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An overview of current graphics hardware

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AN OVERVIEW OF CURRENT GRAPHICS HARDWARE

by

H. Watkins

ECMWF

An overview of current graphics hardware

Contents

1. Introduction

This paper sets out to give an overview of current Graphics Hardware aimed at people who have little or no knowledge of the different types of device available. It is primarily aimed at the meteorological community.

It concentrates on the most popular devices and does not set out to be exhaustive. It also limits itself to output devices and no mention is made of input devices. This is because input devices are only required for interactive graphics which is not heavily used in meteorology.

The main features of the different devices as seen from a user are examined, the aim being to allow a user with a particular application to decide which type of device is most suitable for him.

The paper was presented at the Seminar on Graphical Applications in Meteorology, held at ECMWF, 19-23 October 1982.

2. Categories of Devices

There are many ways of categorising graphical devices. This paper takes "Hard Copy" or "Soft Copy" as the main criterion for distinguishing between devices, and "Stroke" or "Raster" as a secondary criterion. These categories are explained in the next two sections, but note that the terminology is not universally accepted and other papers may use different terms.

2.1 Hard Copy and Soft Copy Devices

By Hard Copy we mean something tangible that can be kept as a permanent record. Examples are pictures drawn on paper and photographs. Note that the quality of the image is not always important - it is sometimes desirable to have a paper copy purely as a reminder and in order to be able to write directly on the graphical image. This is particularly true during the development phase of a program.

By Soft Copy we mean an image that cannot be kept as a permanent record. An example is the image on a television screen. Of course one may use other devices (eg a camera) to make a 'Hard Copy', but the primary image itself is a Soft Copy.

To distinguish between "Hard Copy" as defined above and "Hard Copy" obtained from a "Soft Copy" image we will use the term "Derived Hard Copy" for the latter case.

In Table 2-1 we show the three main differentiating characteristics between Hard and Soft Copy.

In general Soft Copy tends to be drawn at high speed (from a fraction of a second to a minute or two) whereas Hard Copy may take much longer (from a few minutes to several hours). From the user's point of view, it is not only the time the Hard Copy device takes to draw an image, but the turnaround time which is important. "Hard Copy" devices are often only available from a batch job which may need to wait before it can run on the host computer. Furthermore the device itself may be offline implying a further delay.

It is obviously not possible to interact with an image once the controlling computer has relinquished control. For this reason interaction is not possible with Hard Copy devices. For Soft Copy devices interaction may be easy to perform, or may only be partially possible - that is to say it may be possible to select which image to view, but it may not be possible to alter a given image.

Table 2 - 1

Characteristics of Hard and Soft Copy

	Permanent Record	Speed	Interaction
Hard Copy	Yes	Slow	No
Soft Copy	No	Fast	Possible
Derived Hard Copy	Yes	Medium to Slow	No

2.2 Stroke and Raster Devices

Another way of distinguishing between devices is by comparing 'Stroke' devices and 'Raster' devices. 'Stroke' devices are also known as 'Vector','random' or 'Calligraphic' devices.

A stroke device works by directly drawing the lines which constitute the image. Only those parts of the image which contain lines need be processed i.e. a simple picture takes less time to draw than a complex picture (We are talking here only of the drawing time, not the time to generate a description of the image). An example of a stroke device is a pen plotter.

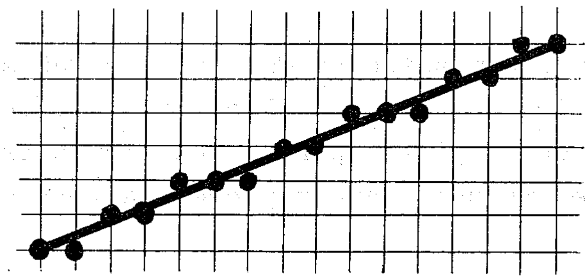
A raster device considers the whole image area to be broken down into picture elements or pixels. A process known as 'vector-to-raster conversion' or 'rasterization' is needed to convert a line into the relevant pixels such that the appearance of the final picture gives lines which:-

- i) appear straight
- ii) terminate accurately
- iii) have a constant density

A discussion of techniques for performing the rasterization will be found in [1]. Figure 2.1 illustrates the rasterization process.

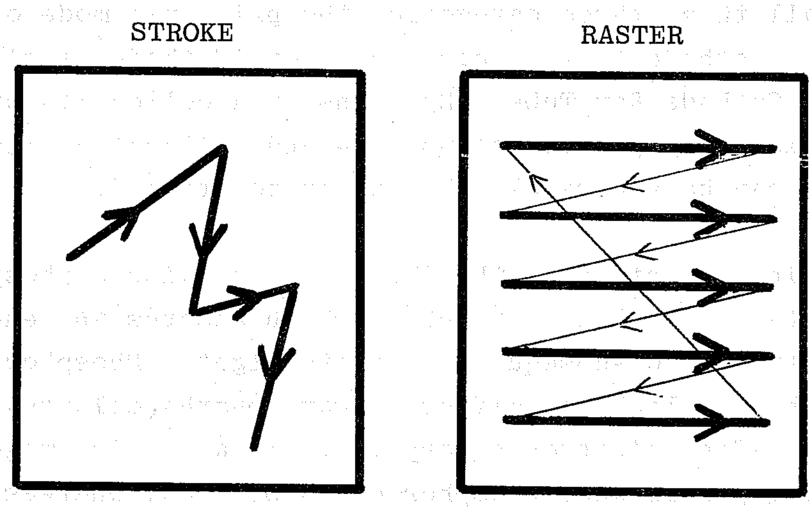
In order to generate a picture on a raster device it is necessary for the device to take account of every pixel within the image and to process the pixels in rows or columns. An example of a raster device is a television screen, (although in the home environment the image is normally derived from a television camera and no rasterization takes place because the camera scans the image and essentially provides a stream of data representing the pixel values).

By means of the hard-copy/soft-copy criterion and the stroke/raster criterion, it is possible to distinguish devices into four distinct categories as illustrated in Figure 2-2.



Rasterization of a line

Figure 2-1



Hard Copy	Pen plotter	Electrostatic plotter ink-jet plotter
Soft Copy	Direct Beam Refresh Storage Tube	Colour raster devices

Examples of Devices in the various categories

Figure 2-2

3.0 Soft Copy Devices

Soft Copy Devices are dominated by Cathode Ray Tubes (CRT's). There are other devices which may collectively be termed "flat panel displays" (such as plasma panels and liquid crystal devices) but they tend to be expensive and represent a very small percentage of the market.

