Comparative Analysis of Random Scan Display Systems

There are presently no generally accepted standards or methods for comparing line-drawing display equipment. Until recently this was not serious in that, with only a few consoles available, a choice was made on the basis of availability and personal preference; equipment cost was only a minor consideration. Today, the proliferation of displays and the increased interest in them requires well-defined measurements as a basis for comparison. The more important of these are discussed below, with listings, charts and comments included.

Flicker-Free Frame Rates

The frame rate specified by the manufacturer is a compromise among phosphor characteristics, the image persistence of the eye, and the desire to display a maximum amount of information. The correctness of this rate can be determined only by demonstration under the proposed lighting conditions. With high ambient light or fluorescent lighting, this rate may be objectionable to many people; with low ambient light, the rate specified may be higher than required. For each console, the manufacturer's recommended refresher rate, and the refresher rate used in the evaluations (based on the phosphor equivalencies as given in the line-drawing definitions) are shown below:

System	Recommended	Evaluation
ICL 928 Graphical Display System	10	10
ICL 4280 Graphical Display System	10	10
ICL 1830 Graphical Display	10	10
Ferranti Argus Display Systems 30/40	16-2/3	16-2/3
Marconi Series X2000 Display System	16-2/3	16-2/3
Telefunken SIG 100 Data Display Unit	25	25
Control Data dd16C Visual Point Plotter	30	30
Control Data Digigraphic Variable Intensity Display	30	30
DEC 338/339 Programmed Buffered Displays	30	30
DEC 340 Precision Incremental CRT Display	30	30
DEC Graphic 15	30	30

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System	Recommended	Evaluation
Evans & Sutherland Line-Drawing Model 1	30	30
IDI Series 10000 Computer Controlled Displays	30	30
IDI Input Output Machine	30	30
III 1050 Graphical Display	30	30
XDS Model 7500 CRT Display System	30	30
SD 1090 Direct View Display	30	30
Control Data Digigraphic 1744/274 System	40	30
Control Data Digigraphic 3344/274 System	40	30
IBM 2250 Model I Display Unit	40	30
IBM 2250 Model III Display Unit	40	30
IBM 2250 Model IV Display Unit	40	30
ITT Modular Alter and Compose Console	40	30
SINTRA VU 2000 Graphical Display System	40	30
Vector General Graphic Display System	40	30
Control Data Grid	50	30
Control Data 250 Digital Data Display	50	30
Tasker Display Consoles Models 9100 and 9110	50	30
Tasker Display Consoles Models 9200 and 9210	50	30
Adage Graphics Terminal	60	30
BB-90 Visual Analysis Console	60	30
IDI Model 1 Graphics Display System	60	30
ITT Operations Planning System Console	60	30
Monitor Systems 8100	60	30
Philco READ	60	30
Sanders ADDS/900	60	30
SEL 816A Computer Graphics System	60	30
Telefunken Schirmbildarbeitsplatz SAP 200	60	30
Telefunken Schirmbildarbeitsplatz SAP 300	60	30
Univac 1557/1558	60	30
Imlac PDS-1 Display Computer	40	40
Raytheon DIDS-1500 Digital Information Display System	48	48
RCA 6320 Integrated Display Console	60	60

The equipment description sheets contain the information

needed to recalculate the flicker-free capacities at other frame rates.

Multiple Displays per Controller

Many systems have display controllers that can accomodate multiple consoles. The maximum number of consoles that can be attached to each display controller is shown below:

BR-90	1
Control Data dd16C	1
Control Data 1744/274	1
Control Data 3344/274	1
Control Data Grid	1
Evans & Sutherland Model I	1
IBM 2250 Model I	1
IBM 2250 Model IV	1
ICL 1830	1
IDI Model E1	1
ITT MACC	1
ITT OPSC	1
RCA	1
Raytheon DIDS-1500	1
XDS 7580	1
SD 1090	1
Tasker 9100	1
Tasker 9200	1
Vector General	1
Control Data VID	2
Monitor Displays 8100	2
SAP 200	2
Control Data 250	3
Univac 1557/1558	3
Adage GT	4
DEC Graphic 15	4
Imlac PDS-1	4
IBM 2250 Model III	4
ICL 928	4
ICL 4280	4
SINTRA VU 2000	4
SEL 816A	4
DEC 340	5
IDIIOM	7

DEC 338/339	8
Marconi X2000	10
Ferranti 30/40	12
III 1050	12
Sanders ADDS/900	12
Philco READ	16
SAP 300	24
SIG 100	32
IDI 10000	to order

Where multiple displays are used, the flicker-free capacities shown for single displays must be divided by the number of displays attached to the controller. There are four exceptions to this; The Control Data Variable Intensity Display has independent processors for each display, and only the refresher memory drum and timing circuitry are shared. The IBM 2250 Model III is organized to permit drawing times for one to three consoles to be overlapped with memory word accesses for the remaining console and is specifically designed for multiple console operation. The third exception is the SAP 300; all 24 displays are able to show 24 independent pictures flicker-free. The SIG 100 controller is a drive unit for 32 independent displays and the number of flicker-free frames is not affected by the number of displays attached. In the figures that follow, the cost per display of multiple display systems can be estimated for the IBM 2250/III by multiplying the single display cost shown by these ratios: for two displays, .706; for three displays, .622; for four displays, .598.

