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VISUAL PERFORMANCE WITH HIGH-CONTRAST CATHODE-RAY TUBES AT HIGH LEVELS OF AMBIENT ILLUMINATION

Prepared for:

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ABSTRACT

Gap-detection thresholds and working level preferences were determined for one standard and three experimental high-contract cathode-ray tubes under four levels of ambient illumination, 100, 1,000, 5,000, and 10,000 ft -c , two angles of incidence, 30° and 60°, and two angles of regard, 0° and -45° The trace brightnesses required to perform the visual tasks were primarily a function of the reflectances and resulting background brightnesses of the cathode-ray tube faces. The results of this study are related to classical psychophysical data on brightness discrimination, earlier work on "masking luminance" for radar displays, and a recent study on visual performance using electroluminescent displays under high ambient illumination.

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INTRODUCTION

Purpose

The purpose of this study was to compare visual performance using one standard and three experimental high-contrast cathode-ray tubes (CRT) under extremely high levels of ambient illumination such as are encountered during high-altitude flight in direct sunlight. Two questions of primary interest were

1. Do any of the CRTs "wash-out" under illumination levels approaching maximum operational levels of 10, 000 ft. -c ?

2. What are the relative merits of the four tubes?

In addition, data were taken at lower levels of ambient illumination of 5, 000, 1, 000, and 100 ft. -c.

In combination, the data from this study permit a direct comparison of the experimental CRTs in terms of several operational criteria In addition, the data from this study confirm and extend the findings of previous studies on brightness discrimination (Graham, 1965) "masking illuminance" (Adler, Kuhns, and Brown, 1958) and electroluminescent display legibility (Semple and Goettelmann, 1969), all of which indicate that ambient illumination, i e., illuminance, is important only insofar as it affects the brightness, i. e , luminance the display face relative to the brightness of the display symbology.

Wash-out

The phosphors of most conventional CRTs are white or very light gray and reflect a very high percentage of the ambient light that falls upon them. For example, the P1 phosphor reflects about 70-80 percent of the incident light.

The visibility of a figure generated on the CRT face depends upon the difference between the amount of light reflected from the face of the tube, B, and the amount emitted by the generated figure, ΔB. The proportionate increment in brightness of the trace over the general background, $\Delta B/B$, required to discriminate a figure formed by the trace varies over a wide range depending primarily upon the visual task and the level of the background brightness.

However, since discrimination depends upon the ratio of the brightnesses, or contrast, it can be seen that if the trace brightness, ΔB, were set for discrimination against a low level of background brightness, B, and then held fixed while the background brightness was increased, the ratio ΔB/B would be reduced. If contrast is reduced to a low enought value, the trace will not be enought brighter than the background to be discriminated

That is basically what happens when airborne displays "wash-out " Depending upon several factors, including location, time of day, orientation, clouds, haze and altitude, the ambient illumination from the sun can vary over several log units, from less than 100 ft -c. under poor visibility conditions at low altitudes to about 10,000 to 15,000 ft.-c at altitudes of 20,000 to 40,000 ft CRT displays set at brightnesses suitable for relatively low ambient levels may "wash-out" at the highest levels.

High-Contrast Cathode-Ray Tubes

Over practical operating conditions, the maximum brightness of the trace of most CRTs is limited to the order of a few hundred foot-Lamberts· usually the display is operated at levels below a hundred foot-Lamberts Discrimination, then, depends upon finding ways of keeping the luminance of the face of the tube at appropriate low levels.

Hoods, light traps, mesh screens, and filters are devices for preventing ambient light from reaching the reflecting phosphor layer Filters not only reduce the incident light on its way in, they also further reduce the reflected light on its way out, while the emitted light is reduced only on the out-going path. The three experimental CRTs used in this study (Figure 1) represented three different techniques of reducing the background luminance.*

The Electro Vision CRT (VC6AEP1(S) S/N 3) uses a thin-film phosphor screen A thin-film, or transparent phosphor is really a special kind of light trap in which the light goes through the phosphor and is trapped inside the tube.

The Hartman CRT (HC-1101 S/N 2) uses a special absorptive filter bonded to the face of a standard production CRT. The filter has a narrow region of high transmittance designed to match the spectral output of the CRT to the peak of the spectral sensitivity of the eye Light from other regions of the spectrum is attenuated greatly.

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*For detailed technical specifications for the CRTs used in this study, please contact the individual manufacturers.

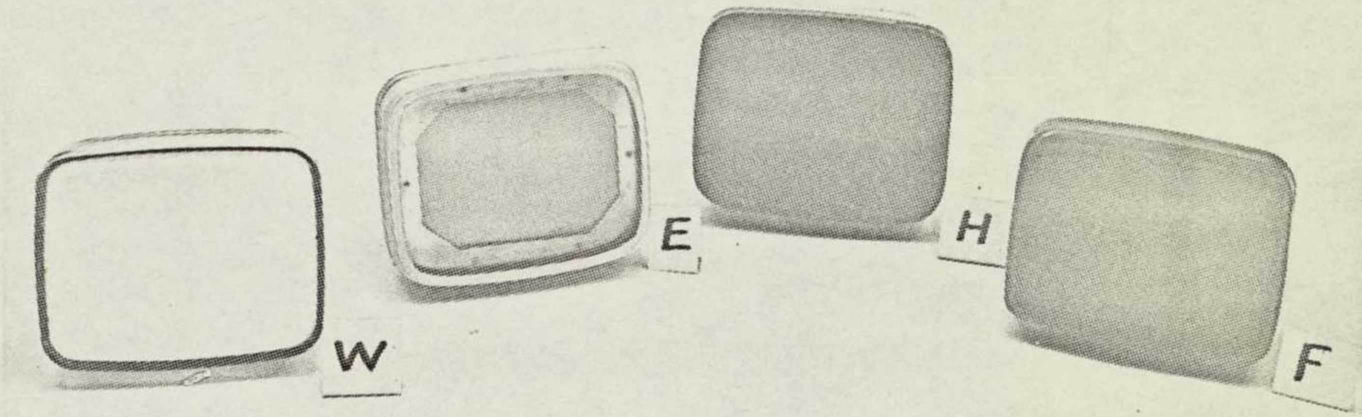

Figure 1. Experimental CRTs. Reflectance values are shown by the gray tone values of the CRT faces. W = Westinghouse (WX-30844P-1), E = Electro Vision (VC6AEP1 (S) S/N 3), H = Hartman (HC-1101 S/N 2), F = Fairchild (KC2920PFC S/N 250658).

The Fairchild CRT (KC2920PFC S/N 250658) uses a pigmented phosphor. In addition, a nonreflective panel, which also acts like a neutral density filter, was laminated to the front surface.

The Westinghouse CRT (WX-30844P-1) was a standard production CRT with a conventional P1 phoshor. No attempt had been made to improve the contrast of this CRT. It was used simply to provide a standard conventional CRT against which to compare the experimental CRTs.

Approach

The general plan of the study was

1. The same operating conditions were used for all four CRTs.

2. A computer-generated direct-write display was used to provide a visual form discrimination task and a tracking task

3. Fixed levels of ambient illumination were provided by high intensity quartzite lamps.

4. Form discrimination thresholds and preferred working levels were determined for four subjects.

5. Data were taken for various combinations of the following conditions

   Ambient Illuminance

   10,000, 5,000, 1,000, 100 ft.-c

   Angle of Incidence

   30°, 60°

   Angle of Regard

   0°, -45°

6 The data were analyzed and the CRTs compared in terms of operational criteria and basic visual parameters

METHOD

Experimental Arrangement

Figure 2 shows the plan view of the experimental arrangement The CRTs were mounted in a plexiglass box on a shelf in a standard equipment rack. The face of the box was painted flat black. The subject sat in a chair with the tracking and detection controls mounted on a right-hand writing arm.

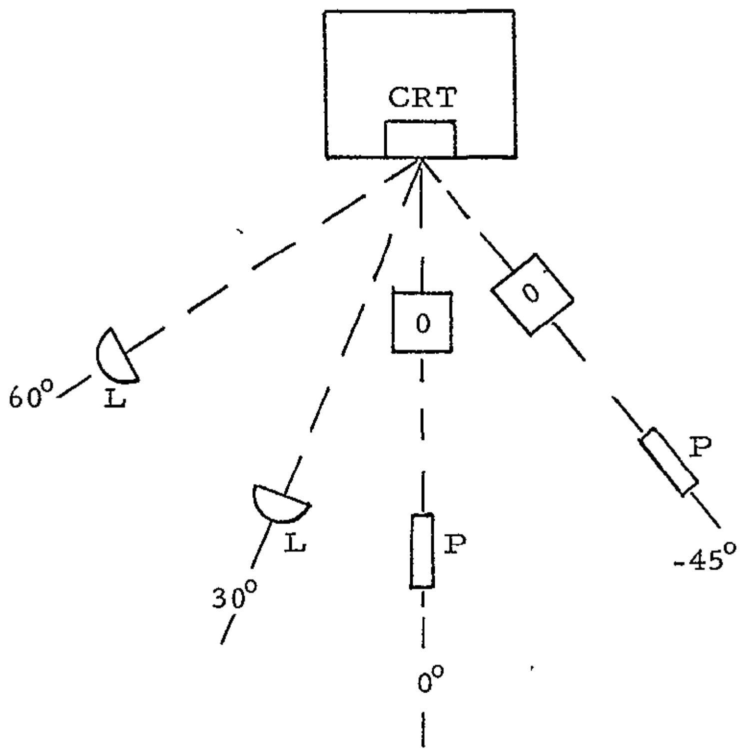

Figure 2. Experimental arrangement. CRT, cathode-ray tube mounted in equipment rack, L, Sun Gun quartzite lamps, O, observer seated in chair with tracking and detection controls, P, Pritchard photometer located for background brightness readings. Distances and settings are described in the text

The center of the face of the CRT was approximately at eye level (46 in.) in a vertical plane normal to the observer's line of sight when the observer was seated at the 0° position. To obtain the -45° viewing angle the observer moved his chair to his right, while the CRT and rack remained fixed. The viewing distance was approximately 24 in. from both observer positions.

Ambient illumination was provided by two quartzite lamps (Sun Guns; 3200°K) mounted on a vertical pipe stand at heights of 5 ft. and 6 ft. The lights were to the left of the observer and were moved along a line either 30° or 60° to the normal, i.e , 0° line, to obtain the desired ambient level and angle of incidence

The basic equation relating ambient illuminance, background luminance, and surface reflectance is

$$B = RA \qquad (1)$$

where A = ambient illumiance (ft.-c.)
B = background luminance (ft.-L)
R = reflectance of the surface

The ambient level was set by placing a sheet of white bond paper with a reflectance of 0.8 over the face of the CRT and adjusting the position of the lights until the photometer reading taken from 30° off-axis satisifed the equation

$$P = 0.8A \qquad (2)$$

where A = nominal ambient desired (ft -c)
P = photometer reading to be obtained (ft.-L.)
0 8 = reflectance of the bond paper

When the lights had been adjusted, the bond paper was removed and the brightness of the CRT face was measured.

In setting the brightness levels at 60°, the equipment rack was turned so the CRT face was normal to the 60° line and the photometer readings were taken from the 30° line. When the lights had been adjusted, the rack was turned back to its standard position and the brightness of the CRT face was measured from the 0° and -45° observer positions

Experimental CRTs

The operating characteristics of the four experimental CRTs are summarized in Appendix A All CRTs were operated at the following voltages

Anode Voltage	9,000 V
Grid 1	-15 to -40 V
Grid 2	300 V
Grid 4	300 V

Trace brightness was varied by a vernier adjustment on the Grid 1 bias. Grid 1 voltages were monitored continuously with a digital voltmeter accurate to ±.01 V

Visual Task

The visual task combined two elements, a tracking task and a form discrimination task, to represent the essential features of tasks for which CRTs are commonly used in aircraft

The display (Figure 3) was generated by an AD-Four computer (Appendix B). The central tracking display consisted of a short, fixed, horizontal reference line and a longer, movable horizon line A low frequency, white noise generator provided a forcing function to the horizon line The observer attempted to null out the displacement with a pencil grip, spring-loaded, viscously damped, K/s hand-controller Inside-out display-control relations were used

The form discimination task consisted of four rings, one pair above and one pair below the tracking task. A 60° arc in any one of the four rings could be blanked by the computer to form a gap in the ring The observer indicated the location of the ring containing the gap by pressing a push button in the corresponding position on a panel located on the arm of his chair next to the tracking control

The form discrimination, or gap-detection, task was configured after it was found to be impossible to generate and control a classical Landolt ring visual acuity target accurately enough to be able to consider it any sort of "pure" measure of visual acuity In the operational environment, changes in trace brightness would be accompanied by changes in symbol line-width, symbol-size, and edge-contour gradient A visual acuity test object at low brightness would not be the same object at high brightness. Even if the best possible compensation for changes in target line-width and size were made in the laboratory, differences in contour gradient as a

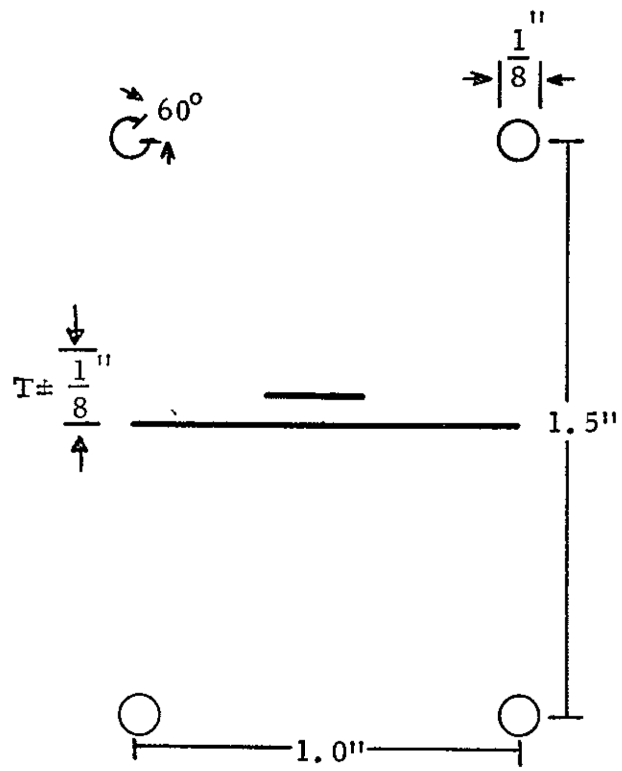

Figure 3. Visual display. The gap-detection task, G, was blanked whenever horizon line of tracking task, T, exceeded the tolerance limits of ±1/8 in from short reference line Postion of the gap was varied randomly by ring and by quadrant.

function of trace brightness would destroy the meaning of "acuity" measures taken with the target Therefore, the gap-detection task was designed to be visually analogous to the kinds of form discrimination demanded by character recognition in the operational environment and to behave similarly with respect to changes in trace brightness, including "blooming "

The gap-detection task was blanked whenever the tracking error on the central task exceeded a narrow tolerance band Otherwise the detection task was self-paced, i.e , the display changed whenever the observer pushed a response button The location of the ring with the gap and the position of the gap in the ring were randomly determined from the computer clock The computer also counted the correct and total number of responses

A trial began when the observer threw a start switch to enable the tracking task and computer logic The trial ended when the operator gave four successive correct detections, or exceeded ten responses

The probability of obtaining four successive correct responses by chance alone is less than 004, so that the thresholds obtained are for virtually 100 percent detectability

No measures of tracking performance were taken since the tracking task was used simply as an auxiliary loading task to force the observer to time-share between elements of a dynamic task as he would be required to do in most operational tasks The forcing function and tolerance band as well as gap-width were set during a number of preliminary runs to establish a level of task difficulty that the observers reported as moderately demanding

<u>Brightness Measures</u>

Brightness measures were taken with a Pritchard photometer accurate to ±5 percent, full-scale.