3.1 Cathode Ray Tubes

CRT's can be considered in three broad categories

i) storage tubes
ii) direct beam refresh
iii) raster scan

In all these three categories the principle mode of operation is for a cathode to fire electrons (or 'Cathode rays') at the surface of a Cathode Ray Tube. By means of a collection of control grids, accelerating plates, focussing- and deflection- structures, the beam can be accurately shaped and positioned.

The inner surface of the CRT is coated with a phosphorescent substance (called a phosphor) which absorbs the energy of the electrons and subsequently limits light. Phosphors are available which emit light at different wavelengths(colours) and in varying times after electron absorption. If a static image is required a long persistance phosphor could be used, whereas for dynamic images such as a TV set, short persistance is required. It is usually the degradation of the phosphor which requires the tube to be replaced.

On a colour television and in colour raster devices the tube is covered with a matrix of separate dots grouped into triangular groups called triads. Within each triad the three dots are phosphors which emit red, green and blue light respectively. The overall impression of colour is obtained by the combination of these separate elements by the human observer.

In order to activate the relevant phosphors, there are normally three electron guns, one for each colour, and a shadow mask just behind the face of the tube. The shadow mask shields all phosphors from each beam except those which emit a particular colour i.e. the 'blue' electron beam can only activate the 'blue' phosphors and so on.

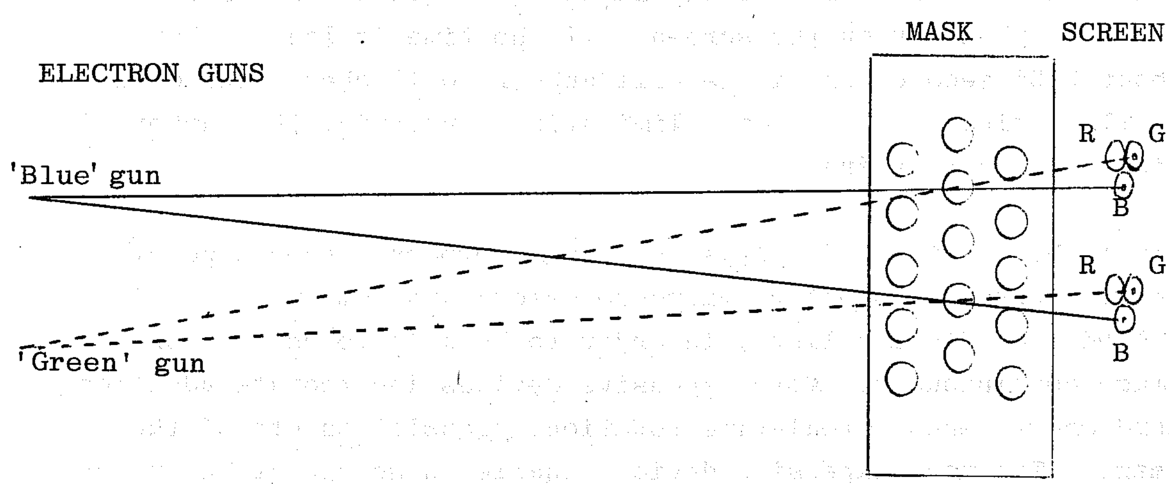


Figure 3-1

Principle of operation of a shadow mask colour television

3.1.1 Direct Beam Refresh

This is a stroke device where the image is created by the electron beam hitting the phosphor. The image will only remain visible if the display is capable of continuously redrawing all the lines within a sufficiently short time.

This time is a function of the human eye-brain combination and also the phosphor on the screen. If the time is longer than about 1/25 second, the image will appear to flicker. The onset of flickering is the primary limitation concerning the number of lines that can be drawn.

Direct beam refresh displays usually incorporate some type of special purpose computer (microprocessor) and some memory (often called the 'display list') in order to be able to refresh the image continuously. More expensive devices incorporate additional hardware to enable real-time rotation, translation etc. of the image. The most expensive devices enable these operations to be performed on images which are defined in three dimensions.

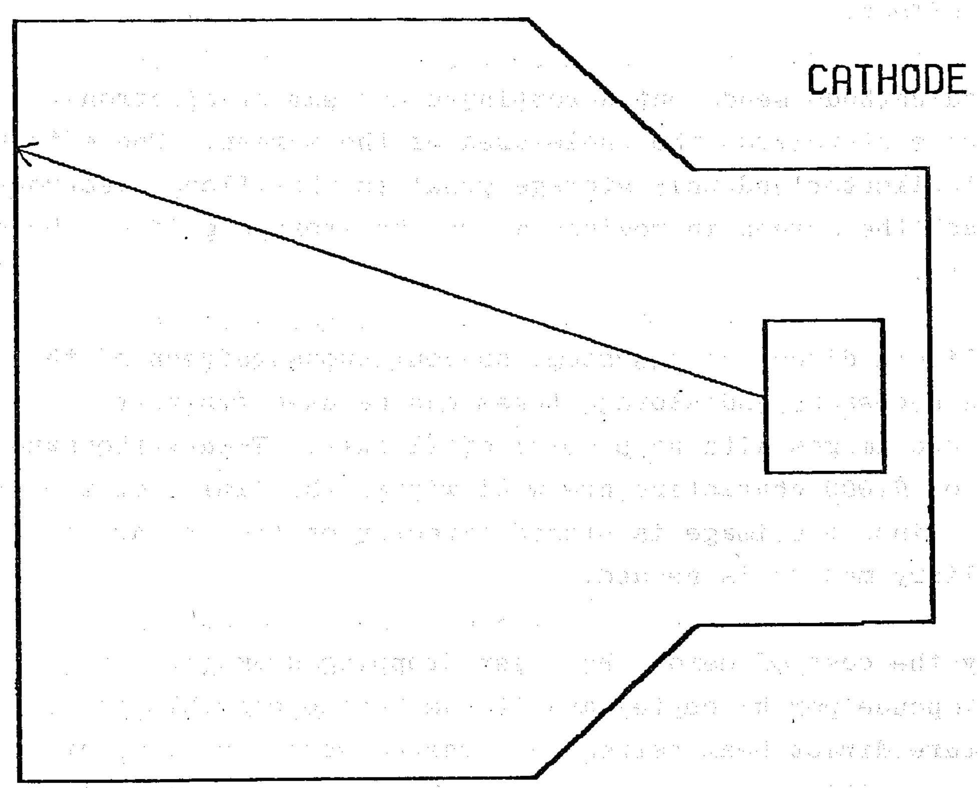
Direct beam systems typically offer a screen resolution of 4096 x 4096. However the only limitation for a line is that its <u>end points</u> must lie on the resolution elements - the line itself is not so constrained.