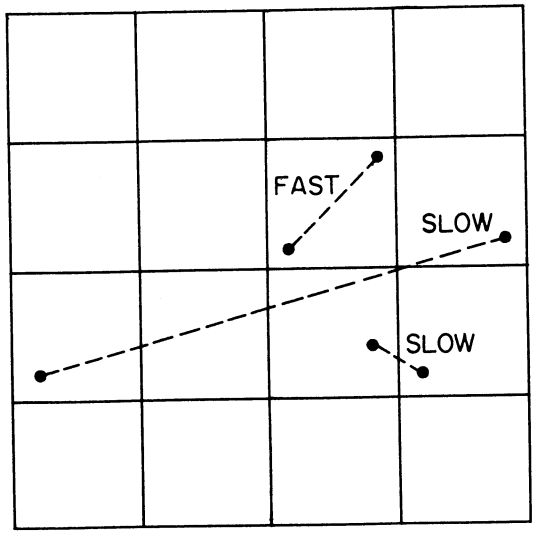
For the application requiring only a single console, the user would be wise not to acquire equipment whose controller hardware is designed, at considerable additional cost, for multiple displays.

Point Positioning

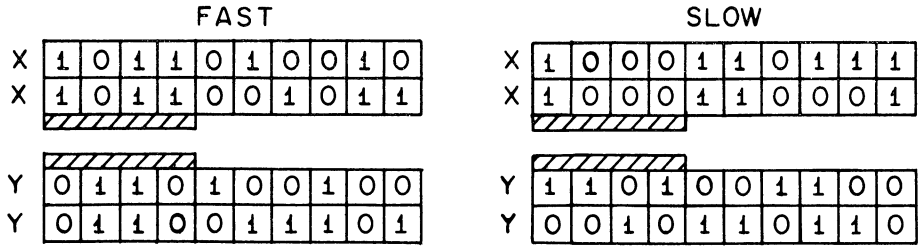
The time required to position and plot points on the cathode ray tube is usually an indication of the speed of the deflection amplifiers (and thus of the amount of randomly-placed information that can be displayed flicker-free) and the delays required to allow the electron beam to settle in place.

Some manufacturers claim to have only one point-positioning time; this must therefore be tuned for the worst case, that is, moving

from one corner of the display area to the opposite corner, so the advantage of shorter settling times for shorter distances is lost. Other systems have their display area segmented into a coarse grid, as illustrated below, and if the change in coordinate position crosses



one of the grid lines, regardless of the distance between positions, the beam settling time is greater. This can be done by comparing the high-order bits of the x and y digital coordinate positions.



The remaining displays have voltage comparator circuits to determine when the deflection amplifiers have defined the desired position of the electron beam. Since point positioning is used in drawing lines and text, good point-positioning time is a factor to be considered.

The minimum and maximum point-drawing times of the various displays are shown below, with the evaluation refresher rates:

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System	Minimum Point-Drawing Time (in microseconds)	Maximum Point-Drawing Time (in microseconds)	Frame Rate
Control Data dd16C	3.0	3.0	30
Sanders ADDS/900	1.8	3.2	30
Adage GT/50	4.0	4.0	30
Univac 1557/1558	3.1	4.1	30
Vector General	3.0	5.0	30
Control Data 250	3.3	5.0	30
Control Data Grid	6.0	6.0	30
IDI Model E1	6.0	6.0	30
Evans & Sutherland Model 1	8.0	8.0	30
ITT OPSC	8.0	8.0	30
SINTRA VU 2000	10.0	10.0	30
Tasker 9200	10.0	10.0	30
ITT MACC	11.0	11.0	30
Philco READ	13.0	13.0	30
SEL 816A	14.0	14.0	30
XDS 7580	11.0	17.0	30
Imlac PDS-1	2.0	20.0	40
DEC Graphic 15	8.0	20.0	30
IDI 10000	9.0	20.0	30
Monitor Systems 8100	20.0	20.0	30
IDIIOM	6.9	21.4	30
Control Data Digigraphics	3,34	25.0	30
Telefunken SAP 200	7.5	25.0	30
Telefunken SAP 300	5.0	28.0	30
Raytheon DIDS-1500	9.5	29.5	48
RCA 6320	30.0	30.0	30
SD 1090	32.0	32.0	30
BR-90	37.5	37.5	30
DEC 340	38.0	38.0	30
Ferranti 30/40	6.0	44.0	16-2/3
Tasker 9100	4.0	48.0	30
DEC 338/339	15.0	48.5	30
III 1050	6.0	56.0	30
Telefunken SIG 100	12.0	84.0	25
IBM 2250 Model IV	8.65	109.6	30
IBM 2250 Model III	8.05	120.0	30
IBM Model I	10.1	125.0	30
ICL 928	30.0	140.0	10
ICL 4280	10.0	150.0	10
ICL 1830	25.5	792.0	10

