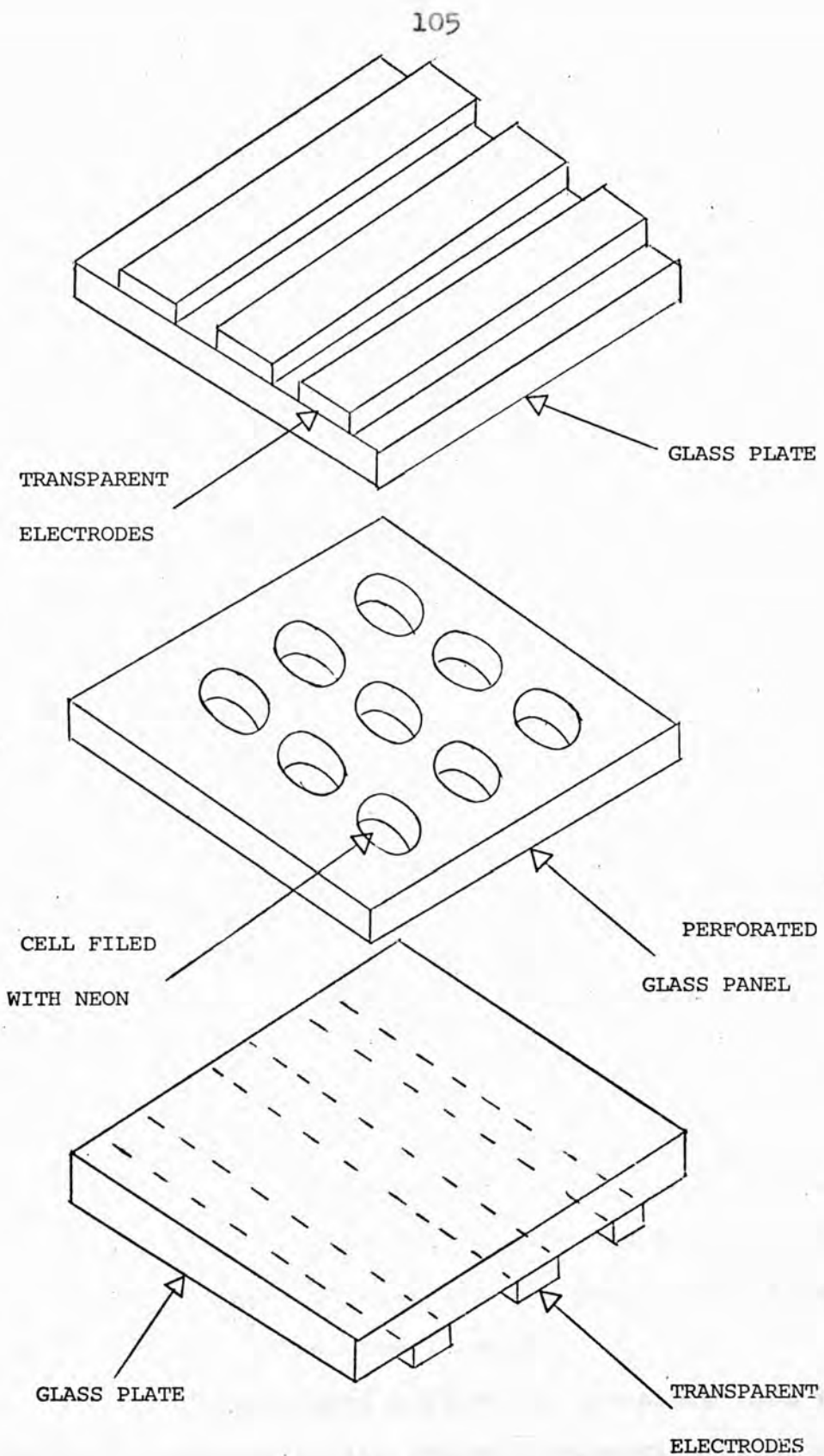
FIG. 22 - EXPLODED VIEW OF A PLASMA PANEL

plasma panel has been built at the Bell Telephone
Laboratories (97). The electrode spacing is 60 lines
per in. with individual cell sizes small enough for
adjacent dots to be resolved. A cell can be written
or erased every 20 u sec. and the entire panel cleared in
a few milliseconds by a separate bulk erase function.
The plasma panel is interfaced to a PDP-11 computer which
generates all display information. Software generation
is adequately fast as speed limitations are imposed by
the panel hardware. Since no refresh of the display is
needed several other plasma panels may be driven by the
PDP-11, depending on the rate they need to be updated.

Problems are met with plasma panels when it is
required for the user to interact with the system to
indicate some position on the display. A moveable
cursor that relates to an external positioning device,
such as a joy stick, would erase all the picture that lies
in the path of the cursor. A method of making an
economical interactive plasma display system has been
developed (98) which uses a light pen. The cells of
the plasma panel are addressed one by one with a sequence
of two interrogating pulses. This causes the addressed
cell to flash without altering its state and a light pen
can be used to detect the flash.

The plasma panel offers many possible uses for
computer graphics as its storage properties allow the
display elements to be read by the computer. The dis-
charge of the display should be sufficient to produce hard
copies from the plasma panel. The shallow depth and

transparent material it is constructed from should make
plasma panels suitable for many applications, for instance
head-up displays.

2.4   PROJECTION DISPLAYS.

Large screen group displays have been provided by using photographic or electromechanical methods to produce an image on a film or a coated slide which is then optically projected onto a screen. Due to their very slow response times they are clearly unsuitable for displaying a dynamic situation. A more suitable device for updating displayed information is the projection C.R.T. (5) which although capable of a high intensity on the tube face can not produce a bright enough image on the projection screen. Resolution of the image is low and cooling of the tube face is required.

A system known as the "light valve" has been developed which utilises an electron beam to modulate the light from a projection lamp. The electron beam was originally used to produce distortions on an oil film that in its turn diffracted the light from an arc lamp. This had several problems due to oil polymerization under electron bombardment and cathode contamination by the oil vapour. A recent development (99) of the light valve uses a dense array of electrostatically deflectable reflective membranes positioned on the inside of a vidicon tube. These membranes act as tiny mirrors, a charge pattern deposited by the scanning electron beam causes the corresponding membrane to be deflected. The light from a xenon arc is reflected off the membrane array, but only those elements that have been deflected reflect light through the slots in a Schlieren mirror and hence to the screen (Fig. 23). This allows a bright image

VIDICON TUBE

ELECTRON BEAM

MIRROR MATRIX TARGET

BEAM REFLECTED FROM

UNDEFLECTED MEMBRANE

LIGHT

SOURCE

SCHLIEREN

MIRROR

BEAM REFLECTED FROM

DEFLECTED MEMBRANE

VIEWING SCREEN
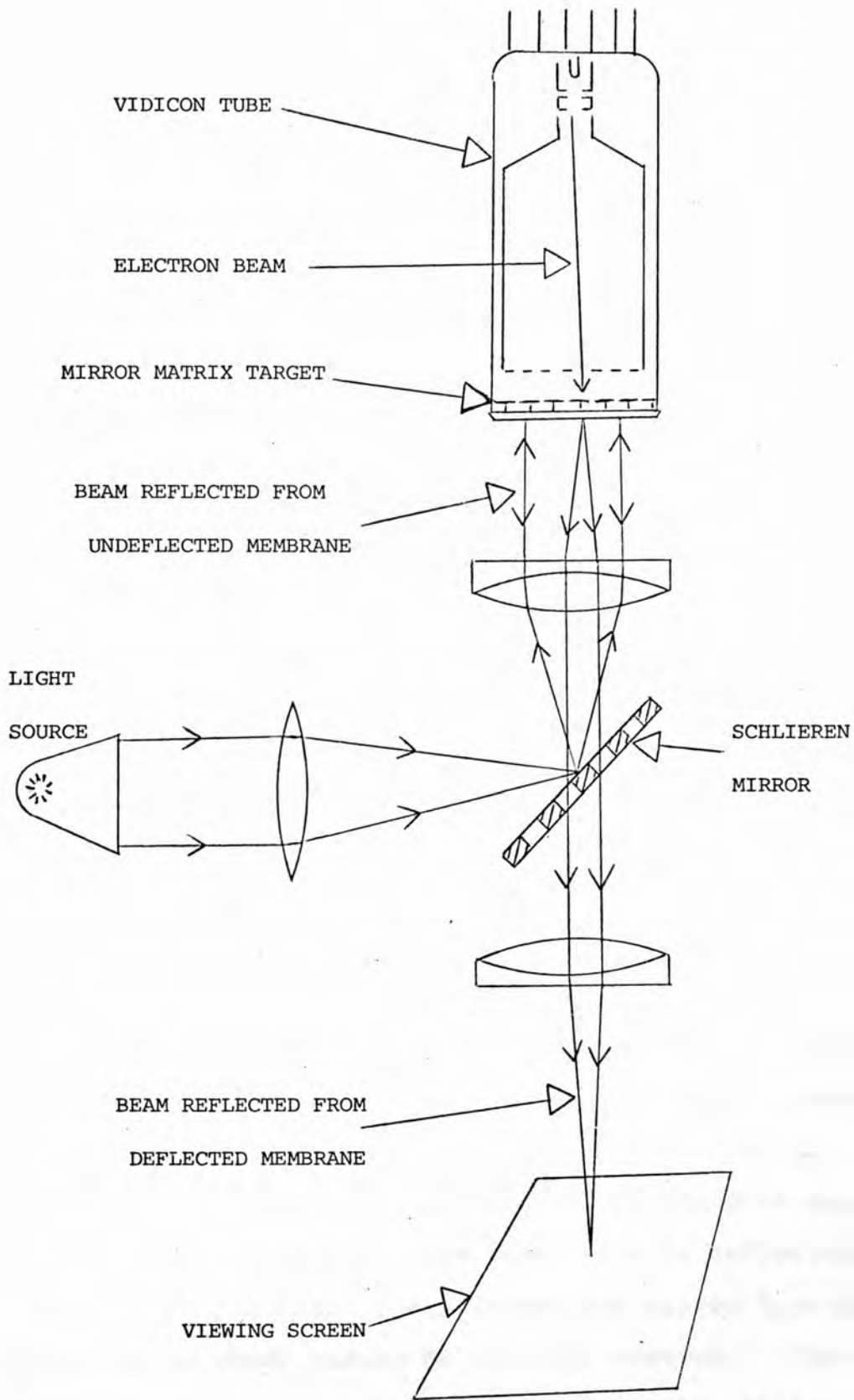
FIG. 23 - DIAGRAM OF MIRROR MATRIX LIGHT VALVE DISPLAY

to be projected onto the screen, with good contrast and resolution.

A device particularly suited for use in large screen displays is the laser due to its intensity of illumination, precision, and speed. One system (96) uses the light from an argon laser which is passed through a dispersing prism and separated into red, blue and green beams. The intensity of each beam is regulated by electro-optic light modulations that are controlled by the information on a drum memory. The light beams from the modulators are recombined by a prism and focused on a 32 - faceted cylindrical scanning mirror which revolves with the drum memory. Each face of the scanning mirror is tilted at a slightly different angle and thus controls the scanning of the viewing screen. A 512 x 512 point 7 colour display is produced that is capable of refreshing the screen fast enough to provide a flicker free picture.

Other systems use lasers to draw an image on photo-chromic material which is then projected onto a viewing screen. A military system (100) uses an argon laser to trace current tactical information on a transparent photochromic film which turns blue along the path exposed to the laser radiation. The laser beam is deflected to the required position by a galvanometer mirror type system which can be under manual or computer control. The image on the photochromic film together with a slide of the area in question are projected onto a large screen by a conventional projector lamp (see Fig. 24).
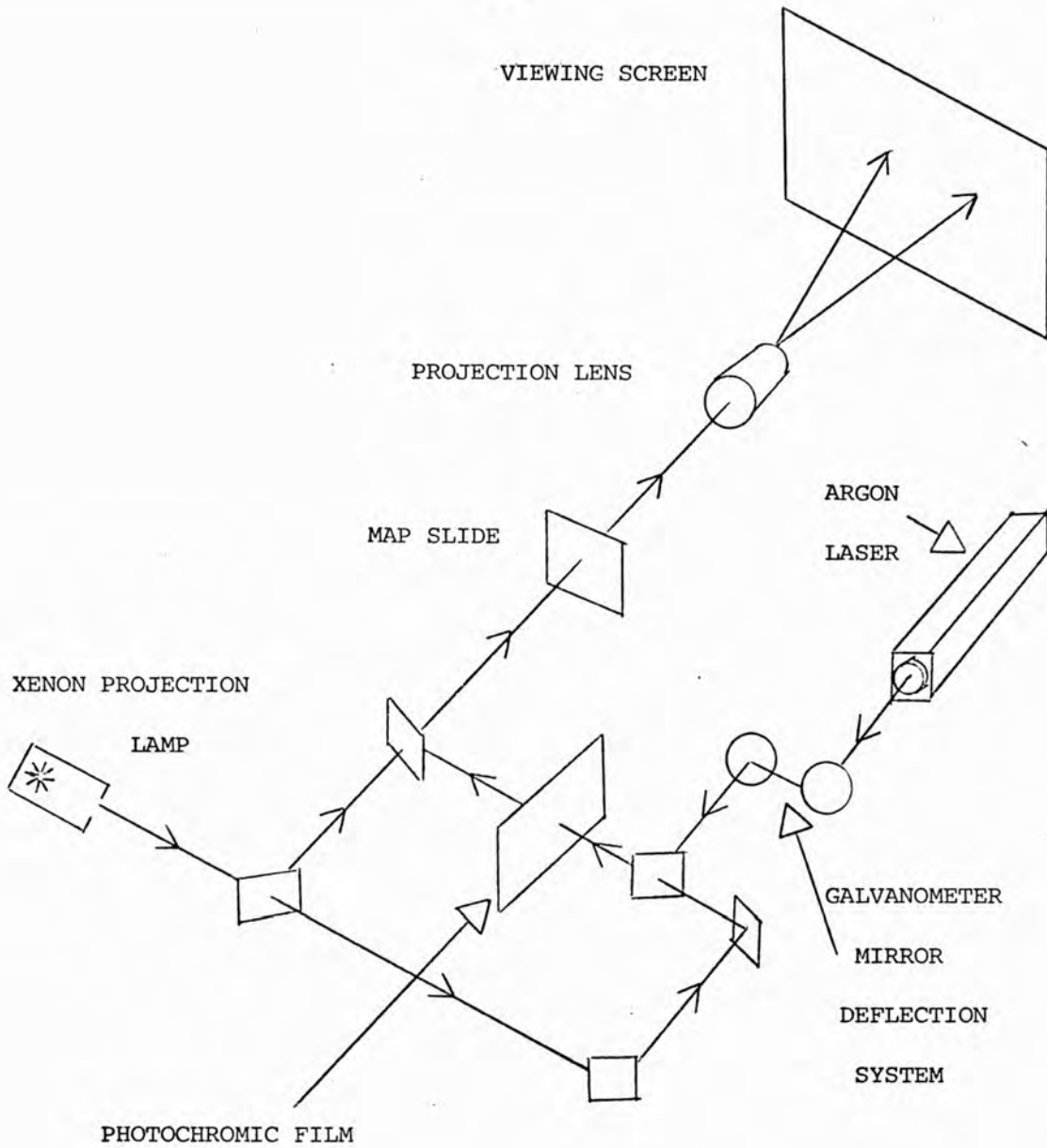
FIG. 24 - LASER PHOTOCHROMIC PROJECTION DISPLAY SYSTEM

(100)

A commercial laser display the HRD-1 is produced by Laser-Scan Limited (101). In this system the laser is also used to trace an image on photochromic film which is then back projected onto a large screen. Interaction is possible with the HRD-1 as a low power laser is used to draw and refresh a temporary image directly on the screen with the image projected from the photochromic film. The laser beam is deflected in the required direction by interferometically governed mirrors controlled from a computer. A feature of the HRD-1 is that the laser beam can be used to write on a diazo microfish as well as on photochromic film which allows the production of hard copies of the displayed image. The laser displays have the disadvantage of not being really interactive, as the user has to wait for the present image to fade from the photochromic film before an altered picture can be clearly seen. The main advantage is the large image that can be displayed at high precision by a laser display, though the apparatus is bulky and expensive.

The HRD-1 Laser Display/Plotter has a 100 cm x 70 cm screen and can draw over 5000 x 3500 resolvable lines. The use of fiche size film (148 mm x 105 mm) gives a higher resolution of 7000 x 5000 lines. The drawing speed of the HRD-1 is 0.5 metres/sec. on the film and 5 metres/sec. on the screen and is such that a map defined by 350,000 bytes can be drawn in under two minutes. The drawing spot size is 20 microns and the image is retained on the photochromic film for about 15 minutes. In refresh mode the spot draws on the

screen at 20 metres/sec. with a quarter of the
addressability.

2.5   LIQUID CRYSTAL DISPLAYS.

Liquid Crystal Displays (L.C.D.s) do not emit
light upon the application of voltage, but control or
modify the passage of externally generated illumination
by light scattering, modulation of optical density or
colour changes (102). The liquid crystal is so called
because it does not exist in a solid or isotropic liquid
phase but in a third phase where it flows like a liquid
with the long range ordering of molecular spacing and
orientation of a solid. The compounds used are organic
with long rod-like molecules. These are confined be-
tween two glass plates as shown in Fig. 25A. The inside
surfaces of the glass plates are covered with transparent
conductive coatings patterned to the desired shape. By
applying voltages above the threshold voltage, the long
axes of the liquid crystal molecules tend to align
parallel to the applied field. Linearly polarized light
propogating perpendicular to the device is normally
rotated by 90°, but ceases to be rotated when an
appropriate field is applied. Hence by laminating the
liquid crystal display between an analyser and a polariser
a black-on-white or white-on-black display can be pro-
duced, depending on the orientation of the polarizer.

An alternative mode of operation that is cheaper
than the polarised method is to use the dynamic scatter-
ing property of L.C.D.s When a threshold voltage is
applied the fluid orientation changes and a vortical
flow with periodic structure develops. As the applied
voltage exceeds the threshold value the fluid flow
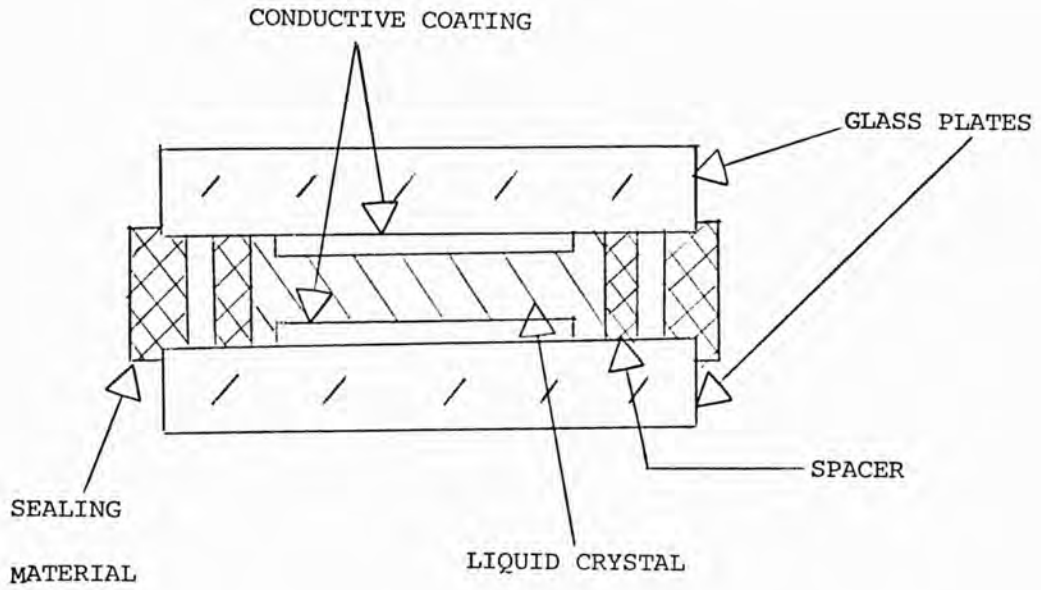
FIG. 25A - CROSS-SECTION OF A LIQUID CRYSTAL DISPLAY
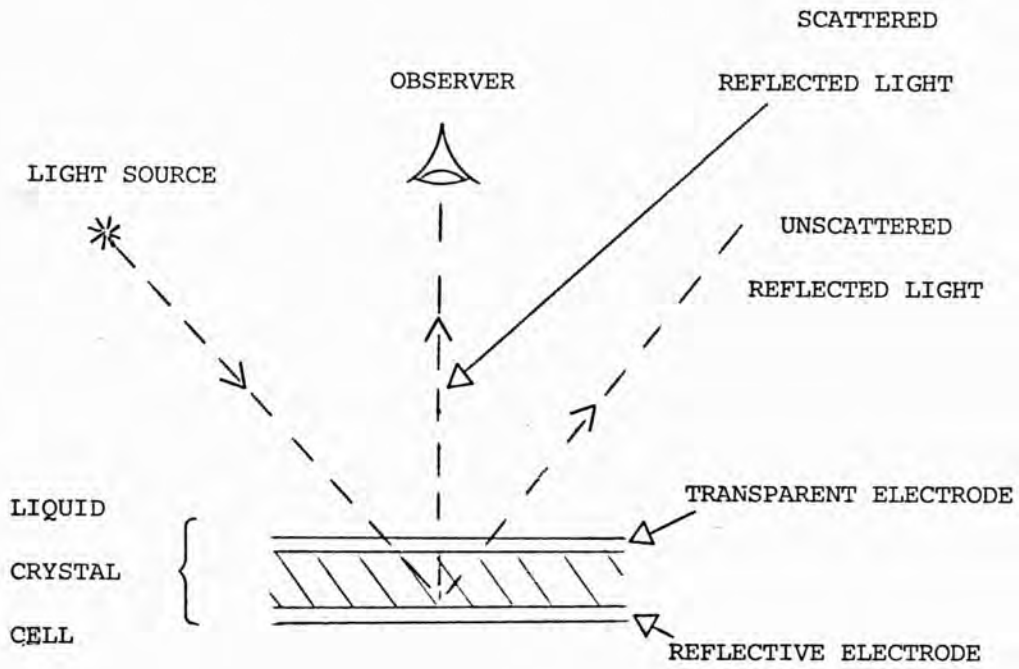
FIG. 25B - REFLECTIVE VIEWING OF A DYNAMIC SCATTERING

LIQUID CRYSTAL DISPLAY

becomes unstable and the periodic structure breaks down.
The resulting turbulence produces a strong, diffuse
forward light scattering due to the formation of micron-
sized birefringent regions in the turbulent fluid. Some
problems are found with reflective dynamic scattering
L.C.D.s as the observer has to be in the right position
so that only the scattered light is within his field of
view and none of the unscattered light (see Fig. 25B).

L.C.D.s are flexible with respect to size
variations and their simple construction means they are
economic to produce. At the moment they are used for
small-to-medium size displays, the largest commercial
L.C.D. being 8 in x 10 in (103). The L.C.D. has a low
current consumption and is also compatible with the low
power CMOS integrated circuit technology. The problems
with early L.C.D.s such as brief life expectancy, and
temperature sensitivity have now been overcome. Chief
disadvantages are the slow response time of L.C.D.s and
the need for a backlight in low ambient lighting.

2.6 ELECTROLUMINESCENT PANELS.

Electroluminescence is the production of light from
a phosphor by placing it in an electrical field.   There
are two types of electroluminescence - D.C. electro-
luminescence consists of the light emission created by the
action of a direct field upon crystals.   More efficient
is A.C. electroluminescence where certain types of
phosphors emit light when placed in an alternating
electric field.   This is attributed to electrons being
excited into a higher energy state by the electric field
and then releasing energy in the form of light on return-
ing to the lower energy level.   The electroluminescent
panel is usually constructed by imbedding the phosphor in
a dielectric material placed between two conductors.   The
conductors are closely spaced to produce a high field and
one of the conductors is transparent, so the light pro-
duced is visible.

