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HIGH RESOLUTION CATHODE RAY TUBE EVALUATION

TECHNICAL DOCUMENTARY REPORT No. ASD-TDR-63-796

APRIL 1964

DIRECTOR OF RECONNAISSANCE ENGINEERING AERONAUTICAL SYSTEMS DIVISION AIR FORCE SYSTEMS COMMAND WRIGHT-PATTERSON AIR FORCE BASE, OHIO

(Prepared under Contract AF 33(616)-4206 by Data Corporation, Dayton 32, Ohio) Confirmed public via DTIC 7/1/2020

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FOREWORD

This report was prepared by Data Corporation, 7500 Old Xenia Pike, Dayton 32, Ohio, on Air Force Contract No. AF33(616)-4206. This Project was covered under Call No. 2 of this contract.

The effort was administered for the Air Force under the direction of Mr. Frank L. Palazzo, Chief, Data Processing Branch, SEQDD, ASD, Wright-Patterson AF Base, Ohio, and Mr. C. E. Heitzman, SEQDD, acted as AF Project Monitor.

Work was started on this project May, 1960 and concluded in July, 1962. This is the final engineering report and concludes work on Call No. 2 of Contract AF33(616)-4206.

Maurice B. Aufderheide, Senior Project Engineer, was Project Manager for Data Corporation on this effort. This work was performed by the Photoscience Department of Data Corporation under the direction of J. R. Madden.



ABSTRACT

This report outlines and provides a means of comparing the four basic methods of CRT testing now employed by the cathode ray tube industry. An analysis of each test method, its restrictions, limitations, and advantages are discussed along with the basic requirements for testing cathode ray tubes. These four methods are selected by a joint industry-government committee as possible test standards. They are:

- 1. Shrinking Raster Technique
- 2. Schade Spatial Frequency Technique
- 3. Line Profile and Single Slit Technique
- 4. Double Line Trace Technique (Westinghouse Method)

Five high resolution cathode ray tubes were subjected to the four

methods of tests and the results indicated for comparison.

Appendix A gives a detailed description of the CRT Analyser designed

and built by Data Corporation for performing the various tests described.

Publication of this technical documentary report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

CONTENTS

SECTION I			
BASIC REQUIREMENTS.			
SECTION II			
DESCRIPTION AND ANALYSIS OF TEST METHODS			
A. SHRINKING RASTER TEST METHOD	7		
B. APERTURE RESPONSE METHOD	20		
C. SINGLE LINE METHOD	29		
D. DOUBLE LINE METHOD. \ldots \ldots \ldots 3	30		
SECTION III			
TEST RESULTS			
APPENDIX A			
DETAILED DESCRIPTION OF THE TEST RACK			

LIST OF ILLUSTRATIONS

Fig. No	Title	Page	No.
Figure 1	Power Supply		5
Figure 2	Raster with Equally Spaced Lines		7
Figure 3	Line Raster with Beam Profile		8
Figure 4	Shrunk Line Raster		8
Figure 5	Persistence Characteristic of Phosphor No. 5	1	.0
Figu re 6	Persistence Charateristic of Phosphor P16	1	.0
Figure 7	Persistence Characteristics of Phosphor No. 11	1	.4
Figu re 8	Line Profile without Background Illumination	1	.6
Figure 9	Line Profile with Background Illumination	1	.6
Figure 10	Rise Time Characteristic at v_{0}	1	.8
Figure 11	Rise Time Characteristic at $\mathcal{T} \times \mathbf{v}_0$	1	.8
Figure 11A	Spot Profile as a Function of Beam Current in Relative Units	1	.9A
Figure 12	Block Diagram of Aperture Response Method of Test	2	22
Figure 13	Spatial Frequency Response Curves	2	23
Figure 14	Spot Distributions of Figure 13	2	25
Figure 15	Approximate Display of Display Oscilloscope	3	32
Figure 16	Aperture Response Spatial Frequency Specimen Na	r. 1 3	8
Figure 17	Linear Graph of Spatial Frequency Test Specimen No. 1 Curve "A" Frequency vs amplitude Curve "B" /Frequency vs amplitude Area under Curve "B" = 17.4 inches $N_e = 17.4 \times 4 = 69.6 \text{ TV Lines/inch}$	3	9
Figure 18	Intensity Distribution of Spot Test Specimen No. 1	4	0
Figure 19	Aperture Response Method Intensity Distribution of Spot Test Specimen No. 1 Single Slit Method Single Line Trace - 5 PPS	4	2
Figure 20	Intensity Function of Beam Profile Test Specimen No. 1 Double Line Test Method Horizontal Sweep Frequency 4 Vertical Sweep Frequency 2 KC And 60 Cps	4 КС	5

Figure 21	Aperture Response Test Spatial Frequency Curve Specimen No. 2 Vertical Height 0.250 inches Operated Under Typical Conditions	48
Figure 22	Intensity Distribution of Spot Test Specimen No. 2 Aperture Response Test	50
Figure 23	Linear Graph of Spatial Frequency Test Specimen No. 2 Curve "A" Frequency Versus Relative Amplitude Curve "B" Frequency Versus Relative Amplitude Area Under Curve "B" - 28.7 Inches $N_e = 10 \times 28.7 = 287 \text{ TV Lines/inch}$	51
Figure 24	Intensity Distribution of Spot Test Specimen No. 2 Single Slit Test Method Single Line Trace 24 PPS	54
Figure 25	Intensity Function of Beam Profile Test Specimen No. 2 Double Line Test Method Horizontal Sweep Frequency 4 KC Vertical Sweep Frequency 2 KC and 60 CPS	55
Figure 26	Aperture Response Test Spatial Frequency Curve Specimen No. 3 512 TV Line Raster Operated Under Typical Conditions	58
Figure 27	Intensity Distribution of Spot Test Specimen No. 3 Aperture Response Method	59
Figure 28	Linear Graph of Spatial Frequency Test Specimen No. 3 Curve "A" Frequency Versus Amplitude Curve "B" Frequency Versus Amplitude Area Under Curve "B" = 19.87 Inches $N_p = 20 \times 19.87 = 397$ TV Lines/inch	60
Figure 29	Intensity Distribution of Spot Test Specimen No. 3 Single Slit Method Single Line Trace - 24 PPS	62
Figure 30	Intensity Function of Beam Profile Test Specimen No. 3'Double Line Method Horizontal Sweep Frequency 4 KC Vertical Sweep Frequency 2 and 60 CPS	64 2 KC
Figure 31	Aperture Response Test Spatial Frequency Curve Specimen No. 4 Vertical Height .125 inches 512 TV Line Raster Operated under typica conditions Dashed Portion of Curve Represents Extra Polated Data	68 1
Figure 32	Intensity Distribution of Spot Test Specimen No. 4 Aperture Response Test	69
Figure 33	Linear Graph of Spatial Frequency Test Specimen No. 4 Curve "A" Amplitude Versus Frequency Curve "B" Amplitude Versus Frequency Area Under Curve "B" - 23.8 inches N _e = 40 x 23.8 = 952 TV Line/Inch	70

Figure 34	Intensity Distribution of Spot Test Specimen No. 4 Double Line Test Method	71
Figure 35	Spatial Frequency Response Curve Aperture Response Method Test Specimen No. 5 Performed at WADD	74
Figure 36	Profile of P11 Phosphor Spot Test Specimen No. 5 Operated Under Typical Conditions Results of Aperture Response Test Intensity Distr	73 ibution
	APPENDIX A	
Figure I	Power Supply Assembly	77
Figure II	Electrostatic Focus CRT Gun	78
Figure III	Magnetic Focus CRTGun	79
Figure IV	Scanning Generator Incorporated in the Test Rack	82
Figure V	Basic Deflection Amplifier Circuit	85
Figure VI	Vertical Deflection Driver	87
Figure VII	Horizontal Deflection Driver	88
Figure VIII	CRT Mount without a Cathode Ray Tube	89
Figure IX	CRT Mount with Magnetic Deflection Type CRT Installed	91
Figure X	The Camera Mount Subassembly	92
Figure XI	Photomultiplier Subassembly	93

SUMMARY OF RESULTS

Each of the four designated methods of test were evaluated in detail. The principal findings with respect to each method are summarized briefly below. Considerably more detail is presented in Section II of the report.

A. Shrinking Raster Method

The shrinking raster test was evaluated theoretically and a prediction made that the results found were directly related to the extinction or "cut-off" frequency of the spatial response characteristic. Experiment shows this to be the case, to a high degree of accuracy compared with the theoretical prediction. The method is also adversely affected by background illumination, phosphor decay time and phosphor rise time. "Eye resolution" and, therefore, the characteristics and inconsistency of the operator are involved. Furthermore, there is a possibility of deflection coil cross-coupling when the method is used for the evaluation of high resolution tubes. The method is useful for production type testing, providing the beam profile has been determined by another test.