An example of a direct beam refresh system is the Megatek 7200. This system is capable of displaying 10,000 flicker-free vectors every 1/30 second and to be able to rotate and zoom the image in 3D.

The advantages of the direct beam refresh system is the high resolution coupled with the possibility of animation and dynamic modification. The disadvantages include the fact that only wire-mesh objects can be drawn and it is a monochromatic device.

Figure 3.2

Direct Beam Refresh CRT



3.1.2 Storage Tube

The storage tube differs from the direct beam refresh device in having two cathodes and a storage grid and collector between the cathodes and the phosphor. (See Figure 3.3).

In simplified terms its operation is as follows: the writing cathode writes an image on the storage grid in much the same way as for a direct beam refresh system. However the image is retained as a charge on the storage grid and causes no direct visible effect.

The flood cathode sends out a continuous stream of electrons which are sent towards the whole area of the screen. The effect of the 'collector'and the 'storage grid' is that flood electrons only reach the screen in regions where the storage grid has been written to.

Thus unlike a direct beam system, no continuous refresh of the <u>image</u> is necessary and storage tubes can be used for very complicated images with no problem of flicker. Twenty thousand vectors or 6,000 characters are well within the limits of the device. Since the image is stored directly on the storage grid, no auxiliary memory is needed.

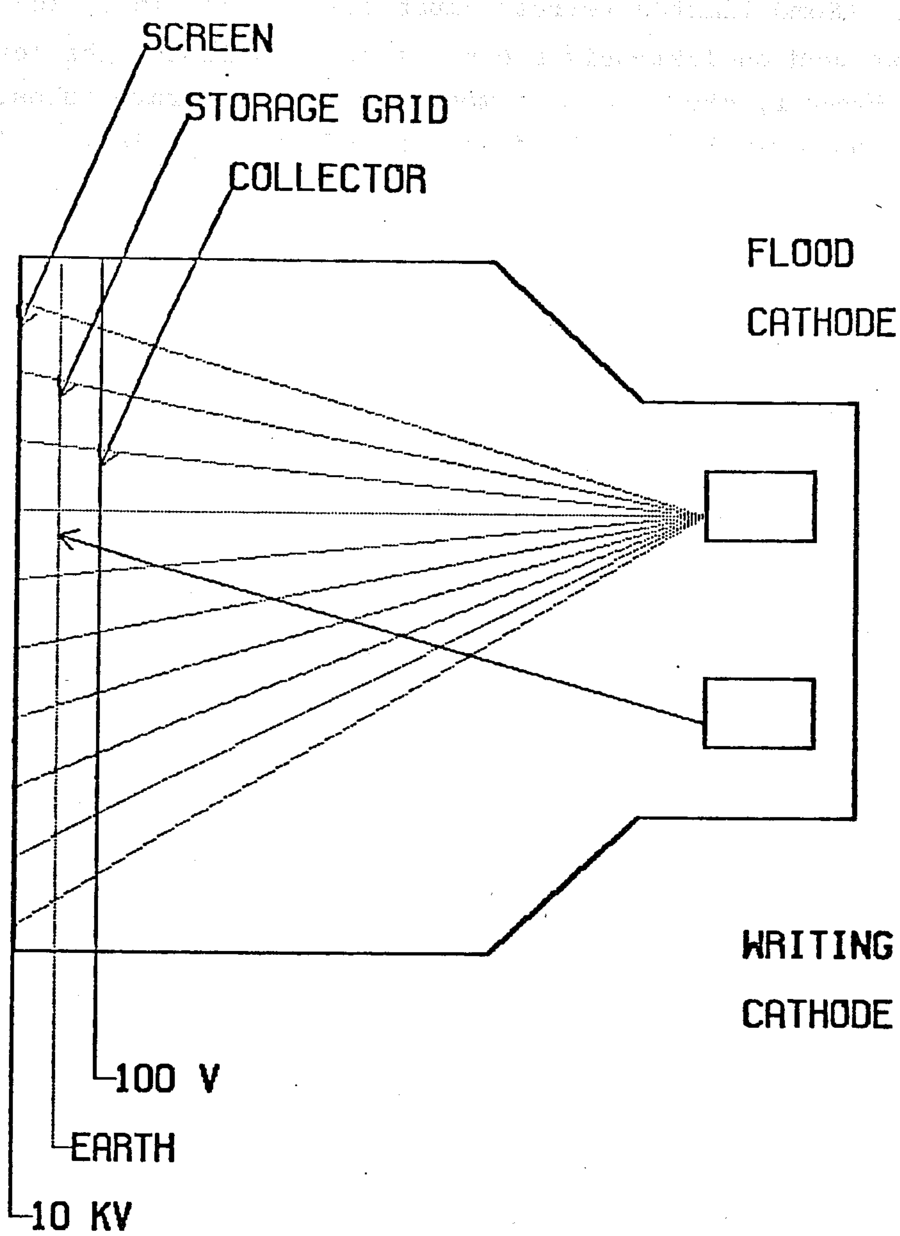
Recently the cost of memory has been dropping dramatically (now about 50 pence per kilobyte) and it has become possible to manufacture direct beam refresh and raster screen devices at prices competitive to storage tubes. However in the late 1960's memory costs were much higher and it was the introduction of the low cost storage tube which contributed to a large extent to an expansion of computer graphics.

Thus although low cost was an advantage of the storage tube, this may soon change. It is still a device worth considering if highly complex images are required.

The major disadvantage of the storage tube is that animation or dynamic modification of an image is impossible. This is because the only way to remove a picture is to reset the entire storage grid. This takes about a second and is accompanied by a 'green flash' over the entire tube face. Further problems are the low luminosity of the screen, the fact that the image is monochromatic, and that essentially only line drawings are possible. (Some limited refresh capability is possible, and is the method used on Tektronix storage tubes to display the 'cross-hairs'. However, except on the most expensive storage tubes, the number of vectors that can be drawn in refresh mode is very limited).