A 6 in x 6 in electroluminescent Display Panel
has been produced (104) which has solid state addressing
circuits built directly on the panel.   This is achieved
by a vacuum-deposited thin film transistor matrix.   The
panel had 12000 elements and was refreshed at T.V. rates
so that monochrome T.V. images could be presented as well
as alphanumeric and vector data.

As an alternative to the use of colour T.V. monitors,
chromatically biased electroluminescent panels are being
investigated (96).   The work involves generating a single
colour on a display panel so that the colour appears
when the panel is electrically de-energised.   The

observed colour is changed by adding specific amounts
of electroluminescent emission, which is controlled by
the voltage and frequency applied to the panel.   Pure
colours can be produced though some hues are not obtain-
able due to the restricted emission of the electro-
luminescent panel.

chapter 3

GRAPH PLOTTING

3.1   SYSTEM REQUIREMENT.

As was discussed in 2.1, the use of incremental graphplotters allows high resolution graphs, pictures, diagrams etc. to be produced by a computer.   One of the drawbacks of the widely used Calcomp type of graphplotters is the time taken to produce a trace.   A complex picture composed of 540,000 increments, for example, would take at least half an hour to draw out on the plotter.   This becomes more important when remote processing is used and programs are input and output via a communications link.

Communication lines and modems (modulators/ demodulators) are available with a wide range of speeds measured in baud (bits per second).   This provides an additional complication,as in the case of slow telephone links the plotter may not be driven at full speed and spend even longer on drawing out a graph.   In the case of faster lines over 1200 baud, the line may be under-used as time is spent after a command has been transmitted waiting for the plotter to finish the increment.   Such lines are usually expensive and plotting a graph would occupy the line for a considerable time during which normal printed output could not be received.   A reduction in the time taken to transmit graphplotter data is desirable as it would decrease program turnaround time and make more efficient use of the communications link.

Royal Holloway College (R.H.C.) has a COMPLOT DP-3 Graphplotter, a C.D.C. SC-17 computer and a Post Office link to the University of London Computing Centre

(U.L.C.C.) as part of its computing facilities.   U.L.C.C. provides a regional computing service to augment what is available locally at Colleges of London University and other Universities in the South East in accordance with guidance given by the Computer Board.   There are three main computers at U.L.C.C., a CDC 7600, CDC 6600 and CDC 6400 and a CDC CYBER 72 used as a communications handler.   Input and output of jobs is via a CDC 200 User Terminal which is connected to the graphplotter via a COMPLOT BTC - 7/200 controller, a cardreader and a line printer (see Fig. 26).   The BTC - 7/200 controller intercepts output data and examines the codes for a start plot sequence.   Until this start plot sequence is recognised the data is passed to the line printer from the BTC - 7/200.   The reception of a start plot sequence causes the BTC - 7/200 to decode the following characters as plotter commands until a stop plot code is recognised. This allows the printer to receive the following data until a start plot sequence is found again.   When graphs or diagrams are required the programs are transmitted to U.L.C.C. where they are executed on the CDC 6600 Computer.

In the original system, plotting a graph kept the Post Office Line tied up for a considerable period due to the time taken by the plotter to perform each mechanical operation.   One coded character has to be transmitted for each pen increment including pen up/down.   On average, plot jobs produce far more output in terms of characters with this system than do ordinary batch jobs. As the communications line was already heavily loaded, it
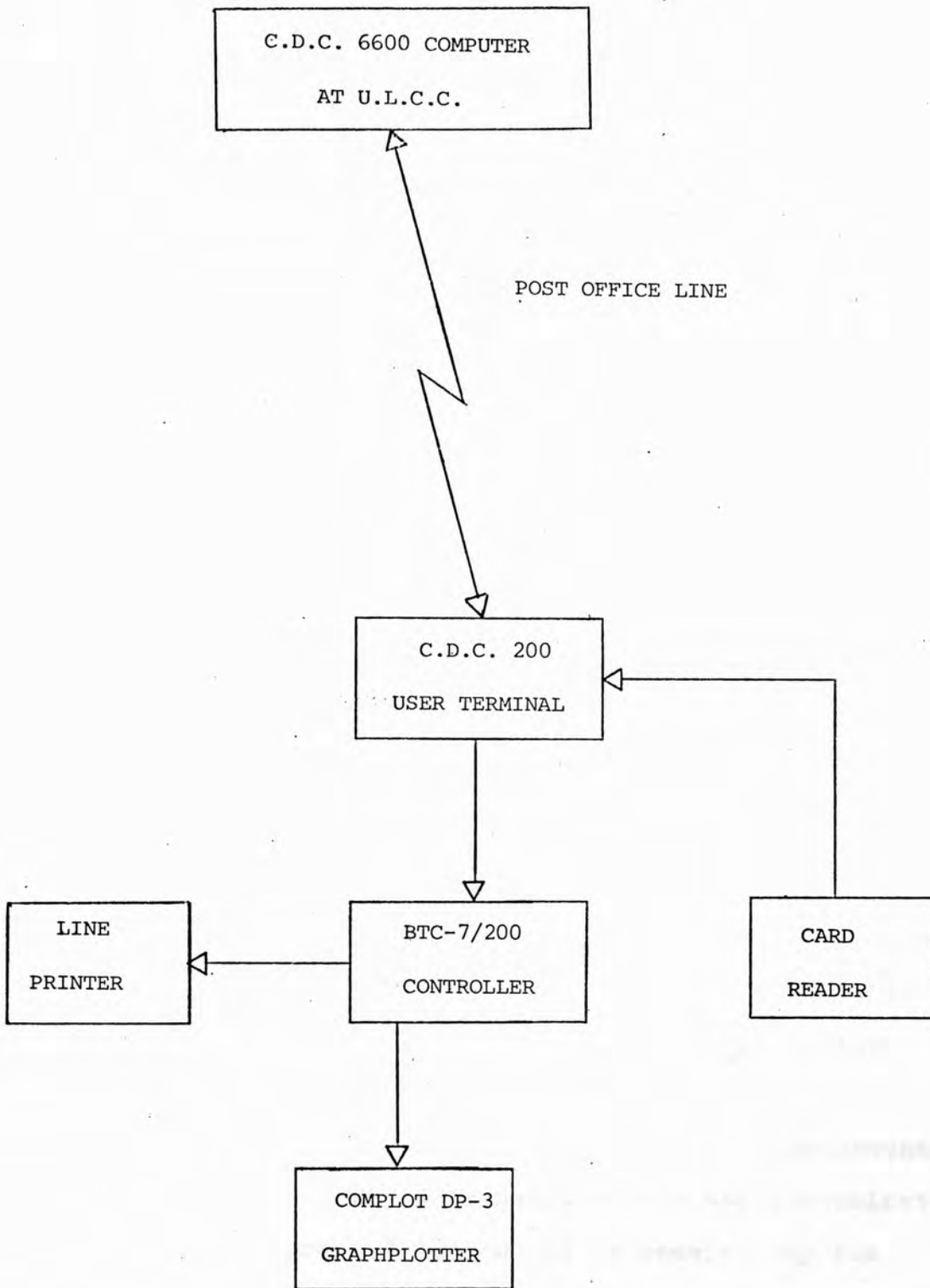
FIG. 26 - ORIGINAL SYSTEM

was highly desirable to reduce the time taken to transmit plot files and allow more jobs to be run. Another consideration was that it was difficult for users to predict the size, in characters of their plot file. Users thus often fell foul of the output limits imposed by the host computer software, losing part of their graphs. A reduction in the number of characters used in the transmission of plots was thus required to ensure even the largest plot fell inside the output limits imposed by the host computer system.

It was not possible to reduce the actual time taken to plot a particular graph as this is controlled by the mechanical speed of the graphplotter. A considerable saving in time could be made instead by incorporating the local minicomputer (a CDC SC-17) into the system using compressed plot files. This would dispense with the BTC - 7/200 Controller and necessitate building an interface to connect the SC-17 to the COMPLOT graphplotter (see Fig. 27). The SC-17 was already capable of being connected to the CDC 6600 via a Post Office line operating at 2400 bits/second.

The data produced by the 6600 would be compressed by software before it is transmitted via the communications line. The compressed data would be received by the SC-17 where the complete file would be read to Storage Disc Zero. At some convenient time the file would be read from Disc Zero, processed by the SC-17, and read onto Disc One. When the plot was needed the file would be read from Disc One via a small program that converts
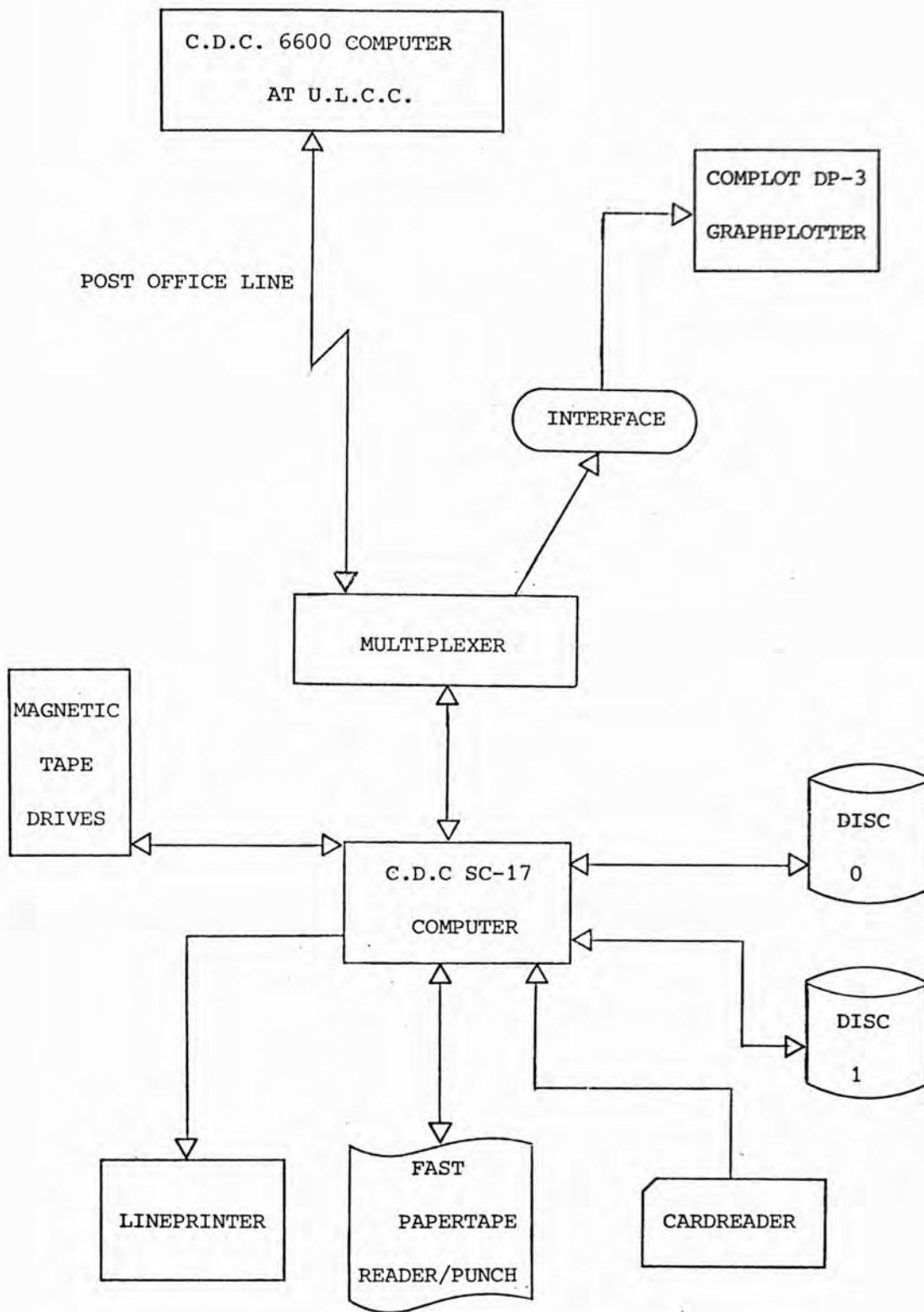
FIG. 27 - RECONFIGURED SYSTEM

the data into a form recognisable by the plotter.   The
signals from the SC-17 would be transmitted by the inter-
face to the graphplotter which would then produce the
required trace.   Programs are still input and output
(apart from graphplotter information) via the original
system using the 200 User Terminal.

3.2   GRAPHPLOTTER INTERFACE.

The System 17 Computer is a 16 - bit word length
minicomputer, with an additional 2 bits for parity and
program protection purposes appended to each word.   The
local configuration had 44K words of memory, two tape
drives, a card reader and line printer, a fast paper tape
reader and punch, and a visual display unit as the
operators console.   Backing store is provided from two
tape drives and two disc drives (0 and 1).   Other
devices are attached via a multiplexer.

The DP-3 Complot Digital Plotter is an incremental
graphplotter capable of a minimum step size of 0.010 inches
or 0.005 inches.   The pen carriage (Y-axis) moves over
a 22 in paper surface, and the paper (X-axis) moves under
the pen beam to provide plots up to 144 feet long.   300
increments per second are possible on both the pen and
paper axes.   The pen may be reised or lowered (Z-axis)
in 100ms.

An interface was constructed to connect the DP-3
graphplotter and the SC-17's multiplexer.   The SC-17's
multiplexer is an input/output device with eight data
parts, each part being interfaced to devices via a
communications adaptor appropriate to the particular
device.   These Communications Adaptors enable devices
such as teletypes and display units to be connected to
the SC-17.   Interfacing the graphplotter involved
designing and constructing a suitable communications
adaptor.

The signals generated by the multiplexer when the

SC-17 executes an output instruction are +5 volts negative logic, and have a duration of 3.8 microseconds. The graphplotter needs a signal of at least +10 volts amplitude, positive logic and a duration of well over 4 microseconds. Before an input or output operation can be performed a reply must be returned to the multiplexer directly a select input signal has been sent, otherwise a reject will be issued by the SC-17. Data input to or output from the multiplexer is handled by a common bus so a logic device is built into the interface to prevent the plotter being activated when devices on other data ports are used.

The status information (see Fig. 28A) that the interface will supply to the SC-17 is that:

(1)   the interface is ready (the "reply" signal);

(2)   that the graphplotter is set to plot remotely;

(3)   that not enough time for the plotter to execute an X or Y motion has elapsed (the "busy" signal);

(4)   that not enough time for the plotter to execute a Z motion has elapsed.

Feature (2) only requires gating and converting the -24 Volt signal that the graphplotter generates when it is correctly set. Features (3) and (4) are needed so a program can check to see if the plotter is ready to accept the next data signal, and they are produced by the interface. The "select input" and "select output" lines provide the only signals that are produced by the multiplexer solely for the addressed port. These two lines are used to enable data input or output operations as required.

A - OUTPUT DATA WORD
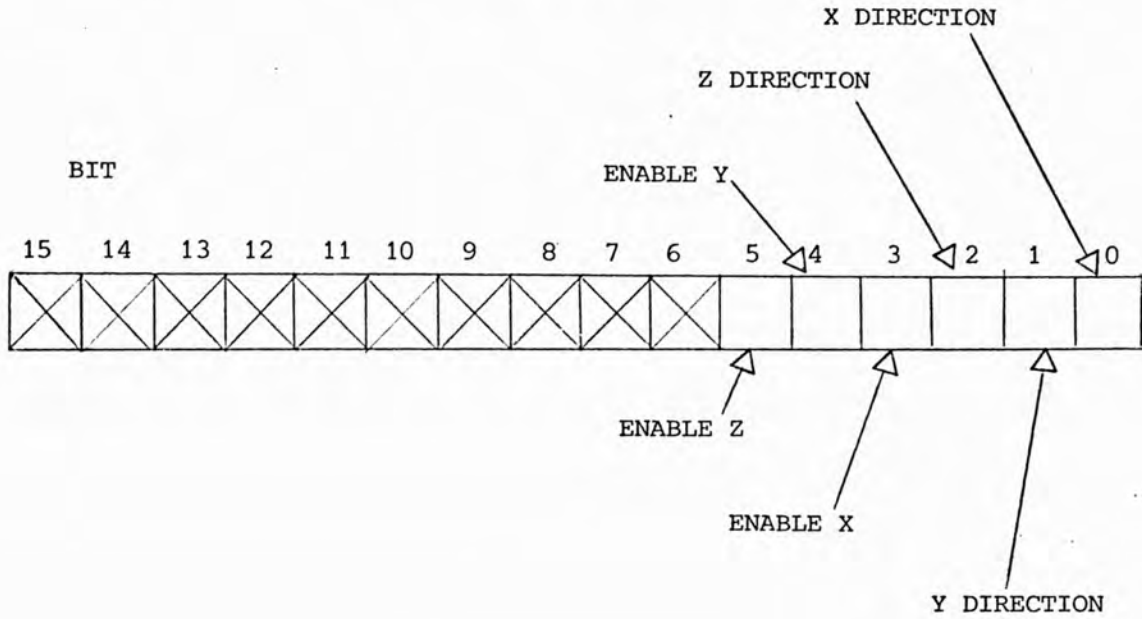
B - INPUT STATUS WORD
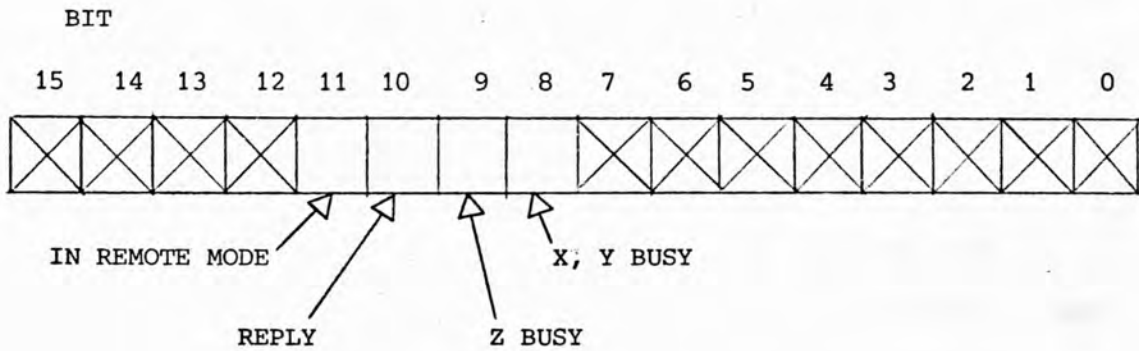
FIG. 28 - TRANSFERS BETWEEN SC-17 A-REGISTER AND INTERFACE

A set of monostables are enabled by the select
output line, the actual monostable(s) triggered, depending
on the operation required. The monostables are used to
send data signals to the graphplotter and are set to
give pulses of approximately 30 microseconds duration.
This is a convenient value that drives the graphplotter
satisfactorily. The status lines to the multiplexer
are enabled by the "select input" line via a system of
"gates". As either data or status are present before
the "select" signals arrive, both "select input" and
"select output" signals are fed through Schmitt Triggers
which ensures that all pulses in the interface are
correctly "shaped."

Six input data lines are used to drive the six
possible directions on the graphplotter $\pm$ X (paper motion),
$\pm$ Y (pen motion) and $\pm$ Z (pen up/down). Three bits are
used to enable the plotter in each dimension, the
corresponding three bits determine the direction in that
dimension (see Fig. 28B). This prevents two conflicting
commands for the same dimension being issued together,
which would result in nothing being drawn.

The output signals from the monostables are
amplified to 12 volts and fed to the graphplotter. Any
reflected signals are stopped from affecting the output
of the monostables by inserting a "driver" in each line.

The six output lines are also used to trigger
two more monostables, which provide the busy status lines.
A +X, -X, +Y or -Y signal triggers the $\frac{1}{300}$ sec. monostable
and a +Z or -Z signal triggers the $\frac{1}{10}$ sec. monostable.

TO/FROM SC-17

MULTIPLEXER

TO/FROM

GRAPHPLOTTER

DATA →

WORD →

PULSE

TIMING

MONOS

SELECT OUTPUT

SELECT INPUT

DRIVERS

PLOTTING

SIGNALS →

STATUS ←

WORD

BUSY

MONOS

PLOTTER READY
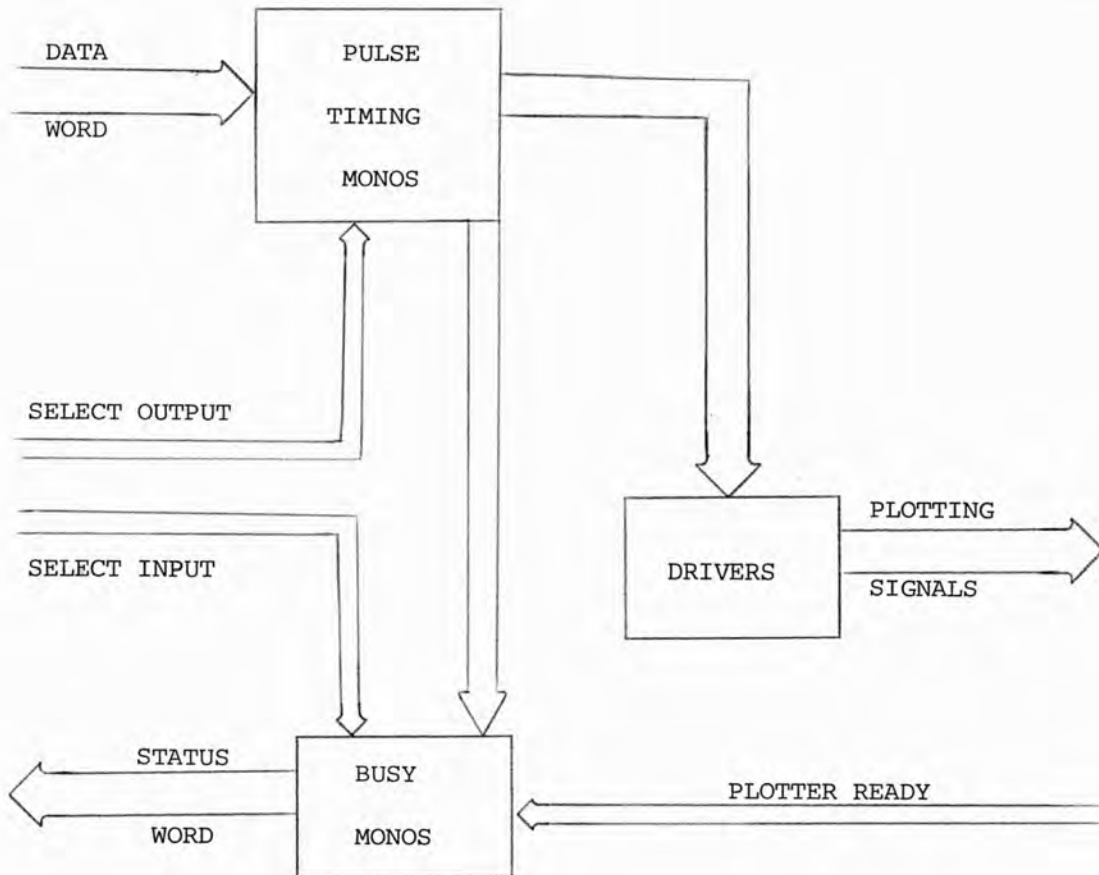
FIG. 29 - INTERFACE CONSTRUCTION

These are the times quoted by the graphplotter manu-
facturer for completion of the pen movements, but the
circuits were constructed so that these timings could be
varied if required.   The -24 Volt signal issued by the
graphplotter when it has been set in the "remote" mode
is converted to + 5 Volts and gated to produce the
"remote plot" status signal.