B. Aperture Response Method

The aperture response method is a conventional application of spatial frequency response techniques. In high resolution tubes, a requirement exists that the observing aperture be extremely small in order to avoid contamination of data by the response function of the observing aperture. Data obtained must be Fourier transformed, although a relatively convenient graphical method is available. Raster generating problems arise in a manner similar to that observed in utilizing the shrinking raster test on high resolution tubes. It is noted that most of the objections to this method of test are applicative rather than inherent in the principle of test.

viii

C. Single Line Method

The primary difficulty with this method of test lies in the necessity for maintaining a slow, stable sweep speed. Under this condition, the tube cannot be operated as it would be under normal operating conditions. Test data may also readily be contaminated by non-linearity in the sweep or in the oscilloscope used for display. A narrow slit is used for observation and aperture restrictions again apply.

D. Double Line (Westinghouse) Method

This method was found to have certain inherent advantages over the other three procedures. Sweep frequencies are relatively low, and the sweep amplitudes are small. Vertical and horizontal deflection coils may be similarly designed with resulting advantages in pattern linearity and the appreciable advantage that tests may be made on both axes without disturbing test conditions or equipment. The method is readily adaptable to laboratory use and presents a speedy method of determining spot profile for production testing. The method appears to be capable of extension to higher resolution tubes as such are developed. Aperture considerations apply.

All the methods discussed are sensitive to power supply ripple, regulation and other perturbing factors to a more or less equal degree. The last method discussed is recommended primarily due to the ease in testing and changing test axes as well as the fact that a complete spot profile is available if desired.

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SECTION I

BASIC REQUIREMENTS

The test methods utilized in this report for measuring spot size can be subdivided into three basic types.

1. The Slit Method: The CRT spot is passed across a very narrow slit. The energy as a function of time is traced out on an oscilloscope. This gives a display of the spread function.

2. The Spatial Frequency Technique: This is essentially a convolution process in which the spatial frequency response of the spread function is measured. By use of the Fourier Integral Transform pair, this information is then converted to the corresponding spread function.

3. The Visual Technique: This refers to methods such as the shrinking raster technique wherein the lines are observed by the eye with aid of a microscope. The line spacing is then reduced until the lines appear as one solid band of light.

Since the cathode ray tubes that were submitted for test were primarily of the high resolution type, the minimum spot sizes (diameters) are known to be in the neighborhood of 0.0005 inches. It should be remembered that regardless of the testing technique that is selected, a number of precautionary measures are of prime importance. Since the resolution of a tube is critically dependent on the test conditions under which it is measured, these conditions must be stable and repeatable if reliable measurements are to be made. If the test facility is required to perform measurements of spot sizes as small as 0.0005 inches in diameter, trace jitter and hum on the face of the test cathode ray tube should be less than 0.05 mils peak deflection. Reflecting this back in terms of the driving deflection current, this means that the short term stability of the power supplies should be such that the deflection driving current fluctuations are less than .005% of the peak deflection current. This is determined in the following manner. Normally, in a push-pull circuit, one radius

of deflection requires a peak deflection current of I amps. This corresponds to a 2.5 inch deflection on a 5 inch diameter tube. Therefore, the maximum tolerable random deflection is $.05 \times 10^{-3}$ inches. Utilizing the relationship that the deflection is proportional to the deflecting current, the maximum allowable ripple can be determined as shown below:

(1)
$$\frac{\Delta I}{I_0} = \frac{\Delta l}{L}$$
 or $\Delta I = \frac{\Delta l}{L} I_0$

where ΔI the normalized allowable ripple

 I_o the required current to produce a half diameter deflection

L the deflection equal to one radius of the tube

 $riangle \mathcal{I}$ the maximum allowable trace jitter

(2)
$$\frac{\Delta I}{I_o} = \frac{.05 \times 10^{-3}}{2.5} = 2 \times 10^{-5}$$
 or 0.002%

This then tells us that if the required current to move the spot one tube radius is 200 milliamperes, the tolerable ripple is equal to 0.004 milliamperes.

The position of the spot is also a function of the accelerating potential. Let us now investigate the dependency of the spot position as function of the accelerating voltage for a 5 inch tube face having a 40° deflection angle. Utilizing the basic law of magnetic deflection

(3)
$$\sin \phi = \frac{KHl}{VEb}$$

where Eb accelerating potential

H magnetic field strength

 \checkmark length of the magnetic deflecting field

K constants of proportionality dependent upon the units of $H \mathcal{L}$ and E bDifferentiating equation (3) with respect to ϕ and Eb explicitly holding K, H, $\xi \mathcal{L}$ as constants

(4)

$$\cos \phi d\phi = -\frac{1}{2} \cdot \frac{KHl}{(Eb)^{3/2}} dEb = -\frac{1}{2} \cdot \frac{\sin \phi}{Eb} dEb$$

Simplifying Equation (4), we have

(5)
$$d\phi = -\frac{1}{2} T_{an} \phi \frac{dEb}{Eb}$$

Equation(5) shows the mathematical relationship of the change in the deflection angle, $(d\emptyset)$, and the normalized accelerating potential variation $(\frac{d\mathcal{E}b}{\mathcal{E}b})$. The greatest displacement of the beam occurs at the largest deflection angle encountered. One can approximate the maximum permissible ripple of the accelerating potential, $(\mathcal{E}b)$, in the following manner. Let us make several assumptions:

- a. The smallest spot diameter to be . 001 inches
- b. The maximum deflection angle to be 20° (full angle of 40°)
- c. The maximum deflection variation due to ripple to be 1/10 beam diameter
- d. The CRT face has a 5 inch usable face diameter

Under the above assumptions, the maximum tolerable deflection $d\phi$ in radians is approximated by equation (6)

(6)
$$d\phi = \frac{1 \times 10^{-4} \text{ inches}}{2.5 \text{ inches}} \times \frac{20}{180} \times \pi = 1.4 \times 10^{-6} \text{ radians}$$

Substituting the value of equation (6) into equation (5)

(6a)
$$\frac{dEb}{Eb} = \frac{2 \times 1.4 \times 10^{-6}}{Tan 20^{\circ}} = \frac{2.8}{.364} \times 10^{-6} = 7.7 \times 10^{-6}$$

From equation (6a), it can be seen that the accelerating potential must be absolutely free of ripple. Otherwise, severe distortion of the spot will be reflected from the accelerating potential.

In a similar manner, the current in the focus coil is very critical. During the evaluation of the various tubes, it was noted that significant changes in focus were caused by focus current variation of 0.1%. Therefore, it is also necessary to reduce the ripple and variation of the focus current to an absolute minimum, preferably to less than 0.1%.

The remaining power supplies that furnish the required voltages and currents to the various tube elements must also be equally filtered and regulated to prevent distortion of the CRT spot. The mechanical rigidity of the entire test fixture is of prime importance. Any random movement or vibration of the cathode ray tube mount relative to the camera-PMT mount will appear as jitter in the display of the test results, regardless of the test method employed. The tolerable amount of vibration and random motion is a function of the smallest beam profile to be measured. Since it was previously stated in this report that the spot diameters are in the neighborhood of .001 inches, it is obvious that the random motion and vibration must be kept well below 0.1 mils if one wishes to consider these contributions of hum and jitter to be secondary effects.

When attempting to perform beam profile tests, it is necessary to move the camera-PMT carriage relative to the CRT test fixture in small increments, nominally 1/10 of the half amplitude profile width. For a 1 mil spot size, this then means that backlash in the carriages must be small enough so that the carriage can be positioned accurately to 0.0001 inch. Otherwise, the test data can not be repeated. Also, since microscope objectives are utilized, the depth of focus is very small. This, also, tells us that the backlash in the focus adjustment must be held to the absolute minimum in order to maintain critical focus during each test. It should be pointed out that in various test methods, focus must be judged by eye rather than electronically. One such method is the aperture response test.

A test rack was designed primarily to accommodate high resolution magnetic deflection type cathode ray tubes that incorporate either electrostatic or electromagnetic focusing, having spot sizes in the order of magnitude of 1.0 mil with a face diameter ranging from 3 to 7 inches. This test rack, however, will accommodate any cathode ray tube for the various resolution tests with little or no modification.

Figure 1 shows a functional block diagram of the test rack. From this diagram, it can be seen that the rack can be subdivided into the following subassemblies.

They are:

- 1. The Power Supply Assembly
- 2. The Scanning Generator Assembly
- 3. The Optical Bench Assembly



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The theory of operation, description, limitations, and advantages of each assembly will be presented in detail in Appendix "A" of this report. They will be discussed in the foregoing tabulated order.

SECTION II

DESCRIPTION AND ANALYSIS OF TEST METHODS

A. SHRINKING RASTER TEST METHOD

The shrinking raster technique is probably the most widely used method of evaluating the resolution capabilities of cathode ray tubes. Currently, this is the test method that is called out in Military Specification MIL-E-1D, which covers the design requirements of electron tubes for military applications. Before we can discuss the merits and limitations of this test method, it is necessary to review the manner in which the test is performed, and then discuss what these test results really mean.

A television scan pattern, known as a raster and composed of a large number of equally spaced lines, is applied to the tube under test. These lines are produced by sawtooth scanning at some given frequency along one axis and at 50 to 500 times this frequency along the perpendicular axis. Figure 2 shows the nature of the pattern that will appear on the cathode ray tube.



Figure 2. Raster with Equally Spaced Lines

The amplitude of the fast scan is first adjusted until the length of the lines is 60% to 90% of the minimum useful screen diameter. The low frequency sweep amplitude is then expanded until the lines are clearly separated. After suitable adjustments of the focus coil current and optimum focus has been achieved, the pattern is slowly compressed until the line structure disappears at the center of the screen. This is usually accomplished with the aid of a microscope. The width of the pattern, at this time, is divided by the total number of visible lines yielding the "line width". This may be expressed in width per optical line or width per TV line.