Trace brightness was measured using a short focal-length lens and a 6′ aperture The trace brightness vs grid 1 bias function for each tube was determined by taking an average of 12 brightness readings at 1 00 V increments over the range of bias settings used by the observers in the experimental trials Three readings were taken around the ring with the gap in it, with the ring positioned in each of the four positions of the figure The line-width of the trace varied with brightness. At the low brightnesses the line just subtended the 6' field of view, at the high brightness the line-width was two to three times as wide

The anode current vs grid 1 bias function was determined at the same time with an micro-ammeter accurate to ± 5μA

Average trace brightness, $\overline{\Delta B}$, and anode current functions for the four CRTs are given in Appendix C.

Background brightness, i e , average brightness over the tube face with no figure being generated, was measured using a long focal-length lens and a 2^{o} aperture. The distance from which the measurements were taken was adjusted so that the area occupied by the tracking and detection figures was subtended within the field of view of the photometer. Background brightness measures were taken along the observer's line of regard each time the ambient lighting condition was changed

Observers

Four observers ranging in age from 25-45 were used All reported normal vision with no color anomalies The oldest wore spectacle corrections to 20/15 for astigmatism.

Procedure

1. An experimental CRT was mounted in the equipment rack.

2. Operating voltages were checked and adjusted

3. The spacing of the rings on the display was checked and adjusted

4. The lights were set-up for 10, 000 ft -c. ambient at the 30° incidence angle

5 The brightness of the CRT face without any signal on was read from 0°

6. Gap-detection thresholds in volts were determined for all four observers at 0°

7 The brightness of the CRT face without any signal was read from -45°

8. Gap-detection thresholds in volts were determined for all four observers at -45°

9 Preference settings in volts were determined for all four subjects at 0°.

10. The lights were set-up for 10, 000 ft -c ambient at the 60° incidence angle.

11. Steps 5-8 were repeated

12. Another CRT was selected and steps 1-11 were repeated until detection threshold and preference setting data in volts had been obtained for the four CRTs at 10, 000 ft -c for a sample of four experimental observers

The CRTs were tested in the following order Westinghouse, Electro Vision, Hartman, Fairchild. The observers served in the following order R K , M C , W K , B B. All the data on one CRT were collected on the same day. This design was used to minimize the variance attributable to errors in positioning the lights and to possible variations in the operating conditions of the CRTs.

After the data for the 10,000 ft -c. ambient condition had been obtained, gap-detection and preference data were obtained for three subjects at ambient levels of 5,000, 1,000, and 100 ft.-c. with the lights at 30° and the observer at 0°.

The data were obtained as follows

1. An experimental CRT was mounted in the equipment rack

2 Operating voltages were checked and adjusted

3. The spacing of the rings was checked and adjusted

4. The lights were set-up for 5,000 ft -c ambient at 30°

5. The brightness of the CRT face without any signal was read from 0°.

6 Gap-detection thresholds in volts were determined for all three observers at 0°

7. Preference settings in volts were determined for all three subjects at 0°

8 The lights were set-up for 1,000 ft -c

9. Steps 5-7 were repeated.

10. The lights were set-up for 100 ft -c.

11 Stepts 5-7 were repeated

12 Another CRT was selected and steps 1-11 were repeated until data had been obtained on all tubes

During this second stage of the test, the Electro Vision tube developed a short so that only partial data were obtained at just the 5,000 ft -c level One observer became unavailable so that the brightness functions are based on only three of the original four observers.

The order in which the experimental conditions were presented is summarized in Table 1

TABLE 1

Summary of Experimental Conditions and Order of Presentation

Ambient Level (ft.-c.)	10,000					5,000***		1,000***		100***	
Light Position (deg)	30			60		30		30		30	
Observer Position (deg)	0		-45	0	-45	0		0		0	
Measure	DT*	WP**	DT	DT	DT	DT	WP	DT	WP	DT	WP
CRT											
Westinghouse	1	3	2	4	5	21	22	23	24	25	26
Electro Vision	6	8	7	9	10	27	28	--	--	--	--
Hartman	11	13	12	14	15	29	30	31	32	33	34
Fairchild	16	18	17	19	20	35	36	37	38	39	40

*Gap-Detection Threshold

**Working Preference

***Three Observers

Gap-Detection Thresholds

The procedure for determining the gap-detection threshold was fairly simple. After the observer was seated and the high intensity lights were turned-on, the experimenter adjusted the control grid bias until the display was quite visible The bias was then increased until the observer reported that the signal was approaching threshold The experimenter then began a series of detection trials in which the bias was descreased in 0 10V. steps between trials until the observer failed to make four successive correct detections within ten responses, or simply gave up. The voltage setting for the last successful trial was recorded as the threshold value for the subject One determination was made for each of the observers and the arithmetic mean of these determinations was taken as the threshold value for the combination of ambient level, incident angle, and viewing angle (See Appendix D, Tables D-1 through D-8) Only descending series were used because the gap-detection threshold was so very near the detection threshold of the entire figure and the detection rings were blanked when the tracking error was out of tolerance. Under these conditions it was not practical to obtain data from ascending series.

Preferred Working Levels

The working preference determinations were made by asking the observer to adjust the bias control until the trace was as bright as he thought he would like to have it if the display were part of an instrument panel The observer was instructed to scan between the CRT display and three or four 4 in meter faces on the equipment rack while performing the detection and tracking task When the observer was satisfied with the setting, the bias voltage was recorded to the neares 0 01 volt One determination was made for each of the observers and the arithmetic mean of these determinations was taken as the working level preference at each level of ambient illumination (See Appendix D, Tables D-1 through D-8)

Conversion From Grid Bias to Brightness Measures

The mean detection and mean preference settings in volts, $\overline{V}$, were converted to trace brightness values, $\overline{\Delta B}$, in foot-Lamberts by use of the $\overline{\Delta B}$ vs G1 bias curves (Appendix C) that had been determined previously The $\overline{V}$ and $\overline{\Delta B}$ values for detection and working preference are given in Appendix D, Tables D-1 through D-8 for all experimental conditions.

RESULTS AND DISCUSSION

Table 2 summarizes the data obtained at the 10, 000 ft -c ambient condition averaged over the four observers at each combination of lamp and observer position for all four CRTs.

Wash-out

It should be noted that under the conditions of this study none of the CRTs washed-out under 10, 000 ft -c. and it was possible to obtain enough light output from every CRT to obtain gap-detection thresholds and working level preferences The extreme heat generated by the Sun Gun lamps did not allow the investigation of higher levels of illumination

Reflectance

The condition with the lamps at 30° and the observer at 0°, allows the best estimate of the reflectance of the display surface. In terms of low reflectance values (Table 2) the CRTs ranked·

Hartman	21%
Electro Vision	83%
Fairchild	2 40%
Westinghouse	73 00%

The reflectance values calculated for other combinations of lamp and observer positions are difficult to interpret because of problems in setting the lights at 60°, the gradient of illumination across the face at 60°, and the presence of specular reflections at the -45° observer position Note that the values for the Hartman CRT have the greatest variability Front surface reflections and noise were particularly pronounced with this CRT

Brightness

The brightness of the CRT face, B, is, of course, a direct function of the reflectance of the face. Under 10,000 ft -c ambient, with the lamps at the 30° position and the observer at 0°, the following luminance measures (Table 2) were obtained

Hartman	21 0 ft -L
Electro Vision	83 0 ft. -L.
Fairchild	245 0 ft -L.
Westinghouse	7, 300. 0 ft. -L

TABLE 2

Summary Threshold Data for CRT Displays at Conditions: 10,000 ft -c Ambient

Measure	CRT	Light Position 30°, Observer Position 0°	Light Position 30°, Observer Position -45°	Light Position 60°, Observer Position 0°	Light Position 60°, Observer Position -45°	Working Preference With Lights at 30°, Observer at 0°
Reflectance, R(%)	Westinghouse	73	70	67	61	—
	Electro Vision	.83	.80	.55	.86	—
	Hartman	.21	.53	.17	.31	—
	Fairchild	2.4	2.4	2.1	3.0	—
Background Brightness B(ft -L.)	Westinghouse	7,300	7,500	3,000	3,500	—
	Electro Vision	83.0	80.0	27.5	54.0	—
	Hartman	21.0	41.0	10.0	21.5	—
	Fairchild	245	270	98.0	190	—
Trace Brightness $\overline{\Delta B}$(ft.-L)	Westinghouse	400	540	110	145	1250
	Electro Vision	2.90	3.80	1.70	2.30	36.0
	Hartman	1.20	3.00	1.20	2.10	25.0
	Fairchild	10.0	14.0	4.00	6.20	45.0
Contrast, $\overline{\Delta B}/B$	Westinghouse	.055	.072	.037	.041	.171
	Electro Vision	.035	.048	.062	.038	.434
	Hartman	.057	.073	.120	.098	1.190
	Fairchild	.041	.052	.041	.033	.184
Anode Current (μA.)	Westinghouse	6.0	8.5	1.5	2.0	40.0
	Electro Vision	*	*	*	*	1.0
	Hartman	*	*	*	*	*
	Fairchild	2.0	3.5	*	1.0	28.0

*Anode Current <0.5 μA.

The corresponding trace brightness, $\overline{\Delta B}$, at detection and at preferred working level (Table 2) were

	Detection	Preference	Increase
Hartman	1.2 ft -L	25 ft -L.	1980%
Electro Vision	2.9 ft -L	36 ft -L	1140%
Fairchild	10.0 ft -L	45 ft -L	350%
Westinghouse	400.0 ft -L	1,250 ft -L.	220%

Brightness Contrast

The ratio of the increment in brightness to the level of background brightness, $\Delta B/B$, is the basic parameter controlling detection and preference levels on the display. Note that for the 30^{o} light position conditions all of the $\overline{\Delta B}/B$ values are of the same order of magnitude, but that the values for the -45^{o} observer position are consistently about 30 percent higher than for the 60^{o} observer position. In terms of the percentage increase in brightness required for off-axis viewing with the lights at the 30^{o} position (calculated from Table 2), the CRTs ranked

1.	Fairchild	26.8%
2.	Hartman	28.0%
3.	Westinghouse	32.7%
4.	Electro Vision	37.1%

However, with the lights at the 60^{o} position there was a decrease in the brightness required at the -45^{o} observer position for the three experimental CRTs, while an increase in brightness was found for the conventional CRT. In terms of the decrease in brightness required for off-axis viewing with the lights at the 60^{o} position (calculated from Table 1), the CRTs ranked

1.	Electro Vision	-38.7%
2.	Fairchild	-19.5%
3.	Hartman	-18.3%
4.	Westinghouse	+10.8%

As indicated previously some of the inconsistencies present in the data from the extreme conditions of lighting and viewing angles apparently are attributable to differences in the reflecting characteristics of the tubes and to difficulties in setting the lights and measuring the background brightness under those conditions. The data obtained in this study indicate that all the CRTs were useable under extreme lighting and viewing angles and that there were difference among the tubes as noted above. However, if any finer discriminations among the CRTs under the extreme angles of lighting and viewing conditions are required, then the data reported here should be verified with further observations.

Power Requirements

Trace brightness, ΔB, is a function, primarily of beam current per unit area per unit time. Since a direct-writing display was used with writing speed and refresh rate held constant over all elements for all tubes, trace brightness is then directly related to beam current While beam current per se is difficult to measure, anode current is a reasonable first approximation, and can be used to provide a relative index of the power required to produce the required trace brightness The absolute values of anode current vary as a function of writing speed, refresh rate, operating voltage, etc

In terms of anode current, measured to the nearest 0.5µA., the CRTs ranked as follows

		Threshold	Preference
1.	Hartman	<0.5µA.	< 0.5µA.
2.	Electro Vision	<0.5µA.	1.0µA.
3	Fairchild	2 0µA.	28.0µA.
4	Westinghouse	6.0µA	40.0µA.

Summary Comparisons

Summary data for the four CRTs on several key measures are given in Table 3 A summary ranking of the tubes is given in Table 4

Brightness Discrimination Functions

Data from psychophysical experiments, e g., Figure 4, indicate the basic relation between ΔB and B. The wide range of reflectances represented in the present sample of four CRTs coupled with a wide range of ambient illumination levels permitted exploration of the same relation for CRT displays

In Figure 5 the $\overline{\Delta B}$ value obtained with each CRT at each level of ambient illumination is plotted against the corresponding B value obtained for the same CRT under the same ambient level Two sets of curves are plotted, one for gap-detection threshold, and one for working preference. (See Appendix D, Tables D-5 through D-8)

TABLE 3

Summary Comparison of CRT Displays: 10,000 ft.-c. Ambient;

Lamp Position 30°, Observer Position 0°

Measure	CRT			
	Westinghouse	Electro Vision	Hartman	Fairchild
Reflectance, R (%)	73	.83	.21	2.45
Contrast, $\Delta B/B$, at Gap Detection	.055	.035	.057	.041
Anode Current At Gap Detection (µA.)	6.0	*	*	2.0
Increase in Detection $\overline{\Delta B}/B$ At -45° Viewing Angle (%)	32.7	37.1	28.0	26.8
Contrast, $\overline{\Delta B}/B$, At Working Preference	.171	.434	1.190	.184
Anode Current At Working Preference (µA.)	40.0	1.0	*	28.0

*Anode Current <0.5 µA.

TABLE 4

Summary Ranking of CRT Displays

Measure	CRT			
	Westinghouse	Electro Vision	Hartman	Fairchild
Reflectance	4	2	1	3
Increase in Brightness for Off-Axis Viewing with Lights at 30°	3	4	2	1
Decrease in Brightness for Off-Axis Viewing with Lights at 60°	4	1	3	2
Anode Current (Working Level)	4	2	1	3
Sum of Ranks	15	9	7	9

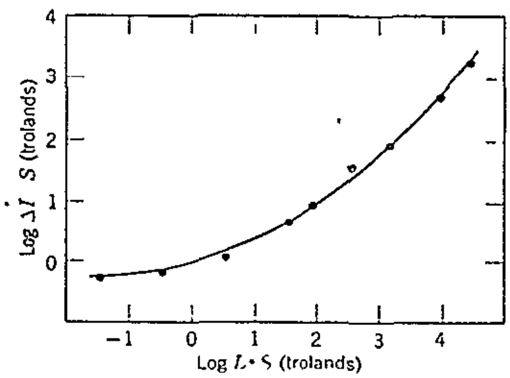

Figure 4 Log retinal illuminance of increment (ΔL S in Trolands) as a function of log adapting retinal illuminance for Subject H in Mueller's 1951 experiment. (As reported in Graham, 1965.)