When these times are divided into the frame rate, the number of points per flicker-free frame (which correspond to the description sheets) is found. In Figure V.6 is shown the minimum, maximum and mean number of flicker-free points per frame for each device.

While the ICL 928 can draw the largest number of closely-spaced flicker-free points, the Sanders ADDS/900 and Control Data 250 can draw a large number of full-deflection points and the Sanders ADDS/900 can draw the greatest average number of points. Electrostatic deflection is used for the Control Data 250 and dd16C. The SD 1090, ITT OPSC, BR-90. DEC 340, ITT MACC and RCA 6320, which have limited displayed-point capacity, are all tuned for the maximum required point-drawing time.

Shown in the table below is the cost per flicker-free point for each display, using the mean number of flicker-free points and the cost of a single display to a local computer. This cost includes the CRT console, light pen, keyboard, function switches, display buffer and controller (if applicable), and character and line generators (if available).

System	Cost/Point
‡Imlac PDS-1	$ 1
*Control Data dd16C	$ 3
*Vector General	$ 3
*IDI Model E1	$ 7
‡Sanders ADDS/900	$ 8
Ferranti 30/40	$ 9
*Control Data Grid	$ 12
‡DEC Graphic 15	$ 13
‡Univac 1557/1558	$ 14
Control Data 274	$ 15
‡Control Data 250	$ 19
‡Adage GT/50	$ 22
XDS 7580	$ 24
‡IDIIOM	$ 24
‡SEL 816A	$ 26
*Evans & Sutherland Model 1	$ 35
‡DEC 338/339	$ 38
III 1050	$ 38

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System	Minimum	Maximum	Mean
Sanders ADDS/900	10,399	18,499	14,449
Control Data dd16C	11,111	11,111	11,111
ICL 928	1,000	20,000	10,500
Univac 1557/1558	8,130	10,752	9,441
Vector General	6,666	11,111	8,888
Adage GT/50	8,333	8,333	8,333
Control Data 250	6,666	8,192	7,429
Imlac PDS-1	1,250	12,500	6,875
Ferranti 30/40	1,363	10,000	5,681
Digigraphics	1,333	10,000	5,666
Control Data Grid	5,555	5,555	5,555
IDI Model E1	5,555	5,555	5,555
ICL 4280	666	10,000	5,333
Tasker 9100	694	8,333	4,513
Evans & Sutherland Model 1	4,167	4,167	4,167
SAP 300	1,190	6,666	3,928
SINTRA VU 2000	3,333	3,333	3,333
Tasker 9200	3,333	3,333	3,333
IDIIOM	1,557	4,901	3,229
III 1050	595	5,555	3,075
XDS 7580	2,222	3,704	2,963
SAP 200	1,333	4,444	2,888
DEC Graphic 15	1,666	4,000	2,833
IDI CM10000	1,666	3,703	2,684
Philco READ	2,564	2,564	2,564
SEL 816A	2,380	2,380	2,380
IBM 2250/III	277	4,140	2,208
IBM 2250/IV	323	3,853	2,088
ICL 1830	126	3,921	2,023
SIG 100	476	3,327	1,901
IBM 2250/I	266	3,300	1,783
Monitor 8100	1,666	1,666	1,666
DEC 338/339	687	2,222	1,454
SD 1090	1,041	1,041	1,041
DIDS-1500	596	1,365	980
ITT OPSC	900	900	900
BR-90	888	888	888
DEC 340	877	877	877
ITT MACC	614	614	614
RCA 6320	555	555	555

Figure V.6

LINE DRAWING DISPLAYS:
POINTS PER FLICKER-FREE FRAME

System	Cost/Point
ǂ Monitor 8100	$ 39
* DEC 340	$ 45
* IBM 2250 Model IV	$ 60
IBM 2250 Model I	$ 67
IBM 2250 Model III	$ 127
ǂ BR-90	$ 172

* Does not include cost of refresher memory or high-speed computer access.
ǂ Includes cost of computer controller.

Although the cost per point varies greatly, the higher priced units generally are designed for large computer and/or multiple console systems. However, display consoles with excellent programming and auxiliary features may be had for less than $30 per point. It should be noted that the Evans & Sutherland display at $35 per point is the most sophisticated piece of equipment on the market today, but is geared primarily to research applications. Imlac's PDS-1 manages to get its cost per point down to $1, which includes the cost of a computer controller.