Figure 3.3

Direct View Storage Tube



3.1.3 Raster Scan

A raster scan device works in a similar way to a home television. The image is scanned in a series of horizontal lines every 1/25 or 1/30 of a second. The intensity of the beam is altered to give different shades of gray from black to white.

A home television set is normally analog driven from a T.V. camera, videocassette recorder or an aerial picking up the broadcast signal. By contrast, a raster scan device is normally digitally driven from a 'frame store' memory.

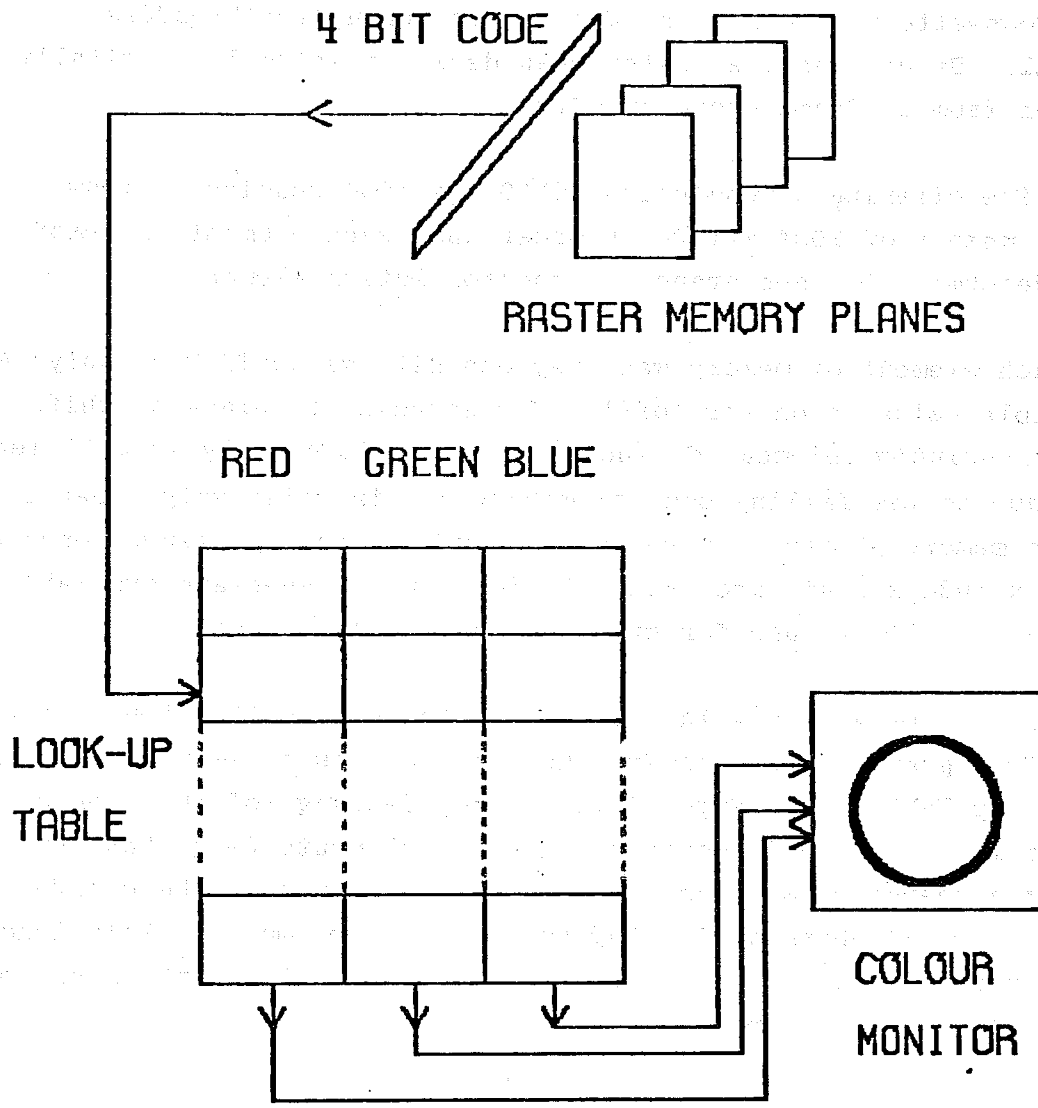
A device offering a resolution of 1024 x 1024 requires a frame store memory of 1024 x 1024 in order that each element of memory can determine the appearance of one resolution element on the tube.

If each element of memory was only one bit, we would have only two possible values ('on' or 'off') corresponding to black or white at each resolution element on the tube. This is clearly insufficient, and due to the falling cost of memory, it is relatively cheap to add extra memory planes. Consequently several 'memory planes' each of 1024 x 1024 x 1 bit are used. If four such planes are available, we have 4 bits to use for grayscale or colour for every pixel.

Instead of using the value of the 4 bits to directly compute the required grayscale or colour, they are used as an address of a 'Look up Table' (see Figure 3.4). The advantage of the Look up Table is that it only consists of a few elements (e.g. 256 bytes) and can therefore be changed much more quickly than the entire framestore (4 Mbits or 0.5 Megabytes in our example). This leads to several useful operational techniques, details of which are beyond the scope of this paper.

Figure 3.4

Raster Scan Device



It is only in recent years that the cost of memory has dropped sufficiently to make the raster scan technique viable. Another contributory factor is that the mass production of home T.V. has reduced the cost of colour monitors considerably - so much so that almost all raster scan devices are colour based.

The advantages of raster-scan displays over other types of CRT's are that colour, filled-in areas and animation are all possible. The present limit of resolution of 1024 x 1024 is capable of giving very good results, and even greater resolution is likely to become available in the near future.

Such high resolution devices are not cheap, and do require some kind of dedicated computer power.