The interface was constructed from standard T.T.L.
integrated circuits and discrete components, high speed
gates were not needed to control the relatively slow
graphplotter.   The construction of the interface logic
is shown diagramatically in Fig. 29.   The complete unit
was installed inside the multiplexer cabinet, and the
interfaces circuitry was so constructed that its power
could be drawn from the multiplexer power supply.

3.3   INCREMENT COUNTING.

Plotting jobs are run on the host computer
(a C.D.C. 6600) where CALCOMP compatible software as
issued by Houston Instruments for their Complot Graph-
plotters was installed.   Ten graphplotter instructions
can be generated – A, B, C, D, E, F, G, H, I and *,
that are interpreted by the B.T.C. – 7/200 Controller
as plotter instructions.   A, B, C and D draw along
the axes +X, -X, +Y and -Y.   E, F, G and H draw at
45° to the axes by simultaneously executing two of the
four basic commands i.e. +X +Y, +X -Y, -X +Y, -X -Y.
I and * are the pen up, pen down functions +Z, -Z.

For each of the eight instructions A to H, the
position of the pen relative to the paper in the graph-
plotter is changed by one step or increment.   To draw
a line of, for example, 100 steps in the +X direction,
an "A" would have to be generated by the 6600 and
transmitted down the Post Office line to the graphplotter
100 times.

The first stage in compressing the information
transmitted was to replace a string of identical
characters with a code that contains the character
required and the number of times it is to be repeated.
This is known as run-length encoding.   The compression
software is contained in a driver routine called "DRVR".
Thus information previously transmitted as AAAAAAAAAAA
GGGGEEEEEEEEIBBBBBBBBBBBB, for example, is replaced by
12A, 4G, 8E, I, 11B.   The characters are packed into
lines of 136 characters and transmitted, so the same

amount of information is packed into fewer line images.

The second stage in this method of compressing plotting information is performed only when the pen is in the up position. The pen would normally follow an approximation to a straight line in moving from point $X_1 Y_1$ to $X_2 Y_2$ (see Fig. 30) by issuing alternating increments along the nearest axis and diagonal. This is replaced by two separate movements $X_1 Y_1$ to $X_3 Y_3$, and $X_3 Y_3$ to $X_2 Y_2$ effectively combining all the increments along each direction. The two movements are reduced by the first stage of the compression into just two coded instructions, replacing a whole string of characters, e.g. CEECEECEECEECEECEECEECEECEE is replaced by 10C, 20E. As the line is not actually drawn, the path taken by the pen is not important. The same number of increments are performed by the plotter so there is no difference in the time taken to move the pen by using this compression method.

The compressed instructions are transmitted via the communications line and then stored on Storage Disc Zero on the SC-17. This is achieved by running SIM 200 which enables data to be transferred from the 6600 via the post office line and the SC-17's high speed channel. "TRANPT" transfers the instructions to Disc One and creates a permanent file of plotter output, adding "PTOOOO" at the end of each plot to produce separate files.

The graphs are actually plotted by "PLOTGO" which first checks the interface to see if the "remote plot"
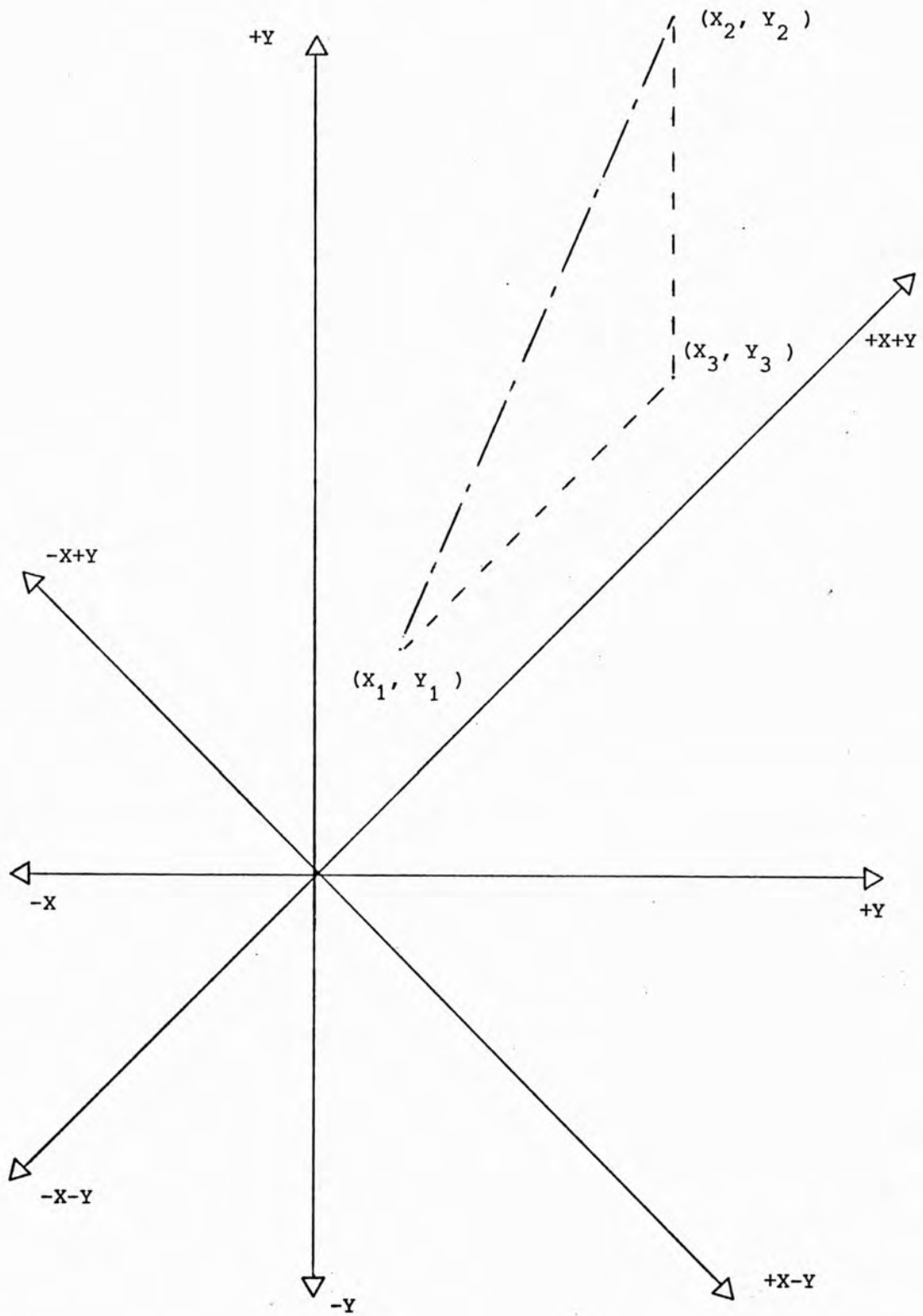
FIG. 30 - PEN UP COMPRESSION

signal from the graphplotter is present.   This indicates
that the plotter is ready to receive plot commands.
PLOTGO reads each item of data from the permanent file
on Disc One and then controls the plotting of the graph,
reading each coded instruction and repeating the plotter
command the required number of times.   Plotting is
actually carried out in foreground while ordinary SP-17
batch jobs are run simultaneously in background.

3.4 PARAMETER TRANSMISSION.

Further work on plot data compression investigated ways of utilising the structure of the CALCOMP Graph Plotting Package. The various features required in plotting a graph, such as scaling parameters, numbers, axes, curves, symbols etc., are obtained by calls to standard subroutines from the users program. The calls to the various subroutines were intercepted by dummy routines. These enabled the parameters in the sub-routine call plus an identifying code to be sent from the 6600 to the SC-17 via the Post Office line.

When the file is processed by the SC-17 the transmitted data is used in calls to the Graph Plotting subroutines which had been installed on the SC-17. The computations of a program would thus be done by the host computer but the graph plotting calculations would be performed by the SC-17.

However several of the more sophisticated Graph Plotting subroutines could not be treated in this way because they use arrays held in the 6600's memory. These subroutines are the ones that calculate scale factors, plot sets of curves, etc. If these subroutines were to be run on the SC-17 the data arrays would have had to have been transmitted as well, which would be impractical as such arrays are often very large.

For simple programs this method produced a con-siderable reduction in the time taken to transmit plotting data. In more complex programs such large compressions were not obtained due to particular subroutines being

within a loop in a user's program. Looping was often
so badly arranged that a large number of subroutine call
parameters are transmitted which result in very small
pen movements. This was also unnecessary as more
detail was produced than the graphplotter was able to
resolve, i.e. lines are required less than a plotter
increment long. In some cases the excessive number of
subroutine calls was due to the looping arrangements in
the user programs. In others the more sophisticated
subroutines (the parameters of which were not transmitted)
were used, each of which called the simpler subroutines
a large number of times.

3.5   STRAIGHT LINE VECTORS.

Another method of compressing graph plotting data
that was investigated was the transmission of straight
line vectors.   This has already been used at Edinburgh
(105) to run a remotely connected plotter with good
results.   Similarly Durham (106) have run a drum plotter
satisfactorily using a straight line vector method.

The user called subroutines of the graphplotting
package all eventually access two basic subroutines which
are not called directly from users' programs, MOVER and
DRVR.   These two basic subroutines calculate the actual
increments issued to the plotter, from the co-ordinates
of the pen before and after movement, and command the
pen to move up or down.   The data was thus intercepted
by dummy subroutines before it reached MOVER and DRVR,
and was coded by means of the 63 character set the 6600
uses.   The distance the pen has to move was expressed as
a X co-ordinate and a Y co-ordinate, each converted to a
two character number of base 63.   This is actually the
number of increments the pen must move in the X and Y
directions, and so would give a maximum graph size of
about 20 inches by 20 inches, adequate for most uses.

The X and Y components were each represented by
two characters, each character being specified by 6-bits.
Thus each component was represented by 12 bits, X and Y
components together occupying 24 bits (see Fig. 31).

A further character was used for control data such
as the directions of the X and Y components, pen up or
down, end of file, etc.   Data not requiring the pen to

6 BITS	12	BITS	12	BITS

CONTROL   X-COMPONENT   Y-COMPONENT
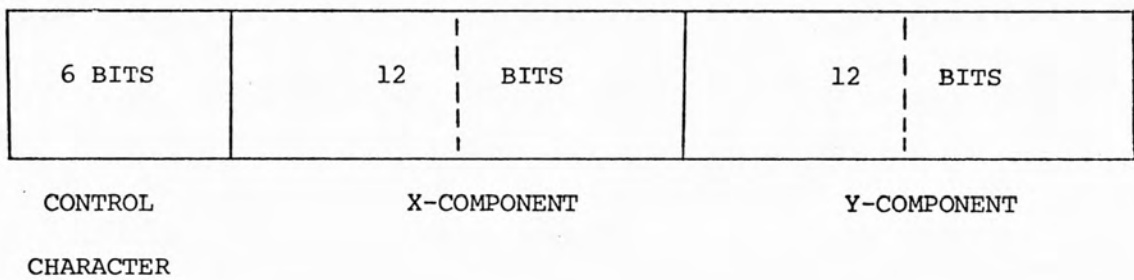
CHARACTER

FIG. 31 - STRAIGHT LINE VECTOR DATA FORMAT

be moved in the X or Y direction, only used the control character which was immediately followed by another control character.   As all data was expressed as 6600 characters it was easy to pack the data containing the plotting information as line images for transmission.

There was a large saving in the time taken for transmitting line information such as graphs and drawings, but to some extent this was offset by the more intricate parts of a graph being plotted such as titles and scales. This is due to a string of numbers or letters being composed of a large number of short vectors, all of which have to be transmitted.

3.6   CODING RESULTS.

The amount of data that had to be transmitted from
U.L.C.C. to plot a particular graph was used to determine
the relative efficiencies of the different methods of
coding graph plotter data.   Sample plots were trans-
mitted using the original system and each of the three
coding methods.   Some plots used were specially written,
but most were copies of ordinary users' jobs selected to
represent the wide range of jobs likely to be run over a
long period of time.   The three methods of compressing
graph plotter data produced widely varying reductions in
the size of the files containing the plotting data.
This is due to the different efficiencies with which each
coding method compresses the various types of plot data.
Overall, compression by the three methods results in plot
data files approximately one fourth to one fifth of the
size of those produced by the original system.   The turn-
around time for a plot job itself is not improved, but the
turnaround time for the ordinary batch jobs processed at
U.L.C.C. is significantly improved.

Fig. 32 gives data for the effect different
compression techniques had for five different types of
plot job.   Figures are given in terms of 6600 words
(60-bit length).   The size of the plot file of each plot
job is given under the original system and then under the
three methods of compression.   The last column gives the
average compression by all three methods for each plot
job.   The bottom row gives the average file length by
the original system and by each method of compression.

	PLOT FILE LENGTH (WORDS)				
METHOD ⟍ JOB NO. ⟍	ORIGINAL SYSTEM	INCREMENT COUNTING	PARAMETER TRANSMISSION	STRAIGHT -LINE VECTOR	% AVERAGE COMPRESSION
1	6144	1280	1819	1999	27.65
2	4800	896	823	1080	19.44
3	3392	642	3019	827	44.10
4	6464	1280	1020	1188	17.98
5	7872	1280	635	1231	12.89
AVERAGE	5734	1075	1463	1265	21.99

FIG. 32 - COMPARISON OF PLOT FILE COMPRESSION

The bottom element of the last column gives the average compression overall.

The increment counting method does not result in any saving in 6600 processing time, but the parameter transmission and straight line vector methods produce a reduction of 1 - 2 seconds of central processor (C.P.) time. Conversely more SC-17 processor time is needed to restore data coded by short line vector or subroutine parameter methods than by the increment counting method. However the 6600 has a far greater load than the SC-17 so it is advantageous to transfer some processing to the SC-17. The manufacturers' recommended speed for driving the graphplotter is 300 movements a second, but it is possible to drive the plotter as fast as 350 movements a second. This higher speed does not result in any loss of data and is the interrupt speed set for the SC-17's multiplexer. The time taken to complete a graphplotter increment is relatively long during which the SC-17 can be used to perform other processing. Thus plotting can be carried out in "foreground" and normal SC-17 batch jobs can be run in "background", preventing a large increase in the turnaround time of SC-17 batch jobs when plots are being drawn. It is clearly more efficient to plot graphs in an interrupt mode rather than require the processor to wait while checking the "busy status" bit after initiating each plotter increment.

The cost of constructing the necessary interface was under £20, and it has worked reliably for over 2 years.

chapter 4

RASTER-SCAN GRAPHICS

4.1.1 THE CROSSING VECTOR ERASURE PROBLEM.

As was seen in 2.2.5, computer graphics in a raster-scan format has many advantages over the X - Y mode of graphics. A flicker-free image, not limited by the available core-store of the computer can be displayed on a T.V. monitor that is far cheaper than a C.R.T. suitable for X - Y graphics. A significant problem in the use of raster-scan graphics, however, is met when an item in a picture is erased or repositioned. As a similar situation is encountered with plasma panels (see 2.3) this problem is clearly worthy of attention.

The raster-scan graphics system is basically a refresh memory of some type that is used to drive a T.V. monitor. The way the image data is held in the refresh memory and the method of conversion into raster-scan format depends on the particular type of refresh memory being used. In general, one bit in the refresh memory represents one point on the display screen, though the method of accessing the data may vary.

Plasma panels though not having a separate refresh memory are effectively similar to a raster-scan system with respect to the crossing vector erasure problem. This is because the picture is maintained by the inherent memory of each plasma cell, and thus there is a similar one memory bit to one display point relation. The memory bit and display element are the same physical device in the case of the plasma panel.

If a vector AB is drawn on the screen, the corresponding memory bits are set as shown in Fig. 33A.
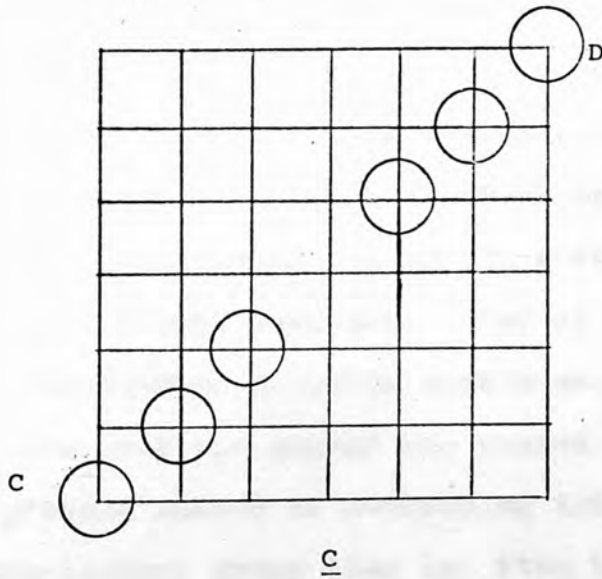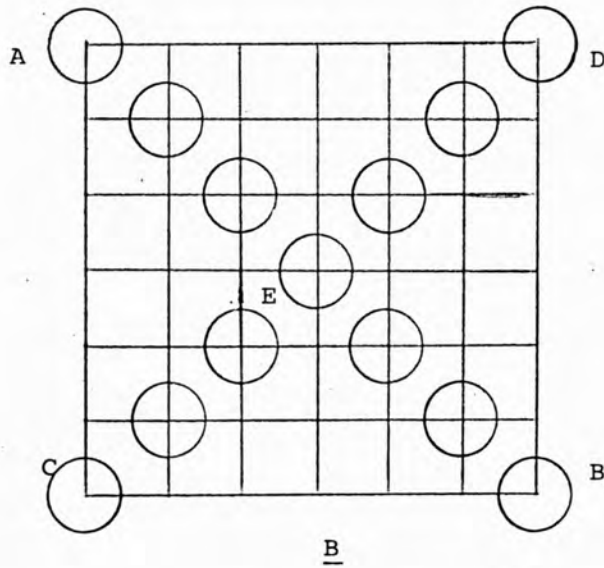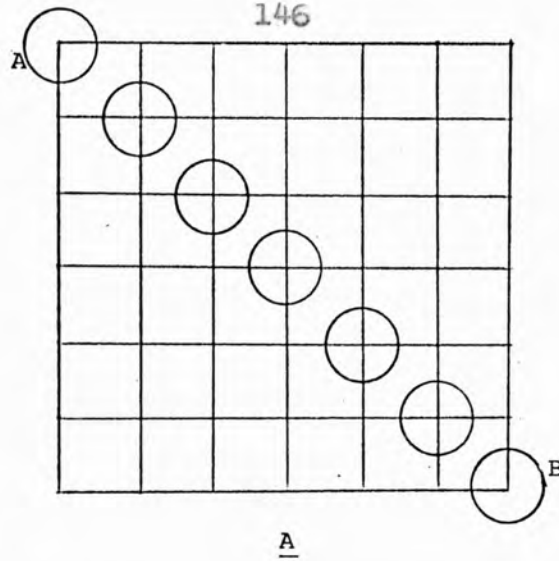
FIG. 33 - THE CROSSING VECTOR ERASURE PROBLEM

Then if a second vector CD is added so that it crosses
AB at E the memory bits are set as shown in Fig. 33B.
Now if either of the vectors are erased, say AB, the
memory bits that compose it, including bit E, are reset.
This means that part of vector CD has also been erased
as shown in Fig. 33C.

For a display with a reasonable resolution, one
point missing from the middle of a long vector would not
be very noticeable. However, due to the digital nature
of the display, approximations to the actual vectors are
drawn on the screen. Thus two vectors crossing at an
acute angle could have a large number of points in common
and leave a large gap in one vector on erasure of the
other (see Fig. 34A). Moreover, the erasure of a number
of lines crossing a particular vector would mean the loss
of a corresponding number of points and the erosion of
the vectors image so that it would eventually become
unrecognisable. Similarly, overlapping areas of two-
dimensional figures, would be lost on the erasure of one
of the figures (Fig. 34B). The movement of a cursor
across the screen by means of a joystick or light pen
involves repeatedly erasing the cursor then redrawing it
in a slightly different position. Use of a moving
cursor in a raster-scan graphics system would thus erase
all the picture that the cursor had passed across.

The present method of overcoming this problem is
to redraw the picture every time an item has to be erased.
The picture is thus completely regenerated with the item
concerned erased or repositioned. This is a very
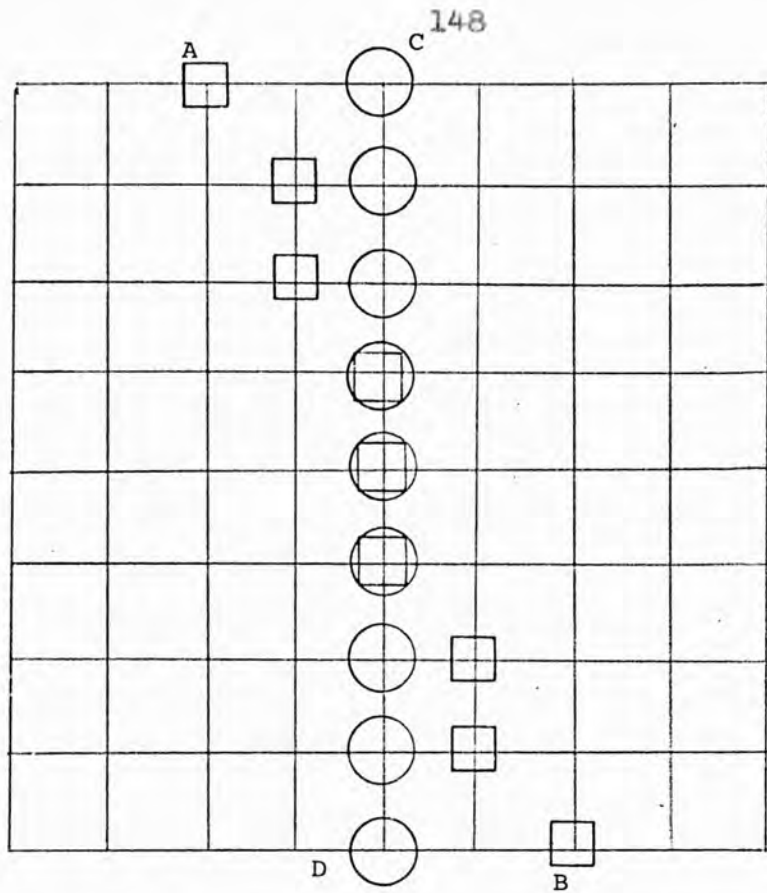
FIG. 34A - VECTORS CROSSING AT AN ACCUTE ANGLE

COMMON POINTS
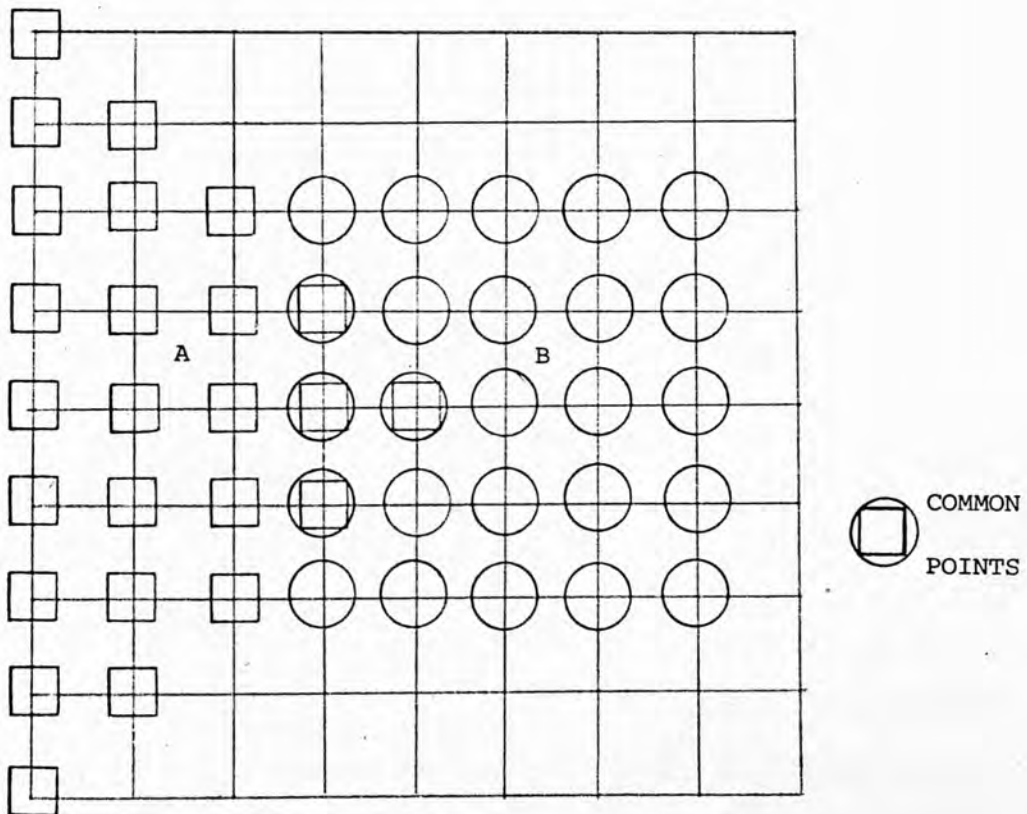
FIG. 34B - OVERLAPPING AREAS OF 2-D FIGURES

inefficient approach as the complete regeneration is necessary even if a very small change in the picture is required. Processing time is wasted each time the picture is regenerated and memory space is permanently used to store the parameters needed to regenerate the picture.