Figure 5 shows that in general and with minor variations the brightness functions for the various tubes simply spanned different segments of one over-all function The major effects are attributable directly to reducing background brightness regardless of the technique employed The relatively small secondary effects are probably attributable to differences in front surface noise, color contrast, and other variables

The two sets of curves in Figure 5 also demonstrate that the preferred working brightness levels vary as a function of background levels in essentially the same manner as the gap-detection threshold level but that the preference levels are about an order of magnitude greater than the threshold levels In other words, while the general form of the brightness function is similar for different tasks the absolute level required varies as a function of the task

Data from classical psychophysical studies of brightness discrimination are most often expressed in terms of contrast, ΔB/B, vs B, e g , Figure 6 The functions obtained in the present study are replotted in terms of log $\overline{\Delta B}$/B, vs. B in Figure 7 It can be seen that the contrasts obtained in this study for gap-detection threshold compare quite well with the values reported in Graham (1965), except for the lower range of background brightness The determinations in this region were made with the Hartman CRT, and the observers also reported that the front surface of that CRT was especially noisy

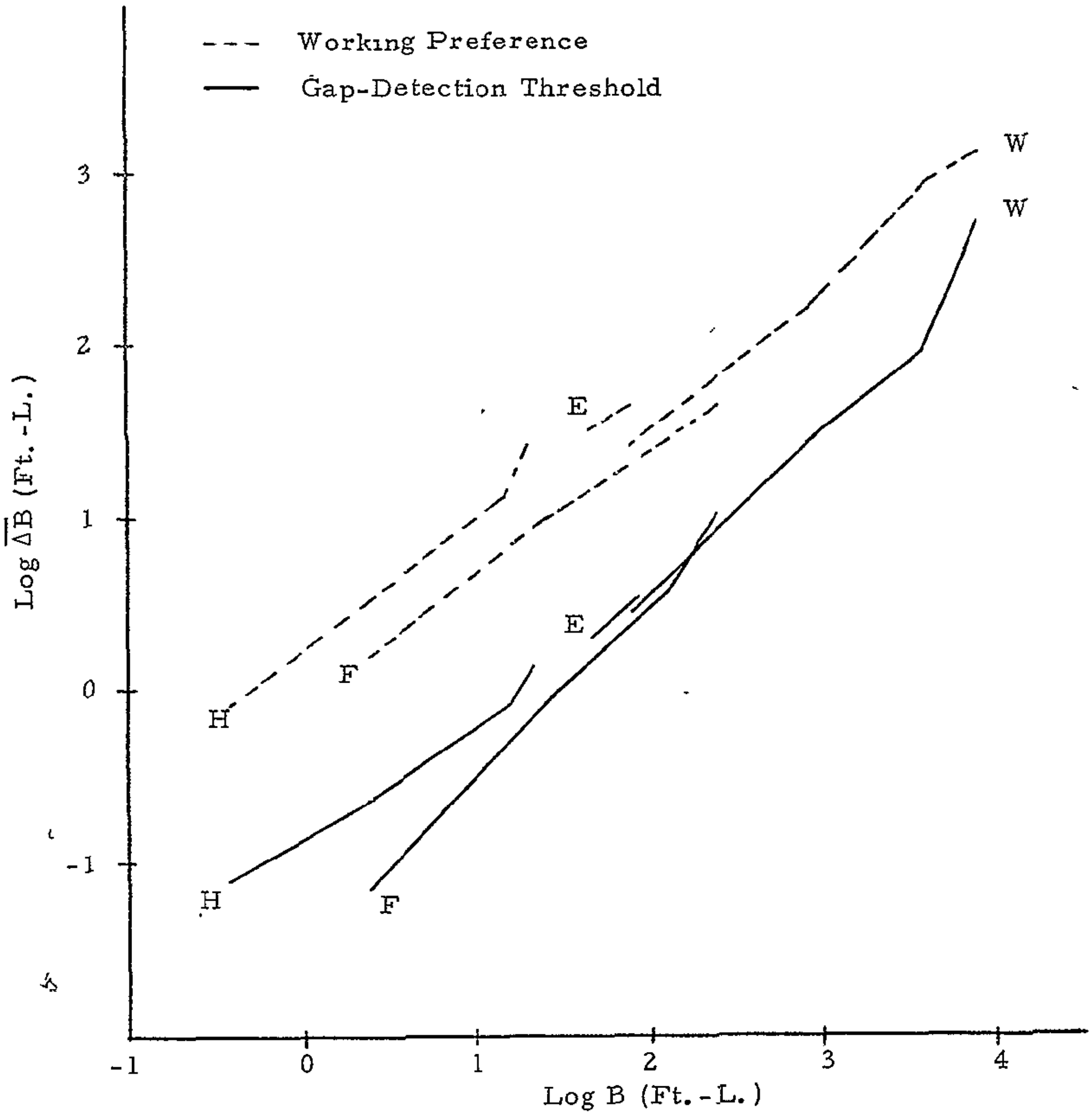

Figure 5. Trace brightness ($\overline{\Delta B}$) vs CRT face brightness (B) for gap-detection thresholds and preferred working levels for CRT displays: Westinghouse (W), Electro Vision (E)(partial data), Hartman (H), and Fairchild (F). (See Appendix D, Tables D-5 through D-8.)

The differences between gap-detection threshold levels and preferred working levels are also shown in Figure 7.

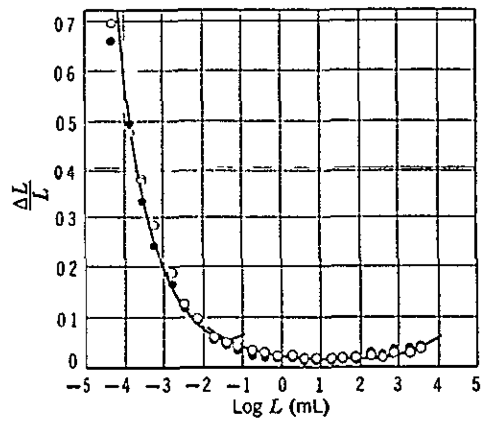

Figure 6. Relation between ΔL/L and log L as shown by König (open circles) and Brodhun (solid circles). (From König and Brodhun 1889 as reported by Graham, 1965.)

CRT Trace Detection and Display Reading Functions

The results obtained in the present study using CRTs are in general agreement with the results of classic psychophysical studies reported as early as 1889 Small differences among the results are attributed to secondary effects, most likely due to differences among stimulus characteristics in the "classical" laboratory and in the "operational" laboratory, such as color temperature of the illuminants effecting color contrast, front surface noise on the CRTs, and the like.

Operationally analogous data have also been obtained by Adler, Kuhns, and Brown (1953) who measured the threshold masking luminance on a radar scope face produced by ambient illuminations expected to be encountered operationally in aircraft The signal to be masked was a trace 15^{o} in visual angle Signal luminance was varied from below -1.0 log mL to above 1.5 log mL Masking luminance was found to range from less than -1 5 log mL to more than 3.0 log mL

The study by Adler, et al (1953) was essentially an experiment on CRT wash-out, i e , how much background brightness is required to wash-out the signal? The results of the Adler study are presented in Figure 8

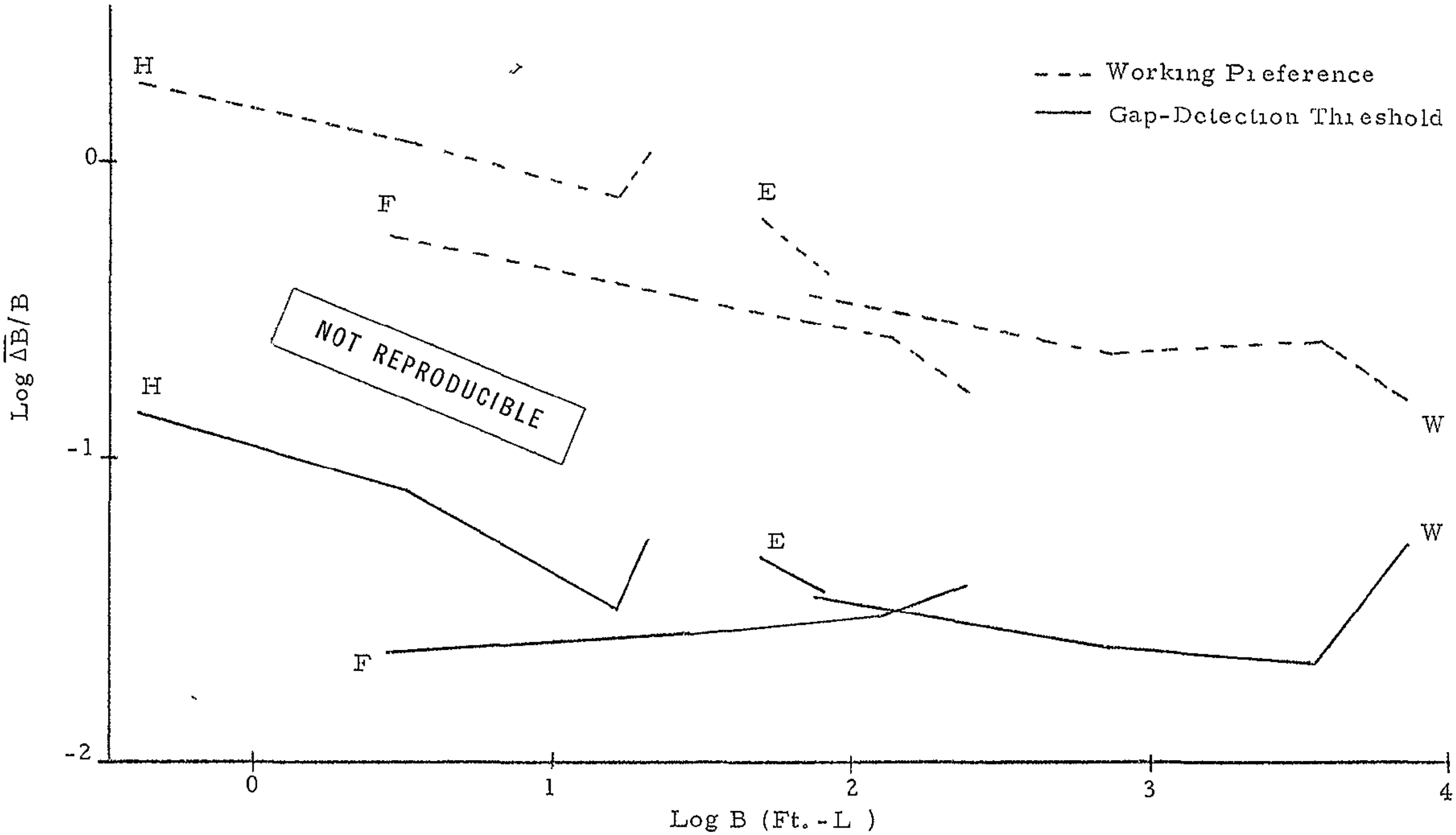

Figure 7. Brightness functions for CRT displays Westinghouse (W), Electro Vision (E) (partial data), Hartman (H), Fairchild (F). (See Appendix D, Tables D-5 through D-8)

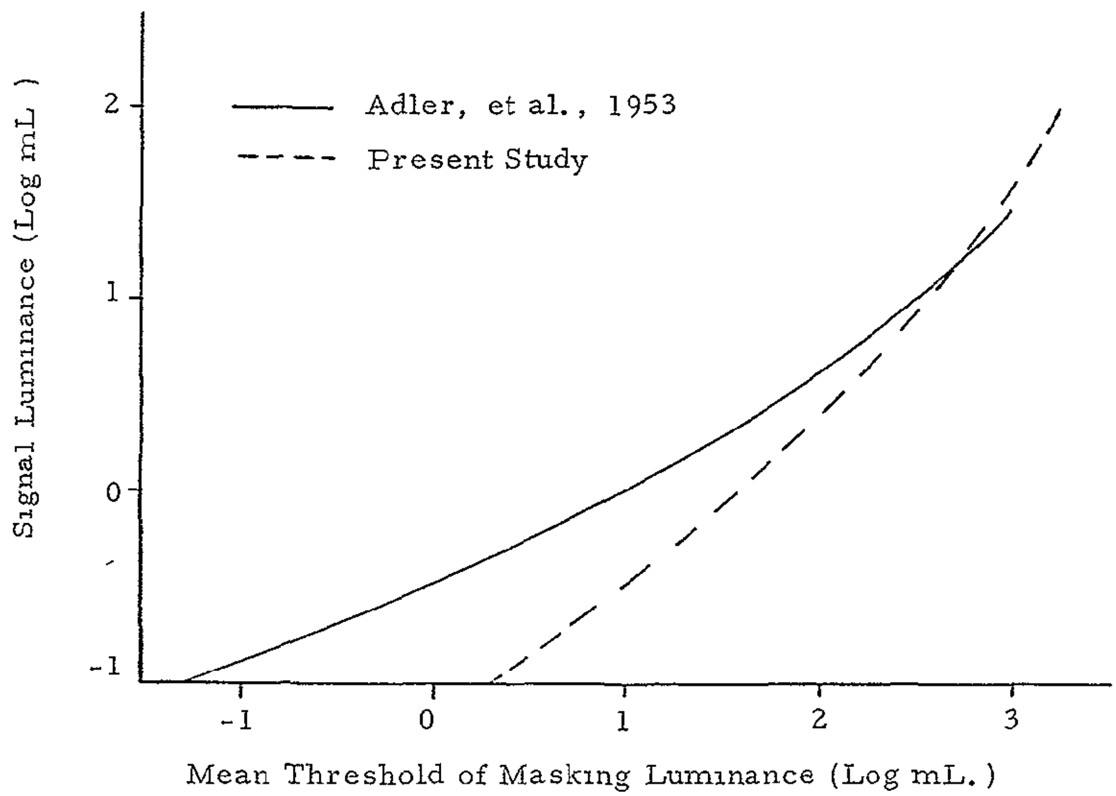

Figure 8. The lowest ambient illuminance required to prevent a radar signal from being detected (i e., threshold masking luminance), plotted as a function of signal luminance. (After Adler, et al., 1953 as reported in Wulfeck, et al, 1958.) Dashed curve is plot of gap-detection data from present experiment.

For comparison the data from the present study in Figure 5 have been converted to log mL. and replotted as the dashed curve superimposed on the data by Adler et al. in Figure 8.

In spite of differences in experimental conditions, correspondence of the results seems remarkable, especially at the high end of the masking range, which is the part of most interest. The increasing discrepancies between the two sets of data as low luminances are reached are very likely attributable to averaging data from Figure 5 across the experimental CRTs and to different CRT effects in performing the function for which they were designed.

So far the present results have been demonstrated to agree with classically obtained brightness discrimination data and with operational laboratory CRT display data using a trace masking criterion

Data obtained by Semple and Goettelmann (1969) under similar ranges of ambient illumination,but with somewhat different visual tasks using electroluminescent displays, permit comparison of the brightness functions for CRT displays with the brightness functions for electroluminescent displays

Results from the study by Semple and Goettelmann (1969) are plotted in Figures 9 and 10. The data in Figure 9 were taken using an electroluminescent bar-graph display under ambient levels of 500, 5,000 and 10,000 ft.-c.

The data in Figure 10 were taken using a numeric display under the same levels of ambient illumination

Three performance measures are shown detection threshold, the point at which the observer reported he could just see that the display was on, legibility threshold, the point at which the observer could read the values portrayed with 100 percent accuracy, comfort setting, the preferred brightness setting averaged over all observers

It is interesting to note that the "detection" and "comfort" functions of the bar-graph display coincide with the "gap-detection threshold" and "working preference" functions of the present study. The corresponding values for the numeric display are about half a log unit higher. Given the differences in visual tasks, this is a rather satisfying agreement.