Line Drawing

The line-drawing speed of a display is indicative of both the cathode ray tube deflection amplifier characteristics and the line-generation method. Displays that approximate lines with displayed points usually calculate the point positions digitally, then plot each position for a specific time per position. Thus the time required to draw a line is roughly in proportion to the length of that line.

Other displays, using analog circuits, draw short vectors at predetermined and fixed angles with only a limited number of vectors available. Lines are composed of a series of intermixed vector commands whose order can be determined either by hardware or programming. If each vector is drawn in the same time interval, the time required to draw a line depends on the number and type of vectors of which it is composed, that is, on both the length and orientation of the line. The Control Data Digigraphic systems are examples of this technique.

The remaining displays use analog line generator circuitry to draw lines between end positions. The time required to do this is a function of the circuitry speed and the CRT deflection amplifiers, subject to the various delay schemes described under point positioning.

The minimum, maximum and mean inches of long (eight-inch component length) lines that can be drawn flicker-free are shown for each display in Figure V.7. The maximum figure is taken directly from the description sheets; the minimum is found by adding the longest point positioning time (or dark vector drawing time, whichever is less) to the longest line drawing time, and dividing this into the refresher rate.

The Vector General Display exceeds the Control Data Grid and Sanders ADDS/900 in the minimum and mean number of inches of eight-inch lines that can be drawn, and draws slightly more maximum number of inches. The displays that draw lines digitally, in particular the ICL 4280, ICL 1830, SD 1090, and DEC 338/339 and 340, all have limited long-line drawing capacity. While digitally drawn lines have advantages, drawing speed is not one of them.

The mean inches of long lines per frame was divided into the cost of each system to obtain the cost per inch as shown below.

System	Cost/inch of long (8") lines
*Vector General	$ 2
‡DEC Graphic 15	$ 5
*Control Data Grid	$ 6
*IDI Model E1	$ 8
‡SEL 816A	$ 8
Ferranti 30/40	$ 9
XDS 7580	$ 10
‡Imlac PDS-1	$ 11
‡Sanders ADDS/900	$ 11
‡IDIIOM	$ 12
Control Data 274	$ 13
‡Monitor 8100	$ 13
‡Control Data 250	$ 16
‡Univac 1557/1558	$ 18
‡Adage GT/50	$ 24

System	Minimum	Maximum	Mean
Vector General	11,592	12,696	12,144
Control Data Grid	9,523	12,121	10,822
Sanders ADDS/900	9,243	11,192	10,717
Control Data 250	8,080	9,520	8,800
SAP 300	5,128	11,111	8,119
SEL 816A	6,349	9,523	7,936
Adage GT/50	7,073	7,913	7,493
UNIVAC 1557/1558	6,488	7,619	7,053
ITT OPSC	3,703	9,999	6,847
Tasker 9200	5,925	7,619	6,772
Digigraphics	4,848	8,669	6,758
DEC Graphic 15	5,128	8,000	6,564
IDIIOM	4,694	8,385	6,539
IDI CM10000	4,938	7,843	6,390
Evans & Sutherland Model 1	5,673	6,837	6,255
Ferranti 30/40	2,545	9,542	6,043
XDS 7580	4,760	6,504	5,632
BR-90	3,555	7,111	5,333
IDI Model E1	4,761	5,333	5,047
Monitor 8100	4,102	5,925	5,014
SIG 100	3,333	6,666	4,999
SINTRA VU 2000	4,301	5,128	4,714
SAP 200	3,555	5,333	4,444
III 1050	2,614	5,797	4,205
Tasker 9100	2,614	4,938	3,776
ITT MACC	2,515	2,806	2,660
IBM 2250/III	1,375	3,933	2,654
IBM 2250/IV	1,516	3,663	2,589
IBM 2250/I	1,230	3,933	2,581
RCA 6320	1,481	2,222	1,851
DIDS-1500	1,233	1,480	1,356
Philco READ	1,206	1,282	1,244
ICL 4280	1,037	1,288	1,162
ICL 1830	511	1,010	760
Imlac PDS-1	724	781	752
SD 1090	391	410	400
DEC 338/339	230	241	236
Control Data dd16C	216	216	216
DEC 340	190	195	193

Figure V.7

LINE DRAWING DISPLAYS
INCHES OF LONG LINES PER FLICKER-FREE FRAME

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System	Cost/inch of long (8") lines
* Evans & Sutherland Model 1	$ 24
III 1050	$ 28
ǂ BR-90	$ 29
IBM 2250 Model I	$ 46
* IBM 2250 Model IV	$ 49
IBM 2250 Model III	$ 105
* Control Data dd16C	$ 171
* DEC 340	$ 204
ǂ DEC 338/339	$ 233

* Does not include cost of refresher memory or high-speed computer access.
ǂ Includes cost of computer controller.