In this technique, it is assumed that the spot intensity distribution of the test tube approximates a three dimensional gaussian surface having cylindrical symmetry. The construction of the spot is then performed utilizing the "line width" measurement. It has become a common erroneous practice to assume the line width to be the half power point of this gaussian surface. Therefore, assuming that a tube possessing a 1 mil line width would have a film resolution capability of 1000 bits per inch.

Let us now examine the mechanics of this test in minute detail. If one were to examine raster with beam profile of each line, they would appear as shown in Figure 3 below.



Figure 3. Line Raster with Beam Profile

During this discussion, the number of parallel lines on the raster has been reduced to three instead of the 100-500 lines. The intensity of the line, as a function of vertical distance, is plotted along each side. Figure 2 shows the raster in its expanded position when each line is visible. Then the raster is shrunk in vertical size until the line structure is not visible. When this occurs, the relative amplitude and the shape of the line profile essentially remain the same. This is illustrated in Figure 4.



Figure 4. Shrunk Line Raster

When the raster is compressed, the Gaussian curves overlap. There are several conditions that may exist which are dependent upon the response and persistence time constant of the phosphor and the sweep duration of the raster pattern.

Case I - Short Persistence Coating

Figures 5 and 6 show the persistence characteristics of P-5 and P-16 phosphor coatings. It should be noted that the horizontal sweep speeds normally used in the performance of the shrinking raster is usually 30 Kc or less. This gives a duration of 33 microseconds or greater each time between painting a line of the raster. From Figures 4 and 5, it can be seen that the light output has decayed to 1.5% of its original value for P-5 phosphor and to less than 7% of its original value for P-16 phosphor. Therefore, for all practical purposes, the preceeding line has little effect on the line being painted.

During this test when the picture is compressed as shown in Figure 4, a superficial interpretation of this procedure would cause one to think that the operator compresses the lines together until the Gaussian profile of both adjacent lines intersect at the 93% to 97% amplitude point of the line profile. However, one must consider the ability of the eye to resolve small objects. It has been pointed out in the literature that the eye has a limiting resolution in the neighborhood of 3 mils. Therefore, the detail line profile is not distinguishable to the eye. The mechanics of this test can best be explained from a spatial frequency concept. When one observes the pattern, the eye scans the overall visible pattern for any variation of field brightness. As the spatial frequency is increased (by compressing the pattern), the contrast between the line and line spacing decreases. When the contrast difference is less than 3%, then the human eye can no longer detect a change in the pattern, and it appears as one solid band of light. Therefore, one actually determines the 2% to 5% spatial frequency response point on the spatial frequency curve. This has been verified in the test results shown in this report. A review of the test data shows that the half amplitude diameter occurs at twice the line width obtained by the interlaced shrinking raster test.

FIGURE 5



PERSISTENCE CHARACTERISTIC

OF PHOSPHOR Nº5

FIGURE 6





PERSISTENCE CHARACTERISTIC

OF PHOSPHOR PI6

These results are shown in tabular form below:

Test Specimen	Shrinking Raster Spatial Frequency	Spatial Frequency Response Amplitude (Normalized Response)
#1	207 TV/inch	. 03
#2	922 TV/inch	. 028
#3	902 TV/inch	. 05
#4	2630 TV/inch	. 04
#5	1886 TV/inch	. 09

The difference in relative amplitude of test specimen #5 was attributed to the instability of the test set up.

It has been observed in photographic evaluation that bar target resolution loss occurs at or near the extinction point of the spatial response curve. In the case at hand, let us presume that the shrinking raster appears homogeneous when the two Gaussian shaped functions overlap sufficiently to yield an incremental flux Δ . Then

$$\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}} \left| -\frac{2}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}} \right|_{x=0} = \Delta$$

or, in decimal terms

$$1 - Z e^{-\frac{X_o^2}{Z\sigma^2}} = \frac{\Delta}{1/\sigma\sqrt{2\pi}} = \delta$$

~

then,
$$\frac{1-\delta}{2} = e^{-\frac{\chi_o^2}{2\sigma^2}}$$
$$-\frac{\chi_o^2}{2\sigma^2} = \ln \left(\frac{1-\delta}{2}\right)$$
$$\sigma^2 = -\frac{\chi_o^2}{2\ln \left(\frac{1-\delta}{2}\right)}$$

Consider now the spatial frequency situation. Since we are, in effect, generating a new function through the convolution of a positional representation with a Gaussian-shaped spreading (illuminating) operator, we introduce the Fourier transform of the spreading function as the system response to a wide-band stimulus. Then

$$\mathcal{F}\left(\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{\chi^2}{2\sigma^2}}\right) = e^{-\frac{\sigma^2\omega^2}{2}} = G(\omega)$$

where ω is expressed as radians/linear dimension or \mathcal{ZM}_{\times} cycles/linear dimension. Then, introducing the value of σ^2 as found earlier,

$$G(\omega) = e^{\frac{\omega^2}{2 \ln (1-S)}}$$

Since we decided that the raster appeared homogeneous at $x = x_o$, the line spacing is therefore Zx_o so

$$L = 1/2 x_0$$

Now let us evaluate $G(\omega)$ at

$$\omega = 2\pi L = \pi/x_{o}$$

$$G(\omega) = e^{\frac{\pi^{2}}{4l_{m}(\frac{1-5}{2})}} \cong e^{\frac{2.46}{l_{m}(\frac{1-5}{2})}}$$

Since the eye can distinguish about a 3% difference in illumination level, presume S = 0.03. Then

$$G(\omega)\Big|_{\omega=2\pi L} \cong e^{\frac{2.46}{l_m \, 0.485}} \cong e^{-3.4} \cong 0.034$$

and resolution is lost at a line frequency corresponding to approximately the 3.4% response point on the spatial frequency response curve. In fact, for any reasonable value of \leq , the results are similar. Take for example $\leq = 0.25$. Then

$$\frac{1-\delta}{2} = +0.375$$

ln 0.375 = -0.98

and
$$G(\omega) = e^{-2.49} \cong 0.083$$
$$\omega = 2\pi L$$

Therefore, one can say readily that the shrinking raster test produces results directly related to the cut-off frequency of the spatial response curve and not to the 'half-power' point. This finding is directly supported by the experimental results reported herein.

Case II - Medium Persistence Phosphor Coating

Figure 7 shows the persistence characteristics of P-11 phosphor coating. In comparison with Figure 5 and 6, the persistence of P-11 phosphor coating is also a function of the beam current density. However, for any given beam current density, the persistence of this coating is much greater than either P-5 or P-16 coating. To more clearly illustrate this characteristic, let us consider several specific operating conditions. When a cathode ray tube having a P-11 phosphor is operated with a beam current density of 50 microamps/cm² and a horizontal sweep duration of 33 microseconds, the initial brightness of the line has decayed to 13% of its original value when the next line is being formed on the cathode ray tube surface. If one were to use this combination horizontal sweep speed and P-11 phosphor coating in performing a shrinking raster test, the residual light due to the persistence of the phosphor would have to be accounted for in the test results in order to accurately determine the beam profile. Let us now consider the P-11 phosphor coating with a raster required by MIL-E-1D. The test conditions are:

- 1. Horizontal sweep frequency 6.3 kc
- 2. Vertical sweep frequency 60 cps

With this set of test conditions, the horizontal sweep duration is 160 microseconds. From Figure 7, it can be seen that when the current density is 50 microamps/cm² then the brightness of the line of the raster has decayed to 3.5% of its peak value when the next line is being generated.

When this set of test conditions is employed, the shrinking raster test will be of the same nature as Case No. I. Therefore, it is of prime importance that the horizontal

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Figure 7. Persistence Characteristics of Phosphor No. 11

sweep duration (the faster of either vertical or horizontal) be selected long enough so that time constant of the phosphor for the desired beam current density be much shorter than the horizontal sweep duration.

If the duration of the horizontal sweep is decreased so that the time constant of the phosphor is in the same order of magnitude as the sweep duration, then the light remaining from the previous line trace must be summed to the light of the line being traced. However, due to the fact that this is a nonlinear function, it is impossible to predict the results of tests conducted under these conditions.

Phosphor coating such as P-1, 20 milliseconds decay to 10% of original brightness

P-7, 1 millisecond decay to 10% of its original brightness

P-19, 300 milliseconds decay to 10% of its original value

present the same problem since their decay time constants are so long, it is impossible to make the horizontal sweep duration greater or in the same order of magnitude as the phosphor decay time constant. Since this would mean that the vertical frame rate would be so low as to cause severe flicker of the raster pattern (to obtain sufficient number of lines on the raster). When shrinking raster tests are performed on these tubes with high horizontal sweep rates, then, there exists considerable amount of background illumination in the raster pattern.

At present we have discussed only the limitations of this test due to decay time constant of the phosphor coatings. There are two other effects which will affect the results of such a test since they are dependent upon the characteristics of the eye. They are background illumination and the rise time constant of the phosphor coating. Unfortunately, both of these effects tend to give an apparent line width less than the actual stationary spot distribution.