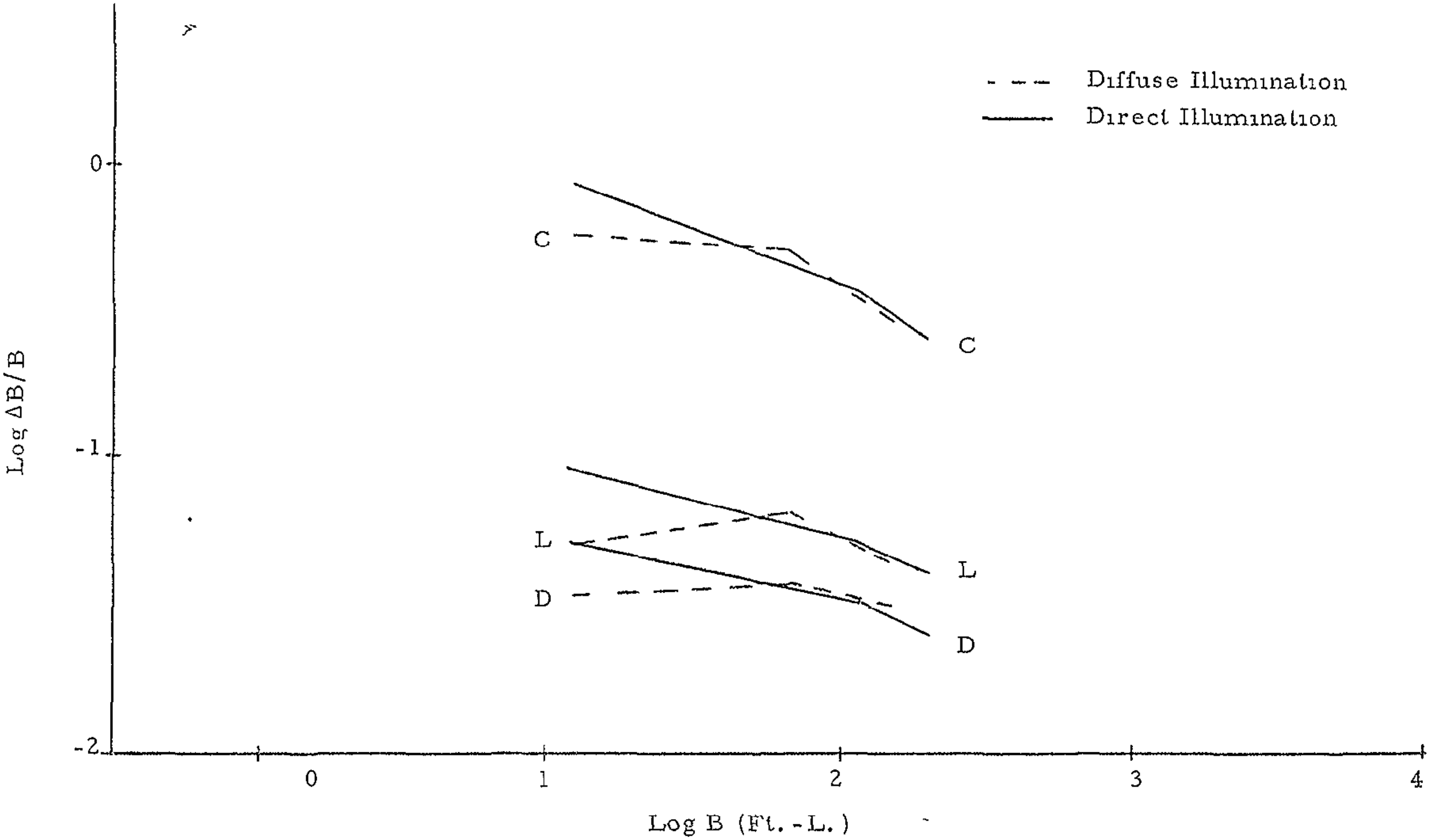

Figure 9. Brightness functions for electroluminescent bar-graph display Detection (D), 100 percent Legibility (L) and Comfort (C) thresholds. (Adapted from Semple and Goettelmann, 1969)

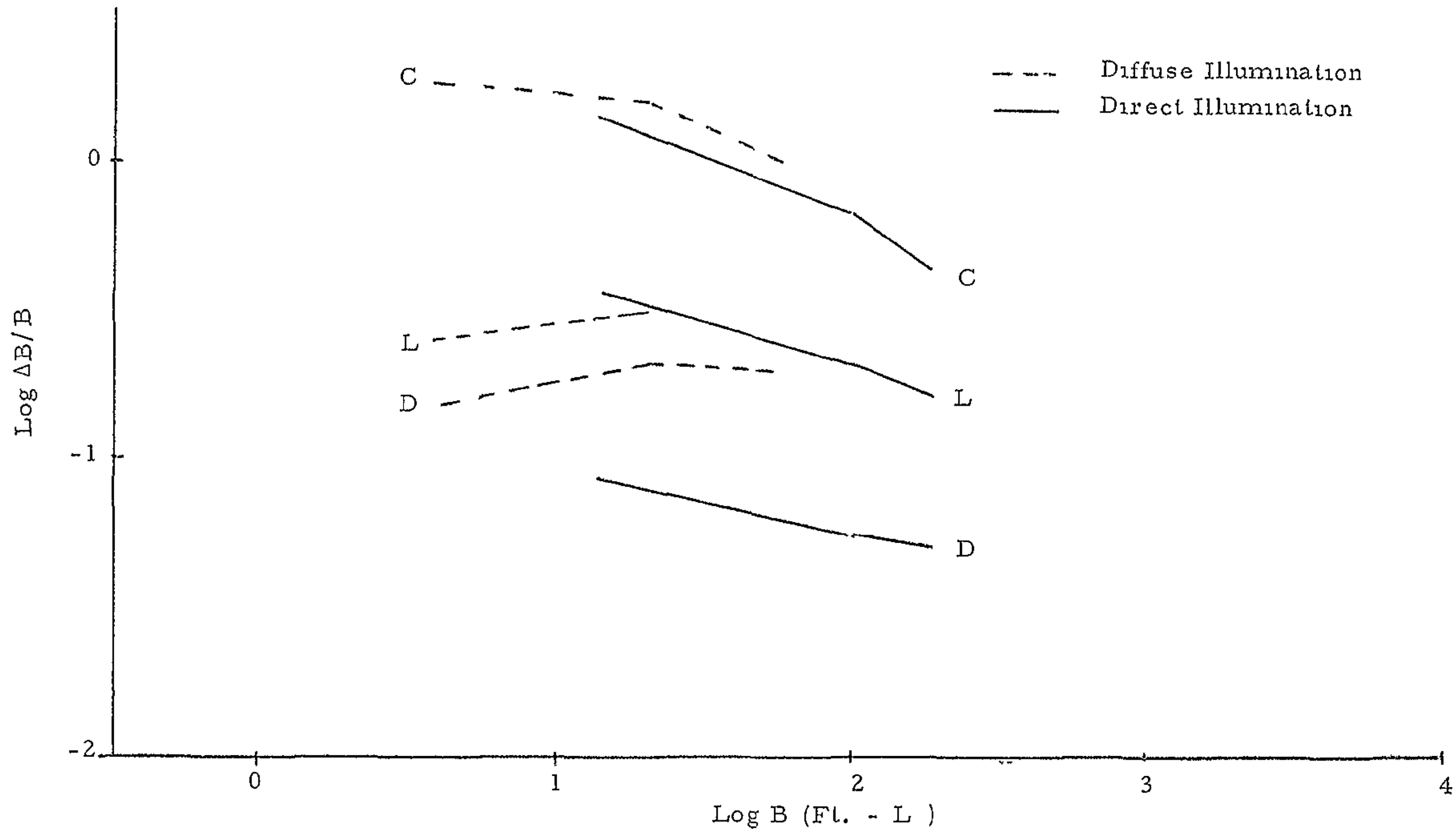

Figure 10 Brightness functions for electroluminescent numeric display. Detection (D), 100 percent Legibility (L) and Comfort (C) thresholds (Adapted from Semple and Goettelmann, 1969)

CONCLUSIONS

1 Under the conditions of this study none of the CRTs tested "washed-out" under the highest level of ambient illumination, 10,000 ft -c That is, gap-detection thresholds, and working preference settings were obtained

2. In general, visual performance was primarily a function of background brightness For a given level of ambient illumination, background brightness is determined by the reflectance of the CRT face. Therefore, as a first approximation the tubes may be rank-ordered in terms of their reflectance values

CRT	Reflectance
Hartman	21%
Electro Vision	83%
Fairchild	2 40%
Westinghouse	73.00%

3 Given the reduction of background brightness to an acceptable level, further discrimination among CRTs depends upon secondary factors such as off-axis viewing, color contrast, front-surface noise, power consumption, cost, and trade-offs among them

4 The agreements among the findings of this study, the data from Adler, et al (1953), the data from the Semple and Goettlemann (1969) study and classical psychophysical data (Graham, 1965) indicate that the classical data on brightness discrimination are adequate for first-order design approximations

5 However, the discrimination functions form a family of curves ranging over one or two log units of brightness depending upon the specific visual task If more precise design data than those reported here are required, a fairly high fidelity simulation of the operational task is in order

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Adler, H. E., Kuhns, M. P., and Brown, J. L. Masking of CRT Displays by Ambient Illumination (WADC Technical Report 53-266) Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. November 1953 (As reported in Wulfeck, et al. 1958.)

Graham, C. H (ed) Vision and Visual Perception. New York John Wiley & Sons, Inc , 1965.

König, A. and Brodhun, E Experimentelle Untersuchungen ueber die psychophysische Fundamentalformel in Bezug auf den Gesichtssinn. Sitzungsber. Preuss Akad Wiss., Berlin, 1889, 27, 641-644 (As reported in Graham, 1965.)

Semple, C. A., Jr. and Goettelmann, G. Electroluminescent Display Legibility Contrast Ratio Requirements as a Function of Ambient Illumination (Technical Report MSS-TR-69-01). Northridge, California Manned Systems Sciences, October 1969.

Wulfeck, J. W , Weisz, A , and Rabin, Margaret W. Vision in Military Aviation (WADC Technical Report 58-399). Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, November 1958

APPENDIX A

SPECIFICATIONS FOR EXPERIMENTAL CRTs

WESTINGHOUSE

Industrial & Military CRT

November 1968

Type	WX-30844P-1 Low Voltage Focus, Magnetic Deflection Compact Monitor Tube Line Width = 0.008"
Basic Charactertistics	4-1/2 " x 5-1/2" Rectangular Low Voltage Focus 90^o Magnetic Deflection Aluminized
Typical Applications	Computer Readout Monitor
Special Features	Compact 0 008" Line Width

Electrical

Cathode . . . . Coated Unipotential

Heater

Voltage . . . . 6 3 Volts
Current . . . . 0 6 Ampere

Direct Interelectrode Capacitances

Grid 1 to All Other Electrodes . . . . 9 pF
Grid 2 to All Other Electrodes . . . . 7 pF
Cathode to All Other Electrodes . . . . 7 pF

Focusing Method . . . . Electrostatic

Deflection . . . . 90^o Magnetic

Optical

Screen Phosphor	Note 1
Faceplate	
Configuration	Spherical
Glass	Clear
Transmission	92%

Mechanical

Mounting Position	Any
Net Weight	1 5 Pounds

Absolute Maximum Ratings

Anode Voltage	15000 max.	Volts
Grid 4 (Focus) Voltage	800 max	Volts
Grid 2 Voltage	600 max.	Volts
Grid 1 Voltage		
Negative Bias Value	180 max	Volts
Positive Bias Value	0 max	Volts
Positive Peak Value	0 max	Volts
Peak Heater-Cathode Voltage		
Heater Negative with respect to Cathode		
During Warm-up Period of 15 sec max.	410 max	Volts
After Equipment Warm-up Period	180 max	Volts
Heater Positive with respect to Cathode		
Peak	180 max	Volts
DC	0 max	Volts

Limiting Circuit Values

Grid 1 Circuit Resistance	1 5 max	Megohms
Grid 2 Circuit Resistance	See Note 2	
Focus Electrode Circuit Resistance	10000 min	Ohms

Typical Operating Conditions

Anode Voltage	9000 Volts
Grid 4 (Focus) Voltage	0 to 300 Volts
Grid 2 Voltage	300 Volts
Grid 1 Spot Cut-off Voltage	-10 to -30 Volts
Maximum Line Width "A" with P4 (note 3)	0.008 Inch
Spot Position (Note 4)	8 mm

NOTES

1. Westinghouse Military and Industrial Cathode Ray Tubes can be supplied with most of the standard JEDEC phosphors.

2. A grid 2 circuit resistance of approximately 0.5 megohm should be provided.

3. Line width is measured by the shrinking raster method with a peak current of 100 microamperes. Line width with other phosphors may vary slightly.

4. With the tube shielded against external magnetic fields, the undeflected focused spot lies within a circle of 8 mm radius concentric with the faceplate.

5 The WX-number identifies a specific laboratory design, the design and, consequently, the data and type number are subject to change No obligations are assumed to manufacture this particular device in the future unless otherwise arranged. These drawings and specifications are the property of Westinghouse Electric Corporation, Electronic Tube Division, and shall not be reproduced or copied or used as the basis for the manufacture or sale of apparatus and/or devices without permission.

ELECTRO VISION INDUSTRIES

DATA SHEET

31 March 1970

TUBE TYPE VC6AEP1 (S) (NASA) S/N's 1, 2 & 3 P.O. TCG 0007

TEST CONDITIONS

EA_2 - 9 KV, EG_2 - 300V, EF - 6 3V, .6 A, Raster - 3" X 4"

OPERATIONS	EG_1	IA_2	L. O	EA_1	Line Width	I_k max	OAL
S/N 1	-39						
	-18	100	11	50	.004"		
	- 9	300	24	0	.0045"		
						1 3	8"
S/N 2	-34						
	-17	100	9	100	.004"		
	- 6	300	23	50	.0045"		
						1.1	8"
S/N 3	-42						
	-20	100	9	150	.0035"		
	-10	300	31	100	004"		
						1.3	8.25"

HARTMAN SYSTEMS COMPANY

HIGH CONTRAST TYPE CRT
HC-1101
S/N-2

Basic Characteristics

4-1/2" x 5-1/2" Rectangular
Low Voltage Focus
90° Magnetic Deflection
Aluminized

Electrical Characteristics

Cathode	Coated Unipotential
Heater	
Voltage	6 3 Volts
Current	0.6 Ampere
Direct Interrelectrode Capacitances	
Grid 1 to All Other Electrodes	9 pF
Grid 2 to All Other Electrodes	7 pF
Cathode to All Other Electrodes	7 pF
Focusing Method	Electrostatic
Deflection	90° Magnetic

Optical Characteristics

Screen Phosphor	P31 Type
Tube Type (Westinghouse)	WX-30844P

Mechanical Characteristics

Mounting Position	Optional
Net Weight	2 0 Pounds

Absolute Maximum Ratings

Anode Voltage	15000 max. Volts
Grid 4 (Focus) Voltage	800 max. Volts
Grid 2 Voltage	600 max. Volts
Grid 1 Voltage	
Negative Bias Value	180 max. Volts
Positive Bias Value	0 max. Volts
Positive Peak Value	0 max Volts
Peak Heater-Cathode Voltage	
Heater Negative with respect to Cathode	
During Warm-up Period of 15 sec max.	410 max. Volts
After Equipment Warm-up Period	180 max. Volts
Heater Positive with respect to Cathode	
Peak	180 max Volts
DC	0 max Volts

Limiting Circuit Values

Grid 1 Circuit Resistance	1 5 max. Megohms
Grid 2 Circuit Resistance	See Note 1
Focus Electrode Circuit Resistance	10000 min. Ohms

Typical Operating Conditions

Anode Voltage	9000 Volts
Grid 4 (Focus) Voltage	0 to 300 Volts
Grid 2 Voltage	300 Volts
Grid 1 Spot Cut-off Voltage	-10 to -30 Volts
Maximum Line Width (Note 2)	0 008 inch
Spot Position (Note 3)	8 mm

NOTES

1. A grid 2 circuit resistance of approximately 0.5 megohm should be provided
2. Line width is measured by the shrinking raster method with a peak current of 100 microamperes
3. With the tube shielded against external magnetic fields, the undeflected focused spot lines within a circle of 8 mm radius concentric with the faceplate

FAIRCHILD

Cathode-Ray Tube
Type KC2920PFC
Serial No. 250658

Typical conditions
- 16 KV = anode
- 500 V = G2
- 6.3 V = EF
- 0 - 300 V = G4

Mechanical
- HEA anti-reflection panel laminated onto face of CRT
- Overall length 7-1/4 inches
- Basing 8HR
- Base B7-208
- Base schematic -

Element	Pin No
Heater	1 and 8
G1	2 and 6
G2	3
G4	4
Cathode	7
NC	5
Anode	Bulb J1-22

Data
- Focus = 200 V
- Cut-off G1 = -31 V
- Zero bias current = 420 μA
- Line brightness = 115 Ft. L (Note 1)
- Reflectivity = 2 5%
- Modulation at 200μA = 23V
- Gas ratio = 10 μA
- Line width at 100 μA = .0075 inch

NOTE 1 Line brightness taken with 2' aperture Pritchard Spectrometer at writing speed 6000 inches/second.