Vector General manages to get its cost down to $2 per inch of eight-inch lines. The (DEC Graphics 15, CDC Grid, IDI Model E1, SEL, Ferranti, XDS, Imlac, Sanders, IDIIOM, Control Data 274 and Monitor 8100 displays are all favorably priced. For the IBM 2250 Model III in the maximum configuration of four displays per controller, the per display cost of each inch is reduced to $62. Displays with good programming and auxiliary features are available for less than $20 per inch.

Figure V.8 shows the minimum, maximum and mean inches of short (two-inch component length) lines that can be drawn flicker-free for each display. The Vector General Display exceeds all other displays in both the minimum and mean number of inches that can be drawn. Displays with uniformly fixed drawing times for all vectors, such as the SIG 100 and BR-90 do not rate as well as before.

In the table below the cost per inch of two-inch lines is shown for each display:

System	Cost/inch of short (2" lines)
* Vector General	$ 3
ǂ DEC Graphic 15	$ 7
Ferranti 30/40	$ 11

System	Minimum	Maximum	Mean
Vector General	7,408	9,524	8,466
Sanders ADDS/900	5,464	9,866	7,565
ITT OPSC	2,777	9,990	6,383
UNIVAC 1557/1558	4,385	7,407	5,896
DEC Graphic 15	2,380	8,000	5,190
Control Data Grid	3,703	5,555	4,929
Control Data 250	3,921	5,555	4,738
Adage GT/50	4,219	5,650	4,934
Ferranti 30/40	1,976	7,185	4,580
Digigraphics	1,888	6,466	4,177
Evans & Sutherland Model 1	2,898	4,444	3,671
SAP 300	1,666	5,555	3,610
SINTRA VU 2000	2,666	4,444	3,555
SAP 200	1,754	5,128	3,441
Tasker 9200	2,564	4,166	3,365
Monitor 8100	1,904	4,444	3,174
IDI Model E1	2,564	3,333	2,948
III 1050	925	4,166	2,545
IDIIOM	1,424	3,058	2,241
IDI CM10000	1,515	2,777	2,146
SEL 816A	1,587	2,380	1,983
Tasker 9100	925	2,777	1,851
IBM 2250/III	452	3,115	1,783
IBM 2250/I	388	2,976	1,682
IBM 2250/IV	524	2,777	1,650
XDS 7580	1,190	1,623	1,406
BR-90	888	1,777	1,333
SIG 100	694	1,666	1,180
Philco READ	1,025	1,282	1,153
DIDS-1500	714	1,360	1,037
ICL 4280	645	1,250	947
RCA 6320	555	1,111	833
Imlac PDS-1	595	781	688
ITT MACC	628	701	664
ICL 1830	198	925	561
SD 1090	343	410	376
DEC 338/339	198	235	217
Control Data dd16C	215	215	215
DEC 340	155	170	163

Figure V.8

LINE DRAWING DISPLAYS:
INCHES OF SHORT LINES PER FLICKER-FREE FRAME

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System	Cost/inch of short (2") lines
‡Imlac PDS-1	$ 12
*IDI Model E1	$ 13
*Control Data Grid	$ 15
‡Sanders ADDS/900	$ 15
‡Monitor 8100	$ 20
Control Data 274	$ 21
‡Univac 1557/1558	$ 22
‡Control Data 250	$ 29
‡SEL 816A	$ 31
‡IDIIOM	$ 35
‡Adage GT/50	$ 37
XDS 7580	$ 41
*Evans & Sutherland Model 1	$ 42
III 1050	$ 46
IBM 2250 Model I	$ 71
*IBM 2250 Model IV	$ 76
‡BR-90	$ 115
IBM 2250 Model III	$ 157
*Control Data dd16C	$ 172
*DEC 340	$ 242
‡DEC 338/339	$ 253

‡Includes cost of computer controller.
*Does not include cost of refresher memory or high-speed computer access.

The minimum, maximum and mean flicker-free inches of small (half-inch) lines for each display are shown in Figure V.9. The ITT OPSC, DEC Graphic 15, Univac 1557/1558, Vector General and Sanders ADDS/900 exceed by far in drawing capacity; the Adage GT ranks well along with SINTRA VU 2000, Ferranti 30/40, III 1050, Control Data Grid and Digigraphics.