Investigation of the crossing vector erasure problem was carried out on the Reading University "PICASSO" System (15). This is a disc based raster-scan graphics system built by the Department of Cybernetics. The PICASSO System was aimed to demonstrate the feasibility of a low cost multiconsole raster-scan interactive graphics system. The research project at Reading had not been satisfactorily finished so the PICASSO System had to be completed before it could be used for investigating the crossing vector erasure problem, involving a substantial redesign.

4.2 THE READING 'PICASSO' SYSTEM.

The data storage capability of a modern magnetic disc is used to refresh a standard T.V. monitor in the P.I.C.A.S.S.O. system (Pad Input to Computer and Scanned Screen Output). A resolution of 512 x 512 points is achieved, while the British Standard of T.V. is a 625 line display. Some lines are absorbed in the frame fly back leaving 585 available, so the 512 lines used in the PICASSO System employ most of the lines provided by a standard T.V. monitor.

The System configured is shown in Fig. 35 and is based on a Modular One computer manufactured by Computer Technology Ltd. The processor, the two 8K store modules and the console teletype are all standard C.T.L. equipment. The Modular One processor operates in parallel with 16 bit words, and has 5 programable registers. Addresses in the range OK to 16K refer to core storage and addresses in the range 56K to 64K refer to other peripheral equipment. Each program may be allocated up to three segments of core storage which will not be necessarily contiguous and which contain a specifiable number of consecutive 256 word pages. The three segments hold 1) instruction code and constants, 2) workspace area, and 3) the file area. Addresses are checked by hardware to see they do not violate the bounds of a segment, an interrupt is generated if such a violation occurs. When subroutine entry is made register values are stored in subroutine workspace and restored when the subroutine is left. A 16 - bit instruction word is
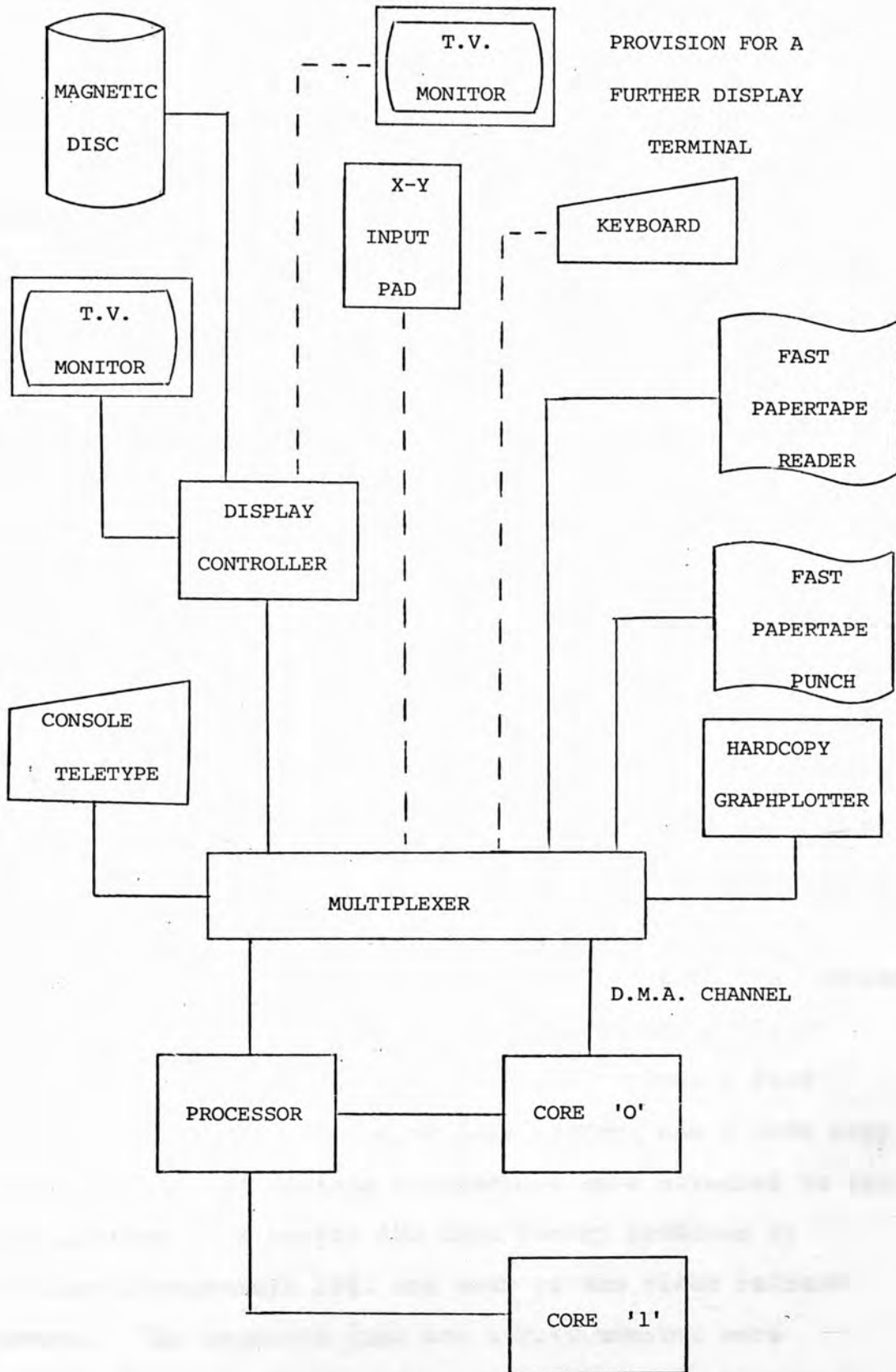
FIG. 35 - PICASSO SYSTEM CONFIGURATION

composed of three fields of 3, 5 and 8 bits, corresponding to mode, function and operand. The mode field specifies the segment being addressed, the index register, if any, being used to augment the operand and the addressing mode. 32 functions are available, specified by 5 bits, additionally a number of different shift, copy and test functions are specified by the 8 bit operand. The operand is a numerical value or an address in the range 0-255. If an indirect addressing mode is used the operand is accessed according to a secondary address located in the workspace segment. A 16 - bit store address also is composed of 3, 5 and 8 bits, corresponding to core block, page, and location within the page (0-255). The processor may also execute programs in special state mode. The addressing mode constructions available in special state are different to those in normal state but a similar function set. Special state mode is necessary for programs dealing with peripheral devices.

To attach various peripheral devices to the Modular One Computer, a multiplexer was designed and built at Reading for a comparatively low price. Thus a fast paper tape punch, fast paper tape reader, and a hard copy graph plotter of various manufacture were attached to the multiplexer. A Series 100 Disc Memory produced by Process Peripherals Ltd. was used as the video refresh store. The magnetic disc and a T.V. monitor were connected to the display controller which was in turn connected to the multiplexer. Provision was made for a further four display terminals to be run by the PICASSO

system. The Display Controller is able to drive the extra four monitors, with each terminal having an ASCII keyboard. These would have been attached to the multiplexer to enable the input of instructions. Graphical information was intended to have been entered at all five terminals by X - Y co-ordinate input pads, also connected to the multiplexer and A/D converters.

The P.P.L. series 100 NRZ coded memory disc has 48 usable tracks and 12 read/write amplifiers. Each amplifier is able to access one of 4 tracks by varying the values of two address lines. The P.P.L. disc used for the video refresh memory is particularly suitable for use with T.V. displays as the disc speed of 50 revolutions per second is servo controlled. A disc driven at 50 revs/sec directly from a synchronous motor may suffer from phase swing, i.e. oscillating about its exact in-phase position, causing the image displayed on the monitor to wobble. The disc is capable of a maximum reliable writing speed of 4 MHz so data is stored on the disc tracks at 2.5 MHz so there are 65.5 K bits per track. Thus the tracks are used in pairs, data being accessed from alternate tracks for each consecutive point to achieve a high enough data rate. Each video frame is divided in two as the data is displayed in interlace mode and two disc tracks are used for each half-frame, i.e. four tracks to refresh each monitor. The single clock track on the disc supplies the high speed 10 MHz clock pulse train for each display, but the flyback synchronis-ing pulses and format waveforms are generated by logic

associated with each display.   The basic clock pulse
rate from the disc is 2.5 MHz, well within its capability,
and the 10MHz rate is generated from it by two stages of
delays.

The PICASSO system offers selective erasure and
editing facilities which enables the interactive use of
raster scan graphics.   This is achieved by maintaining
a sixth set of four disc tracks, in addition to the five
display sets of tracks, to hold edited information.   It
is not possible to switch between reading off, and
recording onto the disc thus editing a set of tracks while
they are maintaining a video image, as this process
occupies several microseconds.   Instead changing the
digital information being displayed on a T.V. monitor
entails reading the existing data off the disc, modifying
the digit pattern, and writing the new data back onto
the disc (Fig. 36).   The read signal voltages are gen-
erated by flux changes detected by the magnetic read/
write heads, this and the editing logic delay the data
signal compared with the reference clock.   The data
cannot therefore be rewritten in the same clock pulse
time, i.e. back into the same position on the disc.   The
storage requirement is too great to allow the whole
image to be held in a buffer store or in the computer
memory.   For this reason the image is rewritten onto
the spare set of tracks as it is modified.   The timing
waveform of the spare set of tracks is delayed by the
same amount as the reading and modification of the data
requires, so the relative addresses of the rewritten

TIMING

WAVEFORM

ORIGINAL

DATA TRACKS

SPARE

TRACKS

<u>1</u>

TIMING

WAVEFORM

ORIGINAL

DATA TRACKS

READ

EDITING

EDITOR

TRACKS

WRITE

<u>2</u>

DELAYED TIMING

WAVEFORM

SPARE TRACKS

ADDED INFORMATION

NEW

DATA TRACKS

<u>3</u>
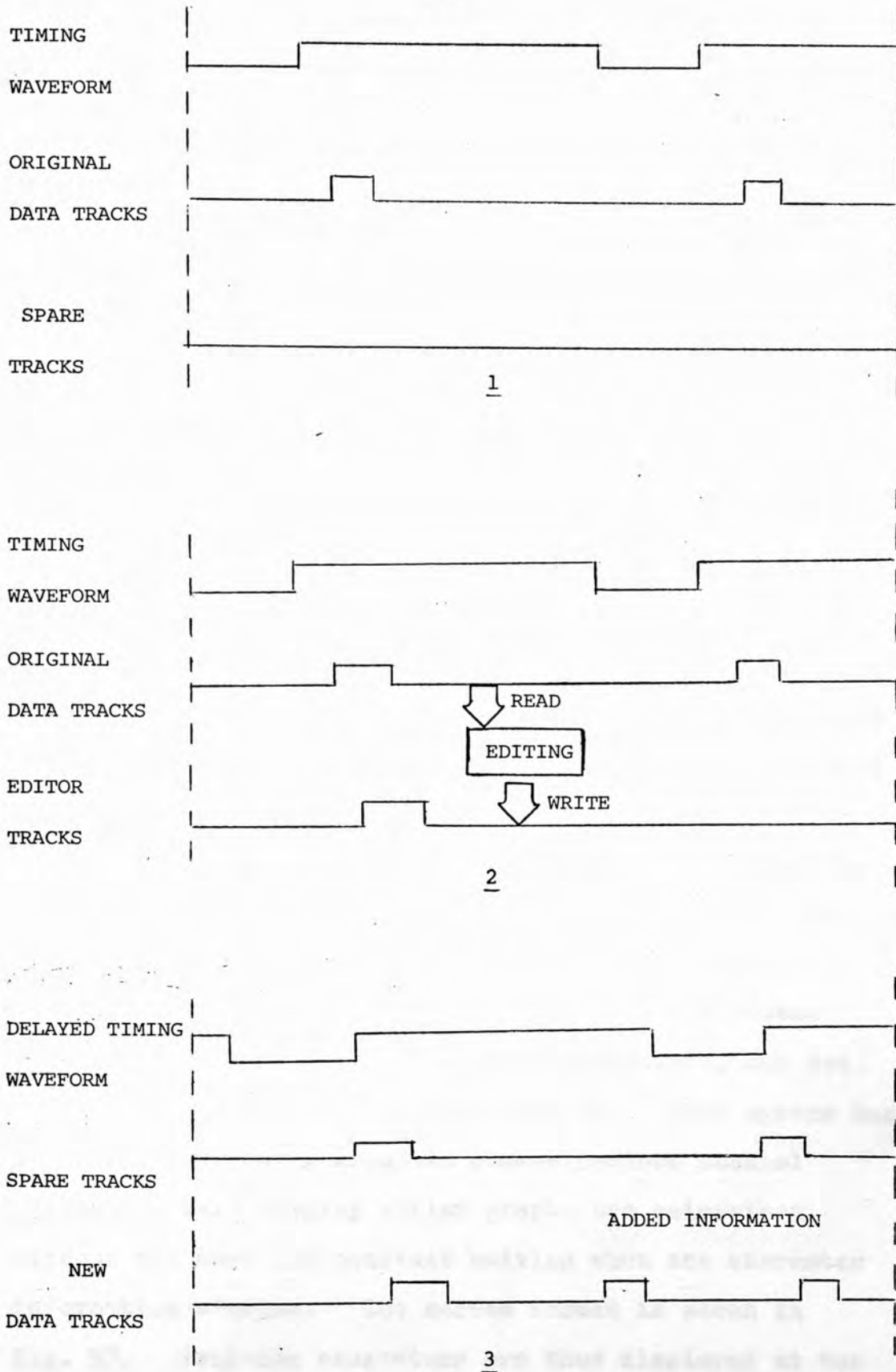
FIG. 36 - DIAGRAM OF THE EDITING PROCESS

data digits in the T.V. monitor frame remains constant.
If the timing wareform was not delayed the image would
appear to move to the right of the T.V. screen every time
an edit took place.   The set of tracks with the edited
information then is switched to refresh the appropriate
display, while the old set of tracks becomes the spare
set for the next editing process.   A hardware controller
maintains a record of which set of tracks is associated
with each display and organises the appropriate changes
when an image is edited.   Though a somewhat complex
system this is an economical approach as a buffer store,
such as another disc, is not needed.

The PICASSO system employed a conventional 7 x 5
dot matrix M.S.I. R.O.M. character generator which was to
have written character symbols on to the disc, this would
have been useful for labelling axis, adding explanatory
comments etc.   A lower portion of the display screen is
used as a character display with the capability of dis-
playing four lines of text each containing up to 64
characters.   These are based on M.O.S. random access
refresh memory and R.O.M. character generators, one set
would have been needed for each display.   This system has
the advantage that a separate communications channel
drives the text display whilst graphs are maintained
without the need for constant editing when the character
information changes.   The screen format is shown in
Fig. 37.   Printing characters are thus displayed at the
current cursor position via the text display unit.
Certain non-printing characters format the textual display

GRAPHICAL DATA (AND TEXT)

HELD ON DISC

```
200  100  300  400  2
100  200  200  100  2
200  100  400  100  2
```

CURSOR

4 LINES OF TEXT HELD IN

M.O.S. RANDOM ACCESS MEMORY
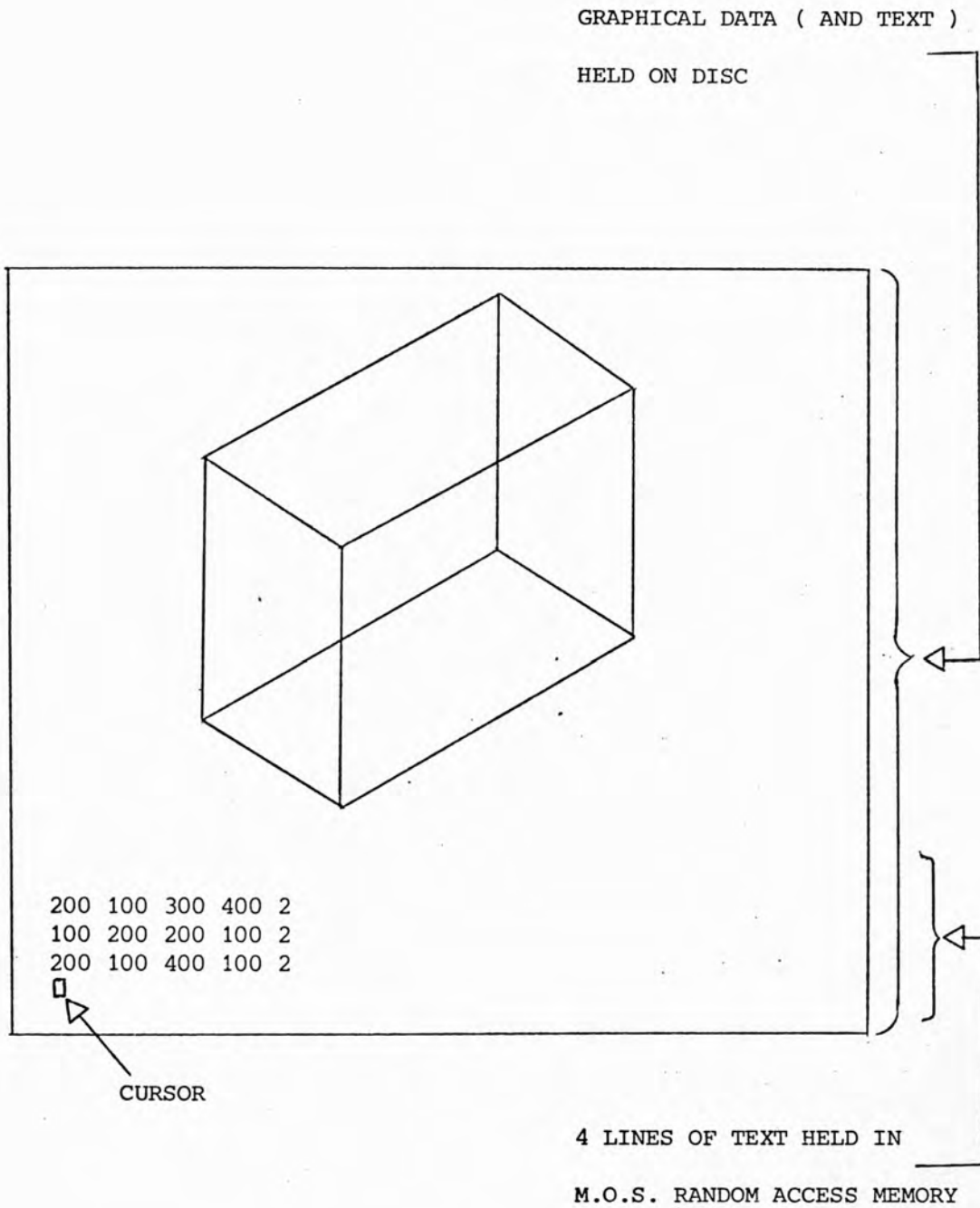
FIG. 37 - DISPLAY FORMAT

by moving the cursor, or by moving the bottom 3 lines of
text up one line. This makes space for a new line of
text, though the top line is lost. It was intended
that another non-printing character would have saved the
top line of text on the appropriate disc tracks when a
new line was needed in the text area. This would have
allowed the display to operate in a "roll-up" mode up the
whole screen and function like a conventional visual
display unit capable of displaying 32 lines 64 characters
per line.

4.3   PICASSO HARDWARE.

The existing electronics of the PICASSO system were built from forty printed circuit boards, with an average of about 10 S.S.I. chips per board.   The logic hardware was originally constructed from standard Transistor Transistor Logic (T.T.L.) integrated circuits in order to minimise costs.   However the delay through a T.T.L. gate, of the order of 10 ns, is significant as the video data bit time is only 100 ns.   The cumulative delays to some signals in passing through the logic hardware was found to be critical to the system, particularly so in the case of the master clock waveform.   This meant that synchronisation was lost between the old image and the new image due to the inaccuracy in the master clock waveform.   To cure this problem an improved Clock Generator, described later, had to be built.   High Speed T.T.L. and Shotcky T.T.L. were selectively used to minimise delays when the master clock signal passed through a number of logic gates.

THE DISPLAY CONTROLLER.

Fig. 38 shows the complete Display Controller, only one of the 5 possible monitors was actually used but a second monitor is shown to illustrate how other monitors would be attached.   Command instructions are sent from the processor via the multiplexer to the Command Accessor. There the instructions are routed to either the Text Display Unit (T.D.U.) or the Display Disc Controller (D.D.C.) as appropriate.