NOTE 2 Line brightness and contrast transfer ratio will be improved by increasing anode voltage. Tube can be operated at 18 KV with an increase of line brightness of 30%

APPENDIX B

COMPUTER DIAGRAMS

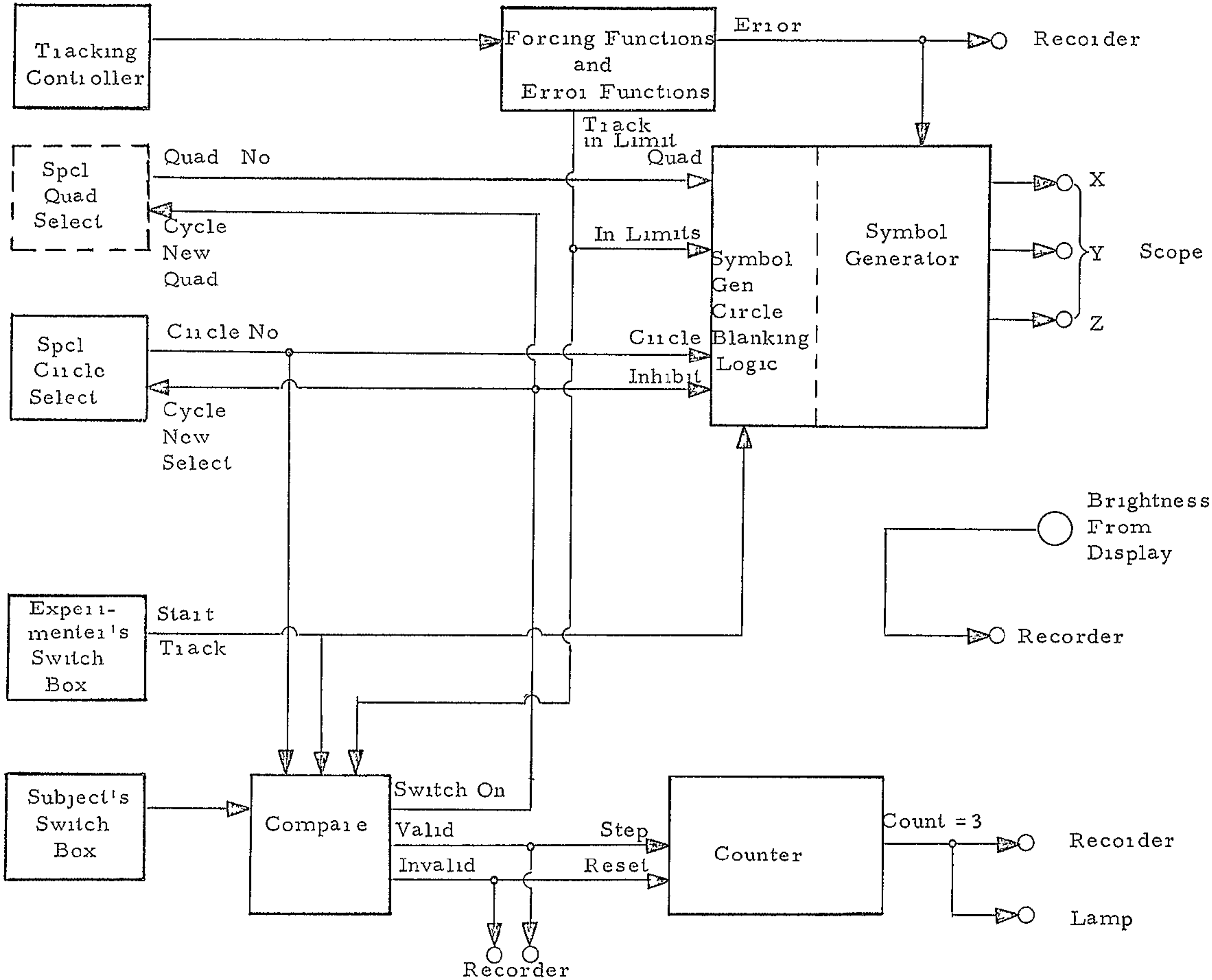


Figure B-1. System block diagram

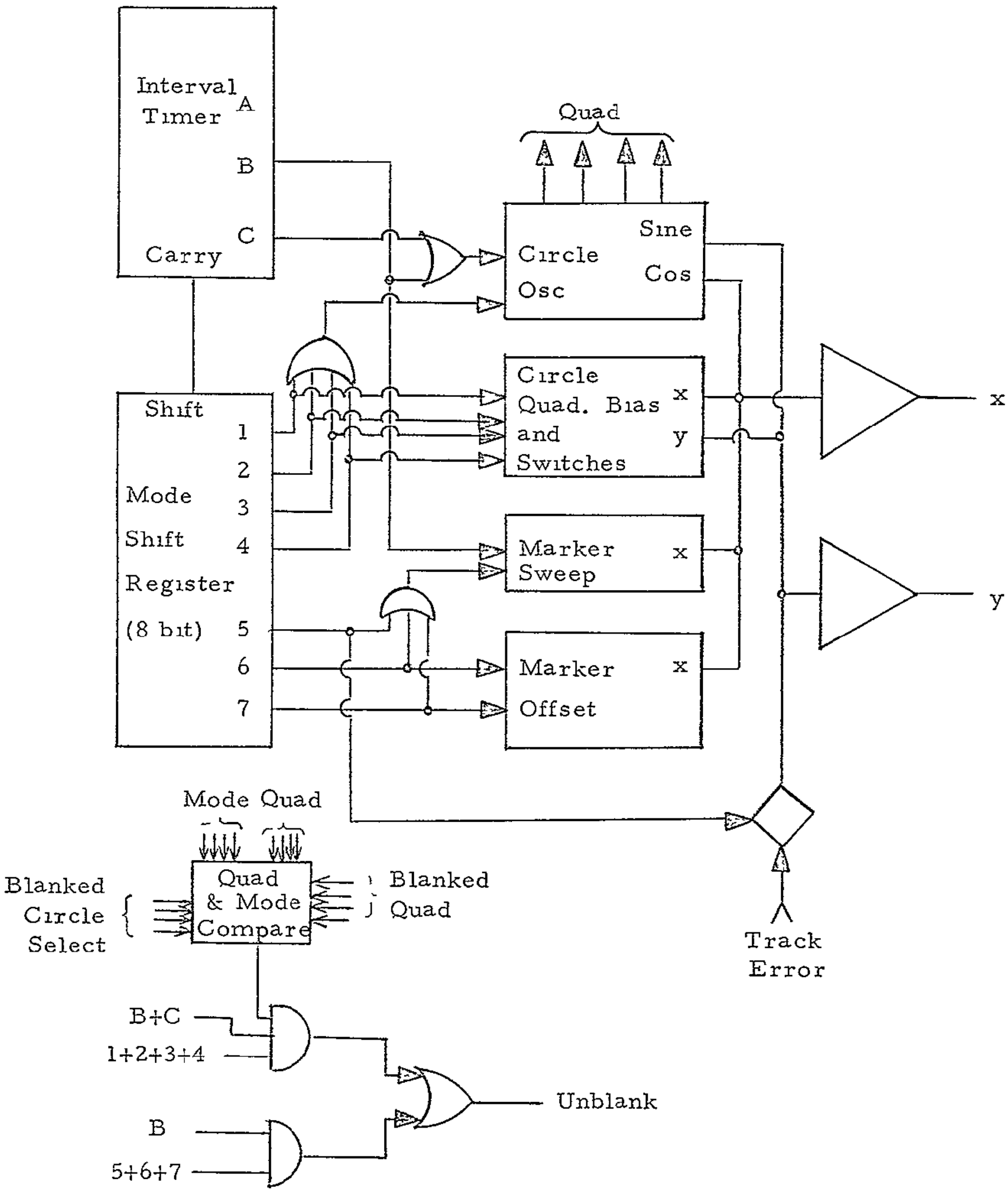


Figure B-2 Symbol generator block diagram

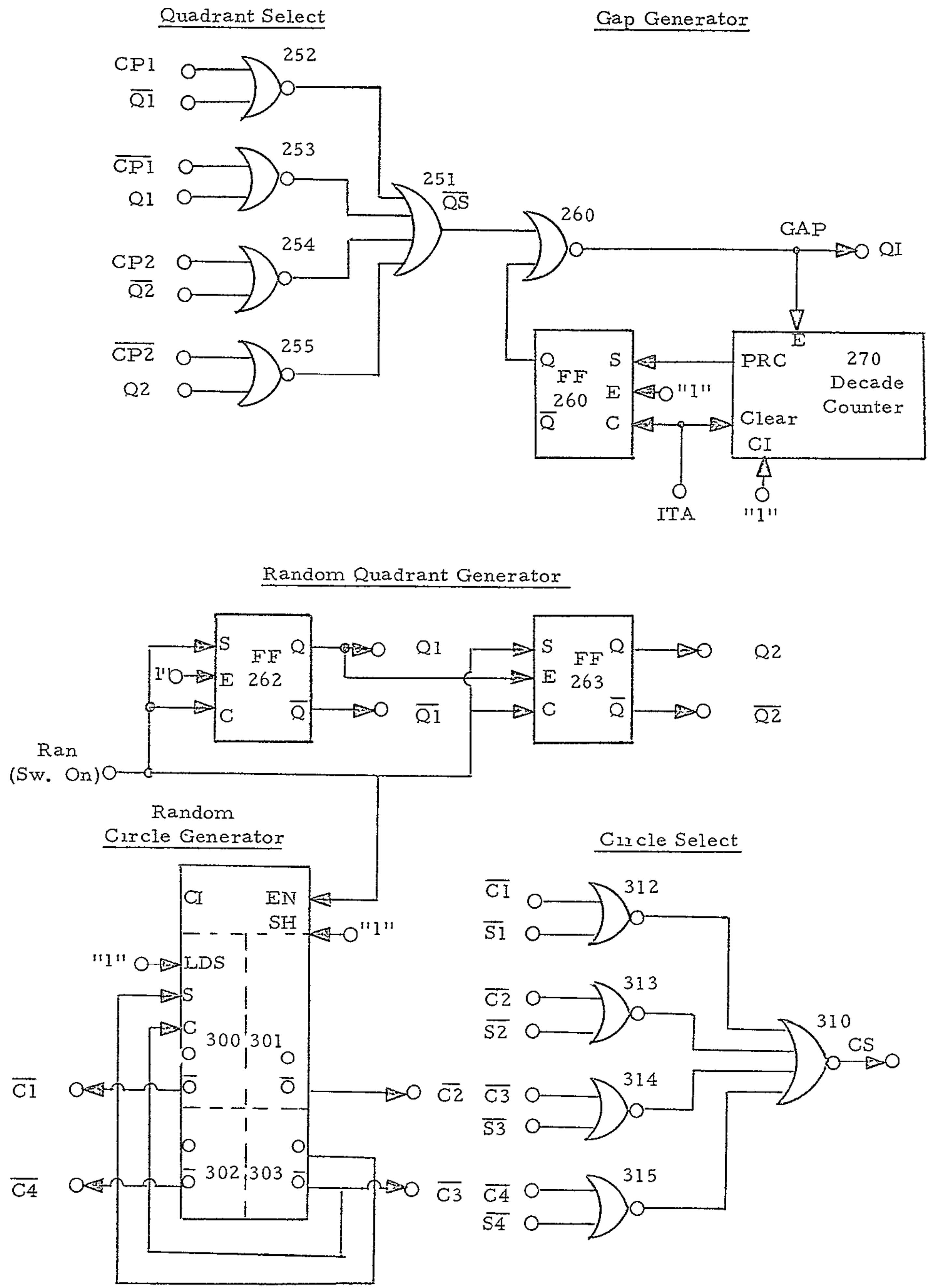


Figure B-3 Symbol logic diagram

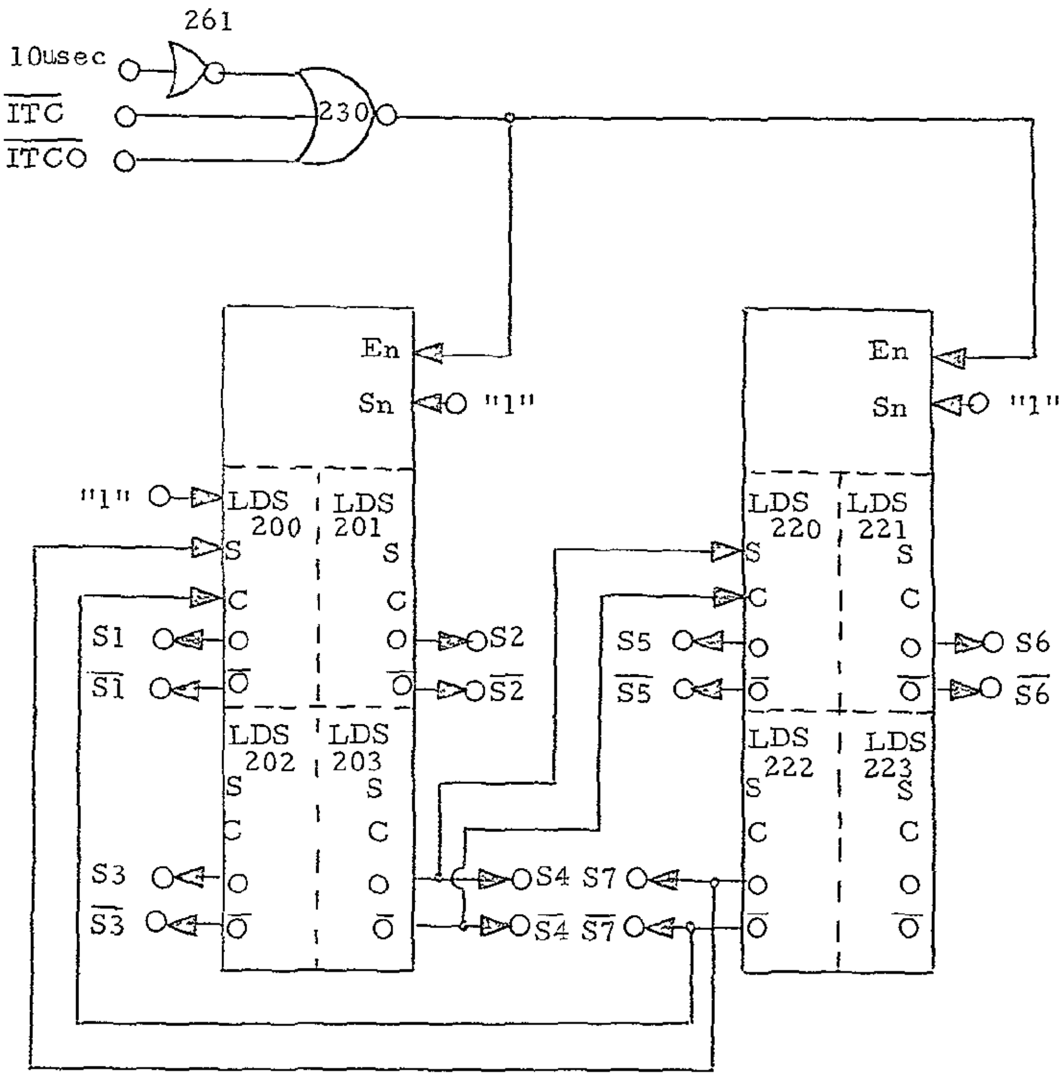


Figure B-4. Symbol generator state register (7 bit shift register). This shift register shifts at the end of each C interval

Selection / State-Interval		Unblank 1	Generator Select	Integrator Mode	Position Select Y-X
1 (Circle)	A	O	C	R	U-L
	B	1	C	O	U-L
	C	O	C	R	U-L
2 (Circle)	A	O	C	R	U-R
	B	1	C	O	U-R
	C	O	C	R	U-R
3 (Circle)	A	O	C	R	D-L
	B	1	C	O	D-L
	C	O	C	R	D-L
4 (Circle)	A	O	C	R	D-R
	B	1	C	O	D-R
	C	O	C	R	D-R
5 (Left Horizon)	A	O	L	R	E-C
	B	1	L	O	E-C
	C	1	L	O	E-C
6 (Right Horizon)	A	O	L	H	E-C
	B	1	L	O	E-C
	C	1	L	O	E-C
7 (Marker)	A	O	L	R	C-C
	B	1	L	O	C-C
	C	O	L	R	C-C

Generator Select C = Circle, L = Line Segment

Integrator Mode R = Reset, O = Operate, H = Hold

Position Select U = Up, D = Down, L = Left, R = Right, C = Center, E = Error

Figure B-5 State switching matrix.