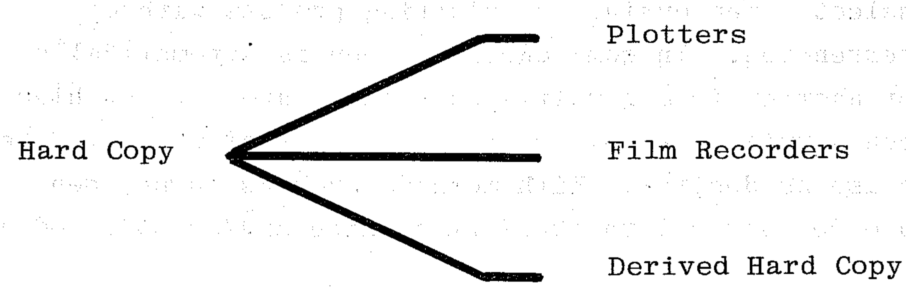
3.1.4 Beam Penetration

Beam Penetration CRT's are direct beam refresh systems with limited colour capability, The inner surface of the CRT is coated with two layers of different phosphors (usually red or green). By varying the energy of the electron beam it is possible to excite one or other of the phosphors. Intermediate energies can produce intermediate colours, but in practise only about 4 colours are possible (red, orange, yellow and green).

Apart from the limited colour range, the major disadvantage of beam penetration devices is the time it takes to change the energy of the electron beam (about 100 microseconds) and hence the time to change colour. Their advantage is that beam penetration is currently the cheapest way to obtain colour with soft-copy stroke devices.

4. Hard Copy

Hard Copy devices can be considered in three categories: plotters, film recorders and 'Derived Hard Copy' devices. The latter category requires a Soft Copy device to draw the image in the first place; a direct copy is then made usually via some combination of photography and/or electronics.



4.1 Plotters

The three main technologies used by plotters are:- pen-plotters, electrostatic plotters and ink-jet plotters. The following table summarises the characteristics of the devices with representative values.

Table 4-1

Characteristics of Plotters

	Colour Filled Areas	Resolution Microns	Speed cm/Sec
Pen Plotters (stroke)	4 Pens Shading	25	25-75
Electrostatic (raster)	Black/White Area Fill	128	2.5 Linear
Ink-Jet (raster)	Many colours by mixing and intensity control	200	1.7 Linear

4.1.1 Pen Plotters

In the case of a pen plotter, a pen is moved across the paper either to position the pen ('pen-up') or to draw a line ('pen-down'). It is therefore a stroke device.

The pen may be a ball-point or ink pen such as the Rotring draughting pens. Various mechanical methods are available to be able to select a pen during the plotting process without operator intervention. In some cases the pen is automatically exchanged for another from a multi-pen holder; another technique is for the pen carriage to hold several pens any of which may be brought into use as desired. With methods such as these, pen plotters can offer several thicknesses of line and/or coloured lines.

Three broad categories may be defined for the way the paper is held on a plotter:-

i) Flat-bed plotter
ii) Drum plotter
iii) Hybrid

A Flat-bed plotter has a large flat table to which a single sheet of paper is attached. The whole of the paper is visible and the pen carriage traverses the paper by a moveable arm to reach all parts of the paper. Generally flat bed plotters are relatively expensive but offer high performance and accuracy. Note that the flat-bed need not be horizontal.

In the case of a Drum plotter, a large roll of paper is stored on a drum and fed to another drum or take-up spool. The pen carriage moves only across the width of the paper, longitudinal movement is achieved by winding/unwinding the paper on the drums. This type of plotter tends to be cheaper than the flat bed plotter but is not usually as accurate. Its great advantage is that many plots may be made without operator intervention.

A Hybrid plotter is a mixture of the two techniques - a single sheet of paper is used rather than a large roll, and this is attached to one or two drums which can move the paper backwards and forwards.

Table 4-2 illustrates the broad differences between the types of pen plotter, and table 4-3 gives some technical details of two representative plotters.

Although pen plotters can generate coloured images by selecting the appropriate pens, it can take a long time to generate an image if filled-in areas are required - even if the area fill is achieved by different styles of cross batching.

One way round this problem is to use pre-printed backgrounds e.g. for weather maps one could use a pre-printed map of the required geographic area. Obviously this is only feasible if one is routinely drawing images on a limited number of backgrounds.

A major drawback to pre-printed paper is that one cannot use a Drum plotter and operator intervention is required <u>each</u> time a new plot is to be produced, whether it is on plain or printed paper. There is also the problem of aligning the background.

The chief disadvantage of pen plotters over other plotters is the relatively slow speed of drawing and the lack of a coloured fill-area. For some applications pre-printed backgrounds can compensate for both these shortcomings.

The advantages of pen plotters are their relatively low cost and their ability to draw coloured lines.

Note that the above discussion is concerned with the large size of plotters generally used in a meteorological environment. There are now available several 'table-top' plotters which offer a good price/performance ratio, but whose size is limited to A4 or A3 size paper.

Table 4-2

Characteristics of Different Types of pen-plotters

	Pre-Printed Background	Paper Length	Accuracy and Performance
Flat Bed	Yes	Limited	High
Drum	No	>50 Metres	Medium
Hybrid	Yes	Limited	Medium

Table 4-3

Some examples of pen-plotters

	Speed cm/Sec	Size cm	Resolution Microns
Calcomp 1051 (Drum)	25	84	25
Calcomp 960 (Flat Bed)	75	84x152	12.5

4.1.2. Electrostatic plotters

Electrostatic plotters are raster devices. They consist of a row of writing nibs across the width of the paper - typically 200 nibs per inch. The writing nibs remain fixed and the paper moves past them at a fixed rate. The nibs create minute electrostatic charges on the paper in positions where plotting is to take place, and the paper is then exposed to a liquid toner which produces a visible permanent image where the paper was charged.

A major disadvantage of electrostatic plotters over pen plotters is the need to rasterize the vector information. This can be particularly time-consuming on small computers. There are a number of devices on the market for performing the vector-to-raster conversion but they nearly all require the vectors to be pre-sorted according to their positions along the length of paper.

Thus although one can avoid the overhead of rasterization, there will still remain an overhead of sorting the vectors. Furthermore for some applications (eg selective erasure - see later) it is necessary to use a rasterization technique which does not sort the vectors, but keeps them in the same temporal order as they were created.

The paper used with electrostatic plotters does not stand up well to pencilled additions being erased. This may, or may not, be a disadvantage depending on the application.

Other disadvantages of electrostatic over pen plotters are the poorer resolution, the need for (expensive) special paper and the lack of colour. Notice however that they need not be treated as monochromatic devices - it is just as easy to turn a bit on (= black) as to turn it off (= white). They are black <u>and</u> white devices.

The major advantage they have over pen plotters is their speed which is independant of the complexity of the image. Although pre-printed backgrounds are not possible, one can define a background file at the software level and merge this with the current information. Such a technique can save considerable computer resources.