Let us first examine the effects of background illumination with the aid of Figures 8 and 9. Figure 8 shows the line profile of a single raster line without background illumination. B_0 is the value of the peak intensity point of the line profile and "D" represents the line width when the intensity has decreased to P% of its peak value on the Gaussian curve.



Figure 8. Line Profile Without Background Illumination



Figure 9. Line Profile With Background Illumination

Figure 9 shows the same beam profile when it is subjected to background illumination.

 B_1 represents the magnitude of the background illumination. The peak brightness under this condition is given by $B_0 + B_1$. The magnitude of the brightness P% point B_2 is now increased. It can be approximated by equation (7)

(7)
$$B_z = \frac{P}{100} (B_0 + B_1)$$

where B_2 is P% of the peak brightness

If the new value of B_2 is found by equation (7), and this value is located on the original line profile curve of Figure 9 then projected on the line profile curve with background illumination, it can be seen that the value of "D" apparent to the eye has decreased. This then shows that the eye will see a narrower line profile than actually exists.

In the first portion of this section, the effect of the phosphor decay time was examined in detail to determine its effects on the shrinking raster technique. However. the rise time characteristics of the phosphor were not considered. Figure 10 shows a typical curve relating the "build up" of the brightness of the phosphor as a function of time. Figure 10 shows a round dot sweeping in horizontal direction with a velocity v_{a} . Let us now examine what occurs as the spot transverses over a very narrow finite vertical strip of the phosphor coating. This phenomenon can best be illustrated using Figure 10. Section 1 of the spot requires t_{i} seconds to transverse the vertical strip. This means that the phosphor is excited for t_{1} (where $t_{1} = \frac{d_{1}}{v_{0}}$) seconds. On the phosphor excitation curve, this corresponds to an intensity of B₁. Section 2 of the round $\frac{d_z}{v_z}$ seconds to transverse the vertical strip of phosphor. Therespot requires fore, the brightness of the phosphor corresponds to B_{0} on the phosphor curve, thereby yielding the Gaussian intensity curve shown in the upper right hand corner of Figure 10, since B_1 and B_2 are approximately the same (that is ΔB is very small). Figure 11 shows the same round spot vertical strip of phosphor and phosphor rise time characteristics, but the horizontal velocity is now \propto times the velocity v of Figure 10. Using the same procedure as above the time of excitation is now $\frac{D_{i}}{\sqrt{\nu_{c}}}$ or $\frac{T_{i}}{\sqrt{\omega}}$ for section 1 of the spot; also, the time of excitation of section 2 of the spot is $\frac{T_{z}}{\sqrt{\omega}}$ seconds. The respective



brightness is now B_3 and B_4 on the phosphor curve. Note that ΔB is much larger, this means that the brightness levels for each section differs by large amounts. This, in turn, causes the Gaussian profile to contract in width as shown in the upper right hand corner of Figure 11.

In addition, to the rise time and decay time constants of phosphor and the background illumination effects, the actual beam profile is a function of the beam current density. When the brightness level of trace is very low, the line profile is approximately Gaussian; however, as the grid bias is decreased, (the brightness level increased) the line profile becomes more bell-shaped rather than Gaussian. This is illustrated in Figure 11A. It is obvious that the beam profile is a function of the beam current. One can immediately realize the insurmountable problems in attempting to correlate the equivalence beam currents for a single line trace raster with and without modulation.

When this test method is utilized, it is of prime importance that the linearity of the raster be maintained during the entire test. This means that if the deflection amplifiers are not carefully aligned that the linearity must be adjusted as the raster is compressed; otherwise, the test results can never be correlated on a reliable basis.

The shrinking raster technique has a number of serious deficiencies. They are:

1. The results are based on an "eye resolution" and does not yield any information concerning resolution capabilities of an integrating device such as film.

2. Since the beam profile is a function of the horizontal sweep speed, phosphor time constant, and beam current density, the actual spot intensity distribution remains undetermined in this test; therefore, it is not feasible to reflect the eye resolution mathematically in terms of the film resolution.

3. If one wishes to utilize the test method in the evaluation of high resolution tests, a large number of lines are required on the raster. Under these conditions, the deflection amplifier must be designed with similar type vertical and horizontal deflection coils otherwise cross coupling of the coils will most



probably be severe. This results in degradation of the raster in the form of line parity, line wrinkling, and line broadening. When the yoke is designed to accommodate high sweep speeds, then the size of both the vertical and horizontal deflection amplifier becomes considerably larger in complexity and cost. This method of test will, however, give consistent results if the same test conditions are maintained, because of the ability of the eye to detect extremely small differences of brightness even over an extreme brightness range. Once the actual beam profile has been determined by some other test method for the given test conditions, the shrinking raster test will provide a production type test procedure of checking the same type tubes to evaluate the reductive resolution of each tube. It does, however, require essentially the same amount of equipment as Schade's Spatial Frequency and other methods. The only "gain" is in the ease with which this test may be performed.

The three remaining test methods that were utilized define the spot characteristics in terms of its spatial frequency response or the spread function characteristics. When the spread function is known, it is possible by means of the Fourier Integral to determine the spatial frequency characteristics. Also, if the spatial frequency characteristics are known, then the spread function can be constructed by use of the Fourier transform pair. This then allows one to directly correlate the test data of these test methods.

B. THE APERTURE RESPONSE METHOD (Schade Spatial Frequency Technique)

The spatial frequency method of determining resolution is analogous to the method of determining the transient response of an electrical filter by determining the sine wave frequency response of the network. With the aid of the Fourier Integral, the frequency response is then transformed into the Time Domain Characteristics. The aperture method requires that the cathode ray tubes have a raster generated on the face of the tube. During the test, the control grid of the cathode ray tube is modulated with a sine wave oscillator. When the frequency of the modulating signal is slightly higher or lower than some multiple of the vertical frame rate of the raster, a standing wave pattern will slowly drift in the

vertical direction. The frequencies of the modulating signal are chosen such that the drift frequency remains constant at all test frequencies throughout the entire test. The modulating frequencies are determined by the following equation.

(8) $f_m = mff \pm f_o$

where $f_{\mathfrak{L}}$ - the frequency of the vertical frame rate

m - any multiple of

 f_d - the desired drift rate

 f_{rr} - the frequency of the modulating signal.

The pattern of the raster is received by a photomultiplier tube through a very narrow slit with the aid of a lens system. Figure 12 is a block diagram of this method. Inspection of Figure 12 shows that the output of the photomultiplier is a series of amplitude modulated pickets, the recurring rate of the pickets being the vertical frame rate of the raster. The sine wave modulation has a frequency equal to the drift frequency. The output of the photomultiplier is fed to a low pass filter.

The output of the low pass filter yields the sine wave modulating signal by itself. The amplitude of the signal is measured by the vacuum tube voltmeter and monitored by the scope as shown in Figure 12.

During this test, the amplitude of the filter output is recorded along with the modulating frequency at each test frequency. The test frequency is then converted in terms of the spatial frequency by

(9)
$$N = \frac{2f_m \times UN}{f_f \times f}$$

where N - the spatial frequency in TV lines per inch

 f_m - the modulating frequency in cycles per second

 f_{f} - the vertical frame rate in cycles per second

 ℓ - the visible vertical length of raster in inches

UN - the normalized unblanked time

The amplitude of the filter output is normalized with respect to the amplitude of the lowest spatial frequency of the test. A normalized amplitude spatial frequency curve



Figure 12. Block Diagram of Aperture Response Method of Test


Figure 13. Spatial Frequency Response Data.

can be graphed from the above data. This data can also be used to obtain the spread function of the CRT spot and the equivalent bandpass (N_e) "the ideal rectangular noise bandpass." The spatial frequency curve can then be Fourier transformed graphically into the spread function using the following technique.

To obtain the spread function, the spatial frequency response data are plotted on log-log graph paper. Curve 0 of Figure 13 displays a typical response curve. In this process, it is assumed that the spread function can be expressed as a number of different Gaussian curves summed together. Therefore, a template is constructed which has the normalized Gaussian curve displayed at the bottom of Figure 10. Once the template has been constructed, it is positioned over the spatial frequency curve, shifting it about until the tails of the normalized Gaussian and frequency response curves coincide. The frequency of the spatial frequency curve that corresponds to the $(\frac{N}{N_{s}} = 1)$ point of the normalized curve defines the index number of the spread function. This then defines the line index number, Ns , of the frequency spectrum curve and the normalized response amplitude of one of the Gaussian curves used to synthesize the spread function. The normalized Gaussian curve is then subtracted from the original response curve. This gives curve #1, Figure 13. The same process is then repeated for curve #1 as for curve #0. This process is then continued in an iterative manner until the difference between the remaining frequency curve and normalized Gaussian curve is insignificant.

After the mathematical equation of the Gaussian curves is determined by the above process, then they are summed on a point by point basis giving the resultant spread function of the spot. This technique is shown in its entirety using the data of Figure 13. Figure 14 shows the resultant spread function obtained from the three Gaussian curves.

The spatial frequency curve is merely the plot of the relative amplitude as a function of the spatial frequency. This curve is normally plotted on rectangular coordinate graph paper.