The cost per inch of small lines is as follows:

System	Cost/inch of small (0.5") lines
*Vector General	$ 7

System	Minimum	Maximum	Mean
ITT OPSC	1,041	9,990	5,515
DEC Graphic 15	757	8,000	4,379
Univac 1557/1558	2,032	5,376	3,704
Vector General	2,778	4,166	3,472
Sanders ADDS/900	2,150	4,099	3,124
SINTRA VU 2000	1,666	3,333	2,500
Digigraphics	576	4,284	2,430
Adage GT/50	1,754	3,030	2,392
Ferranti 30/40	573	3,614	2,093
Control Data Grid	1,190	2,083	1,636
Control Data 250	1,253	2,008	1,630
Evans & Sutherland Model 1	1,041	2,083	1,562
III 1050	268	2,777	1,522
Monitor 8100	595	2,084	1,339
Tasker 9200	757	1,388	1,072
XDS 7580	618	1,389	1,003
SAP 300	416	1,388	902
SEL 816A	595	1,190	892
SAP 200	438	1,282	860
IBM 2250/III	123	1,461	792
IBM 2250/IV	145	1,412	778
IBM 2250/I	108	1,388	748
IDI Model E1	641	833	737
ICL 4280	256	1,111	683
Philco READ	505	833	666
DIDS-1500	256	1,020	638
Tasker 9100	256	980	618
IDI CM10000	396	757	577
Imlac PDS-1	347	781	564
IDIIOM	356	764	560
ICL 1830	57	694	375
BR-90	222	444	333
SD 1090	231	410	320
SIG 100	209	416	312
Control Data dd16C	213	213	213
RCA 6320	138	277	207
DEC 338/339	128	217	173
ITT MACC	157	175	166
DEC 340	121	168	145

Figure V.9

LINE DRAWING DISPLAYS:
INCHES OF SMALL LINES PER FLICKER-FREE FRAME

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System	Cost/inch of small (0.5") lines
‡DEC Graphic 15	$ 8
‡Imlac PDS-1	$ 15
Ferranti 30/40	$ 25
Control Data 274	$ 35
‡Univac 1557/1558	$ 35
‡Sanders ADDS/900	$ 37
*Control Data Grid	$ 42
‡Monitor 8100	$ 49
*IDI Model E1	$ 54
XDS 7580	$ 58
‡SEL 816A	$ 70
‡Adage GT/50	$ 76
III 1050	$ 77
‡Control Data 250	$ 85
*Evans & Sutherland Model 1	$ 95
‡IDIIOM	$ 141
IBM 2250 Model I	$ 159
*IBM 2250 Model IV	$ 162
*Control Data dd16C	$ 174
*DEC 340	$ 272
‡DEC 338/339	$ 318
IBM 2250 Model III	$ 353
‡BR-90	$ 459

‡Includes cost of computer controller.
*Does not include cost of refresher memory or high-speed computer access.

The per display cost of the IBM 2250 Model III system with the maximum of four displays per controller is about $207 per inch.

Text Display

Characters for the line-drawing displays are mostly defined by stroke counts or by extruding the beam through a mask; the extrusion method has a uniform character drawing speed which is a function of the desired brightness of the character. The time required to draw a stroke character is usually proportional to the time needed to draw very small lines in the particular display.

The minimum, maximum and mean characters per flicker-free frame for each display are shown in Figure V.10. The ICL 928 and 4280, and Sanders ADDS/900 rank well, each with 7,000 or more characters per frame. Both the ICL and Sanders systems permit the drawing of characters at high speed using ultra-high-speed electromagnetic deflection.

The cost per flicker-free character for each display is given below:

System	Cost/character
* Vector General	$ 7
ǂ Imlac PDS-1	$ 8
* Control Data Grid	$ 11
ǂ DEC Graphic 15	$ 14
* IDI Model E1	$ 15
ǂ Sanders ADDS/900	$ 16
ǂ Control Data 250	$ 20
Ferranti 30/40	$ 25
ǂ Univac 1557/1558	$ 27
ǂ Monitor 8100	$ 29
ǂ SEL 816A	$ 35
III 1050	$ 40
Control Data 274	$ 40
ǂ BR-90	$ 45
ǂ IDIIOM	$ 48
* Control Data dd16C	$ 53
* DEC 340	$ 56
ǂ Adage GT/50	$ 64
IBM 2250 Model I	$ 79
* IBM 2250 Model IV	$ 80
Control Data 270	$ 85
ǂ DEC 338/339	$ 111
XDS 7580	$ 130
IBM 2250 Model III	$ 184
* Evans & Sutherland Model 1	$ 194

ǂ Includes cost of computer controller.
* Does not include cost of refresher memory or high-speed computer access.