A further point is that having fewer mechanical parts than a pen plotter, they tend to be more reliable.

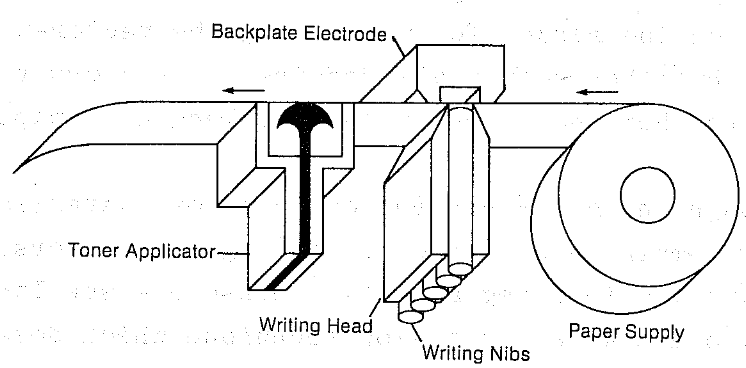


Figure 4-1

Principles of Operation of an Electrostatic Plotter

4.1.3 Ink-jet plotters

Only one manufacturer (Applicon) markets an ink-jet plotter. It consists of a fixed size of paper - 22 x 34 inches (550 x 860 mm) which is attached to a drum. The drum revolves at high speed and a writing head consisting of 3 ink-jets travels along the length of the drum. In the terminology we used for pen plotters, it is a Hybrid device, but unlike pen plotters it is a raster device.

The jets can deposit variable amounts of ink on the paper at a resolution of 127 dots per inch. The use of 3 jets of primary colours allows the full spectrum of colours to be created. Creating a full sized plot takes about 8½ minutes regardless of complexity.

The obvious advantage of the ink jet plotter over the other plotters is its ability to produce coloured images with coloured areas of different intensities. Its major disadvantage is its relatively high cost and the operator intervention needed for each new set of pictures. It also has the poorest resolution of all the plotters we have considered.

4.2 Film Recorders

Film Recorders are also known as graphical COM recorders where COM stands for Computer Output on Microfilm. Typical film formats are 16 mm film (for movies), 35 mm (for slides) and 105 mm microfiche format at different magnifications (for archival purposes).

COM recorders are directly driven by computer control and the graphical information reaches them from a link with a large main-frame computer (on-line) or via a magnetic tape (off-line).

Some Film Recorders can only be programmed as stroke devices (eg the III FR80), whilst others can be treated as either stroke or raster (eg Dicomed).

Film recorders tend to be very expensive to buy, especially if colour is required. It is also expensive to use computer bureaux for graphical COM, and at the time of writing the choice is limited in the U.K. to three sites:-

- i) the Rutherford Laboratory
- ii) University of London Computer Centre
- iii) Rank Hovis McDougal

On the other hand film recorders can offer high resolution and the ability to draw images directly on film.

4.3 Derived Hard Copy Devices

For each type of Soft Copy Device there are devices available for making Derived Hard Copy. In all cases a camera may be used by pointing it directly at the screen and taking a photograph. There are many problems with this approach and it can only be regarded as giving low quality results. Firstly there is the problem of avoiding reflections in the screen of the CRT. Secondly most CRT's have curved tube faces leading to barrel distortion when photographed.

For colour the problem is even worse because the CRT uses an additive colour process whereas the film uses a subtractive colour process. This is made worse by the lateral colour elements of the CRT (the triads) and the vertical colour elements of the film (emulsion layers) and also by the different spectral response of film and phosphors.

High quality colour hard copy devices overcome these problems by using special high resolution flat CRT's. These have white emitting phosphors and three colour filters. The exposure is controlled for intensity for each colour filter thus matching the spectral response of the film.

There are three such devices on the market at the moment, Videoprint, Dunn and Matrix and all are driven by the same RGB signals that drive the colour monitor of a colour raster device. The most sophisticated of these colour hard copy devices can offer different cameras for making 8 x 10 inch Polaroid, 35 mm, 16 mm, 4 x 5 inch polaroid.

The capital cost of these devices is high (Videoprint is cheaper but has a restricted range of film formats and will not work with high resolution colour raster devices). The running costs are essentially that of the film cost - which is quite cheap for 35 mm film. The time to make one image is of the order 1 - 2 minutes.

Another device which can be interfaced to some colour raster devices is the Xerox 6500 Colour Graphics Printer. This is a very expensive device but does have the advantage of also being a colour photocopier.

Small versions of electrostatic plotters (typically 8½ or 11 inch wide) can be interfaced to virtually any CRT device and are quite popular for Direct Beam Refresh displays and Storage Tubes. They are not frequently used for colour raster devices as they lack colour. The time to make one copy is of the order 10 seconds, depending on the resolution and size of plotter chosen.

Dry Silver paper copiers are the usual choice for Storage Tubes - the most common example being the Tektronix 4631. Video copiers also use dry silver paper and are available for colour raster devices. Although they do not reproduce colour, they can use grayscales (typically 8 or 16 levels). This makes them much cheaper than colour hard copy devices, and for some purposes they are perfectly adequate. For both Storage Display copiers and Video copiers, the time to make a copy is of the order of 15 - 30 seconds.

Lastly there are a number of printer plotters such as the Trilog. These use 3-colour ribbons and dot matrix impact technique (100 dpi) to produce coloured images on plain paper. They have the advantage of being able to double-up as ordinary line-printers. Their chief disadvantage is that is takes 3 minutes to produce an image on one 13 x 11 inch sheet of paper. The quality of the image is not very good compared to other derived hard copy devices. (For this reason, they have not been considered under 'hard copy' devices in this paper, although they can be used in this manner).

5. Some Capabilities of devices

In this section we will explain some of the features one may require of a graphical device and compare the different devices we have previously described.

5.1 Erasure

It is often required to be able to erase part of a picture already drawn. We are not concerned here with animation where each frame could be considered separately, but rather the fact that we may not know beforehand where erasure is to be needed.

A good example is the selective erasure facility of contour line labels in ECMWF's Contour Package. Before the label is drawn an area is erased in order to make the label stand out. The erasure affects everything already drawn in the area under interest, whether it be coastlines, other contour lines, or even other labels. The two diagrams (5-1 and 5-2) illustrate the effect of selective erasure and how it makes the contour labels more readable. An example of a complete image with contour labels is also shown (5-3).