Text commands such as to display a particular
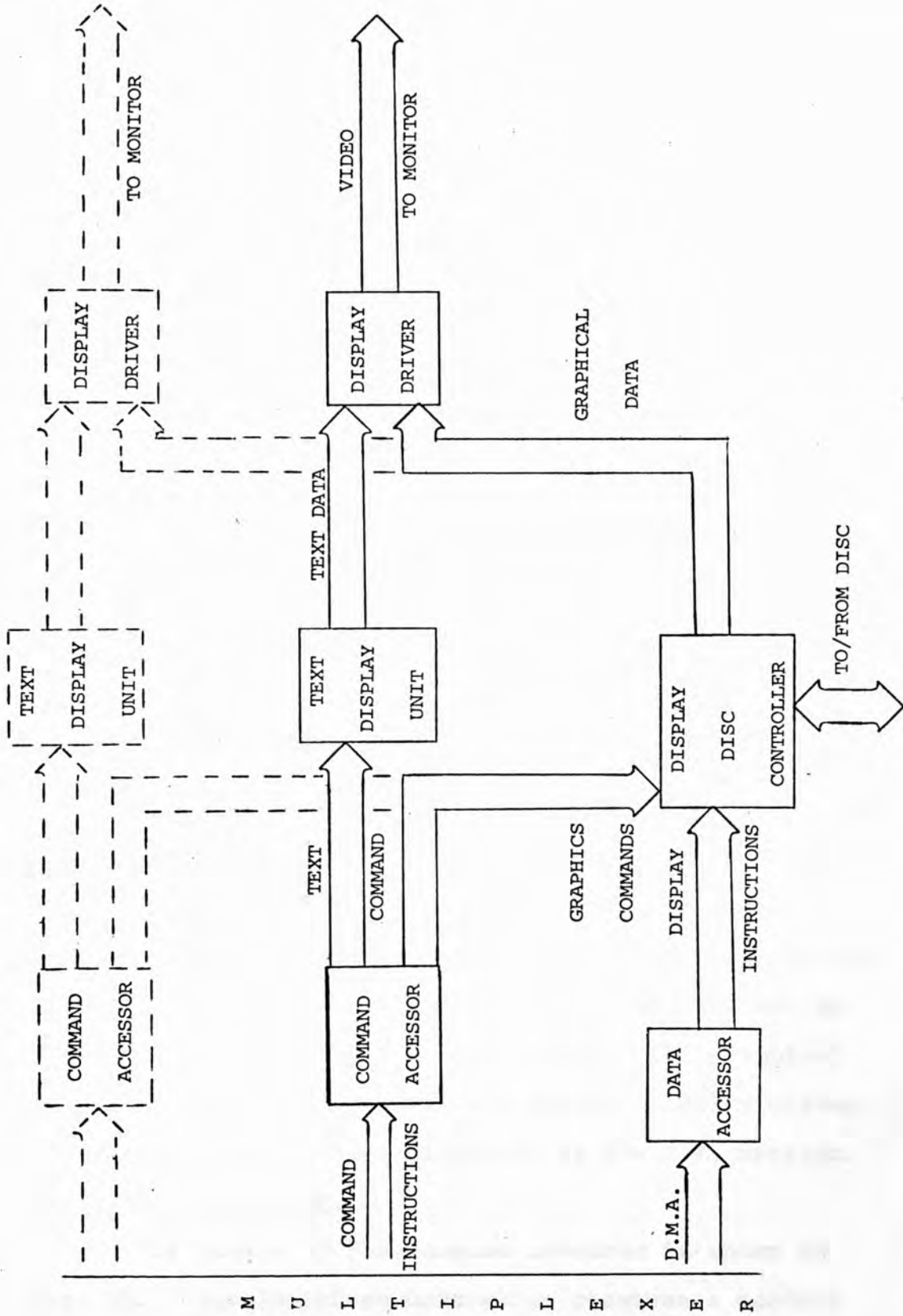
FIG. 38 - DISPLAY CONTROLLER

character, move the cursor, or line feed, are used by the Text Display Unit to update the contents of its RAM store. Data from the T.D.U. store is then streamed out to the Display Driver and hence to refresh the T.V. monitor image.

Graphics commands to write a completely new picture, add an image to the picture, or erase an image from the picture, are sent to the Display Disc Controller. The Data Accessor is then sent a signal from the D.D.C. to read in image data from core memory module O via the Direct Memory Access (D.M.A.) channel and the multiplexer. The data is in the form of display instructions describing the point or set of points it is required to display. Meanwhile the current picture data is streamed off the appropriate disc tracks to the D.D.C. and, depending on whether a write, erase or add operation is required, is combined with the new data formed from the display instructions. The edited data is then streamed onto the spare set of disc tracks. The picture data for the monitor is taken from the most recently updated set of tracks and sent to the display driver. The graphical data is mixed with the text data in the display driver and the combined picture displayed on the T.V. monitor.

THE COMMAND ACCESSOR.

The detail of the Command Accessor is shown in Fig. 39. The Interface Controller receives a control signal from the multiplexer and enables the Command Controller if it is not busy. The command instruction is sent from the multiplexer to the Instruction Decoder.
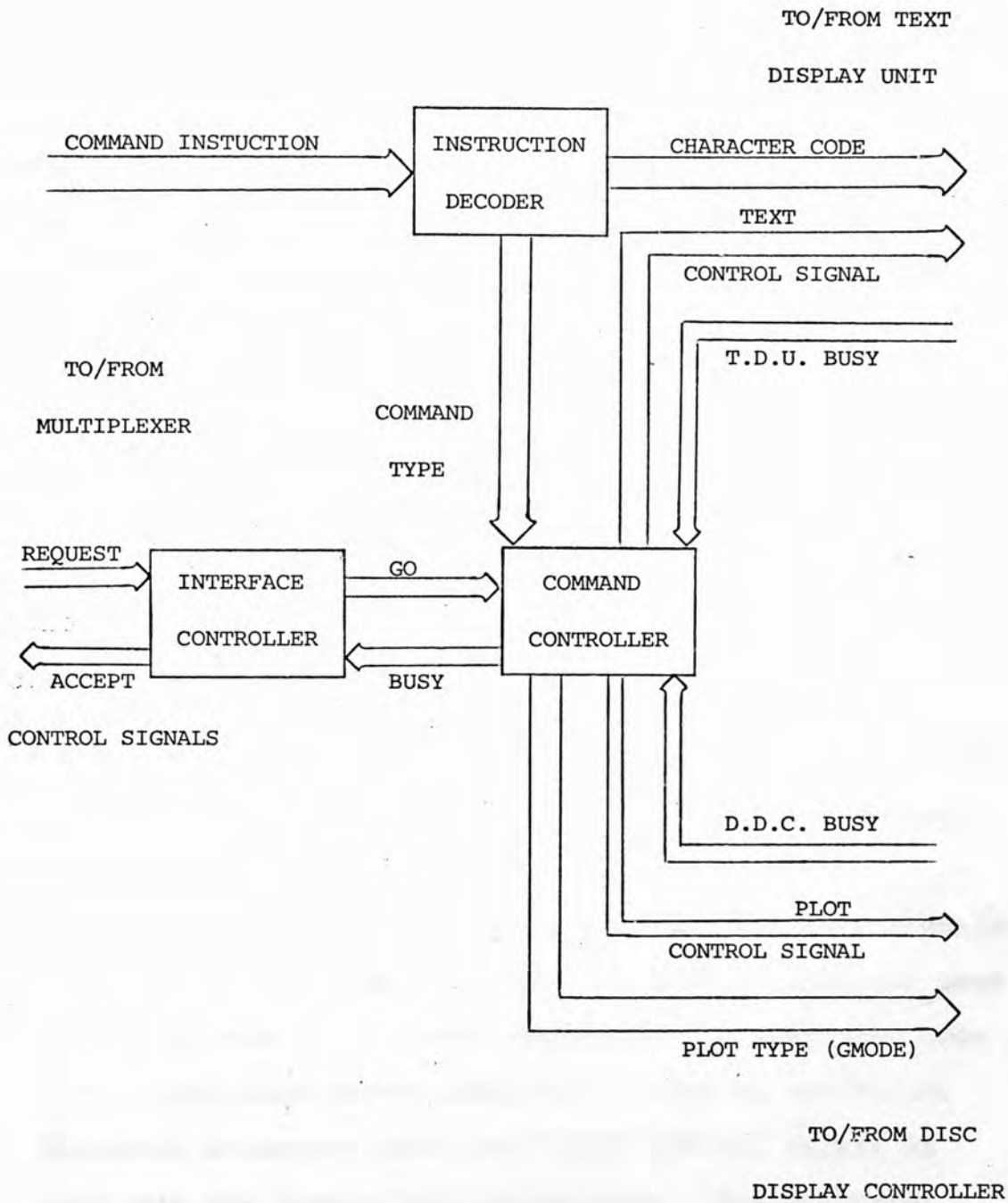
FIG. 39 - COMMAND ACCESSOR

The information containing the command type is then sent from the Instruction Decoder to the Command Controller and a control signal indicating text or a plot sent to the appropriate unit.

On receiving the control signal the Text Display Unit accepts the character code from the Instruction Decoder. If the T.D.U. or the Display Disc Controller are busy they send a signal to the Command Controller which in turn sends a busy signal back through the Interface Controller to the Multiplexer.

THE TEXT DISPLAY UNIT.

The Text Display Unit is shown in Fig. 40 and works in the same manner as a standard V.D.U., but only handles 4 lines of text. When a "text" signal is received by the Memory Write Controller the current cursor address is sent to the R.A.M. Refresh Memory. On receipt of the "write" control signal the character code from the Command Accessor is put into the addressed memory location. The Memory Write Controller also deals with non-printing characters such as moving the cursor, line feed, etc.

The Memory Read Controller receives timing signals generated by the Display Driver. These signals are used to produce the R.A.M. read address. The character code for a particular screen position is sent to the R.O.M. Character Generator when the "read" control signal is sent from the Memory Read Controller. The Character Generator is sent a control signal from the Memory Read Controller that selects the particular row of a character
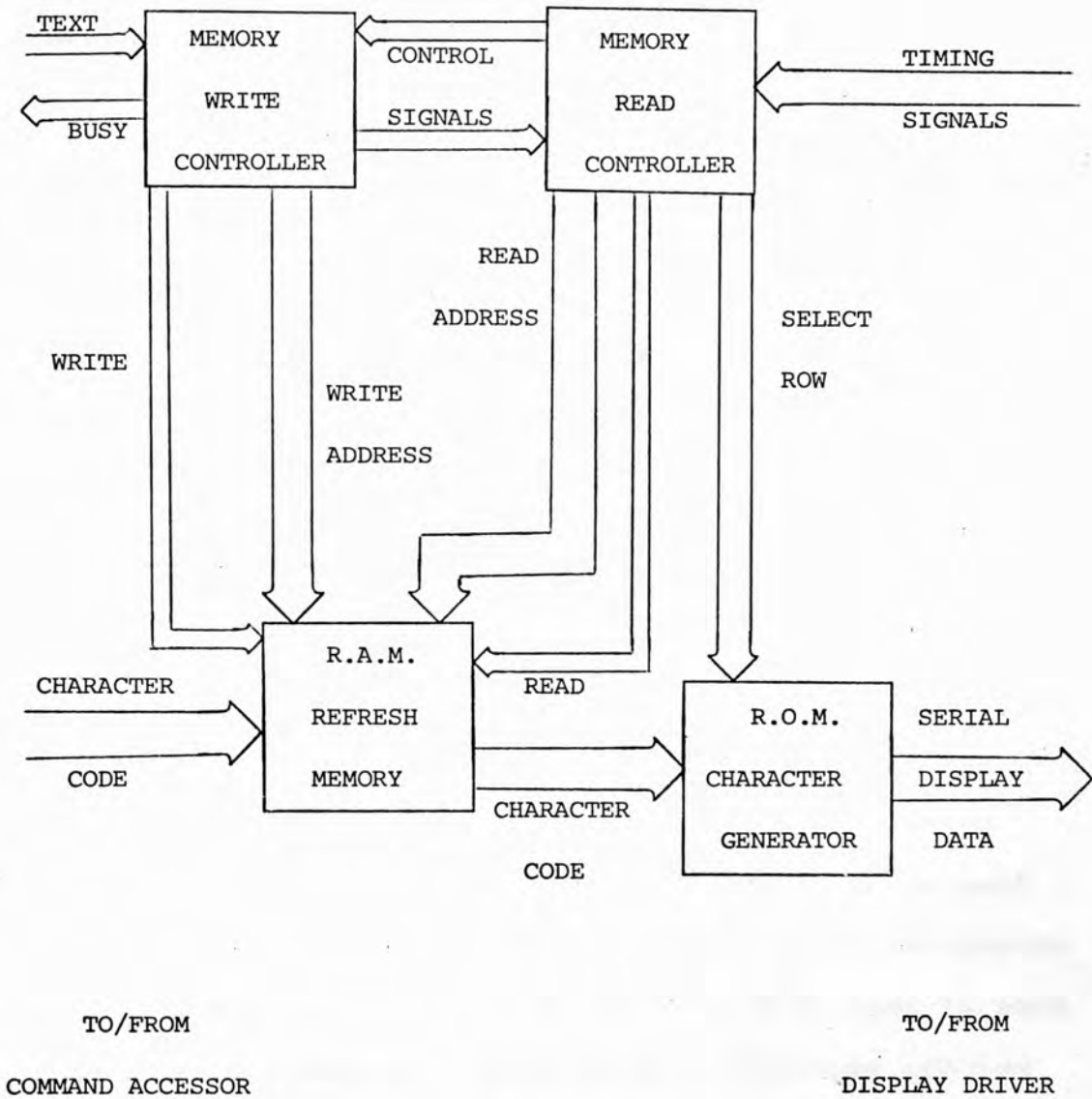
FIG. 40 — TEXT DISPLAY UNIT

being generated.   This is so that a time can be generated composed of the dot patterns of the required characters.   The display data for the four lines of text is thus generated in a serial stream and sent to the Display Driver.

THE DATA ACCESSOR.

The Data Accessor controls the D.M.A. Channel through which the display instructions are sent in hesitation mode to the Disc Controller.   The Data Accessor is initialised by the "graph edit" signal generated in the Display Disc Controller (see Fig. 41). This signal causes the graph pointer location address for the terminal to be sent to the core memory block.   The contents of this location, which is the start address of the display instructions, are sent back via the multi-plexer and loaded into the Core Address Register.   Then successive display instructions are taken from the core memory module using the Core Address Register to address the core locations.   When the data word arrives the D.D.C. is signaled that the data word is ready to be accepted.   After the D.D.C. has processed the current data word it sends a "next data" signal which increments the Core Address Register and the next data word is sent from the core memory.   This process continues loading successive data words until it is halted by a "graph change Address" signal sent from the D.D.C.

THE DISPLAY DISC CONTROLLER.

The Display Disc Controller is the heart of the PICASSO system and is composed of several interdependent
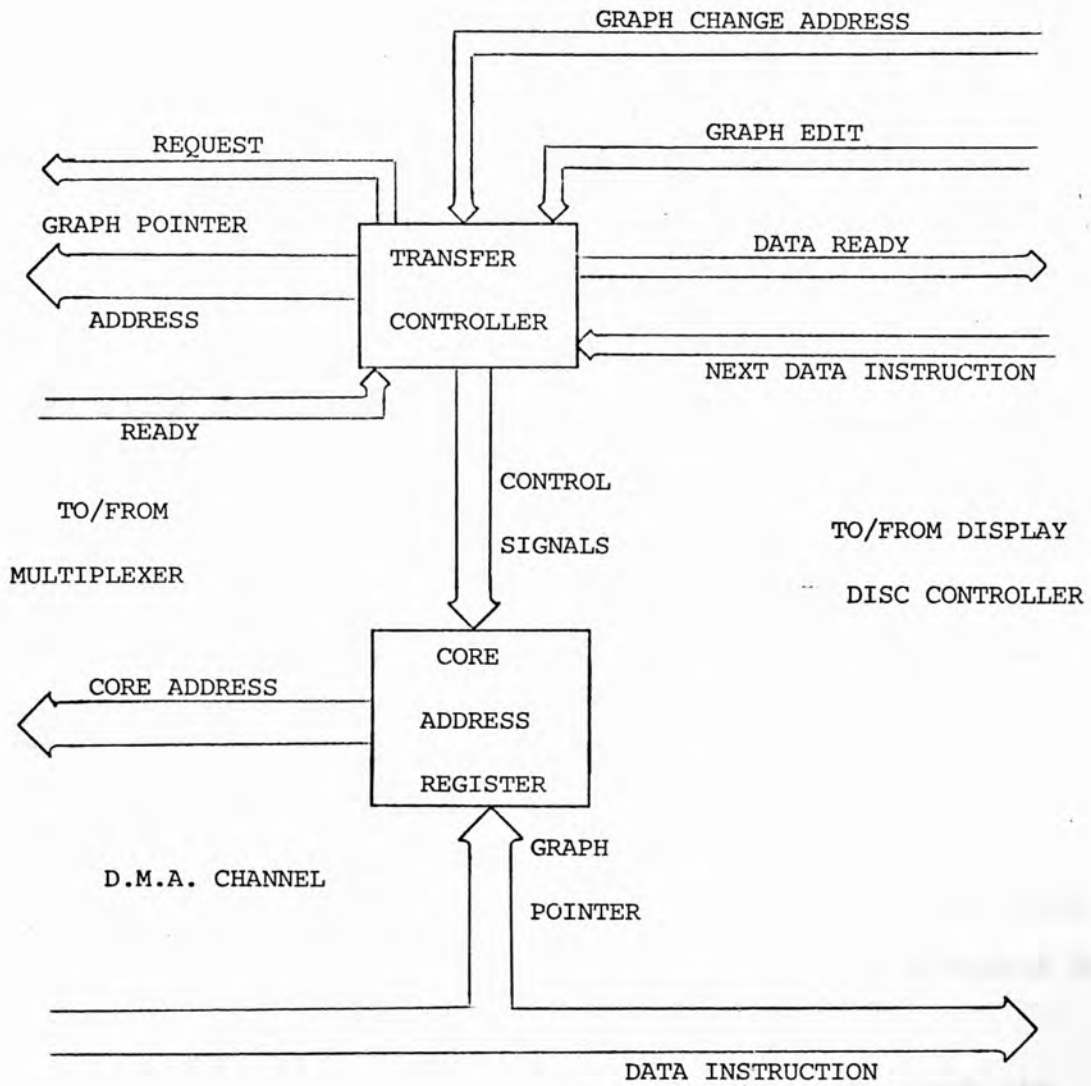
FIG. 41 - DATA ACCESSOR

units as shown in Fig. 42. The master clock for the whole DDC and the Display Driver clock are generated from the recorded clock disc track for synchronisation reasons (see 4.2). The Clock Generator is critical to the whole system and as good a 10 MHz clock as possible is produced from the 2½ MHz clock recorded on the Disc. This is achieved by precisely adjusting the delays used in synthesising the master clock signal.

Display data is output from the disc tracks on a bus to the Display Driver. The Disc Track Selector sends the address of the most recently updated set of tracks to the terminals display driver. By this means the terminal is constantly refreshed and the displayed information read off the appropriate set of tracks after the editing process has been completed. The delay to the data signal during editing, explained in 4.2, is compensated for by similarly delaying the monitor timing signals. This is achieved by suppressing the display driver's clock for the correct time at the end of an edit operation. This occurs when the disc tracks being read by the Display Driver are changed and is governed by the Edit Cycle Controller.

The ordering of the processor commands sent via the Command Accessor are dealt with by the Compressor. The timing adjustments made to the terminal display after an editing operation result in the timing signals occuring at an arbitary time relative to the D.D.C. Thus the Compressor starts an editing operation on the first available index pulse ensuring a minimum of time

TO/FROM

COMMAND COMPRESSOR

FROM

CLOCK GENERATOR

RESET

CONTROL SIGNALS

EDITOR BUSY

MASTER

CLOCK

CONTROL CODE

DISPLAY

INSTRUCTION

CONTROLLER

EDITOR

TIMING

CONTROLLER

PATTERN

DOT &

PATTERN

GENERATOR

NEW DATA

D.M.A.

TO DATA

MODIFIER

POSITION

COMPARATOR

CO-ORDINATE

DATA

TIMING SIGNALS

DISPLAY MARKER

TO/FROM DATA

ACCESSOR
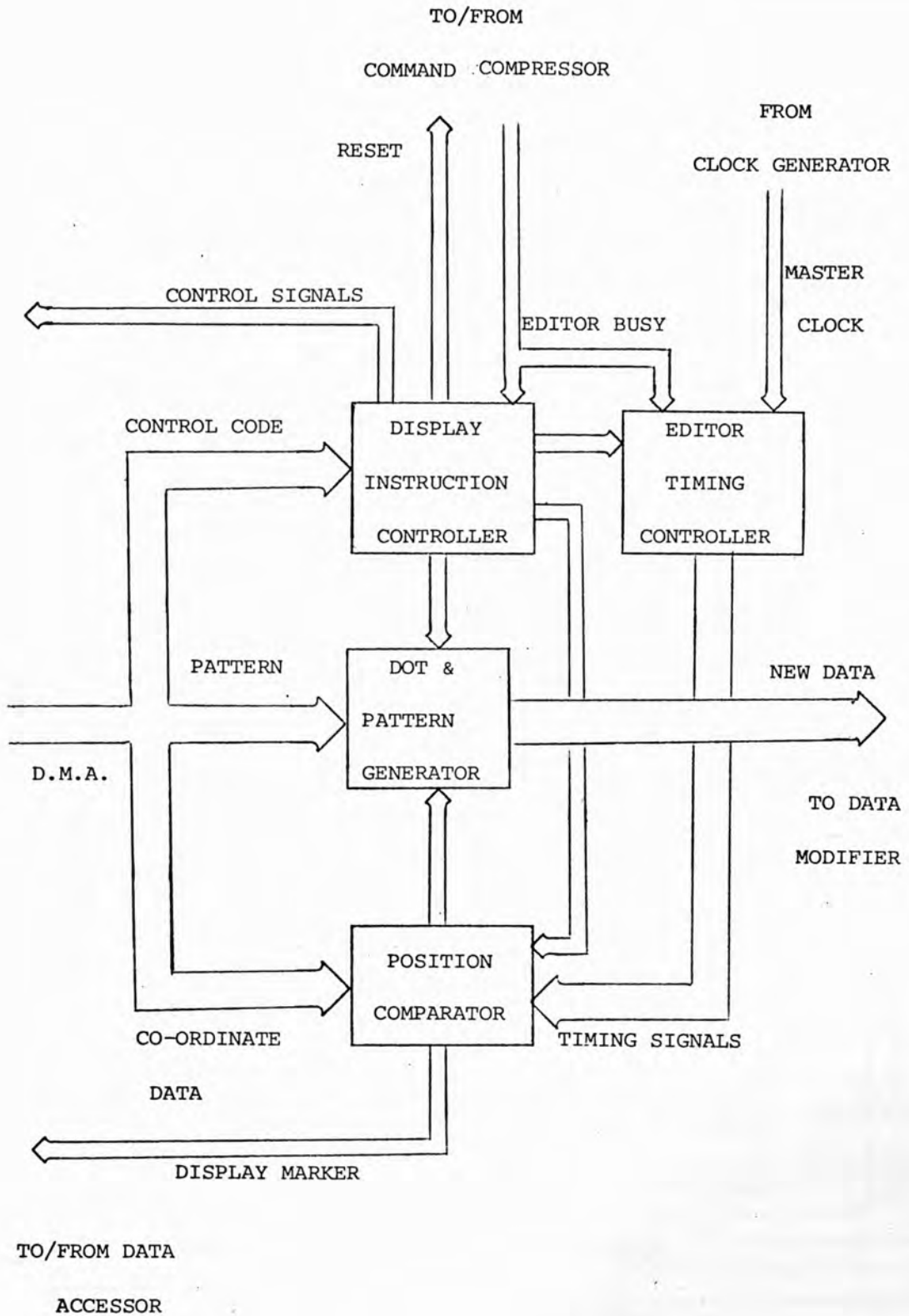
FIG. 42 (PART A) — DISPLAY DISC CONTROLLER
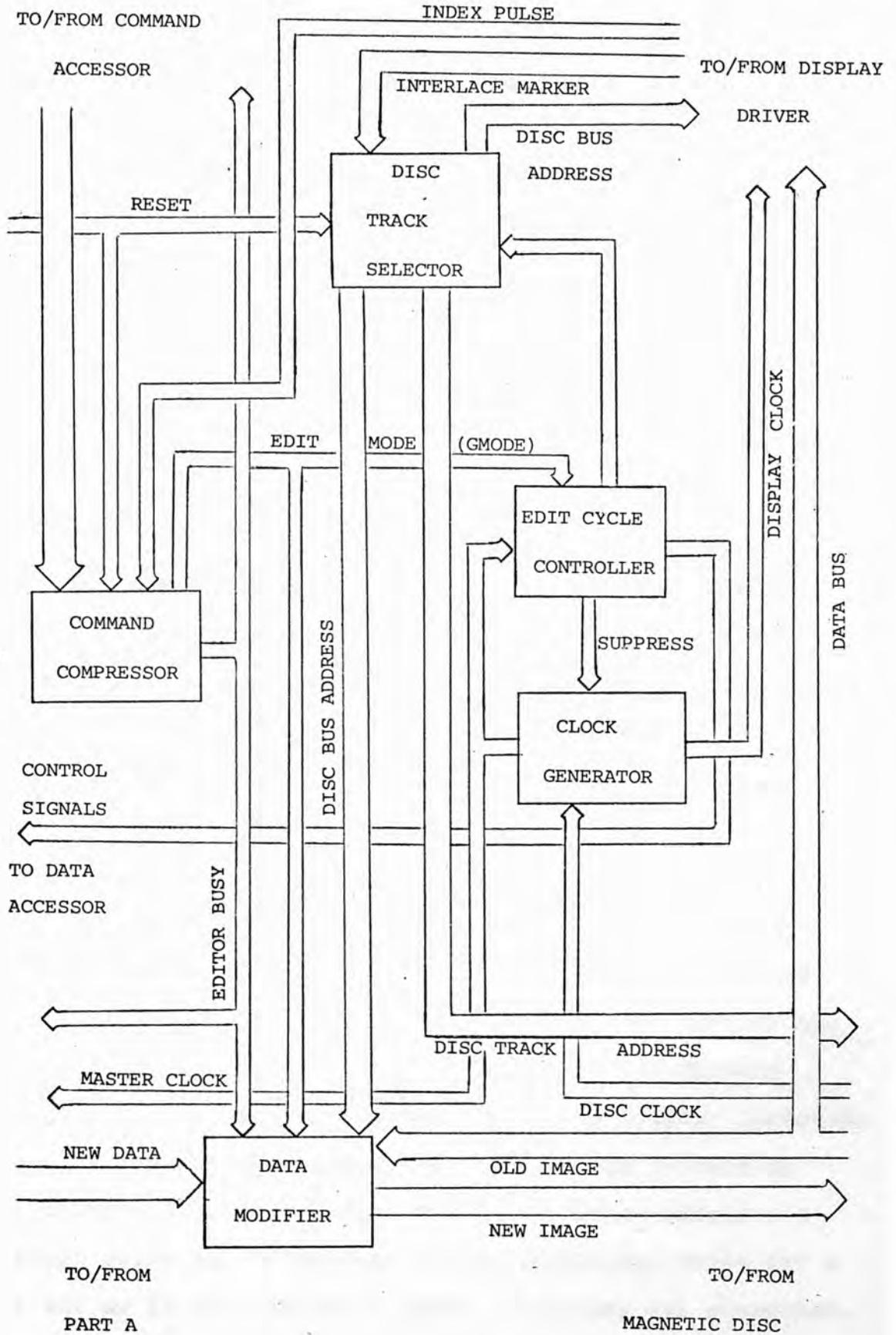
FIG. 42 (PART b) - DISPLAY DISC CONTROLLER

is spent waiting for an edit to commence.