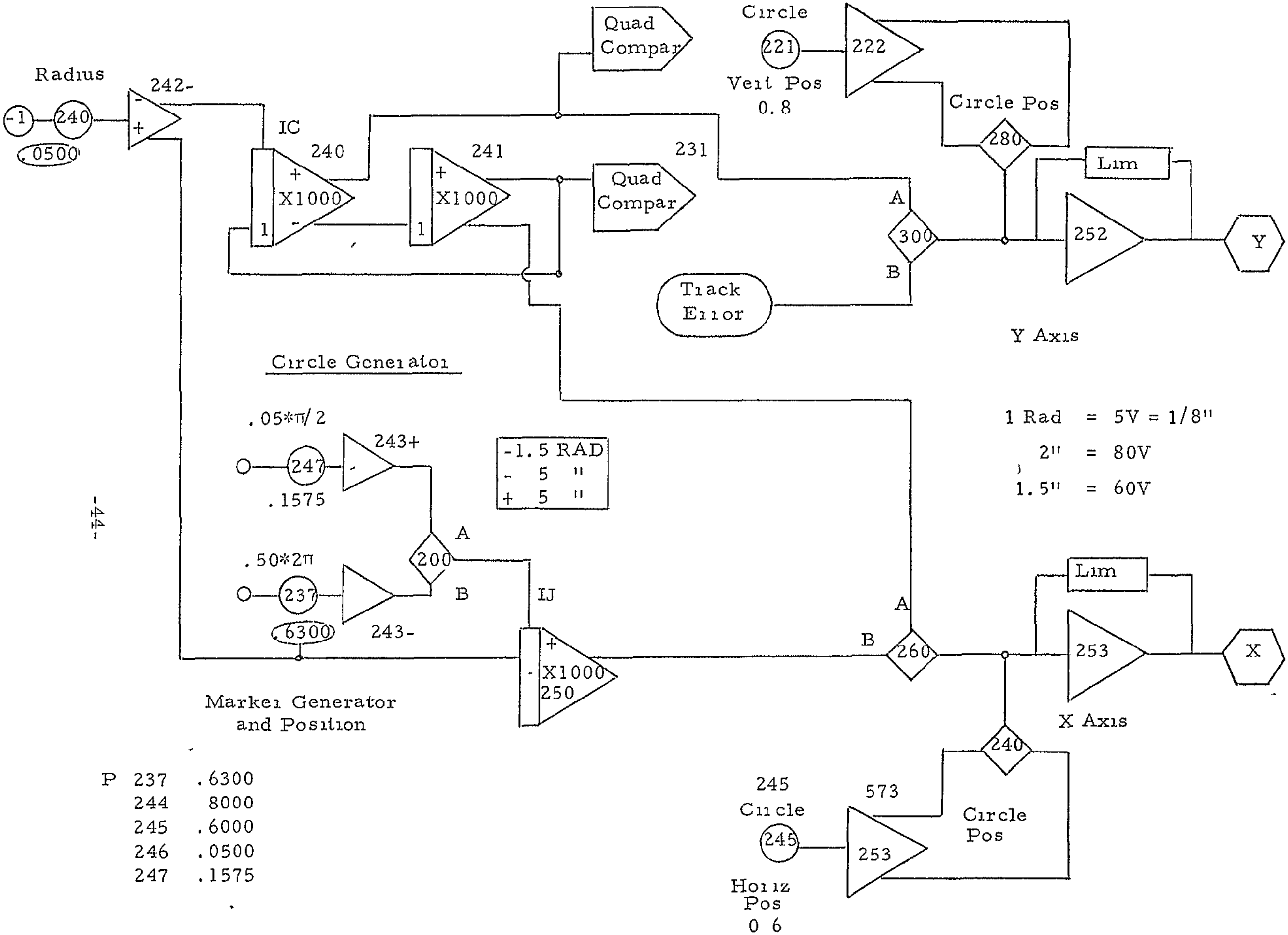


Figure B-6. Symbol generator analog diagram.

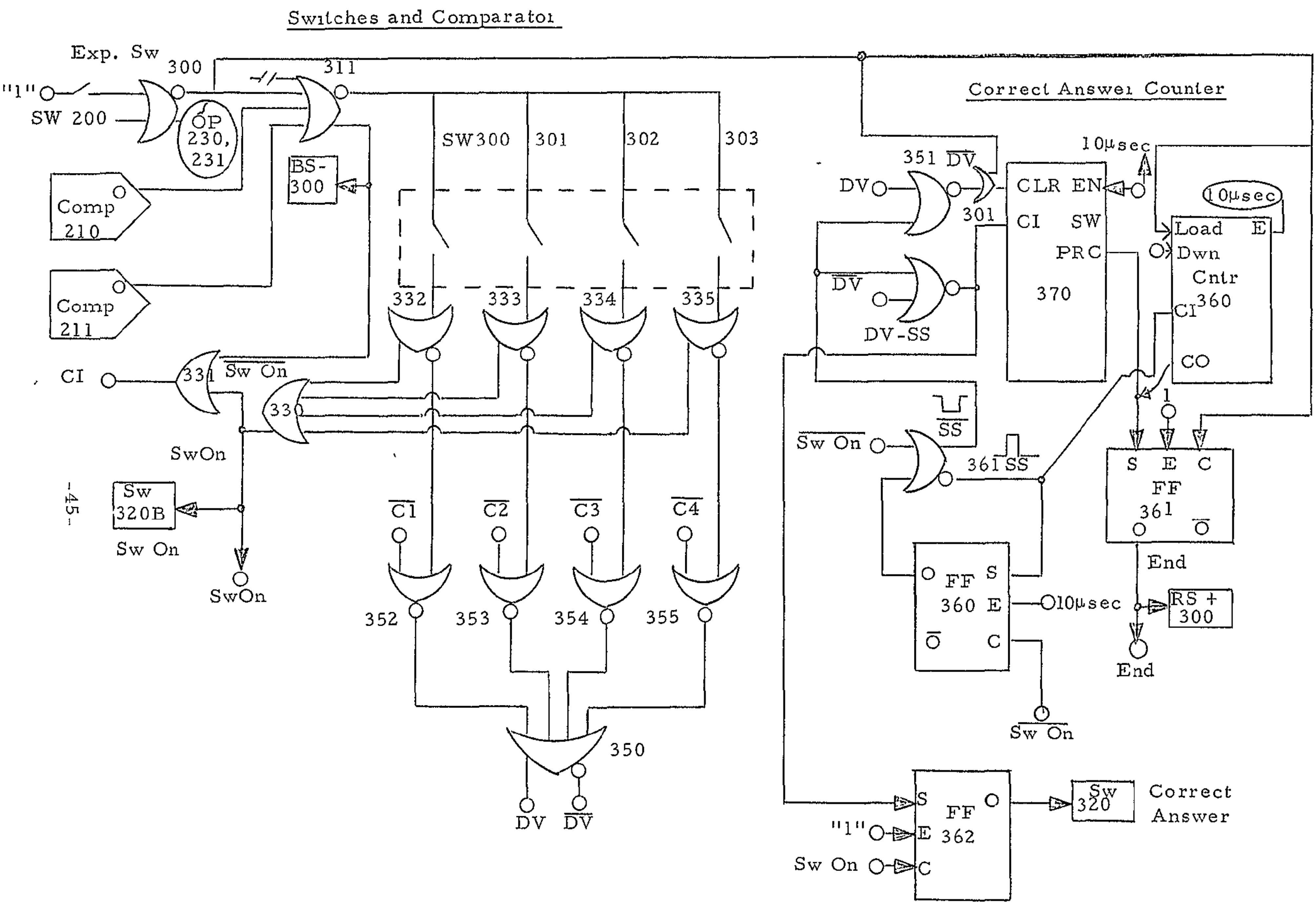
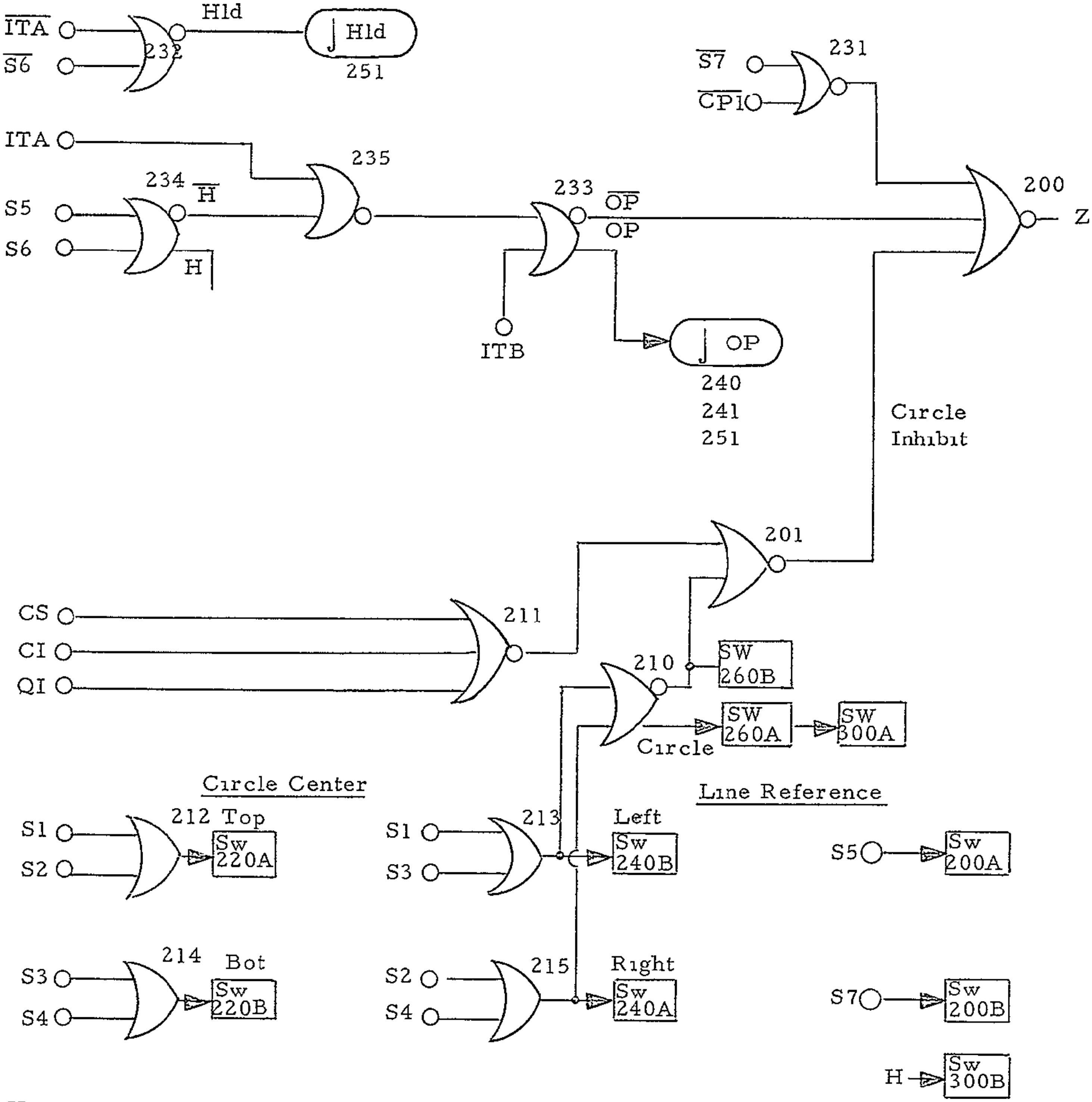


Figure B-7 Control logic diagram.