It is also feasible to obtain the equivalent bandpass (Ne) from the spatial frequency data. First the amplitude at each frequency is squared. Then the "squared" response data are plotted on rectangular coordinate paper. The area enclosed by this curve is then determined by graphical means. This by definition is "Ne" since



Figure 14. Spot Distributions of Figure 13

$$Ne = \int \left[T(N)\right]^2 dN$$

when T(N) is the normalized response amplitude

N is the line number

When the aperture response method is used to evaluate high resolution cathode ray tubes, several problems exist since the spot size of these tubes may be as small as 0.5 mils or even much smaller (half power diameter). The basic relationship between the spatial frequency spectrum and the space domain can be observed by considering the normalized Fourier transform pairs of the Gaussian function for this approximates the intensity distribution as a function of distance in the space domain. The transform pair of the Gaussian functions are

(10)
$$f(N) = e^{-\frac{N^2}{Z\sigma^2}}$$

(11)
$$g(\omega) = e^{-\frac{\sigma^2\omega^2}{Z}}$$

From equations (10) and (11) it can be seen that as σ decreases in magnitude the spot distribution decreases in width while frequency spectrum increases in width thus yielding higher frequency components.

The spatial frequency characteristics of a 0.5 mil spot can be approximately calculated using the Fourier transform equation of the Gaussian curve. This equation is shown below in normalized form:

(12)
$$A = e^{-[4 N_{S}r]}$$

where A - normalized amplitude at a radius r - any radius of the Gaussian curve N_S - line index number of the Gaussian distribution Therefore for the half amplitude point

$$A = 0.5$$
 $r = 0.25 \times 10^{-3}$ $N_8 = TV \frac{lines}{inch}$

Solving equation (12) for N_{S} in terms of A and r we have

(12A)
$$N_{g} = \frac{\sqrt{\log 0.5}}{4 \times 0.25 \times 10^{-3}} = 832 \text{ TV} \frac{\text{lines}}{\text{inch}}$$

If we placed the normalized curve shown in Figure 13 over the log-log graph of Figure 13 so that one of the "N" axis of the template coincides with the 832 line number of the log-log plot of Figure 10, we can determine the line number N as a function of their relative amplitude. They are:

Line Number	Relative Amplitude
4000	. 2
4900	.1
6400	. 05

The data of the above table are taken from an extended graph of Figure 13. In this Figure, the normalized Gaussian curve was placed such that $N_{\delta} = 832 \left(\frac{N}{N_{\delta}}\right) = 1$ at 832 on graph). The highest value of N to be attained is a function of the vertical frame rate, f_{ξ} ; the vertical height of the trace, λ ; the modulating frequency, f_{m} .

Of these parameters, the highest values of f_m is restricted to less than half of the horizontal sweep frequency; this is necessary to prevent "beating" of the pattern (which will cause diagonal motion of the standing wave pattern). The vertical frame rate is also restricted by flicker and the drift rate. The drift rate is normally selected to be 5 - 15 cps per second. Since the technique requires a sharp cut off low pass filter, it is necessary that the frequency of the vertical frame rate be 40 to 60 cycles per second. Otherwise, it is extremely difficult to attain the necessary attenuation in the low pass filter to eliminate the vertical frame rate from the modulated envelope.

The width of the slit used in this test method is limited by the failure of the approximation

(13)
$$\frac{\sin(\pi N l)}{\pi N l} \cong 1$$

where N - the highest measurable spatial frequency

l - slit width (same units as N)

As the width of the slit is increased, excessive attenuation of the higher spatial frequency component occurs. From Table I it can be seen that for a 0.5 mil spot size the spatial frequency response is 10% at the spatial frequency of 5,000 cycles/inch. With these test conditions imposed, equation (13) must be valid. This tells us that the effective slit width relative to the spot should be less than $.025 \times 10^{-3}$ inches. The approximation given by equation (13) is within 3% under the above conditions. The actual slit can be made as much as $.15 \times 10^{-3}$ inches if a high quality microscope objective is used to view the spot. However, as the spot is magnified, distortion will occur due to the lens; also, since the face plates of these tubes are about 1/4 inch thick, it is impossible to focus on the phosphor coating with conventional microscope objectives having magnification greater than 6 because of their short focal lengths. High power microscope objective would have to be specially made which would not be economically feasible for most cases. This then defines the maximum permissible slit width to be .15 mils.

Inspection of equation (9) reveals that the measurement of the higher spatial frequency components can be accomplished by (1) increasing the modulating frequency, (2) decreasing the vertical frame rate, (3) decreasing the vertical height of the raster.

In the evaluation of the test specimens, it was determined that it is necessary to limit the vertical height to more than 1/8 inch to prevent burning of the phosphor coating. The minimum vertical frame rate is fixed by the drift frequency and low pass filter requirements. Since the drift frequency has a minimum value of 5 to 20 cps, the vertical frame rate must be at least 2 to 3 times the drift frequency for it is extremely difficult to design a low pass filter with sufficient attentuation in the stop band. This, then, requires that the vertical frame rate have a minimum repetition rate of 40 to 60 pulses per second. If the vertical frame rate were less than this, extreme difficulty would occur in attempting to focus and adjust the raster as a result of raster flicker.

Rearranging equation (9) so that f_m is a function of f_{f} , l, UN and N, we have

(14) $f_{m} = \frac{N \int f_{f}}{2(\sigma B)}$ since N = 4900 TV lines/inch $f_{f} = 50 \text{ cps}$ UN = .85 $\int = .25$

Substituting the required test condition, the modulating frequency is

(15)
$$f_m = \frac{4900 \times \frac{1}{8} \times 50}{2 \times 0.85} = 17.4 \text{ kilocycles}$$

It is also necessary that the horizontal sweep frequency be twice the highest modulating frequency. This is necessary for beating of the raster pattern will occur at lower horizontal sweep periods. The horizontal sweep frequency should be 35 Kc per second in order to evaluate a half mil spot size accurately. The problems associated with generating such a raster were discussed in detail previously in the section discussing the shrinking raster technique. Obviously, if one encounters cross coupling of deflection coils in the generation of a 500 TV line pattern then the problems that exist in a 1400 line raster are even more difficult. As the state-of-the-art increases, spots may eventually be less than 0.1 mil. With this sort of a test method, it would be impossible to evaluate such a tube.

The aperture response method does not lend itself to a production type of measurement nor does it provide a method of evaluating the tube along the axes unless the test specimen is physically rotated. The limitations of this test method are primarily of a physical nature rather than the test method itself.

C. THE SINGLE LINE METHOD OF TEST

In the analysis of the various test methods, the single slit method was also investigated to obtain the spread function of the CRT spot. This test method consists of producing a single line recurring trace on the face of the cathode ray tube.

The trace is viewed by a photomultiplier tube through a very narrow slit which is perpendicular to the axis of the line trace. The output of the photomultiplier is then fed to the vertical amplifier of an oscilloscope. In order to obtain satisfactory display, it is necessary that the oscilloscope possess delayed and expanded sweep facilities. The delayed sweep is then triggered by the sawtooth generator that provides the sweep signal for the test specimen.

In attempting a test of this nature, it is of prime importance that the line trace have a very low sweep velocity. This is necessary to reduce the effects of the rise time and decay time of the phosphor coating to a minimum. However, when these slow sweep speeds are used, extreme care must be exercised to prevent burning of the phosphor coating. In order to accomplish this, the beam current and grid bias must be adjusted so that the light output is small. Because of these restrictions, the cathode ray tube can not be tested under its normal operating beam current and fast sweep speeds. Therefore, the test can not simulate normal operating conditions. Also, the deflection amplifier sweep and display oscilloscope must possess extremely good linearity or considerable error will result in this test.

D. THE DOUBLE LINE METHOD

A brief discussion of this method of measurements is given below. The full description of this test method was presented as a paper at the Cathode Ray Tube Recording Symposium, held in Dayton, Ohio, January 13, 14, 1959. The title of this paper is "An Accurate Method of Measuring the Spot Size of High Resolution Cathode Ray Tubes" presented by Mr. Lawrence E. White. The refinement of this equipment to measure spot sizes of .1 mil is covered in detail by the report "High Resolution Cathode Ray Tubes", Scientific Report No. 2, United States Air Force Contract No. AF33(616)-6219.

This test method utilizes a two line raster pattern consisting of a 2000 cycle per second vertical sweep and a 4000 cycle per second horizontal sweep. These sweeps are applied to the tube being tested. This pattern is then projected with a magnification of X6-X10 through a microscope on the plane of a slit that is aligned with the image of the pattern lines.

The pattern is also moved vertically in synchronization with a third sweep obtained from a display oscilloscope so that the double line image is moved across the microscope slit, and there is a point by point correspondence of the image position over the slit and position along the horizontal display oscilloscope trace. The light passing the slit is detected by a photomultiplier, and the corresponding electrical signal is applied to the vertical axis of the display oscilloscope and with each successive trace of the 4000 cycles sweep, a sample pulse is generated and displayed. Every other pulse occupies interweaving positions on the display oscilloscope because of the 2000 cycle vertical scan so that the oscilloscope pattern consists of the intensity distribution of two adjacent lines. When the line to line spacing (on the cathode ray tube under test) is known, the spot diameter at any amplitude may be determined by direct scaling from the oscilloscope. When the slow vertical sweep amplitude is increased, the Gaussian curves of Figure 15 are compressed together. The intensity distribution of the spot can also be obtained by photographing the display oscilloscope or by scaling both the vertical and horizontal axis of either Gaussian trace.