The display data that is transfered to the D.D.C.
via the D.M.A. Channel is sent in sequences of one to
three words which make up a complete display instruction.
The most significant 7 bits of the first word of the
sequence contains the display instruction control code.
These 7 bits are loaded into the Display Instruction
Controller which then controls the loading of the rest
of the display instruction sequence into the correct units.

When the Command Compressor starts an edit
operation the Editor Timing Controller starts to perform
the monitor timing operations in synchronism with the
Display Driver. The X and Y co-ordinates of the display
instruction are loaded into the Position Comparator where
they are compared with the timing signals being produced
by the Editor Timing Controller. If the display
instruction co-ordinates are smaller than the current
value of the Editor Timing Controller, co-incidence will
not be found for that display instruction during the
edit cycle and the next display instruction is fetched.
If co-incidence is found a signal is sent to the Dot and
Pattern Generator and a '1' written into the display
marker of the display instruction. The Display Instruct-
ion Controller determines whether a dot or pattern is
generated from the control code. A dot is simply a
short pulse at the correct display position, while for a
6 bit or 15 bit pattern a series of pulses are generated.
The exact pattern is given by the bits set in the data
word of the display instruction that are loaded into the

Dot and Pattern Generator.

The display instructions are all sequentially loaded into the Position Comparator until a "stop plotting" display instruction is received. The display instructions are used to generate a stream of new data that is sent to the Data Modifier. The current data for the terminal is read from the data bus into the Data Modifier where the editing of pictures is carried out. In the case of writing a new picture the old data is not used, the new data is just streamed out onto the spare set of disc tracks used for editing. To add to the existing picture, the new data is used in an "OR" operation with the old data so that a combination of the two is written onto the Editor Tracks. When erasing from the existing picture the new data is inverted and used in an "AND" operation with the old data. This results in the picture written on the Editor Tracks being the old picture with blanks at the points specified by the new data.

THE DISPLAY DRIVER.

The display clock signal sent from the D.D.C. is used by the Display Counter to generate the timing signals required by the Timing Decoder (see Fig. 43). The timing signals produced by the Timing Decoder are sent to the D.D.C. and the Text Display Unit. In return text data is sent from the T.D.U. to the Data Mixer, and graphical data sent along the disc data bus to the Data Multiplexer. The disc bus address selects the data lines holding the most recent image and so the graphical
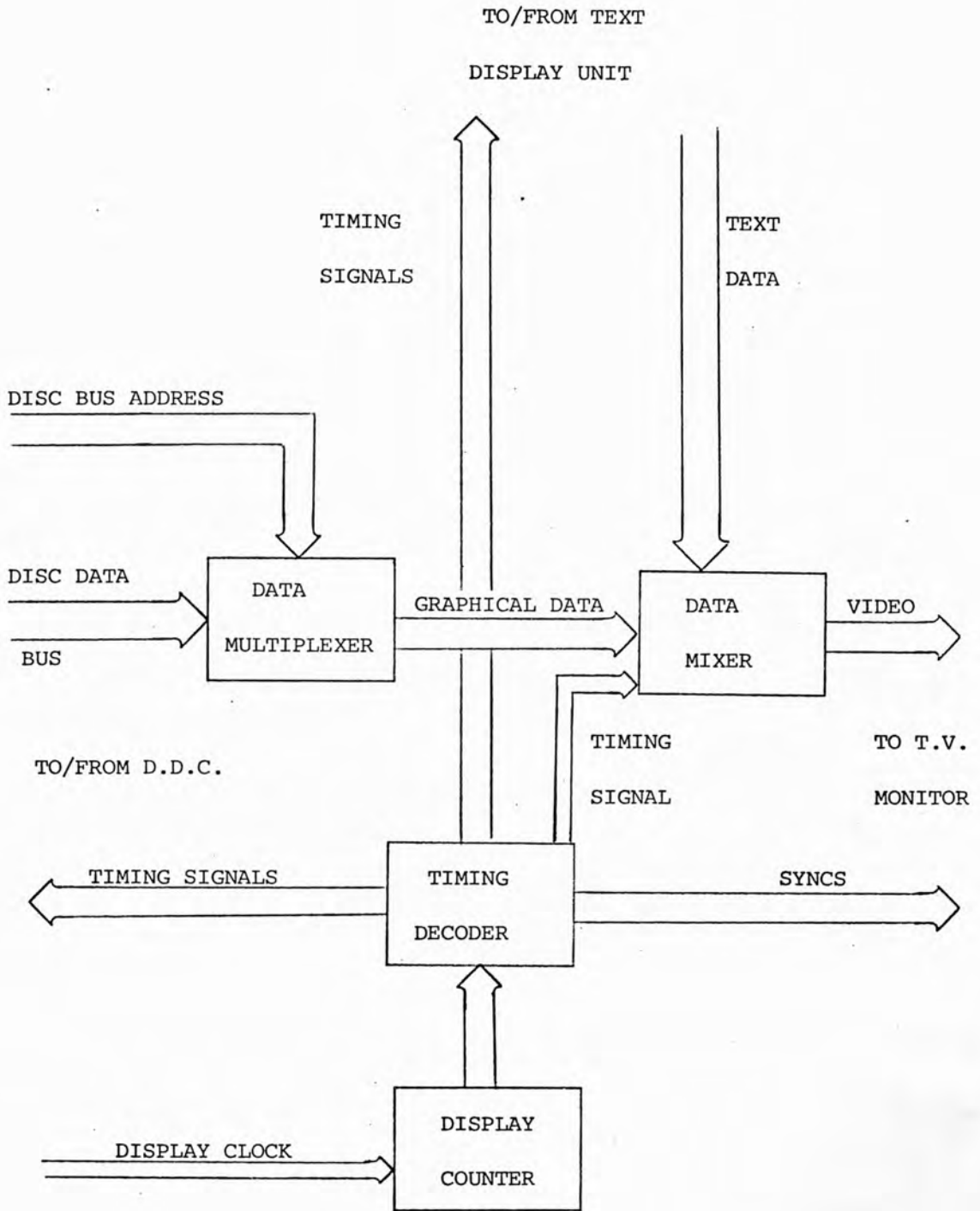
FIG. 43 - DISPLAY DRIVER

data is sent from the Data Multiplexer to the Data Mixer.

The Timing Decoder sends timing signals to the Data Mixer which blanks out data during frame and line flybacks to prevent any spurious information being displayed. For the same reason text data is also blanked out at times when the 4 lines of text are not being displayed. The text and graphical data signals are combined by an "OR" operation and sent to the T.V. monitor as a video signal. Frame and line synchronisation pulses are also required by the T.V. monitors and these are produced by the Timing Decoder. The video signal and synchronisation pulses can be combined after the Display Driver depending on the requirements of the particular monitor used.

4.4   PICASSO SOFTWARE.

The main drawbacks of the Modular One configuration used in the PICASSO System are that most of the peripherals are non-standard devices and only a small size of core store is available.   The normal Computer Technology Limited software operating systems E1 and E2 have the disadvantage of taking up at least 4K of core store and being slow in operation.   The standard executives also lack facilities for programming in special state and there are difficulties in the on-line debugging of programs.   A version of E1 is available which has been adapted to enable the use of the non-standard fast paper tape reader.   The fast paper tape punch, however, does not operate under the standard executive and so it is impossible to use the symbolic editor with high speed output.

A set of programs developed specifically for the PICASSO Modular One configuration is used as an alternative.   IMP6 is a software console (there is no hardware console) and interactive program monitor that handles system interrupts.   The operator is enabled to access and alter the contents of any core location and set breakpoints as desired.   IMP6 command breaks each 16 bit word into three fields of 3, 5 and 8 bits, (see 4.2) and prints them as octal numbers.   This is more useful for interactive modification and debugging of programs than printing each 16 bit word in a decimal format as CTL Assembly Language does.

A small special purpose executive, EO.6, is

available that occupies about 2.75 K words of core and
will handle a single program.   Calls are provided that
allow control of all peripheral devices, and interrupts
are handled with fast response times.   Programs are
run under EO.6 by the operator who specifies the value
of some, or all, of the 5 registers and the 3 segment
bounds.   When the Executive types a carriage return,
line feed and percent sign (%) on the teletype an
executive command can be given.   This is usually a
single letter which specifies the register to change or
the operation to perform.   If the name of a register
or sector is specified then its current contents are
printed out in octal and the register reset by typing
a new value in.   Other commands print out the contents
of a specified core location, which may then be altered,
or print out the contents of a block of core store.
The contents of a block of core store may also be punched
out on paper tape or loaded from paper tape into core.
A further command causes a user program defined by the
values of the registers and segment bounds to be
activated.   Interrupts are identified with a printed
code letter, such as breakpoint encountered or violation
occurred and the program status current when the interrupt
was received is saved.   Executive routines set break-
points, print a character on the teletype or read a
character from the teletype.

An interactive symbolic text editor,EDIT, is used
that operates under EO.6, so fast output of a symbolic
program is possible.   The C.T.L. assembler LAS 4 is used

to provide assembled programs that will run under special
purpose executives such as EO.5. Control of peripheral
devices is achieved by sending a data word to or from a
device. Each device is assigned one or more addresses
as if they were located in an eighth memory module.
Data words are sent between the processor and the
peripheral address just as if the device addresses were
core memory addresses. Data is transferred to and from
the processor A register and the peripheral address is
usually held in the B register. The transfer may be
accepted, in which case the transfer takes place and the
next instruction is skipped. Alternatively the transfer
may be rejected, in which case the transfer does not take
place, a value is forced into the B register, and the
next instruction is executed. The value returned in the
B register corresponds to a standard rejection qualifier.
When a device is handling a transfer is appears busy and
will reject further commands with the appropriate
standard rejection qualifier till ready to receive a new
command.

The particular graphics terminal in use has nine
addresses assigned to it (starting at 7, 13, 140) and a
corresponding fixed core location (2, 134) for the display
instruction pointer (gtptr) (see 4.2). The status of the
terminal is requested and sent to the processor by
addressing the first location (7, 13, 140). The fifth
location (7, 13, 145) when addressed enables four lines
of text to be displayed and sets "gmode" according to
the value sent from the processor's A register. Gmode

determines the type of graphical data editing operation to take place - if gmode is "1" a new picture is written, "2" adds an image to the picture, and "3" erases an image from the picture. The ninth location (7, 13, 150) when addressed actually starts the Display Controller taking words from the core address held in gtptr onwards, and editing the picture according to the value of gmode. The 13th location (7, 13, 154) displays an ASCII character when it is addressed, according to the value transmitted from the A register.

The format of the display instruction's 1st word has the most significant seven bits containing its function code, and the least significant nine bits containing the Y co-ordinate. Function code 4 produces a single dot with the X co-ordinate contained in the following word. Function 5 gives a six bit pattern, the second word of the display instruction contains the X co-ordinate in its 9 least significant bits and the pattern itself in the 7 most significant bits. Function 10 produces a 15 bit pattern, the X co-ordinate is contained in the second word of the display instruction and the bit pattern required is contained in the whole of the third word of the display instruction. Function code 20 is the command to stop taking any further display instructions from the core memory.

The most significant bit (bit 15) of the last word of each display instruction is reserved for a display marker. This marker is set to "1" if coincidence was found and the item displayed, and "0" otherwise (Fig. 44).
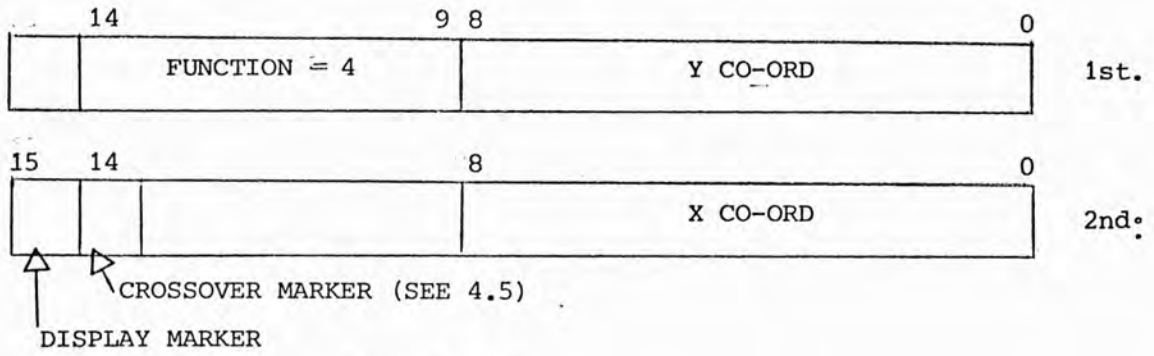
SINGLE DOT
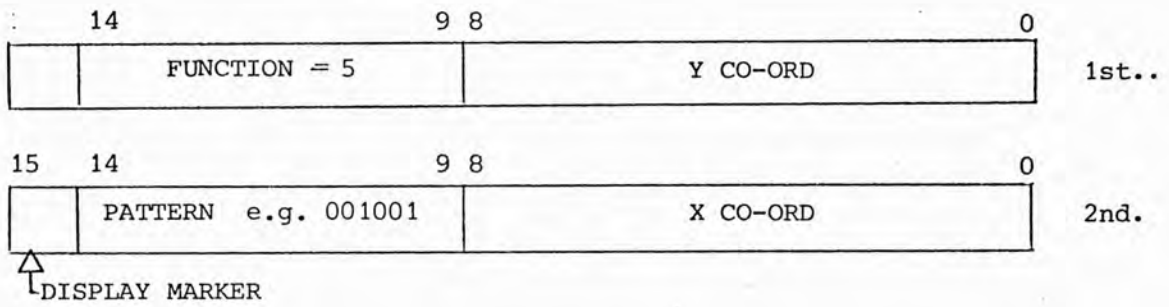
6 DOT PATTERN
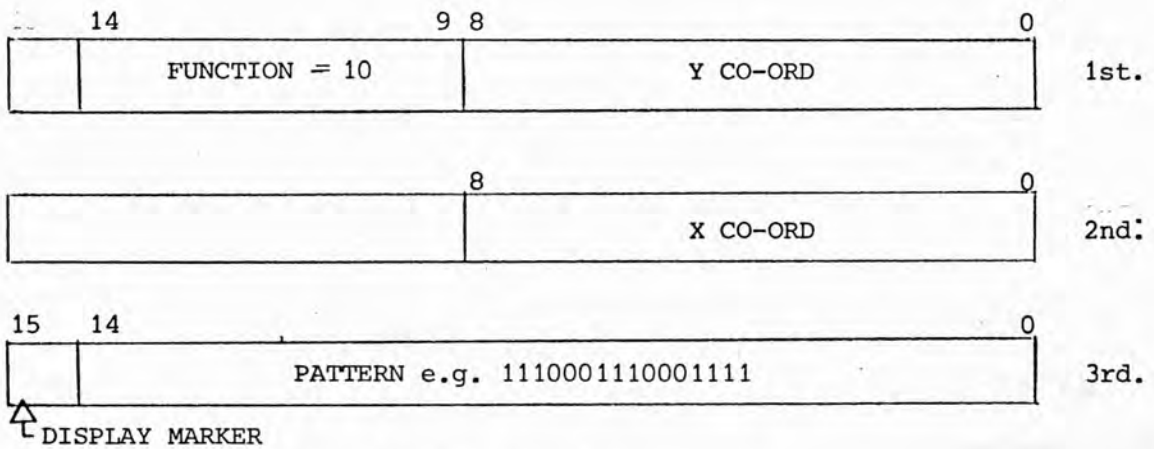
15 DOT PATTERN
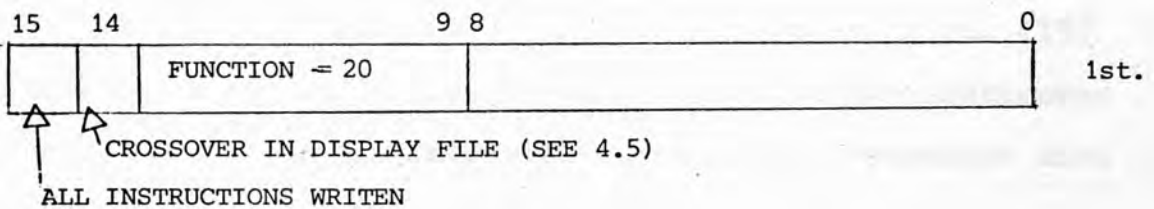
STOP PLOTTING

FIG. 44 - DISPLAY INSTRUCTION FORMAT

When the Store Accessor receives a display instruction
with the most significant bit of the last word set to
"1" the next display instruction is immediately fetched.
This is to prevent time being wasted waiting for co-
incidence to be found for items that have already been
displayed.   If coincidence is found for every display
instruction, i.e. they were all successfully displayed,
"1" is placed in the most significant bit of the "stop
plotting" command, this bit is left as "O" otherwise.

As a preliminary step towards investigating the
crossing vector erasure problem basic software was needed
that would display any vectors required on the T.V. screen.
It is not possible to draw a continuous line with the
PICASSO System as the discrete grid permits intensificat-
ion of points lying on intersections of the co-ordinate
grid only.   However a sequence of dots can be displayed
that approximate to the required vector.   Digital
vector generation algorithms calculate a sequence of
points, with co-ordinates Xi, Yi, to be intensified.
To save software complexity an incremental algorithm is
used, the calculation of any point (Xn, Yn) depending
on the co-ordinates of the previous point (Xn-1, Yn-1).

The Digital Differential Analyzer or D.D.A. (13)
produces only a discrete approximation to the continuous
solution of the differential equation of a straight line -

$$\frac{dY}{dX} = \frac{DY}{DX}$$

but this approximation provides the digital positioning
commands for use with PICASSO.   The D.D.A. generates
points that are spaced one grid unit apart along the
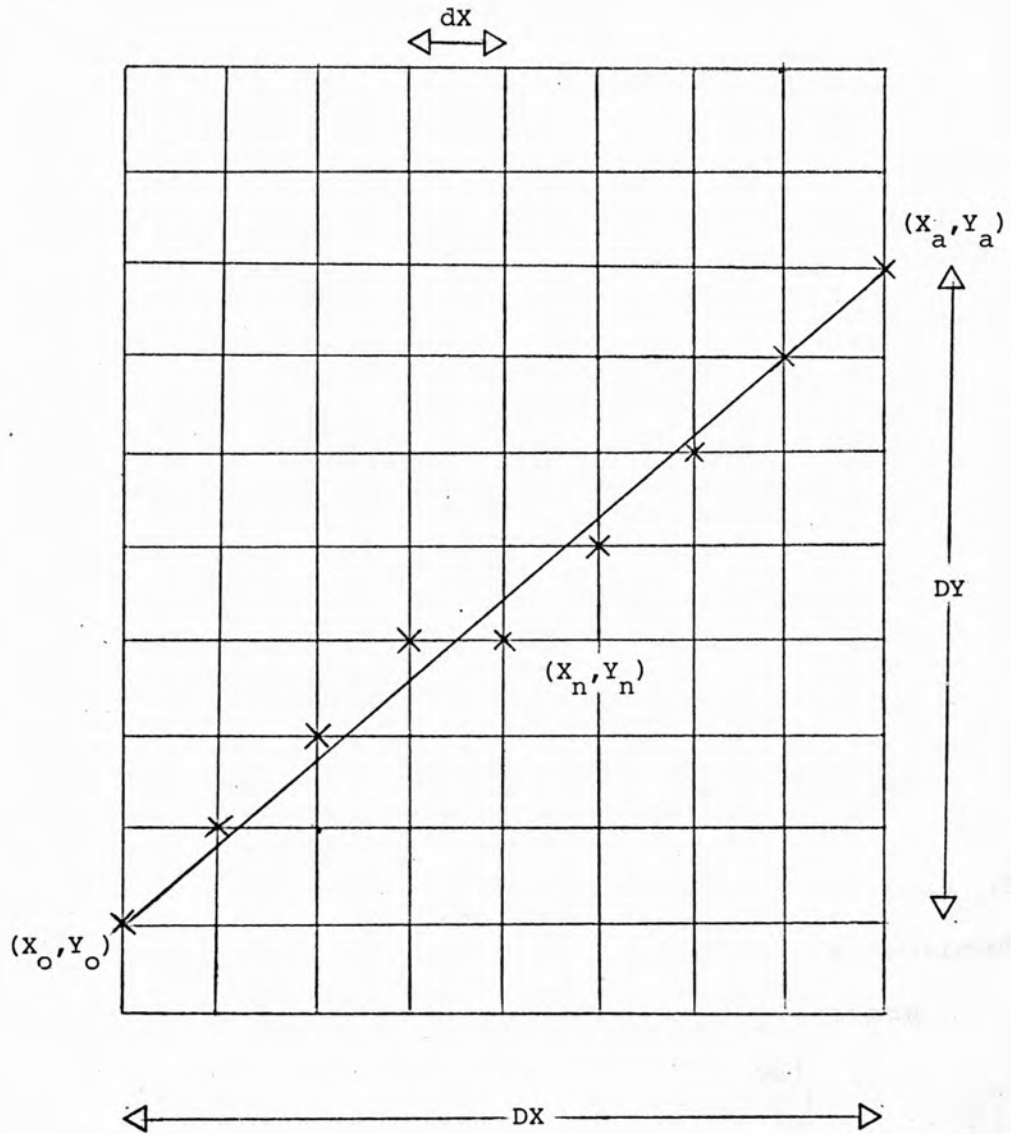
FIG. 45 - DIGITAL DIFFERENTIAL ANALYSIS

greater of the vector's X or Y dimension. The spacing
along the other dimension is the best approximation to
$\frac{DY}{DX}$ units or $\frac{DX}{DY}$ units, as appropriate. For example for
Fig. 45 DX is larger than DY so points would be spaced
one unit apart along the X dimension, dX = 1, and the
spacing of the points in the Y dimension would be given by

$$dY = \frac{DY}{DX}$$

which would always be less than or equal to 1. The
computation of the X co-ordinate of successive points
is by adding one grid unit each line so

$$Xn = Xn-1 + 1$$

which is repeated DX times. The fraction $\frac{DY}{DX}$ is used to
compute an approximate Y value for each X value so

$$Yn = Yn-1 + Xn\left(\frac{DY}{DX}\right)$$

This would have a fractional part which could not be dis-
played so the integer part of Yn is used by truncating

$$Yn = \left\lfloor Yn-1 + Xn\left(\frac{DY}{DX}\right)\right\rfloor$$

However the points generated would be biased to lie off
the correct line. Instead the value of Yn is rounded to
the nearest integer by adding ½ before truncating

$$Yn = \left\lfloor Yn-1 + \tfrac{1}{2} + Xn\left(\frac{DY}{DX}\right)\right\rfloor$$

This is not necessary if the division instruction within
the Modular One is used. The result of a division is
always rounded to the nearest integer.