It is possible to affect a similar result with software by a technique known as 'shielding'. However this technique - if it is to be as effective as using hardware features - implies a double processing of the complete image: once to identify the shielded areas, and twice to plot the image taking them into effect.

Table 5-1 identifies the erasure capability of the various devices.

Table 5-1

Erasure capability of various types of devices

Not Possible	-	Pen Plotters
	-	Storage Tubes
	-	Film Recorders
Possible	-	Electrostatic Plotters
	-	Ink Jet Plotters
	-	Direct Beam Refresh
	-	Raster Scan

Figure 5-1

Labelling contour lines without selective erasure

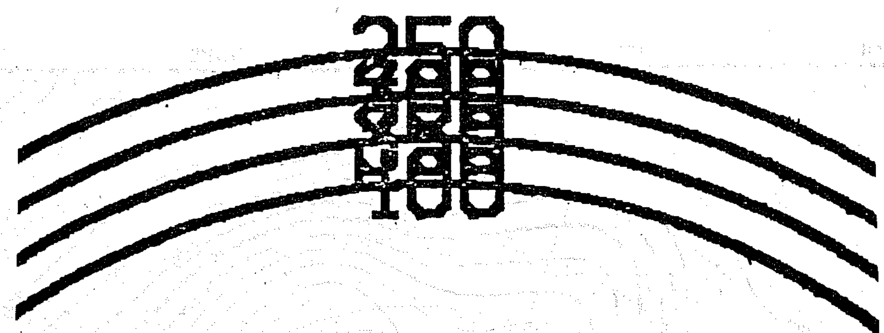


Figure 5-2

Labelling contour lines with selective erasure

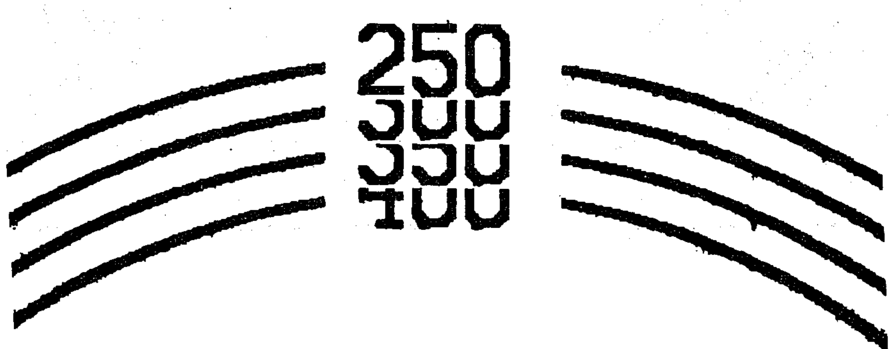
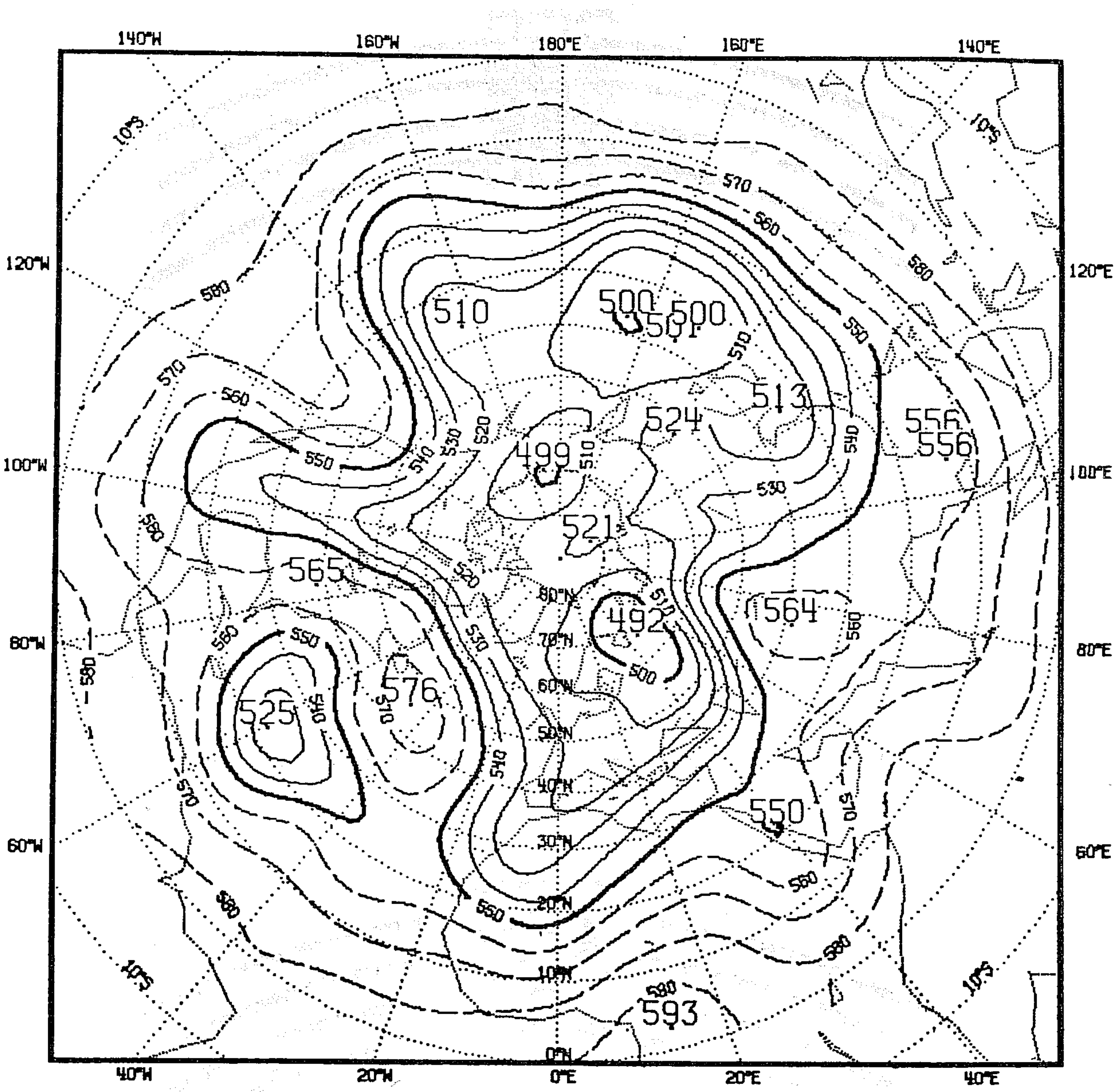


Figure 5-3

A complete image showing the effectiveness of selective erasure on contour labels



5.2 Colour and filled-in areas

Colour can be used to differentiate lines or to differentiate areas. The latter possibility is only available on raster devices such as colour raster CRT's or ink-jet plotters; it can be simulated on stroke devices by means of shading (see figure 5-4). Electrostatic plotters can either use shading or can fill an area with a pattern.