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System	Minimum	Maximum	Mean
ICL 928	6,666	20,000	13,333
ICL 4280	598	14,285	7,441
Sanders ADDS/900	4,098	10,556	7,327
Control Data 250	4,016	10,000	7,008
Control Data Grid	3,472	9,259	6,365
SINTRA VU 2000	2,487	9,803	6,146
Univac 1557/1558	2,754	6,667	4,710
Vector General	3,704	4,762	4,233
Philco READ	1,754	5,555	3,654
SAP 300	565	6,666	3,630
Tasker 9200	2,020	5,128	3,574
BR-90	775	6,060	3,417
III 1050	497	5,376	2,963
Adage GT/50	2,380	3,333	2,856
IDI Model E1	2,083	3,333	2,708
Tasker 9100	606	4,761	2,683
DEC Graphic 15	1,190	4,000	2,595
ITT OPSC	2,564	2,720	2,642
SAP 200	1,010	4,166	2,588
ITT MACC	1,960	3,072	2,516
DIDS-1500	610	4,096	2,353
Monitor 8100	1,111	3,333	2,222
Digigraphics	952	3,333	2,142
Ferranti 30/40	960	3,243	2,101
SIG 100	600	3,327	1,996
RCA 6320	476	3,333	1,904
SEL 816A	1,190	2,380	1,785
IDI CM10000	980	2,380	1,680
IDIIOM	877	2,398	1,637
IBM 2250/IV	266	2,873	1,569
IBM 2250/III	245	2,801	1,523
IBM 2250/I	223	2,801	1,512
ICL 1830	120	2,857	1,488
SD 1090	641	1,666	1,153
Imlac PDS-1	694	1,562	1,128
Evans & Sutherland Model 1	694	833	763
DEC 340	456	952	704
Control Data dd16C	694	694	694
DEC 338/339	323	666	494
XDS 7580	378	510	444

Figure V.10

LINE DRAWING DISPLAYS:
CHARACTERS PER FLICKER-FREE FRAME

Test Patterns

In many ways the test patterns are more revealing of a display's drawing ability than its line and character capacities. The weather map, made entirely of beam resets and one-tenth inch line segments, tests the ability of a display to draw very small lines; the electronic schematic pattern tests circle drawing, and the architectural drawing reflects shading or hatching ability. The percent of each test pattern that can be displayed is shown in Figure V.11. These were averaged to find the mean percent; this figure was then divided into the cost per system to find the cost per flicker-free frame, that is, per 100 percent.

Hardware and Programming Characteristics

A summary of some of the hardware and software characteristics of the various display systems is given in Figure V.12. An asterisk (*) indicates that the feature exists, except that H indicates the feature is provided by hardware and S that it is supplied by software.

As shown in the last column, several manufacturers have made serious efforts to supply software systems with their displays. Adage provides software for real-time construction, rotation and translation of figures. Control Data Digigraphic Laboratories furnishes a complete set of 1700 and 3000 series computer programs for generating and manipulating displays as well as for building a library of console functions. IDI is developing a programming system for constructing graphics at the IDIIOM console. IBM provides display utilizing routines, such as pen-tracking program, and a set of 1130 or System/360 programs for manipulating data structures. ICL and Marconi are developing display manipulation programs. Ferranti supplied programming for its Sketch module, and Bunker-Ramo has programmed its console function switches.

A significant breakthrough in hardware design has been achieved by Evans and Sutherland. Their Model 1 display is currently the only one which provides perspective projection with proper 3-D clipping in hardware. Also, the Model 1 automatically combines nested linear transformations into a single linear transformation (an important feature in nested subroutining), allows separation of pic-

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Unit Name	Map	Graph	Drawing	Schematic	Text	Mean %	Cost/Frame
Vector General	1,043	2,574	668	1,493	261	1,208	$ 2,024*
DEC Graphic 15	2,718	1,637	697	1,348	222	1,324	$ 2,726ǂ
Imlac PDS-1	325	400	55	120	125	205	$ 4,146ǂ
Ferranti 30/40	463	1,350	418	902	174	661	$ 7,792
Sanders ADDS/900	504	3,472	554	1,500	428	1,251	$ 9,272ǂ
Control Data Grid	289	1,795	422	516	501	704	$ 9,786*
IDI Model E1	116	1,158	152	372	184	396	$ 9,959*
Univac 1557/1558	731	3,113	667	968	362	1,168	$ 11,044ǂ
Monitor 8100	394	1,270	314	616	181	555	$ 11,712ǂ
Control Data 274	1,046	1,093	389	723	134	677	$ 12,703
Control Data 250	460	2,208	534	808	548	912	$ 15,116ǂ
SEL 816A	164	1,004	218	240	130	351	$ 17,706ǂ
Adage GT/50	575	2,182	423	763	185	826	$ 22,010ǂ
Control Data dd16C	156	388	88	159	38	166	$ 22,289*
XDS 7580	375	365	100	282	77	239	$ 24,267
III 1050	443	701	368	392	298	440	$ 26,562
IDIIOM	109	781	150	310	129	296	$ 26,689
IBM 2250/IV	288	674	241	297	279	356	$ 35,393*
DEC 340	84	204	64	100	52	101	$ 38,993*
IBM 2250/I	265	542	210	258	210	297	$ 40,134
Evans & Sutherland Model 1	287	715	144	364	46	311	$ 47,580*
DEC 338/339	115	216	68	120	51	114	$ 48,245ǂ
IBM 2250/III	333	702	266	339	218	371	$ 75,363
BR-90	61	262	89	194	323	186	$ 82,258ǂ
SINTRA VU 2000	720	2,289	674	812	513	1,001	-
ITT OPSC	287	1,484	353	849	361	666	-
Tasker 9200	230	1,589	272	333	278	540	-
SAP 200	342	1,083	256	406	358	489	-
ICL 4280	224	665	322	369	371	390	-
SAP 300	363	923	224	192	218	384	-
IDI CD10000	105	871	157	312	124	313	-
DIDS-1500	141	543	197	208	212	260	-
Philco READ	128	503	173	186	297	257	-
SD 1090	281	440	150	281	91	248	-
Tasker 9100	146	457	176	193	234	241	-
SIG 100	158	310	91	110	192	172	-
ICL 1830	129	172	108	99	109	123	-
RCA 6320	38	162	55	59	166	96	-
ITT MACC	24	143	50	41	171	85	-