The flowchart of the program vector is shown in
Fig. 46. The X and Y co-ordinates of both ends of the
vector are read into the program from the teletype. Two
subroutines convert the input ASCII codes to characters,

```
                    ┌─────────────┐
                    │    START    │
                    └─────────────┘
                           │
              ┌────────────────────────┐
              │   INPUT VECTOR         │
              │   END CO-ORDS          │
              └────────────────────────┘
                           │
                    ◇ EXCHANGE ◇
                    ◇ VECTOR ENDS ◇
                    ◇     ?      ◇
                           │
                    ◇    X      ◇
                    ◇ INCREMENT ◇
                    ◇  + OR -   ◇
                    ◇   1?      ◇
                           │
┌──────────────┐  ODD  ◇ Y CO-ORD ◇  EVEN  ┌──────────────┐
│ STORE IN ODD │◄──────◇ PARITY   ◇──────►│ STORE IN EVEN│
│ INTERLACE    │       ◇    ?     ◇        │ INTERLACE    │
│ FILE         │                           │ FILE         │
└──────────────┘                           └──────────────┘
       │                                          │
       └──────────────────┐        ┌──────────────┘
                          │        │
                   ◇ VECTOR ◇
          YES      ◇ COMPLETE ◇
       ◄───────────◇    ?     ◇
       │                │ NO
┌──────────┐            │
│ COMBINE  │     ◇ X OR Y ◇   Y
│ FILES    │     ◇ GREATER ◇──────┐
└──────────┘     ◇    ?    ◇      │
       │              │ X         │
┌──────────┐    ┌────────────┐  ┌────────────┐
│ ADD 'STOP│    │ INCREMENT X│  │ INCREMENT Y│
│ PLOTTING'│    └────────────┘  └────────────┘
│ INSTRUCTION│        │              │
└──────────┘    ┌────────────┐  ┌────────────┐
       │        │D.D.A. FOR Y│  │D.D.A. FOR X│
┌──────────┐    └────────────┘  └────────────┘
│ INPUT    │
│ MODE     │
└──────────┘
       │
┌──────────┐
│ START    │◄─────────────────────┐
│ EDIT     │                      │
└──────────┘                      │
       │                   ◇  IF      ◇
       │                   ◇ MODE 1   ◇
   ◇ WAIT ◇               ◇ CHANGE TO ◇
   ◇ TILL EDIT ◇          ◇ MODE 2    ◇
   ◇ COMPLETE ◇                │ NO
       │                       │
       │                ◇ ALL        ◇  YES  ┌──────┐
       └───────────────►◇ INSTRUCTIONS◇─────►│ END  │
                        ◇ WRITEN ?    ◇       └──────┘
```

FIG. 46 - 'VECTOR' FLOWCHART

check they are octal figures and pack the figures into three figure octal numbers (in range 0 - 512).

The most efficient way to display a set of points (i.e. finding coincidence in the least number of edit cycles) is by sending the display instructions to the D.D.C. in sequence with the instruction with the smallest Y co-ordinate value first. For this reason the two Y co-ordinates of the vector endpoints are examined and exchanged if necessary. Thus the vector endpoint dealt with by the program first always has the lower Y co-ordinate value. The values of the endpoints X co-ordinates are similarly compared to determine if the X value has to be incremented positively or negatively (i.e. decremented) when generating the set of points.

The parity of the first points Y co-ordinate is checked, and the display code consisting of function code, X and Y co-ordinates, is stored as two data words in the even interlace file or odd interlace file as appropriate. The current X or Y co-ordinate value is then incremented, depending on which dimension the vector is larger. It is then determined if the other co-ordinate value is also incremental using the D.D.A. process already outlined. The new co-ordinate pair produced is again stored as a display instruction in the appropriate interlace file and the next set of co-ordinates determined by D.D.A. This process continues until the last point stored has the same co-ordinate values as the other end point of the vector, when the complete set of points will have been generated.

The two interlace files are now combined to form
the display file, the odd interlace file is relocated
to continue immediately after the end of the even inter-
lace file. The "stop plotting" display instruction is
added to the end of the display file. The edit mode
(new write, add or erase) is input from the teletype, and
the edit operation initiated accordingly. The location
of the start of the display file is held in "gtptr" and
the display instructions are taken one by one from the
core and sent to the D.D.C. The program goes into a
waiting loop until the edit cycle is completed, as defects
in the multiplexer prevent the reliable use of interrupts.
If the "start edit operation" command to the Display
Controller is rejected the program returns to the
executive to allow the operator to take corrective action.

After completion of the edit operation the con-
dition of the most significant bit of the "stop plotting"
display instruction is examined. If this bit is "1"
all display instructions were written successfully and a
new set of vector co-ordinates are required to generate
a different vector. If the bit is "0" the edit cycle is
repeated as all display instructions have not been written,
i.e. coincidence was not found for all points. If the
edit mode was originally a "new write" (mode 1) it is
changed to an "add" (mode 2) so that data written in the
first edit cycle is not lost in the next. Edit cycles
are thus continuously repeated until bit 15 of the "stop
plotting" display instruction is set to "1" and all the
display instructions have been written.

4.5 CROSSING VECTOR PROBLEM.

A number of possible approaches to the crossing vector erasure problem present themselves, and the main methods possible are examined below.

PICTURE REGENERATION.

The regeneration of the whole image is the method currently being used in raster scan graphics systems. Writing a new picture or adding an image to an existing picture is performed normally. The endpoint co-ordinates of the vectors that the picture is built up from are retained and stored in the vector file. When the command to erase a vector in the existing picture is given, the endpoint co-ordinates of that particular vector are deleted from the vector file. The whole picture is then completely regenerated from the vector endpoint co-ordinates remaining in the vector file. The new picture has the desired vector removed and there is no missing information in other vectors as they have all been completely rewritten.

The drawbacks to this method are that a large file containing all the vector endpoint co-ordinates has to be maintained, and a large amount of processor time may be needed to regenerate a complex picture when only a small change in it is needed. This method is unsatisfactory in that the whole picture is always regenerated even when the vector being erased does not cross any other vector and there is thus not problem with information being lost.

CORE MAP.

A method that checks if one vector actually crosses

another is a preferable way of dealing with the problem
of vector erasure.   By keeping an exact copy of the
picture displayed on the screen in the core memory,
checks can be made as each new vector is added.   If any
bits are already set when the new vector information is
added into core, the co-ordinates of the bits concerned
are stored in a "crossover point" file.   When a vector
is to be erased, the crossover point file is checked to
see if it contains any of the points that compose the
vector.   Any points in the vector display file that are
present in the crossover point file are not erased with
the rest of the vector so previously written information
is not lost.   As core store is expensive and a large
amount would be required for a reasonable display
resolution, this method does not present a practical
solution.

HARDWARE COMPENSATOR.

It is possible to overcome the crossing vector
erasure problem by the use of hardware logic alone.
This would be achieved by checking the old data and the
new data for any coincident pulses during an "add" edit
operation (Fig. 47A).   Comparison would take place just
before the two sets of data were combined in the Data
Modifier so that any coincident pulses would mean a point
being overwritten by another image.   A coincident pulse
would be stored in Random Access Memory.   The R.A.M.
could simply have a one to one relation with screen grid
points, a memory bit being set to "1" if the corresponding
screen point was overwritten by another image.   The
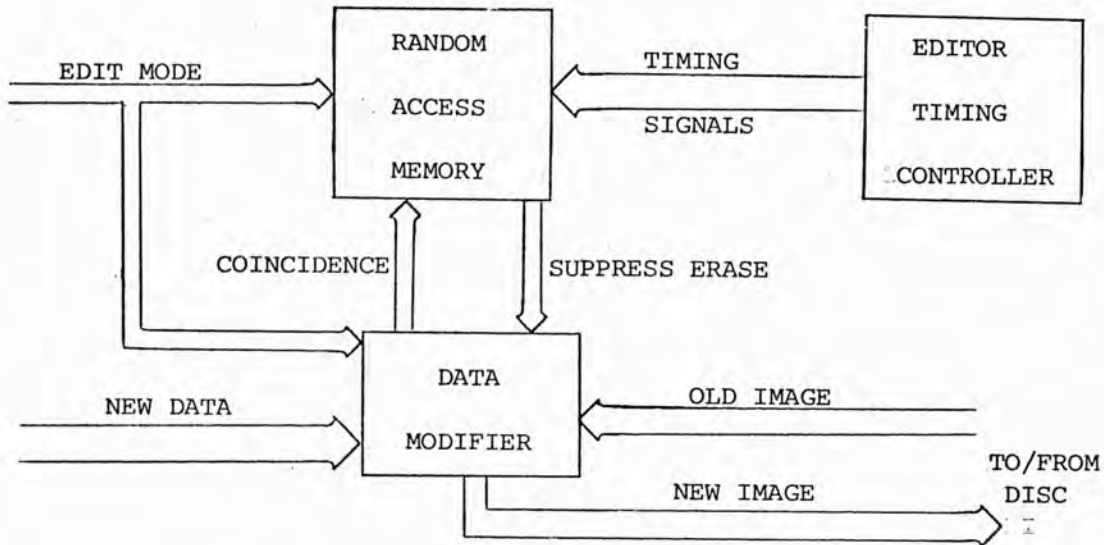
A - BIT PER POINT
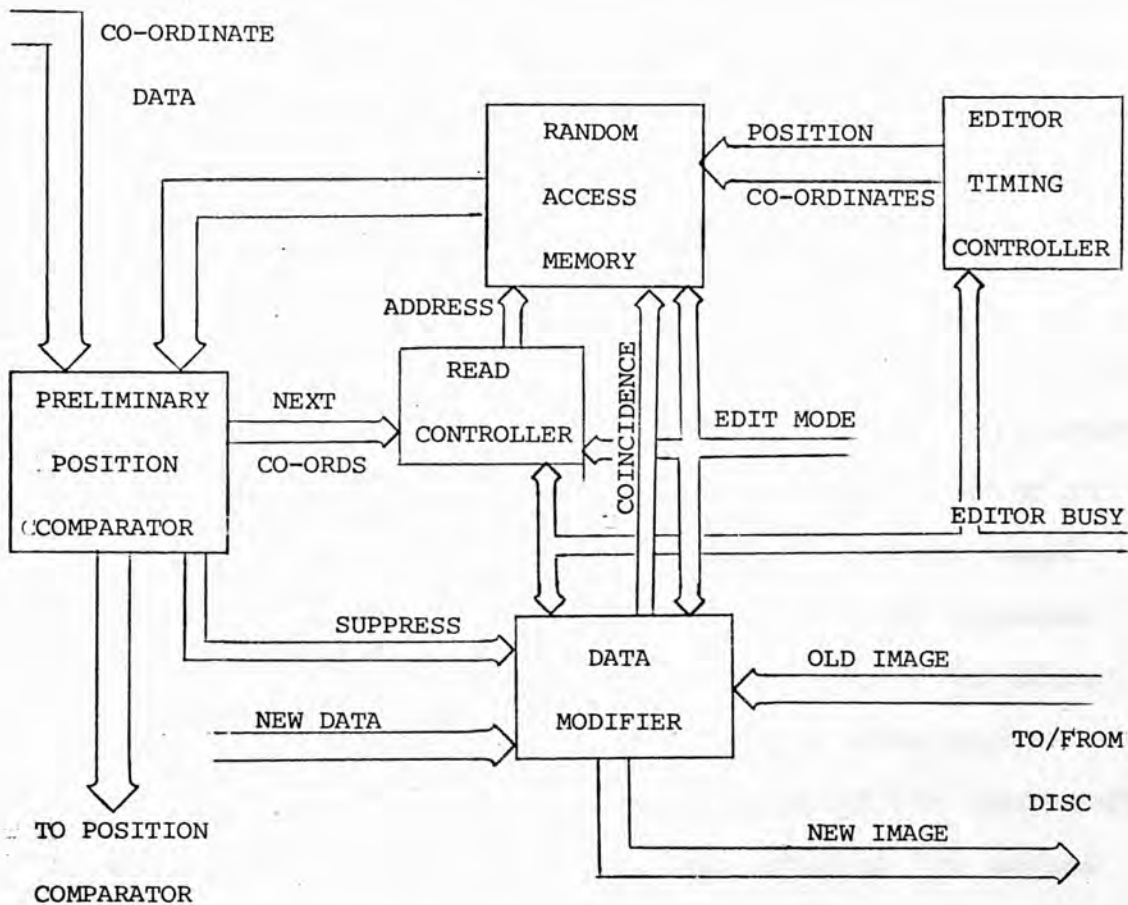
B - CROSSOVER CO-ORDINATES

FIG. 47 - HARDWARE COMPENSATOR

R.A.M. would be addressed by the timing signals produced
by the D.D.C. to store crossover information during an
"erase" edit operation.   If a memory bit was set to
"1", the erase pulse corresponding to that spot would
be suppressed and the memory bit set back to "0".   This
arrangement has the disadvantage that only two vectors
crossing at one particular point could be handled.   If
several vectors crossed at the same point the erasure of
more than one of them would result in the loss of
information.   Thus two or three memory bits would be
needed for each screen point to record the number of
times the addition of new data had resulted in the old
image being overwritten.   The memory bits assigned to
a particular screen point would be updated as images were
added or erased.   However this method would use so much
R.A.M., e.g. 250K for only one bit per PICASSO screen
point, that it would be far too expensive.

A variation of this approach would be to store the
current point co-ordinates in R.A.M. whenever a new image
overwrites the old image (Fig. 47B).   When a vector was
being erased all the co-ordinates held in R.A.M. would
be checked through.   If coincidence was found erasure
would be prevented for that particular spot.   To allow
for more than two vectors crossing at the same spot,
extra bits would be used to keep a count of the number of
times a point is overwritten.   Only storing the actual
crossover point co-ordinates would require far less
R.A.M. than the bit per spot method.   Problems would
arise in comparing each of the stored crossover co-

ordinates with the co-ordinates of the point that is
being erased.   If a large number of crossover points
are stored in the R.A.M. they will not all be able to
be checked in the current edit cycle.   This would mean
that several edit cycles might be needed to erase a
single point, so erasing a complete vector would take an
unacceptably long time.

Solving the crossing vector erasure problem by
using a hardware device is possible but clearly will be
more expensive and complex than other methods.   The
hardware will have to be built into a graphics display
but it may be that most of the displays will not
involve erasure of crossing vectors.   Due to the lack
of flexibility, expense, and problems in operation of
a hardware crossover compensator, other methods need
to be considered.

SOFTWARE CALCULATION.

The actual point two vectors will cross can be
calculated by co-ordinate geometry.

Two crossing vectors A, with endpoint co-ordinates
$(X_1, Y_1)(X_2, Y_2)$, and B, with endpoint co-ordinates
$(X_3, Y_3)(X_4, Y_4)$ are shown in Fig. 48.
Vectors A and B conform to the general line equation

$$Y = mX + c \qquad\qquad (1)$$

which when differentiated gives the line gradient

$$m = \frac{dY}{dX}$$

Thus for vector A

$$m_A = \frac{Y_2 - Y_1}{X_2 - X_1}$$
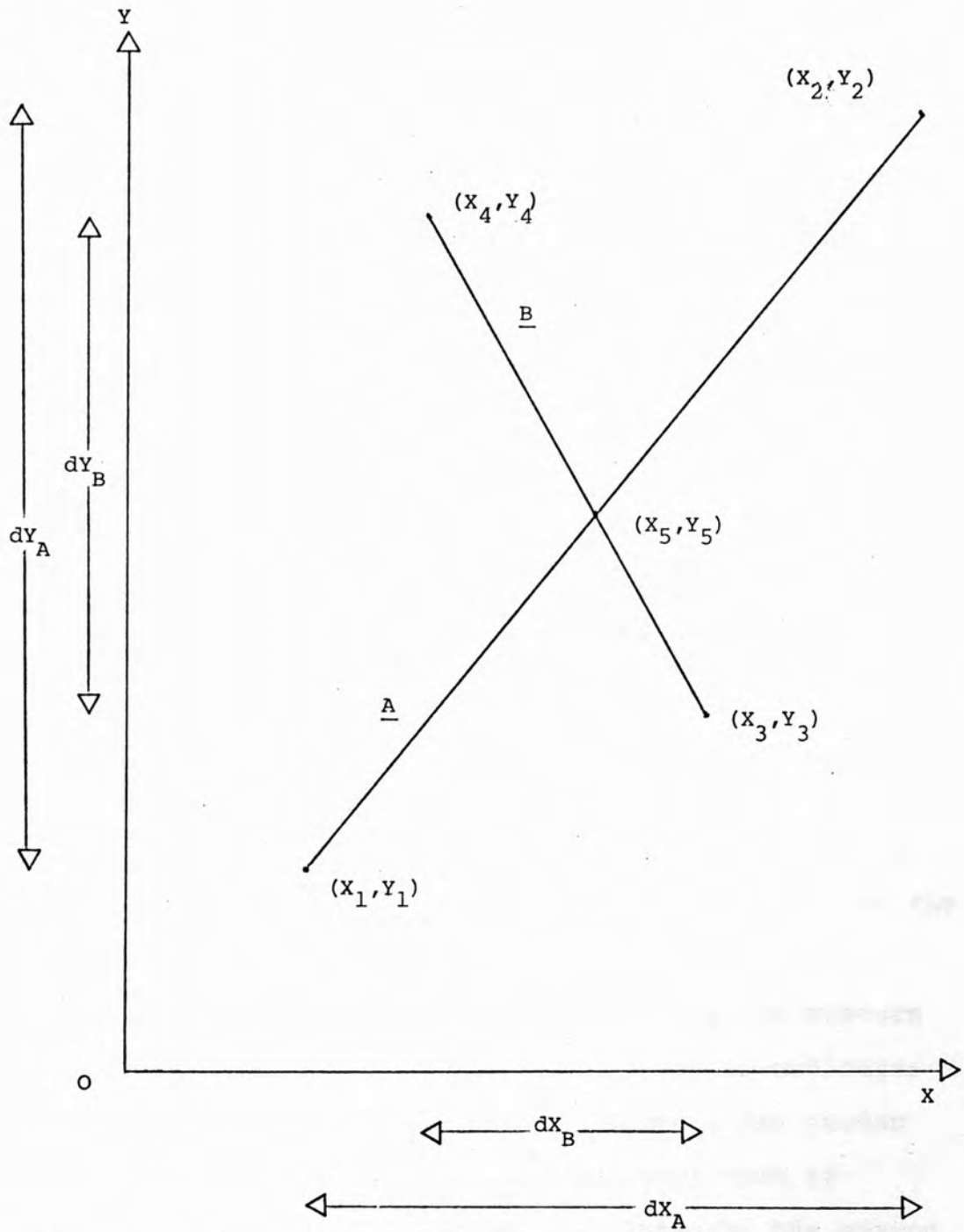
FIG. 48 - CROSSOVER CALCULATION

and vector B

$$m_B = \frac{Y_4 - Y_3}{X_4 - X_3}$$

Substituting the values for a vector endpoint and the gradient into the general line equation (1) gives values for the constants

$$c_A = Y_1 - m_A X_1$$

$$c_B = Y_3 - m_B X_3$$

The equations of the two vectors at the crossover point (X_5, Y_5) are

$$Y_5 = m_A X_5 + c_A \qquad\qquad (2)$$

and

$$Y_5 = m_B X_5 + c_B \qquad\qquad (3)$$

Subtracting the equation (3) from equation (2) and rearranging gives

$$X_5 = \frac{(c_B - c_A)}{(m_A - m_B)}$$

where c_B, c_A, m_A and m_B are known. When the X co-ordinate of the crossover point X_5 has been determined this is substituted into equation (2) and (3) to find the value of Y_5.

A system can thus be envisaged where the vectors that compose a picture have their endpoint co-ordinates retained in the "vector" file. Whenever a new vector is added to the picture the point (if any) that it crosses each existing vector is calculated by the method outlined above, and the co-ordinates stored in the "crossover" file. When a vector is to be erased from the picture each of the points in the "crossover" file is compared with the points generated and held in the display file. If coincidence is found between any

points they are deleted from both the crossover file
and the display file. Thus when the display file is
sent to the Display Controller only those parts of the
vector that do not overwrite other vectors are erased.
The "vector" file is similarly checked to delete the end-
point co-ordinates of the vector being erased.

Being implemented in software this approach has
the advantage of not requiring provision of special hard-
ware and has the flexibility to be able to handle several
vectors crossing at the same point. Complex pictures
can easily be handled by allocating enough store to
hold the "vector" and "crossover"files. However as
the picture became increasingly complex, more processing
would be required which could produce an appreciable
delay and prevent other operations from being performed.

In view of the potential of the Crossover
Calculation Method trials were carried out with it on the
PICASSO System to judge its effectiveness. Unfortunately
due to the timing problems inherent in the PICASSO hard-
ware (see 4.3) there is a small inaccuracy in the
positioning of images on the screen. This results in
an adjacent point often being drawn or erased rather than
the point specified by the display instruction. This
inaccuracy is not perceptible as far as the operator is
concerned but is sufficient to mean that the crossover
point calculated by software is <u>not</u> usually the actual
crossover point on the screen. When a vector is
erased any crossover points are erased also leaving
"holes" in other vectors and spurious points that should

have been erased. The Crossover Calculation Method
thus proved unfeasible in practice and some other approach
is needed.

CROSSOVER DETECTION AND DELETION.

As the Crossover Calculation Method was unsatis-
factory because the crossover point predicted by soft-
ware was incorrect, a direct method of determining the
actual crossover point was needed. Hardware was added
to the Data Modifier that compared the old data taken
from the disc with the new data generated from display
instructions (see Fig. 49). The hardware examined the
two sets of data just before they were combined, so two
coincident signals correspond to an overwritten point.
When an "add" edit operation is initiated, the display
instruction for each point is processed by the Display
Disc Controller. If the new point being added to the
picture overwrites the old image, bit 14 of the second
word of the display instruction is set to "1". Each
display instruction once processed, is written back
into the appropriate place in core by a D.M.A. transfer
in the reverse direction, as it takes the same time to
transfer a whole word as a single marker bit. A register
is set if any of the points generated during the whole
edit cycle overwrote the existing picture. At the end
of the edit cycle bit 14 of the "Stop Plotting" display
instruction is changed to "1" if the register is set,
and then transferred back to core by D.M.A. transfer.