The problem of two lines crossing and giving a different colour at the intersection is a complex one. There is firstly the problem on film recorders of the extra intensity at the point of intersection which may give a white colour even if the two lines are the same (non-white) colour.

Next there is the question whether the colour combination is by the additive process (as with coloured lights) or the subtractive process (as with paints). Furthermore on pen plotters, there may be no mixing at all if the ink from the first line is dry when the second line is drawn. Table 5-2 lists the colours in the two processes.

Lastly there is the possibility of defining any colour one likes with the aid of the look-up table on raster scan devices. One could simulate the subtractive process, or give one colour priority over another e.g. the intersection of a blue and red line could be forced to be red.

Table 5-3 shows the range of colours available on different devices and table 5-4 summarises the methods of filling-areas for different devices.

Figure 5-4

An example of filling areas by shading

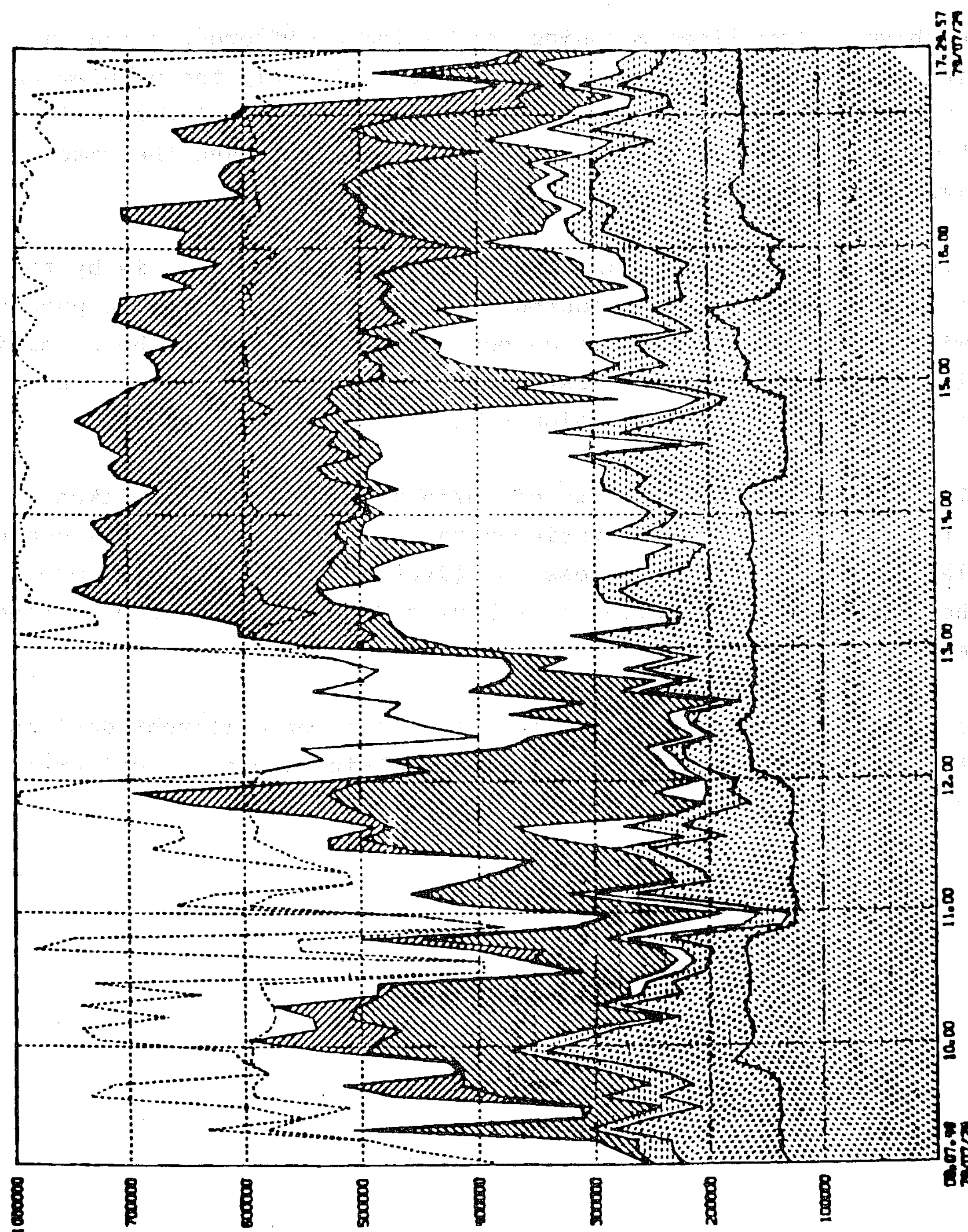


Table 5-2

Additive process

		primary	+	primary	=	secondary
		red	+	green	=	yellow
		red	+	blue	=	magenta
		blue	+	green	=	cyan
red	+	blue	+	green	=	white

Subtractive process

		primary	+	primary	=	secondary
		yellow	+	magenta	=	red
		yellow	+	cyan	=	green
		magenta	+	cyan	=	blue
yellow	+	magenta	+	cyan	=	Black

Table 5-3

Colour

Monochromatic	-	Storage tubes
	-	Direct Beam Refresh
Bichromatic	-	Electrostatic plotters
Small range (typically 4)	-	Pen plotters
Large range	-	Raster Scan
(Mixing intensity)	-	Film recorders
	-	Ink jet plotters

Table 5-4

<u>Filling Areas</u>

Shading	-	Storage tubes
	-	Direct Beam Refresh
	-	Pen plotters
Area-fill	-	Electrostatic plotters
	-	Ink-jet plotters
	-	Raster scan