H	=	Horizon = SS+S6
OP	=	Operate = ITB + H·$\overline{\text{ITA}}$
HLD	=	Hold = S6·ITA
RESET	=	$\overline{\text{OP+HLD}}$
CIR	=	S1+S2+S3+S4
CI	=	Circle Inhibit
QI	=	Quad Inhibit
CS	=	Circle Select
CP1	=	Comp 230
CP2	=	Comp 231

Figure B-8. Control logic diagram

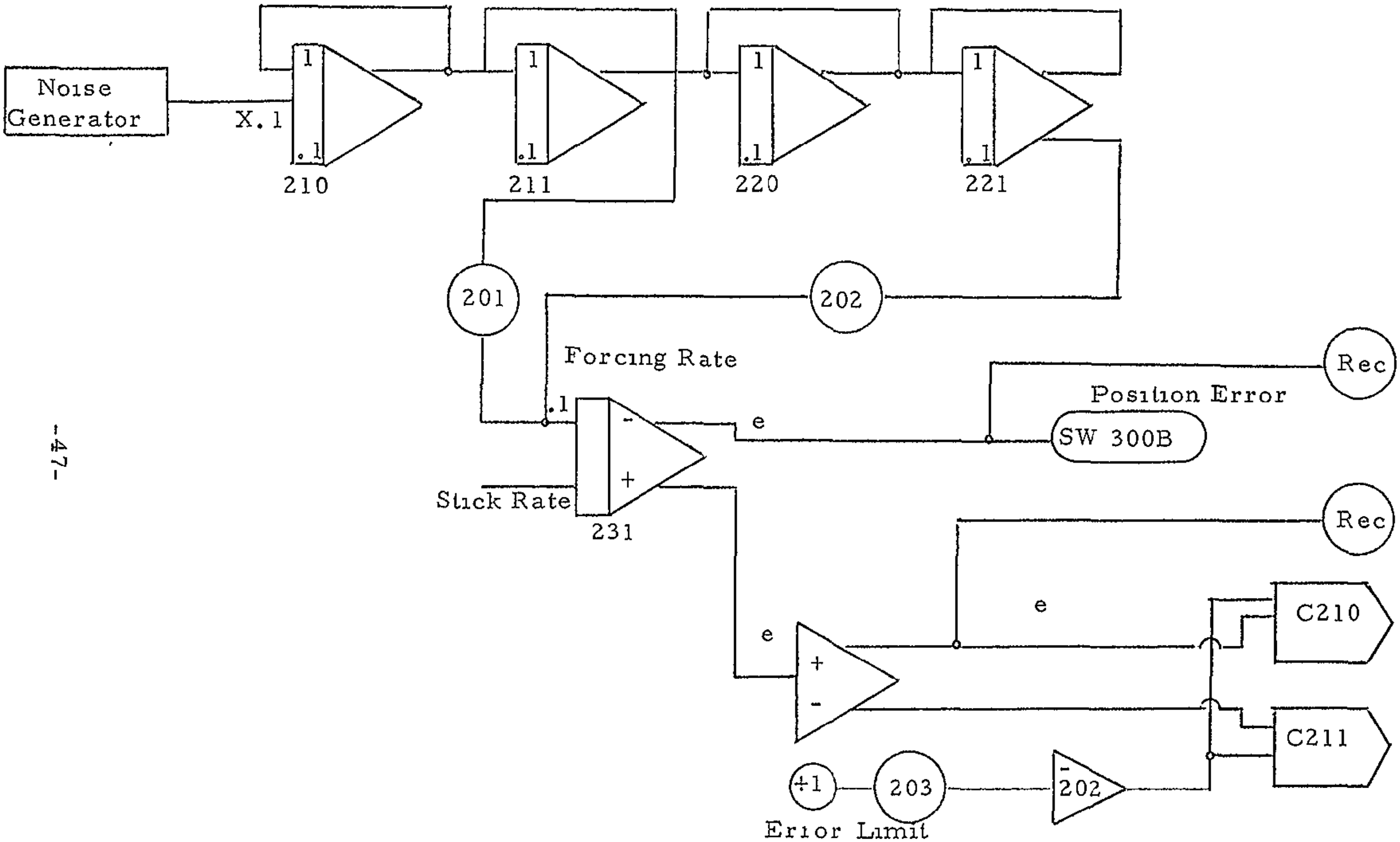


Figure B-9. Tracking system analog diagram.

APPENDIX C

BRIGHTNESS AND ANODE CURRENT TRANSFER FUNCTION

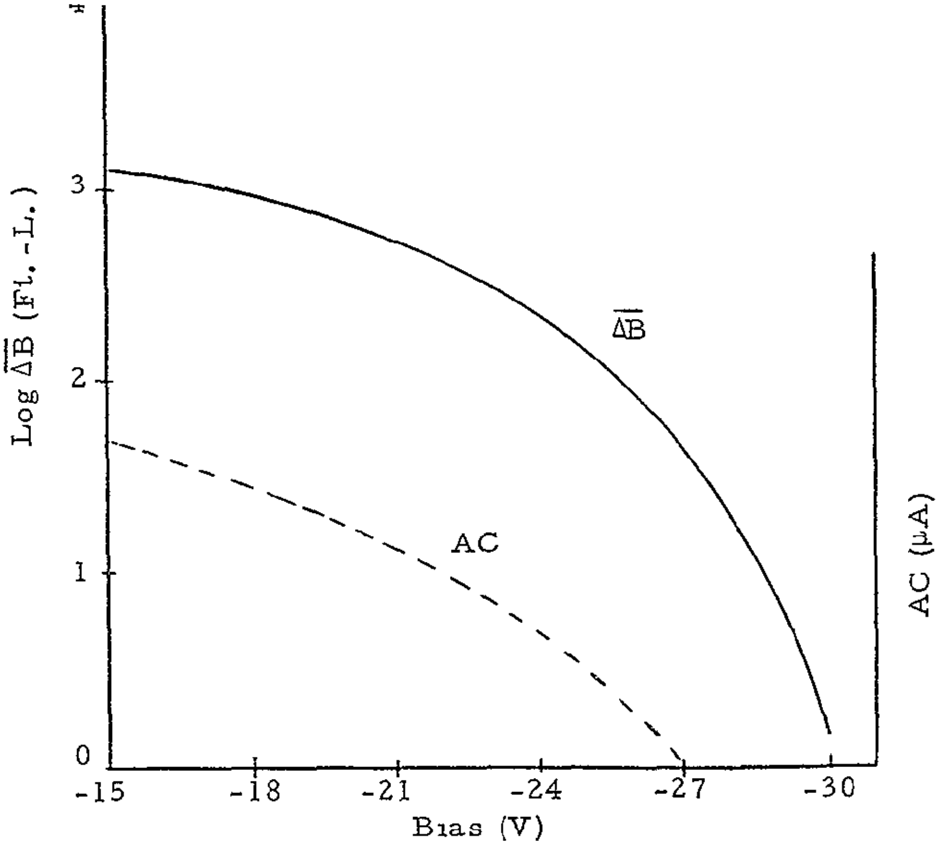


Figure C-1. Westinghouse mean trace brightness ($\overline{\Delta B}$) and anode current (AC) vs G1 bias.

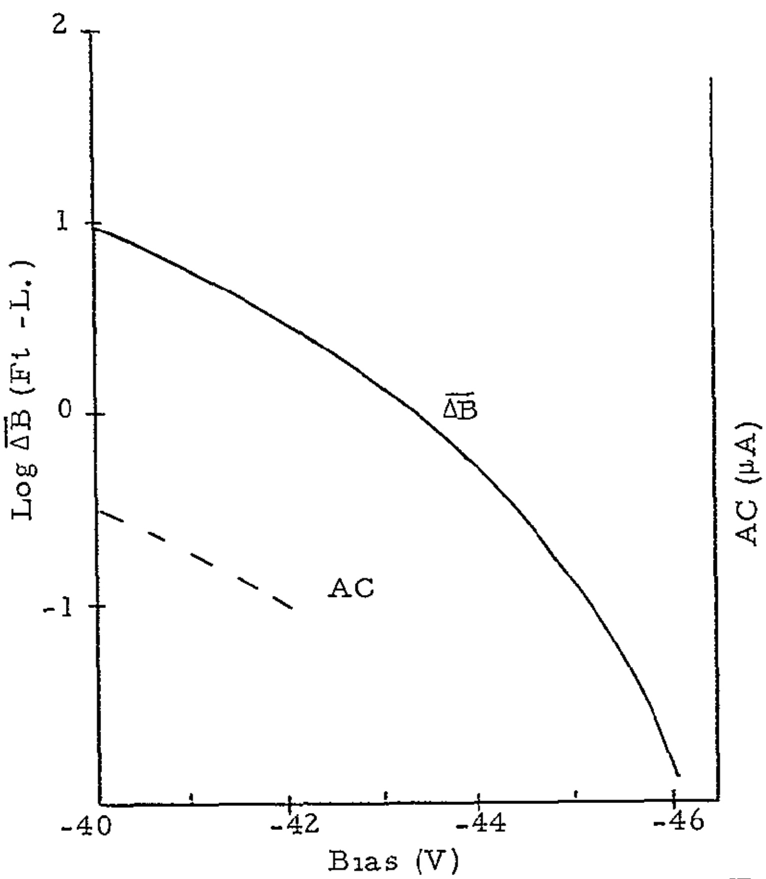


Figure C-2. Electro Vision mean trace brightness ($\overline{\Delta B}$) and anode current (AC) vs G1 bias.

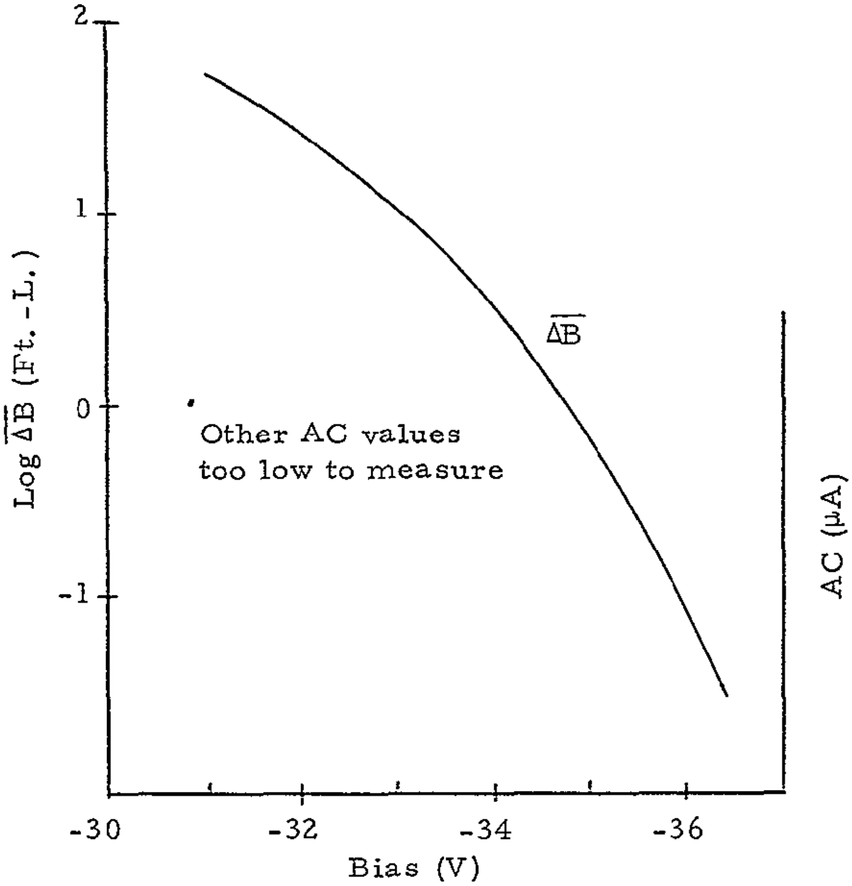


Figure C-3 Harman· mean trace brightness ($\overline{\Delta B}$) and anode current (AC) vs G1 bias.

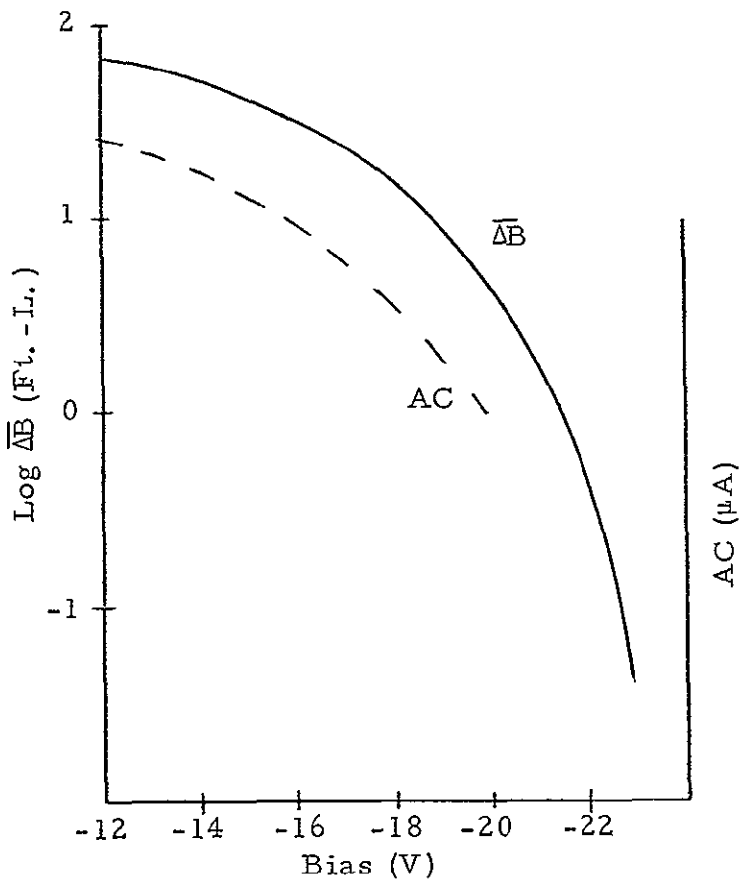


Figure C-4 Fairchild: mean trace brightness ($\overline{\Delta B}$) and anode current (AC) vs G1 bias

TABLE C-1

Westinghouse: Figure Brightness, ΔB, (ft.-L.)

G1 Bias (Volts)	Gap Position 1	2	3	4	$\overline{\Delta B}$	Anode Current (μ A.)
30.00	1.90	2.70	2.85	1.90	2.21	*
	1.70	1.90	2.55	2.40		
	1.80	1.90	2.90	2.05		
29.00	9.50	10.5	13.5	10.5	12.2	*
	9.00	10.5	15.0	15.0		
	9.50	13.0	15.5	11.5		
28.00	28.0	34.0	42.0	48.0	38.5	*
	31.0	46.0	43.0	38.0		
	32.0	34.0	48.0	38.0		
27.00	50.0	68.0	88.0	92.0	71.8	1.0
	50.0	82.0	92.0	56.0		
	74.0	70.0	84.0	56.0		
26.00	115	95.0	115	75.0	100	1.5
	100	100	100	80.0		
	110	85.0	120	105		
25.00	155	200	230	190	199	3.0
	165	220	200	200		
	210	200	210	210		
24.00	245	320	380	340	308	4.5
	220	360	360	280		
	265	320	300	300		
23.00	400	440	480	440	437	7.0
	400	460	500	400		
	360	460	500	400		
22.00	540	540	780	640	615	9.5
	500	580	680	620		
	600	620	700	580		
21.00	540	720	820	700	733	12.0
	580	760	820	780		
	560	780	840	900		
18.00	920	1000	1000	950	1020	27.5
	900	1050	1100	1000		
	1000	1100	1150	1100		
15.00	1050	1350	1450	1600	1380	49.0
	1200	1300	1450	1450		
	1200	1300	1600	1650		

*Anode Current <0. μ A.

TABLE C-2

Westinghouse: Reflectance, R, (%) and Background Brightness, B, (ft.-L.)

		Light Position				
		30°			60°	
		Observer Position				
Ambient (ft.-c.)	Surface	0°	-45°	30°	0°	-45°
10,000	Paper	8,000	8,600	8,000	3,600	4,600
	CRT	7,300	7,500	7,400	3,000	3,500
	R (%)	73	70	74	67	61
5,000	Paper	4,000				
	CRT	3,700				
	R (%)	74				
1,000	Paper	800				
	CRT	720				
	R (%)	72				
100	Paper	80.0				
	CRT	74.0				
	R (%)	74				

TABLE C-3

Electro Vision: Figure Brightness, ΔB, (ft. -L.)

G1 Bias (Volts)	Gap Position 1	2	3	4	$\overline{\Delta B}$	Anode Current (μ A.)
46.00	.160	.140	.140	.150	.143	*
	.120	.140	.130	.140		
	.140	.140	.200	.120		
45.00	1.25	1.10	1.35	1.10	1.15	*
	1.25	1.15	.950	1.25		
	1.00	1.10	1.20	1.05		
44.00	5.40	4.80	4.60	5.40	4.76	*
	4.60	5.00	4.00	4.60		
	5.2	4.60	4.30	4.60		
43.00	16.0	13.0	11.5	15.0	13.8	*
	14.5	14.0	13.0	13.0		
	15.0	13.0	14.5	12.5		
42.00	34.0	30.0	30.0	29.0	30.4	1.0
	30.0	32.0	30.0	28.0		
	34.0	28.0	26.0	34.0		
41.00	54.0	48.0	56.0	50.0	50.4	1.5
	46.0	54.0	48.0	50.0		
	46.0	48.0	52.0	53.0		
40.00	74.0	68.0	82.0	70.0	73.3	3.0
	70.0	74.0	72.0	74.0		
	74.0	72.0	80.0	70.0		

*Anode Current <0.5 μ A.