This method of test does not provide directly the spatial frequency response of the cathode ray tube nor does it provide a method of obtaining the ideal noise band-pass Ne. However, by use of the Fourier transform pairs of the Gaussian function, the spatial frequency response can be obtained in terms of the spread function. This method is similar to technique employed in the aperture response method. In addition to the above limitations, it should be pointed out that this technique requires that the display oscilloscope be intensity modulated if one desires to photograph the display oscilloscope pattern. This test method also has five basic advantages over the other test methods outlined in this report. They are:

- 1. Requires only a 2 and 4 Kc sweep plus low frequency sweep obtained from display oscilloscope. Since these frequencies are low, a minimum amount of drive power is required. The amplitude of the sweeps are also small. Therefore, it is readily attainable with good linearity.
- 2. Since the horizontal and vertical sweep frequencies differ by a multiple of two, the horizontal and vertical coils can be designed the same. This reduces the cross coupling of the coils and other pattern distortions to a minimum.



Figure 15. Approximate Display of Display Oscilloscope

- 3. The vertical and horizontal coils may be interchanged, since the coils used are identical, so that tests can be made in both axes without disturbing the physical and electrical test conditions, thereby making all test results repeatable.
- 4. With this method of test. it is possible, with modification of the optical system and slit to increase the measuring capability beyond 0.5 mils as the state-of-the-art increases (This is certainly a basic requirement of any test method)
- 5. Since the raster of the test tube is also swept in a vertical direction at a low frequency, the possibility of burning the face of the test cathode ray tube is reduced considerably.

It is these advantages that make it self-evident that this method is the best measure of determining the spot size of high resolution cathode ray tubes since it does lend itself to laboratory type of evaluation of spot size and also a fast direct method of determining the half power diameter for production type testing. As one can see, the method of the half power point or any diameter is far more precise than the shrinking raster, yet it is accomplished with the same amount of ease.

The aperture response method provided a very accurate method of determining the tail of the spread distribution (This is defined by the low frequency components of the spatial frequency). This, however, for the available film sensitivities is insignificant since it is less than the threshold of the film.

SECTION III

TEST RESULTS

The initial portion of this report outlined the various methods of test employed by the cathode ray tube industry. The theory of operation of each test method was discussed in detail. Also, from this detailed discussion of the theory operation, a proper interpretation of the test results was developed. The physical limitations and the physical problems associated with each test method were also examined in detail so that when these tests are performed on a number of tubes that it may be possible to correlate the test results and determine a meaningful definition CRT resolution. Therefore, five high resolution cathode ray tubes were subjected to each of the test methods. The tubes that were utilized were numbered 1 through 5, rather than designated by their RTMA number, since this would automatically define the manufacturer of the tube. The prime mechanical and electrical characteristics and the test operating conditions of each tube are given below

Type No. 1:

- a. Magnetic Deflection
- b. Electrostatic Focus
- c. 4" Diameter Flat Face Plate
- d. Settled Phosphor (P-11)
- e. High Resolution Type
- f. Deflection Angle ~42

Evaluated as per typical operating conditions:

Accelerator Voltage	-	12 kilovolts D. C.
Focusing Electrode Voltage	÷	1400 to 1800 volts (best focus)
Grid No. 2	-	300 volts D. C.
Grid No. 1	-	-45 to -85 volts (dependent upon desired
		brightness)

Type No. 2:

- a. Magnetic Deflection
- b. Magnetic Focus
- c. 5" Di ameter Flat Face Plate
- d. High Resolution Type P-16 Settled Phosphor
- e. Deflection Angle -42°

Evaluated as per typical operating conditions:

Accelerator Voltage	- 20 kilovolts D. C.
Grid No. 2 Voltage	- 1000 volts D. C.
Grid No. 1 Voltage	35 to -110 volts D. C. adjust to yield desired
	brightness)

Type No. 3:

- a. Magnetic Deflection
- b. Magnetic Focus
- c. 5" Diameter Flat Face Plate
- d. High Resolution Type P-11 (fine grain phosphor)

Evaluated as per typical operating conditions:

Accelerator Voltage	- 20 kilovolts D. C.
Grid No. 2	- 2 kilovolts D. C.
Grid No. 1	33 to -77 volts D. C.(adjusted to yield desired
	brightness)
Deflection Angle	-50°

Type No. 4:

- a. Magnetic Deflection
- b. Electrostatic Focus
- c. 5" Diameter Flat Face Plate
- d. High Resolution Type P-11 Phosphor Deposited Electrophoretically on the Face Plate

Evaluated as per typical operating conditions:

Accelerator Voltage	-	20 kilovolts D. C.
Focusing Grid	-	5 kilovolts D. C. (adjusted for best focus)
Grid No. 2	-	300 volts D. C.
Grid No. 1	-	-40 to -70 volts D. C (adjusted for desired brightness)

Type No. 5:

- a. Magnetic Deflection
- b. Magnetic Focus
- c. 5" Diameter Flat Face Plate (approximately)
- d. High Resolution Type P-11 Settled Phosphor

Evaluated as per typical operating conditions:

Accelerator Voltage	- 20 kilovolts D. C.
Grid No. 2	- + 140 volts
Grid No. 1	40 to -120 volts (adjusted to yield desired
	brightness)

Note: The deflection coils and focus coil are an integral part of the tube; therefore, this tube was evaluated as an integral unit.

The test specimen numbers 1 through 4 were subjected to the various test methods utilizing the test rack designed and fabricated by Data Corporation which is described in the Appendix of this report. Test specimen No. 5 was evaluated on the Cathode Ray Tube Display Unit located at Aeronautical Systems Division since this unit incorporates test specimen No. 5 as part of the equipment itself. However, the display unit was not adaptable to performing the double line method of test without considerable amount of modification; therefore, this test method was not used in evaluating test specimen No. 5. It should be noted that when the evaluation of specimen No. 5 was performed on the Cathode Ray Tube Display Unit, the operation of the Display Unit was very unstable, therefore, and the results may not be the maximum that could be anticipated.

I The results of the evaluation of Specimen No. 1 are as follows:

a. The Shrinking Raster Test

12.5 kilocycles/sec
97.66 cycles/sec
14 Percent
128 Lines (optical)
220 Lines (TV lines)
1-1/16 inches
207 TV lines/inch
.00484 inches

b. The Aperture Response Method

Horizontal Sweep Frequency Vertical Sweep Frequency Percent Blanking Number of Lines (total) Vertical Height of Raster Drift Rate of Pattern 12.5 kilocyles/sec 48.83 cycles/sec 14 Percent 256 Lines (optical) 1 inch 8 cycles/sec

Modulating Frequency	Relative Amplitude	
Cycles/Sec	Normalized to Unity	
34.	1.0	
64	. 995	
83	990	
194	980	
127.	. 500	
225	970	
200	. 510	
292.	. 900	
434.	. 960	
576.	. 955	
860.	. 920	
1144.	.850	
1710.	.700	
2000.	. 635	
2280.	.570	
2850.	. 440	
3420.	. 305	
3980.	. 205	
4270.	.176	
4920.	. 110	
5120.	.080	
5540.	. 05	

To convert the above table into spatial frequency, the following equation is used.

(16)
$$N = \frac{Z \times f_m \times 0.86}{f_f \times l} = f_m \times 3.6 \times 10^{-2}$$

where 1 = 1 inch

 $f_{f} = 48.83$ cycles/sec (Vertical Frame Rate) f_{m}^{f} = The modulating sine wave signal in cycles/sec

Spatial Frequency (TV Lines/Inch)	Relative Response (Normalized to Unity)	(Relative Response) ² (Normalized to Unity)
1.22	1.0	1.000
2.30	.995	.990
2.98	.990	.981
4.47	.980	.960
6.42	.975	.950
8.47	. 970	.940



SPATIAL FREQUENCY (TV LINES/INCH)





10.50	. 965	.931
16.00	.960	. 920
20.7	.955	.910
31.0	.920	. 845
41.2	.850	.722
61.6	.700	. 49
72.0	. 635	.403
82.1	.573	. 328
103.	.440	.193
123.	. 305	. 093
143.	. 205	. 042
153.	.176	.0301
177.0	.110	. 0121
184.	.080	.0064
199.	. 05	. 0025

Figure (16) is a plot of the spatial frequency response of Specimen No. 1. From this plot, it can be seen that N_{ξ} is equal to 44 TV lines/inch. The beam profile can now be plotted from the transform equation: $-[4N_{\xi}\times7^{2}]$

$$y(x) = e^{-[4N_S]}$$

where

 \times - the radius of the spot in inches

q - amplitude of the energy of the radius (d)

The graph of the beam profile is shown in Figure (18). From this plot, it can be seen that the half amplitude point of the intensity occurs at a radius of 4.75 mils (diameter 9.5 mils). Figure (17) displays the spatial frequency - relative amplitude characteristics of this tube on a linear graph. It also displays the relative amplitude squared - spatial frequency characteristics. The value of \mathcal{N}_{e} has been determined from this graph by obtaining the area under the amplitude squared curve. This has been determined to be 69.6 TV lines/inch. N_{e} is the ideal equivalent noise bandwidth.

c. The Single Line Method of Evaluation of Test Specimen No. 1

During this test a recurring single line trace was applied on the face of the test specimen; the frequency of the line trace was 5 pulses per second. The line trace was then viewed by the photomultiplier tube through a slit waving an effective width of .05 mils. The output of the photomultiplier tube was direct coupled to the vertical amplifier of a scope.