ǂ Includes cost of computer controller.
* Does not include cost of refresher memory or high-speed computer access.

Figure V.11

LINE DRAWING DISPLAYS:
PERCENT OF TEST PATTERNS PER FLICKER-FREE FRAME

System	Computer Controller	Display Logic Subroutining	Relative Vectors	Programmable Character Generator	Display Logic Scissoring	Pointer Tracking	Item Identification	Remote Console Operation	Systems Software
Adage GT/50	*	*	*	-	*	S	S	*	*
SAP 200	-	-	*	-	*	H	-	*	*
SAP 300	*	-	-	-	-	H	S	*	-
SIG 100	-	*	-	-	-	H	-	-	-
BR-90	*	*	*	-	*	*	S	*	*
Control Data dd16C	-	-	*	-	-	-	-	-	-
Control Data 250	-	*	*	-	-	*	-	*	-
Control Data 274	-	*	*	-	-	*	H	-	*
Control Data Grid	-	*	*	-	-	H	H	*	-
Control Data VID	-	-	*	-	-	-	H	-	*
DEC 338/339	*	*	*	*	*	S	S	*	-
DEC 340	-	*	*	-	-	-	-	-	-
DEC Graphic 15	*	*	*	-	*	H	H	*	-
Evans & Sutherland Model 1	-	*	*	-	H	H	H	-	-
Ferranti 30/40	-	-	*	*	-	H	-	-	*
Imlac PDS-1	*	*	*	*	*	H	*	*	*
IDI CM10000	-	*	*	-	*	*	*	*	-
IDIIOM	*	*	*	-	*	S	S	*	*
IDI Model E1	-	*	*	-	*	*	*	*	-
III 1050	-	*	*	-	*	-	-	-	-
IBM 2250/I	-	-	*	-	-	-	-	-	*
IBM 2250/III	-	*	*	-	*	S	S	-	*
IBM 2250/IV	-	*	*	*	*	-	-	-	*
ICL 928	-	*	*	-	*	*	*	-	*
ICL 4280	-	*	*	-	*	-	-	-	*
ICL 1830	-	-	*	-	-	H	-	-	*
ITT MACC	-	-	-	-	-	H	-	-	-
ITT OPSC	*	-	*	*	-	H	-	-	-
Marconi X2000	-	*	*	-	-	-	-	-	*
Monitor Systems 8100	*	*	*	*	-	S	*	-	-
Philco READ	-	-	-	-	-	H	H	-	-
RCA 6320	-	-	-	-	-	H	-	-	-
DIDS-1500	-	-	-	-	-	-	-	-	-
Sanders ADDS/900	-	*	*	-	-	*	*	*	*
SINTRA VU 2000	-	*	*	-	-	H	H	-	-
SD 1090	-	-	*	-	-	H	-	-	-
SEL 816A	*	*	*	-	-	S	S	*	-
Tasker 9100	-	-	-	-	-	H	-	-	-
Univac 1557/1558	*	*	*	*	*	*	*	*	-
Vector General	-	-	*	-	-	-	-	*	-
XDS 7580	-	*	*	*	-	H	H	-	-

Figure V.12

LINE DRAWING DISPLAYS
HARDWARE AND PROGRAMMING CHARACTERISTICS

ture structure from picture data, and is the fastest system in handling 3-D information. The system is priced at $200,000. On the other hand, Imlac's PDS-1 display, which includes a line-drawing CRT, keyboard, and 2 usec mini-processor, can be purchased for $8,900; by far the lowest price on the market.

Storage tube devices currently available include BBN Teleputer, Computek Series 400, Computer Displays ARDS, Digital Equipment KV Graphics, and Tektronix T4002; all priced under $10,000.