TABLE C-4

Electro Vision: Reflectance, R, (%) and Background Brightness, B, (ft.-L.)

		Light Position				
		30°			60°	
		Observer Position				
Ambient (ft.-c.)	Surface	0°	-45°	30°	0°	-45°
10,000	Paper	8,000	8,000	8,000	4,000	5,000
	CRT	83.0	80.0	60.0	27.5	54.0
	R (%)	.83	.80	.60	.55	.86
5,000	Paper	4,000				
	CRT	50.0				
	R (%)	1.00				
CRT Shorted						

TABLE C-5

Hartman: Figure Brightness, ΔB, (ft.-L.)

G1 Bias (Volts)	Gap Position 1	2	3	4	$\overline{\Delta B}$	Anode Current (μ A.)
36.50	.034	.032	.041	.036	.033	*
	.032	.030	.040	.030		
	.028	.030	.038	.026		
36.00	.115	.120	.120	.140	.115	*
	.110	.100	.125	.100		
	.100	.100	.145	.100		
35.00	.440	.480	.500	.400	.527	*
	.380	.560	.860	.500		
	.340	.500	.540	.820		
34.50	1.50	1.30	1.35	1.20	1.45	*
	1.40	1.50	1.65	1.50		
	1.35	1.45	1.50	1.75		
34.00	3.00	3.80	3.00	3.20	3.29	*
	3.20	3.60	3.80	3.60		
	2.60	3.70	2.80	3.20		
33.00	13.0	13.5	16.0	12.5	13.3	*
	12.5	13.5	12.0	13.0		
	12.5	14.0	15.0	12.5		
32.00	28.0	32.0	32.0	28.0	29.8	*
	27.0	30.0	30.0	26.0		
	24.0	32.0	34.0	34.0		
31.00	50.0	60.0	66.0	60.0	55.3	1.0
	52.0	60.0	60.0	40.0		
	46.0	62.0	64.0	44.0		

*Anode Current <0.5 μA.

TABLE C-6

Hartman: Reflectance, R, (%) and Background Brightness, B, (ft.-L.)

		Light Position				
		30°		60°		
		Observer Position				
Ambient (ft.-c.)	Surface	0°	-45°	30°	0°	-45°
10,000	Paper	8,000	7,800	8,000	4,600	5,600
	CRT	21.0	41.0	22.0	10.0	21.5
	R (%)	.21	.53	.22	.17	.31
5,000	Paper	4,000				
	CRT	16.5				
	R (%)	.33				
1,000	Paper	800				
	CRT	3.20				
	R (%)	.32				
100	Paper	80.0				
	CRT	.410				
	R (%)	.41				

TABLE C-7

Fairchild: Figure Brightness, ΔB, (ft.-L.)

G1 Bias (Volts)	Gap Position 1	2	3	4	$\overline{\Delta B}$	Anode Current (μ A.)
23.00	.045	.035	.034	.035	.040	*
	.038	.038	.044	.034		
	.042	.039	.047	.045		
22.00	.580	.570	.630	.530	.555	*
	.580	.500	.620	.650		
	.440	.500	.500	.560		
21.00	1.60	2.20	2.50	2.20	2.24	*
	2.60	2.60	2.10	1.90		
	2.50	2.10	2.80	1.80		
20.00	5.80	5.00	6.20	5.40	5.70	1.0
	5.80	5.40	5.80	5.20		
	5.20	4.80	7.00	6.80		
19.00	13.0	11.0	12.0	9.50	11.4	2.5
	12.5	9.50	13.0	10.5		
	11.5	10.5	11.0	12.5		
18.00	18.0	14.0	16.0	18.0	16.4	4.5
	19.0	15.0	16.0	15.5		
	17.0	15.0	18.0	15.5		
17.00	26.0	23.0	20.0	21.0	22.5	7.5
	24.0	21.0	19.5	22.0		
	22.0	23.0	22.5	26.0		
16.00	32.0	28.0	28.0	28.0	28.8	11.0
	30.0	26.0	27.0	32.0		
	30.0	28.0	30.0	27.0		
14.00	44.0	40.0	40.0	34.0	40.1	21.5
	42.0	42.0	38.0	36.0		
	43.0	41.0	42.0	39.0		
12.00	48.0	48.0	51.0	52.0	48.8	38.0
	48.0	47.0	50.0	46.0		
	47.0	47.0	54.0	48.0		

*Anode Current <0.5 μ A.

TABLE C-8

Fairchild: Reflectance, R, (%) and Background Brightness, B, (ft.-L.)

		Light Position				
		30°			60°	
		Observer Position				
Ambient (ft.-c.)	Surface	0°	-45°	30°	0°	-45°
10,000	Paper	8,000	8,800	8,000	3,700	5,000
	CRT	245	270	240	98.0	190
	R (%)	2.4	2.4	2.4	2.1	3.0
5,000	Paper	4,000				
	CRT	135				
	R (%)	2.7				
1,000	Paper	800				
	CRT	28.0				
	R (%)	2.8				
100	Paper	80.0				
	CRT	2.80				
	R (%)	2.8				

APPENDIX D

DETECTION THRESHOLDS AND WORKING LEVEL PREFERENCES AS A FUNCTION OF AMBIENT ILLUMINATION

TABLE D-1

Westinghouse: Detection Thresholds and Preferred Working Levels (Volts) At 10,000 ft.-c. Ambient

		Light Position			
		30^o		60^o	
		Observer Position			
Observer	Working Preference* (Volts)	0^o	-45^o	0^o	-45^o
MC	15.20	23.40	22.10	26.30	24.90
RK	15.19	23.50	23.20	26.60	26.30
WK	15.78	23.50	22.20	26.20	25.70
BB	17.50	22.90	22.30	26.00	26.00
$\overline{V}$	15.92	23.33	22.45	26.28	25.73
$\overline{\Delta B}$(ft.-L.)	1,250	400	540	110	145
AC (μ A.)	40.0	6.0	8.5	1.5	2.0
B(ft.-L.)	7,300	7,300	7,500	3,000	3,500
$\overline{\Delta B}/B$	.171	.055	.072	.037	.041

*Light Postion = 30^o; Observer Position = 0^o

TABLE D-2

Electro Vision: Detection Thresholds and Preferred Working Levels (Volts) At 10,000 ft.-c. Ambient

		Light Position			
		30°		60°	
	Working Preference*	Observer Position			
Observer	(Volts)	0°	-45°	0°	-45°
MC	41.65	44.50	44.20	44.70	44.50
RK	41.50	44.70	44.40	45.00	44.80
WK	41.75	44.10	43.90	44.50	44.40
BB	41.96	44.20	44.20	44.70	44.40
$\overline{V}$	41.72	44.38	44.18	44.73	44.53
$\overline{\Delta B}$(ft.-L.)	36.0	2.90	3.80	1.70	2.30
µA.	1.10	**	**	**	**
B(ft.-L.)	83.0	83.0	80.0	27.5	54.0
$\overline{\Delta B}$/B	.434	.035	.048	.062	.038

*Light Position = 30°; Observer Position = 0°

**Anode Current <0.5µA

TABLE D-3

Hartman: Detection Thresholds and Preferred Working Levels (Volts)
At 10,000 ft.-L. Ambient

Observer	Working Preference* (Volts)	Light Position 30° Observer Position 0°	Light Position 30° Observer Position -45°	Light Position 60° Observer Position 0°	Light Position 60° Observer Position -45°
MC	31.95	34.60	34.00	34.60	34.20
RK	31.86	34.90	34.20	34.90	34.30
WK	32.66	34.40	34.00	34.50	34.00
BB	32.63	34.40	34.00	34.40	34.50
$\overline{V}$	32.28	34.58	34.05	34.60	34.25
$\overline{\Delta B}$(ft.-L.)	25.0	1.20	3.00	1.20	2.10
μA.	**	**	**	**	**
B(ft.-L.)	21.0	21.0	41.0	10.0	21.5
$\overline{\Delta B}$/B	1.19	.057	.073	.120	.098

*Light Position = 30°; Observer Position = 0°

**Anode Current <0.5μA

TABLE D-4

Fairchild: Detection Thresholds and Preferred Working Levels (Volts)
At 10,000 ft.-L. Ambient

Observer	Working Preference* (Volts)	Light Position 30° Observer Position 0°	Light Position 30° Observer Position -45°	Light Position 60° Observer Position 0°	Light Position 60° Observer Position -45°
MC	11.74	19.20	18.60	20.50	19.90
RK	14.72	19.40	18.90	20.50	20.20
WK	10.60	19.00	18.20	20.20	19.80
BB	14.60	19.00	18.30	20.40	19.60
$\overline{V}$	12.92	19.15	18.50	20.40	19.88
$\overline{\Delta B}$(ft.-L)	45.0	10.0	14.0	4.00	6.20
µA.	28.0	2.0	3.5	**	1.0
B(ft.-L)	245	245	270	98.0	190
$\overline{\Delta B}$/B	.184	.041	.052	.041	.033

*Light Position = 30°; Observer Position = 0°

**Anode Current <0.5µA.

TABLE D-5

Westinghouse: Detection Thresholds (Volts) vs. Ambient/Background Brightness (Light Position = 30°; Observer Position = 0°)

Ambient (ft.-c.)	Observer	Detection Threshold (Volts)	Working Preference (Volts)	Ambient (ft.-c.)	Observer	Detection Threshold (Volts)	Working Preference (Volts)
10,000	RK	23.50	15.19	1,000	RK	28.90	26.00
	WK	23.50	15.78		WK	28.40	25.50
	BB	22.90	17.50		BB	28.50	25.19
	$\bar{V}$	23.30	16.16		$\bar{V}$	28.60	25.56
	$\overline{\Delta B}$(ft.-L.)	400	1,210		$\overline{\Delta B}$(ft.-L.)	18.0	158
	μA.	6.0	38.0		μA.	*	2.5
	B(ft.-L.)	7,300	7,300		B(ft.-L.)	720	720
	$\overline{\Delta B}$/B	.055	.166		$\overline{\Delta B}$/B	.025	.219
5,000	RK	27.20	17.39	100	RK	30.00	28.10
	WK	26.70	19.05		WK	29.80	28.30
	BB	26.40	19.14		BB	29.90	28.34
	$\bar{V}$	26.77	18.53		$\bar{V}$	29.90	28.25
	$\overline{\Delta B}$(ft.-L.)	82.0	960		$\overline{\Delta B}$(ft.-L.)	2.70	26.5
	μA.	1.50	24.00		μA.	*	*
	B(ft.-L.)	3,700	3,700		B(ft.-L.)	74.0	74.0
	$\overline{\Delta B}$/B	.022	.259		$\overline{\Delta B}$/B	.036	.358

*Anode Current <0.5 μA.

TABLE D-6

Electro Vision: Detection Thresholds (Volts) vs. Ambient/Background Brightness (Light Position = 30°; Observer Position = 0°)

Ambient (ft.-c.)	Observer	Detection Threshold (Volts)	Working Preference (Volts)	Ambient (ft.-c.)	Observer	Detection Threshold (Volts)	Working Preference (Volts)
10,000	RK	44.70	41.50				
	WK	44.10	41.75				
	BB	44.20	41.96				
	$\overline{V}$	44.33	41.74				
	$\overline{\Delta B}$ (ft.-L.)	3.10	35.0				
	μA.	*	1.0				
	B(ft.-L.)	83.0	83.0				
	$\overline{\Delta B}$/B	.0373	.4217				
5,000	RK	45.00	41.84				
	WK	44.00	41.88				
	BB	**	**				
	$\overline{V}$	44.50	41.86				
	$\overline{\Delta B}$(ft.-L.)	2.40	33.0				
	μA.	*	1.0				
	B(ft.-L.)	50.0	50.0				
	$\overline{\Delta B}$/B	.048	.660				

*Anode Current <0.5 μA.

**CRT Shorted

TABLE D-7

Hartman: Detection Thresholds (Volts) vs. Ambient/Background Brightness (Light Position = 30°; Observer Position = 0°)

Ambient (ft.-c.)	Observer	Detection Threshold (Volts)	Working Preference (Volts)	Ambient (ft.-c.)	Observer	Detection Threshold (Volts)	Working Preference (Volts)
10,000	RK	34.90	31.86	1,000	RK	35.60	33.34
	WK	34.40	32.66		WK	35.30	33.94
	BB	34.40	32.63		BB	35.40	34.44
	$\bar{V}$	34.57	32.38		$\bar{V}$	35.43	33.91
	$\overline{\Delta B}$(ft.-L.)	1.20	23.0		$\overline{\Delta B}$(ft.-L.)	.260	3.80
	μ A.	*	*		μ A.	*	*
	B(ft.-L.)	21.0	21.0		B(ft.-L.)	3.20	3.20
	$\overline{\Delta B}$/B	.057	1.095		$\overline{\Delta B}$/B	.082	1.188
5,000	RK	35.20	33.28	100	RK	36.30	34.56
	WK	34.90	32.83		WK	36.10	34.97
	BB	35.00	33.30		BB	36.20	35.01
	$\bar{V}$	35.03	33.14		$\bar{V}$	36.20	34.85
	$\overline{\Delta B}$(ft.-L.)	.540	11.0		$\overline{\Delta B}$(ft.-L.)	.060	.740
	μ A.	*	*		μ A.	*	*
	B(ft.-L.)	16.5	16.5		B(ft.-L.)	.410	.410
	$\overline{\Delta B}$/B	.033	.667		$\overline{\Delta B}$/B	.146	1.804

*Anode Current <0.5 μA.

TABLE D-8

Fairchild: Detection Thresholds (Volts) vs. Ambient/Background Brightness

(Light Position = 30°, Observer Position = 0°)

Ambient (ft.-c.)	Observer	Detection Threshold (Volts)	Working Preference (Volts)	Ambient (ft.-c.)	Observer	Detection Threshold (Volts)	Working Preference (Volts)
10,000	RK	19.40	14.72	1,000	RK	22.00	17.91
	WK	19.00	10.60		WK	21.70	19.39
	BB	19.00	14.60		BB	21.70	20.00
	$\overline{V}$	19.13	13.31		$\overline{V}$	21.80	19.10
	$\overline{\Delta B}$(ft.-L.)	9.60	43.0		$\overline{\Delta B}$(ft.-L.)	.76	10.0
	μA.	2.2	27.0		μA.	*	2.2
	B(ft.-L.)	245	245		B(ft.-L.)	28.0	28.0
	$\overline{\Delta B}$/B	.039	.176		$\overline{\Delta B}$/B	.027	.357
5,000	RK	20.60	14.60	100	RK	22.80	21.00
	WK	20.30	14.39		WK	22.80	21.42
	BB	20.10	14.70		BB	22.90	21.42
	$\overline{V}$	20.33	14.56		$\overline{V}$	22.83	21.28
	$\overline{\Delta B}$(ft.-L.)	4.20	36.0		$\overline{\Delta B}$(ft.-L.)	.064	1.60
	μA.	*	18.0		μA.	*	*
	B(ft.-L.)	135	135		B(ft.-L.)	2.80	2.80
	$\overline{\Delta B}$/B	.031	.266		$\overline{\Delta B}$/B	.023	.571

*Anode Current <0.5 μA.

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