The sweep of the scope was triggered by the sweep applied to the test specimen. The scope used incorporated a delayed sweep feature so that the output of the photomultiplier could be expanded and positioned across the 5 inch oscilloscope face. The results are shown in the table below. Some smoothing idealization of this curve was necessary. Starting from the center of the oscilloscope tube:

Relative Amplitude	Distance from the Center of Scope Tube Calibrated in Terms of Mils
	on the Face of the Test Tube
1.00	
. 95	1.25
.90	1.90
.85	2.4
.80	2.84
.75	3.3
.70	3.65
.65	4.0
.60	4.3
.55	4.6
.50	4.9
. 45	5,3
.40	5.5
. 35	5.8
.30	6.1
. 25	6.4
.20	6.8
.15	7.2
.10	7.7
. 05	8.4

Figure 19 is a plot of the above data and shows the intensity distribution of test Specimen No. 1. The half amplitude point occurs at a radius of 4.9 mils (9.8 mils diameter). This compares favorably with the results of the aperture response method. It should be pointed out that in the first portion of this report it was shown that the beam profile is a function of the beam current. Therefore, it is of prime importance that the peak brightness of the single line be the same brightness as each line in the raster of the aperture response method. Otherwise, good correlation between the two methods can not be anticipated.

d. The Double Line Method

The test specimen was operated under the same test conditions as the aperture response test with two exceptions.

- 1. The horizontal sweep frequency 4 kc The vertical sweep frequency - 2 kc
- 2. The control grid bias was adjusted to yield the same line brightness as the line brightness of the aperture response method.

During this test, the amplitude of the 62.5 cps sawtooth was varied to determine the diameter of the Gaussian envelope for various amplitude. The intensity amplitude as a function of diameter (or radius) can then be plotted to determine the approximate shape of the beam profile. The results of this test are shown below. Some idealization of the curve had to be employed since these values were obtained by using cathode ray tube scope face as a means of relative measurement.

Relative Amplitude	Diameter in	Radius in
of Intensity	Mils	Mils
.1	14.8	7.4
. 2	13.4	6.7
. 3	12.4	6.2
.4	11.0	5.5
. 5	10.	5.0
. 6	8.6	4.3
. 7	7.4	3.7
. 8	5.8	2.9
. 9	3.6	1.8
1.0	0.	0.

Figure 20 is a plot of the data above. This, then, gives the approximate beam profile as determined by the double line method of test.

The results of the aperture response method, single line slit method, and double line method yield similar beam profiles, except the lower intensity portion of the envelope. Neither the single line trace or the double line method technique displays the tail of the Gaussian profile for amplitude less than 30%. The half amplitude points, however, compared rather well. The aperture response method yields 9.5 mils, the double line method



10 mils, and the single line trace 9.8 mils. The shrinking raster value of .005 inches does correlate when proper interpretation of this test method is applied (See Section I of the report).

- II The Results of the Evaluation of Test Specimen No. 2:
 - a. The Shrinking Raster Test

Horizontal Sweep Frequency	12.5 kilocycles/sec
Vertical Sweep Frequency	48.83 cycles/sec
Blanking (percent)	10 percent
Number of Lines (total)	256 Lines (optical)
Number of Visible Lines	461 Lines (TV lines)
Vertical Height of Compressed Rasters	.50 inches
Spatial Frequency	922 TV Lines/inch
Line Width by Shrinking Raster Method	1.08 mils/TV Lines

b. The Aperture Response Test

Horizontal Sweep Frequency Vertical Sweep Frequency Blanking (percent) Number of Lines (total) Vertical Height of Raster Drift Rate of Modulated Pattern 12.5 kilocycles/sec 48.83 cycles/sec 10 percent 256 Lines (optical) .250 inches 8 cycles/sec

Modulating Frequency	Relative Amplitude
(Cycles/Sec)	(Normalized to Unity)
62.	1.00
76.	1.00
143.	. 99
223.	.98
279.	. 97
346.	. 96
414.	. 94
482.	.94
550.	. 94
61 8.	. 93
685.	. 92
1020.	.86
1360.	.80
1700.	.71

2040.	.64
2720.	.51
3390.	.375
4010.	.26
4750.	.165
5430.	. 095

To convert the above table into spatial frequency, the following equation is used

(17)
$$N = \frac{2f_m \times 0.9}{48.8 \times 0.25} = 0.1475 f_m$$

where N - TV lines/inch

f m	- modulating frequer	ncy in cycles per second	1
	Spatial Frequency	Relative Amp	Relative Amp^2
	(TV Lines/Inch)	(Normalized to Unity)	(Normalized to Uni

v Lines/anch)	(Normalized to Unity)	(Normalized to Unity)
9.16	1.00	1.00
11.2	1.00	1.00
21.1	. 99	.98
32,9	. 98	.96
41.1	. 97	.94
61.0	.94	.882
71.0	.94	.882
81.1	.94	.882
91.1	.93	.864
101.	.92	.846
150.	.86	.739
200.	.80	.640
250.	.71	.505
300.	.64	. 41
400.	.51	.260
500.	. 375	.1405
591.	.26	. 0675
700.	.165	. 0272
800.	. 095	.0090

Figure 21 is a log-log plot of the spatial frequency response of test specimen No. 2. It should be noted that the spatial frequency characteristics of this test specimen can best be approximated by the composition of two Gaussian spectrums. Therefore, the spot distribution can be obtained as the sum of the two Gaussian functions representing



the respective Fourier transform pair of the spatial frequency spectrum. Since the cross section of the spot is the sum of the component spatial frequency spectrum transforms, the intensity distribution can be stated in general form

(18)
$$I(x) = C \left[A_{i} \left(\frac{N_{\delta_{i}}}{N_{\delta_{2}}} \right)^{2} e^{-\left[4N_{\delta_{i}} x \right]^{2}} + A_{z} \left(\frac{N_{\delta_{2}}}{N_{\delta_{i}}} \right)^{2} e^{-\left[4N_{\delta_{2}} x \right]^{2}} + \dots A_{n} \left(\frac{N_{\delta_{n}}}{N_{\delta_{n}}} \right)^{2} e^{-\left[4N_{\delta_{n}} x \right]^{2}} \right]$$

For the spatial frequency curve of Figure 21

(19)
$$A_1 = .94, N_5, = 200$$

(20)
$$A_2 = .16, N_{52} = 20$$

C = Constant required to normalize equation (18) to unity (or any desired value).

The constant, C, can be determined by setting I(x) = 1 for x = 0 with the other above constant applied in equation (18)

(21)
$$1 = C[.94 + .0016]$$
 or $C = 1.602$

The spot cross section can not be written in its entirety

(22)
$$I(x) = 1.602 \left[.94 e^{-[800 \times]^2} + .0016 e^{-[80 \times]^2} \right]$$

Simplifying above equation, we have

(23)
$$\frac{-[800x]^2}{1(x) = .9983e} + .0016e^{-[80x]^2}$$

Inspection of the above equation reveals that it is only necessary to consider the Gaussian spectrum given by Curve "B" of Figure 21 since the remaining spectrum contains less than 0.2% of the energy. Figure 22 is a normalized plot of the spot profile using the approximation $y = e^{-[800 \times 7^2]}$. It can be seen that the half amplitude point occurs at a diameter of 2.08 mils. Figure 23 is a linear plot of the relative amplitude as a





function of the spatial frequency. This Figure also contains a curve of the relative amplitude squared as a function of the spatial frequency. The area under the relative response squared curve has been obtained by means of a polar plainometer to be 28.7 inch². Therefore, the Ne for this tube is 287 TV lines/inch.

c. The Single Line Method of Evaluation of Test Specimen No. 2

Utilizing the same test procedure outlined for test specimen No. 1, this test was performed on test specimen No. 2. The results of this test are shown in the table below:

Relative Amplitude	Distance from the Center of Scope
	Tube Calibrated in Terms of Mils
	on the Face of the Test Specimen
. 05	+2.18
. 1	+1.85
. 2	+1.45
. 3	$+1. \bar{25}$
.4	+1.15
. 5	+1.1_
. 6	+ . 93
. 7	+ .85
.8	. 60
.9	+.43
1.0	+.0_
.9	45
.8	63
.7	75
. 6	95
. 5	-1.0
.4	-1.2
. 3	-1.3
. 2	-1.4
.1	-1.5_
. 05	-1,55

- over the last digit indicates that this digit is an approximation

+ values of right side of scope tube

- values of left side of scope tube

Figure 24 is a graph of the above data. The tail on the right side of the curve is most probably due to nonlinear time delay properties of the phosphor coating of the test specimen. In comparison with Figure 19, it can be seen that the data does not display the stability of test specimen No. 1 as the light output energy is considerably less. The half amplitude point occurs at a diameter of 2.2 mils (four times smaller).

d. The Double Line Method of Test Specimen No. 2

Utilizing the same test procedure as outlined under the evaluation of test specimen No. 1, test specimen No. 2 was subjected to the Double Line Test Method. The table below shows the test results.