An example of a display file before and after
being added to an existing picture is given in Fig 50.
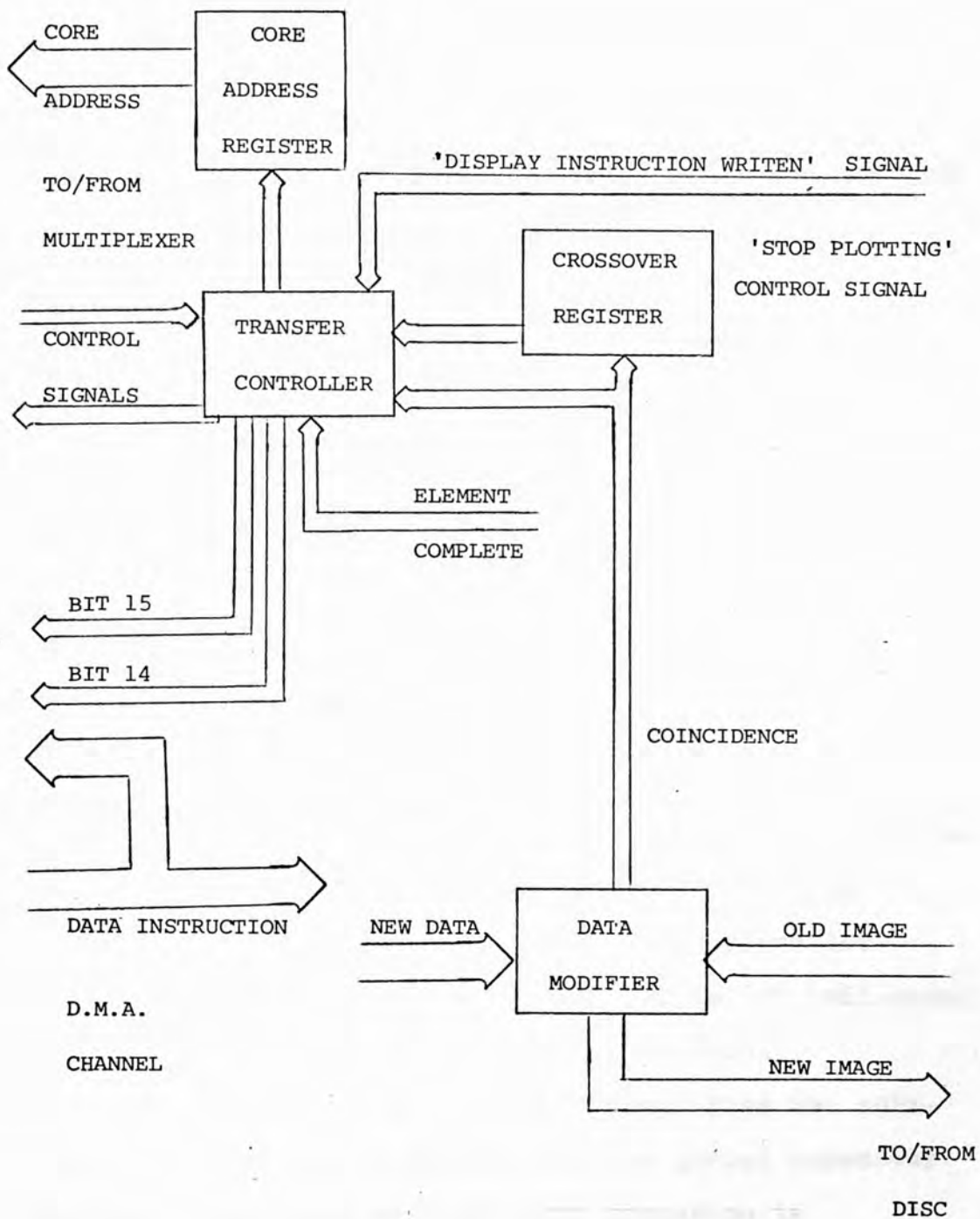
FIG. 49 - CROSSOVER DETECTOR

The display instructions for a short diagonal vector
(from 108, 100 to 100, 108) are shown in (A) before the
editing process has been initiated.   This is how the
display instructions would be held in core store in a
raster arrangement with even Y co-ordinates first
followed by odd Y co-ordinates and then the stop
plotting instruction.   (The formats of dot and stop
plotting display instructions are shown in 4.4).   The
display file is shown in (B) after the completion of the
edit process.   Dot display instructions have a "1" set
in bit 15 of the second word indicating they were
written correctly.   As all display instructions have
been written correctly bit 15 of the stop plotting
display instruction is also a "1".   In this example the
short diagonal has crossed part of the existing picture
when it was written and this is indicated by bit 14
of the stop plotting display instruction also being set
to "1".   The diagonal vector overwrote existing
information at points 104, 104 and 105, 103 as indicated
by bit 14 of the second word of these two display
instructions being set to "1".   All the other dot
display instructions have this bit set to "0" indicating
they did not overwrite existing information.

This approach considerably simplifies the soft-
ware task, as well as determining the actual crossover
points.   Each time an "add" edit operation is
completed bit 14 of the "Stop Plotting" display instruct-
ion is examined (see Fig. 51).   If it has been set to
"1" by the hardware, the display file of the vector just

	(A)		(B)	
4,	100		4,	100
	108	1,0, ,	108
4,	102		4,	102
	106	1,0, ,	106
4,	104		4,	104
	104	1,1, ,	104
4,	106		4,	106
	102	1,0, ,	102
4,	108		4,	108
	100	1,0, ,	100
4,	101		4,	101
	107	1,0, ,	107
4,	103		4,	103
	105	1,1, ,	105
4,	105		4,	105
	103	1,0, ,	103
4,	107		4,	107
	101	1,0, ,	101
20,		1,1,20,	

FIG. 50 - PROCESSING A DISPLAY FILE

drawn has to be checked through. Bit 14 of the second word of each display instruction is examined to see if if has been set to "1". Those display instructions that have, are stored in a "crossover" file and the crossover file pointer is updated to keep a count of the number of crossover points in the picture. A "write" edit command causes the crossover pointer to be reset to zero, effectively erasing the contents of the cross-over file. When an "erase" edit operation is initiated the crossover file is checked after the display file of display instructions has been generated, but before the edit cycle is started. Each display instruction in the crossover file is compared with the contents of the dis-play file. If both co-ordinates are identical that display instruction is deleted from the display file and the crossover file, and the crossover file adjusted accordingly. The edit cycle is now started with the display file having been modified so that those points which are part of other vectors are not erased.

This method was successfully implemented on the PICASSO System and provides a flexible solution to the crossing vector erasure problem. Several vectors crossing at the same point can be dealt with and complex pictures can be handled without requiring such a large amount of processing. The small amount of extra hard-ware required can be provided at a low enough cost for it to be reasonable even if a particular application did not make use of the additional hardware very often. If several terminals were being used together a crossover
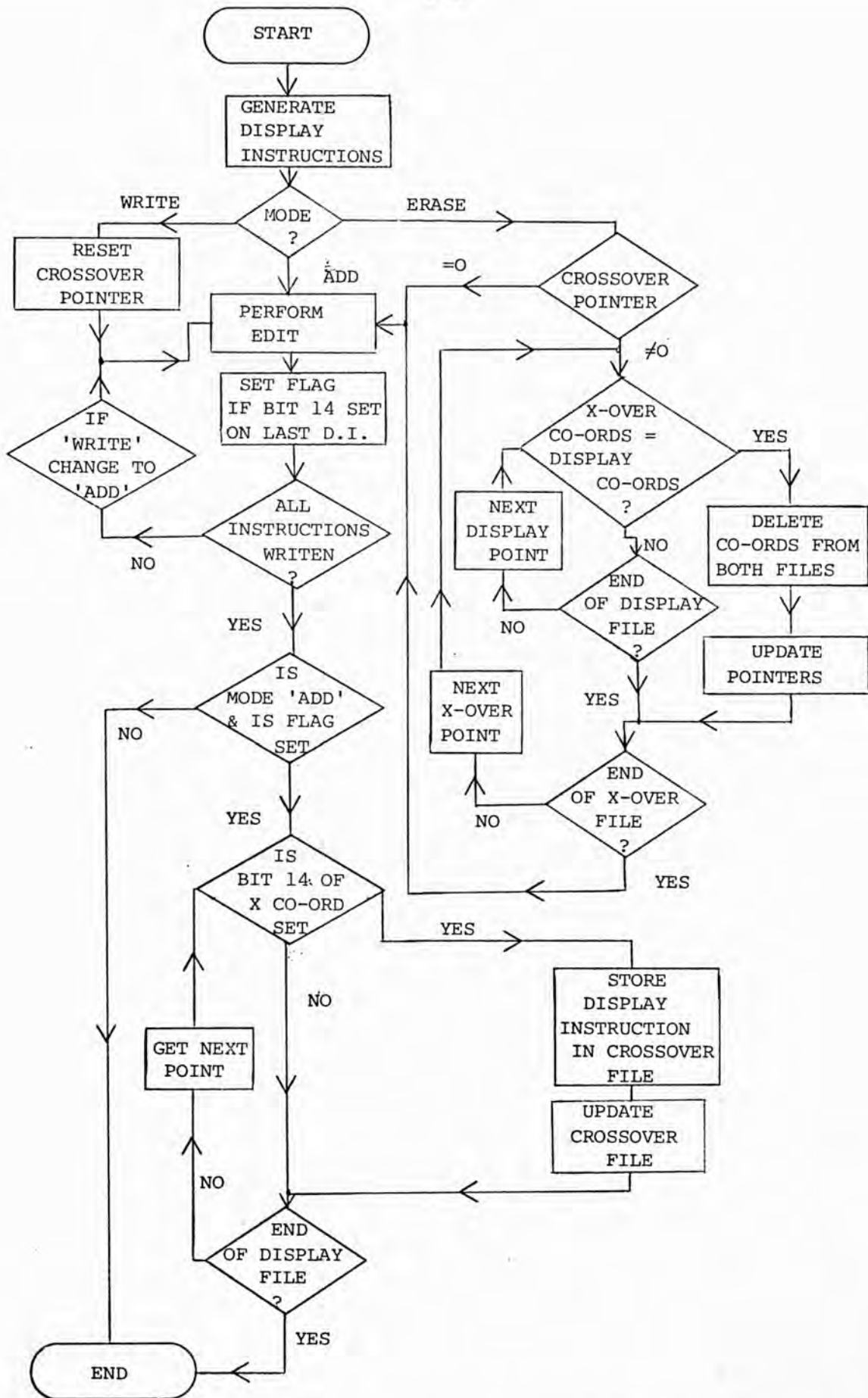
FIG. 51 - CROSSOVER DELETION FLOWCHART

file would be needed for each one, but only one set of
extra hardware would be required as it could be shared
between the terminals.

chapter 5

CONCLUSION

5.1 GRAPH-PLOTTING.

The work, described in Chapter III, on coding graphplotter data resulted in a reduction of the information needed to be transmitted from a remote computer to at least one quarter the size.   The time the communications line is occupied transmitting plotting information is drastically reduced, improving the turn-around of other jobs processed by the remote computer. Of the three methods investigated, the straight line vector method and the subroutine parameter method both resulted in a reduction in use of the remote (or "host") processor.   The interface that was needed to connect the graphplotter to the SC-17's multiplexer was constructed very cheaply and made a substantial improvement to the system.

Transmission errors are serious in the case of plot files, due to the incremental nature of graphplotters. A transmission error in lineprinter data may only produce one erroneous character than can be ignored.   One error in graphplotter data would distort the rest of the picture so the whole set of data would probably have to be retransmitted.   Compression of the data significantly improves the chances of a plot being transmitted success-fully, as there are far few characters that can be erroneously transmitted.   Far less time is taken in the event of there being errors in the plot data and a retransmission being necessary.   The use of a plotter with a slow telephone line may mean the plotter is not being driven at its full speed and is inefficient in use.

Transmitting the plot data in compressed form and plotting a graph on a local processor allows the plotter to be driven as fast as possible.

By combining the straight line vector method and the subroutine parameter method a greater degree of plot data compression can be attained while reducing the load on the remote computer. The two methods complement each other in being more efficient at transmitting different types of plot data (see 3.4 and 3.5). Symbols, number, axes and labels would be transmitted more efficiently by the subroutine parameter method. Other plotting data for graphs, histograms, pictures etc., would be transmitted by the straight line vector method. A control character would be added to the different types of coded information, so that they can be distinguished between by the decoding program run on the local processor.

Although it was possible to implement the system described in 3.2 for very low cost this was mainly due to the availability of the SC-17. Though compressing graph-plotter data is always beneficial when using a remote computer, most terminal sites do not have a computer available to perform the decoding and plotting operations. For such a situation a microprocessor can be used to replace the SC-17 in the system. Microprocessors are cheap devices but quite adequate to perform the necessary processing of the compressed graph plot data. Enough random access memory (RAM) would be needed to store the compressed plot data transmitted down the communications line and retain it until a plot was required.

Alternatively a low-cost floppy disc unit could be
attached to the microprocessor so that a large number of
plots could be stored and then all produced in one
session.   The plot data, once drawn, would still exist
on the floppy disc which could be saved so the plot could
be redrawn as many times as required at later dates, or
standard picture segments (such as symbols or characters)
could be incorporated in composite plots.

5.2   RASTER-SCAN GRAPHICS.

The PICASSO System described in Chapter IV suffered
from a number of problems inherent in its original concept
that had to be overcome to obtain a working system.
Originally it had been intended that five separate graphics
terminals be maintained by the PICASSO System and each
user be allowed timesharing facilities on the Modular
One Computer for computer aided instruction (C.A.I.).
However, it had been decided that the PICASSO System
would be used for experimental work and its use for C.A.I.
dropped.   Work was thus concentrated on getting the
PICASSO System working with one display rather than
five, which considerably simplified the problem.

The most basic problem with the PICASSO System
was that it had originally been designed in standard
TTL logic to keep costs low, but in practice the TTL
logic was too slow at the speeds PICASSO was required to
work at.   A redesign of the PICASSO System was undertaken
using faster logic and reducing the loadings on gates
where necessary.   The most critical area was found to
be the system clock signals and several methods were
attempted to ensure the synthesis of the system clock
signal from the disc clock was as accurate as possible.
Part of this problem was due to the large amount of logic
hardware and the complex routing of critical signals to
different parts of the system.   A microprocessor could
be used as the basis of the PICASSO System which would
much reduce the hardware logic needed with a substantial
saving in cost.   Microprocessors are already used for

several X - Y graphic displays (107, 108).   The display driver and position comparator would still need to be constructed from logic chips as higher speeds would be required, but the microprocessor would be able to decode display instructions, route data to and from the disc, and similar functions performed at slower speeds.

The display was constantly refreshed by reading picture data off the disc, but the performance of the disc was such that some of the data in each picture frame was not read off the disc correctly.   As the display was being refreshed at a fast rate, random errors in the displayed data were not noticeable.   However during an edit operation only one frame of the data read off the disc is used and after modification is the new display image.   This means that the data not correctly read off the disc is permanently lost and if a picture is repeatedly edited it gradually deteriorates.   The best tracks on the magnetic disc unit were selected so that very little data was lost from a picture during an edit operation, but the drawing of horizontal lines requires a large number of successive edits, so the picture would still lose a significant amount of information.   As a horizontal line consists of a series of points on the same scan line there is insufficient time to load the consecutive point co-orindates, thus adding each point to the picture requires a complete edit operation.   No facility for drawing horizontal lines had been originally designed in PICASSO, but a facility could be added so horizontal lines could be written in a single edit operation.   A new display instruction would be needed

containing the line's starting point co-ordinates the
length of the line given in display points.   When
coincidence was found that, and all the following points,
are written into the new image by counting off the
appropriate number of clock pulses.   This would reduce
the loss of information during edit operations to an
acceptable level, but really a better performance, and
hence more expensive, magnetic disc is needed.

The investigation into the crossing vector erasure
problem produced several possible approaches but due to
inaccuracies in the PICASSO System a method that used
hardware and software techniques was eventually developed.
This method successfully dealt with the erasure of
crossing vectors on the PICASSO System, was economical to
construct, and efficient in its use of computer memory
space and processor time.   Further improvements in the
software efficiency could probably be made.   An advantage
of the solution finally developed is it is flexible
enough to be applied to other types of raster-scan
graphics systems without major changes being made.   The
PICASSO System at present uses a magnetic disc to refresh
one monochrome display, rather than five, an uneconomic
arrangement.   A more cost effective way of refreshing
a single display would be from random access memory,
R.A.M.,or by the use of shift registers, as explained in
2.2.5.   The cost of semiconductor memory has fallen so
much that a disc refresh memory is only feasible if its
cost is shared between several displays or several
channels (e.g. to provide colour graphics).   The cost of

semiconductor memory is expected to fall even more over
the new few years (109) so that eventually magnetic discs
will only be economic for refreshing a large number of
clustered displays.   However the crossing vector erasure
method can easily be adapted to a semiconductor refresh
memory raster-graphics system, though developed for a
disc based system.   When adding new information to the
semiconductor memory, hardware would check if a
particular memory bit was set before new data was written
in that bit.   This test would produce a "data over-
written" signal which would be dealt with by the soft-
ware in exactly the same way as that developed for the
PICASSO System.   Plasma panel graphics terminals are
now beginning to appear on the market (110) and also need
an adaption of the crossing vector erasure method.   In
the case of the plasma panel display, the screen and
display memory are the same device, so that a particular
plasma panel element would be tested before new data was
added and so produce the "data overwritten" signal used
by the software.

5.3   FURTHER WORK.

It is often the case that users generate a number of graphs or diagrams from a single set of data, not to eliminate errors, but because the users are searching for the best presentation of their data.   It is time consuming for the user to wait for the graphplotter to draw out a number of traces to obtain the correct format, scaling etc. by trial and error.   However where a remote computer is used the communications line is occupied for an excessive time as the same plot data is repeatedly transmitted, only slightly altered.

By extending and combining some of the work described in Chapters III and IV, an economic solution could be produced to the problem of finding the best presentation of a graph or diagram.   The plot data would be transmitted in coded form to a microprocessor based system where it would first be displayed on a raster-scan display.   The plot data would be manipulated by the user and the effect observed on the display. When the desired presentation of the data had been obtained the plot would then be drawn out on the graph-plotter under control of the microprocessor.

It is envisaged that plot data would be trans-mitted from the remote computer in coded form and stored in the microprocessor memory (either R.A.M. or possibly on a "floppy" disc).   The microprocessor would decode the plot information and write it into the R.A.M. video refresh memory on a bit per screen element basis.   A display driver will be needed to supply the necessary

synchronisation pulses for the T.V. monitor and provide
the output address of data stored in the refresh memory
(see Fig. 52). The picture could thus be maintained
on the display screen while the microprocessor was
calculating a different presentation of the plot data
from programs held in read only memory (R.O.M.) or
programable read only memory (P.R.O.M.). The plot data
could be scaled up or down, rotated, clipped, windowed
etc. and the resulting picture displayed on the T.V.
monitor screen. Calculations would be most easily
performed on the compressed plot data to produce modified
data still in a compressed form, which would be stored in
the microprocessor memory. When the desired present-
ation had been generated on the display screen the
modified plot data held in the microprocessor memory
would be decoded and drawn out on the graph plotter under
the control of the microprocessor.

Thus transmission of information from the remote
computer would only be necessary when completely new plot
data had been calculated. It would also be possible to
generate pictures needing little computation under local
control of the microprocessor. However erasing an image
from a picture displayed on the T.V. monitor, whether
produced locally or remotely, would need the use of the
crossing vector erasure method to prevent the picture
having to be regenerated each time an item was erased.
The system outlined above would considerably reduce the
loading on the communications line to a remote computer,
and allow a user to interactively format and modify his
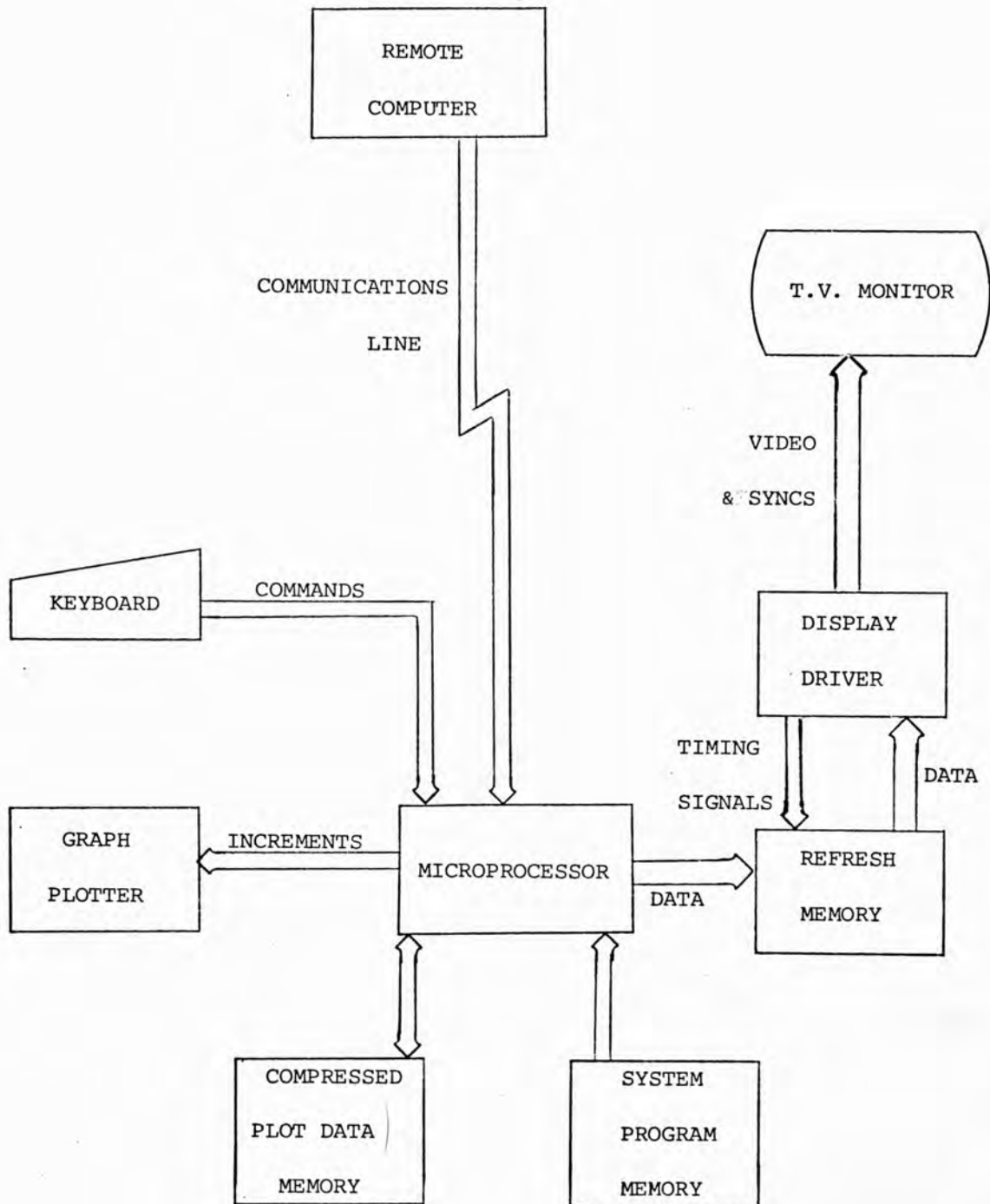
FIG. 52 - PROPOSED GRAPHICAL DISPLAY SYSTEM

plot as desired for a fairly low outlay in equipment.

In the preliminary survey it became clear (see 1.3) that although a large amount of effort is being put into improving the technology of information display, far less work has been done to determine exactly what information should be displayed, when to display it, and how best it would be presented. More work is needed on the physiological and psychological factors relevant to information display in view of the use of displays across a wide range of applications (see 1.8).

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