Relative Amplitudes of Intensity	Diameter in Mils	Radius in Mils
1.0	0	0
. 9	1.0	.5
.8	1.4	.7
.7	1.75	.875
. 6	2.00	1.100
.5	2.30	1.15
.4	2.50	1.25
. 3	2,75	1.375
. 2	3.0	1.5
.1	3.4	1.7

Figure 25 is a plot of the above data. It can be seen that half amplitude diameter is 2.3 mils. This compares favorably with the results of the Aperture Response Test (2.08 mils) and the Single Line Test (2.2 mils).

III The Results of the Evaluation of Test Specimen No. 3.

a. The Shrinking Raster Test Method

Horizontal Sweep Frequency	12.5 kilocycles/sec
Vertical Sweep Frequency	48.83 cycles/sec
Blanking (percent)	10 percent
Number of Lines (total)	256 Lines (optical)
Number of Visible Lines	46 Lines (TV lines)
Vertical Height of Compressed Raster	.151 inches
Spatial Frequency	902 TV Lines/inch
Line Width by Shrinking Raster	1.18 mils/TV lines





b. The Aperture Response Test

Horizontal Sweep Frequency	12.5 kilocycles/sec
Vertical Sweep Frequency	48.83 cycles/sec
Blanking (percent)	10 percent
Number of Lines (total)	256 Lines (optical)
Vertical Height of the Raster	.25 inches
Drift Rate of Pattern	8 cycles/sec

Modulating Frequency	Relative Amplitude
Kilocycles/Sec	(Normalized to Unity)
.144	1.00
.380	. 99
. 620	. 98
. 667	.98
.968	. 95
1.34	.90
1.67	. 85
1.98	.80
2.25	.75
2.48	.70
2.79	.65
2.99	.60
3.40	. 55
3.60	.50
3.88	. 45
4.28	.40
4.50	. 35
4.76	. 30
5.30	. 25
5,45	.20
6.11	.15

To convert the above data in terms of spatial frequency, we use the following equation

(24) $N = .1475 f_m$

where N - TV lines/inch

 f_m - Modulating Frequency cps

Using the above equation, the spatial frequency characteristics of test specimen No. 3 are shown in tabular form below:

Spatial Frequency	Relative Response	Relative $\mathbf{Response}^2$
TV Lines/Inch)	(Normalized to Unity)	Normalized to Unity
20	1.0	1.0
55	. 99	. 98
90	. 98	. 96
100	. 98	. 96
145	. 95	.902
200	. 90	.81
245	. 85	.722
290	.80	.640
330	.75	.562
365	.70	.490
410	. 65	. 423
440	. 60	.360
500	. 55	. 302
530	.50	. 250
570	. 45	. 202
630	.40	.160
660	. 35	.1225
700	. 30	. 09
780	. 25	.0625
800	. 20	. 04
900	.15	. 0225

Figure 26 is a graph of the spatial frequency characteristics on log-log paper. By superposition of the normalized Gaussian curve, N_{ς} has been determined to be 250 TV lines/inch. Therefore, the spot distribution can be closely approximated by the function $Y = e^{-[1000 \times 3]^2}$. Figure 27 is a graph of this function. The half amplitude point of this error function occurs at a diameter of 1.67 mils. Figure 28 is a linear graph of the spatial frequency characteristics. By integration of the response squared curve, $\mathcal{N}e$ has been determined as 397 TV lines/inch.

c. The Single Slit Test Method

The test specimen was set up in the same manner as test specimen No. 1. The results of this test are shown in tabular form on the following page:






Relative Amplitude	Radius
(Normalized to Unity)	Display Oscilloscope calibrated
	in Terms of mils Distance of the
	Face of the Test Specimen
05	-1 5
10	-1 33
20	-1 1
.20	975
.40	015
. 30	00
.60	75
.70	05
.80	50
.90	35
. 95	20
1.00	0
. 95	+ .25
.90	+.40
.80	+.60
.70	+.70
.60	+.80
.50	+.90
.40	+1.10
.30	+1,20
. 20	+1.35
. 10	+1.60
. 05	+1.80

over the last digit indicates that this digit is an approximation
values of right side of the display scope face
values of left side of the display scope face

Figure 29 is a graph of the test results. It can be seen that the half amplitude point occurs at a spot diameter of 1.75 mils. This compares quite favorably with the results of the Aperture Response Test (1.67 mils diameter). Some departure from Gaussian profile is apparent. This is most probably due to decay and rise time characteristics of the phosphor.

d. The Double Line Test Method

Test specimen No. 3 was tested in accordance with procedure outlined in Part "d" of test specimen No. 1. The results of this test are listed in tabular form.



Relative Amplitude	Diameter	Radius
-	(Mils)	(Mils)
.1	2.90	1.45
.2	2.60	1.30
. 3	2.40	1.20
.4	2.20	1.10
.5	2.00	1.00
. 6	1.80	.90
.7	1.40	.70
.8	1,10	. 55
. 9	.80	.40
1.0	0	. 0

Figure 30 is a graph of the beam profile as determined by this test method. It can be seen from this graph that the half amplitude point occurs at a diameter of 2.0 mils. The results of this test compare with the results of the aperture response test (1.67 mils diameter) and the single line trace method (1.75 mils diameter). The results of this test method did not reveal the tail of the Gaussian profile accurately.

IV The Results of the Evaluation of Test Specimen No. 4.

- a. The Shrinking Raster Test
 - Horizontal Sweep Frequency Vertical Sweep Frequency Blanking (percent) Number of Lines (total) Number of Visible Lines Height of Compressed Raster Spatial Frequency Line Width
- b. The Aperture Response Test

Horizontal Sweep Frequency Vertical Sweep Frequency Blanking (percent) Vertical Height of Pattern Drift Rate of Pattern 12.5 Kilocycles/sec
48.83 cycles/sec
10 percent
256 Lines (optical)
461 Lines (TV lines)
0.175 Inches
2630 TV Lines/inch
.38 inches/TV line

12.5 Kilocycles/sec
48.83 cycles/sec
10 percent
0.125 inches
8 cycles/sec



Modulating Frequency	Relative Amplitude
(Kilocycles/Sec)	(Normalized to Unity)
. 345	1.00
.685	. 99
. 850	, 98
1.25	. 95
1.70	. 90
2.04	. 85
2.38	.80
2.72	.75
2.99	.70
3.29	. 65
3.57	.60
3.91	. 55
4.25	.50
4.58	.45
4.76	. 40
5.44	. 35
5.77	. 30
6.11	25

To convert the above data into spatial frequency, the following equation is used

(25) N= 3.39 fm

where $f_{\rm vr}{\rm -}$ modulating frequency (cps)

Spatial Frequency (TV Lines/Inch)	Relative Response (Normalized to Unity)	Relative Response (Normalized to Unity)
100	1.0	1.0
202	. 99	. 98
251	. 98	. 96
377	. 95	. 902
500	. 90	.81
600	.85	.722
700	.80	. 64
800	.75	.562
880	.70	. 49
970	. 65	. 423
1050	.60	. 36
1150	.55	. 302
1250	.50	. 25

1350	. 45	. 202
1400	.40	.16
1600	. 35	.1225
1700	. 30	. 09
1800	. 25	. 0625
*2000	. 20	. 04
*2100	.15	.0225
*2400	.10	.01

*approximated from the graph of Figure 31 with the aid of the normalized Gaussian curve.

Figure 31 is a log-log plot of the above data. By superposition of the normalized Gaussian function, $y = e^{-\left[\frac{\pi}{\delta}\frac{N}{N_{s}}\right]^{2}}$ on the frequency spectrum curve of Figure 31, N_s is found to be 600 TV Lines/inch. The profile of this spot can be closely approximated by the error function $-\left[2490\times7\right]^{2}$

$$y = e^{-[2400 \times]}$$

Figure 32 is a graph of this function. It can be seen that this test method defines the half amplitude diameter of the spot profile to 0.7 mils. Figure 33 is a linear graph of relative amplitude and relative amplitude squared characteristics as a function of the spatial frequencies. Mechanical integration of the relative amplitude squared curve defines the value of Ne to be 952 TV Lines/inch. It should be noted that during this test, the test specimen developed internal shorting of the elements. The surface of the phosphor coating was very thin and irregular; therefore, all tests were performed in the center of the tube.

c. The Double Line Test Method

Test specimen No. 4 was tested in accordance with the procedure outlined under Part "d" of test specimen No. 1. The results of this test are shown in tabular form below:

Diameter (Mils)	Radius (Mils)
0.2	0.1
0.3	0.15
0.48	0.24
0.60	0.30
0.68	0.34
0.75	0.375
	Diameter (Mils) 0.2 0.3 0.48 0.60 0.68 0.75

.40	0.84	0.420
.30	0.90	0.45
. 20	0.96	0.49
.10	1.05	0.525

Figure 34 is a graph of the above data. This test method defines the relative half amplitude spot diameter as .75 mils. This compares favorably with results of the Aperture Response Method (.70 mils diameter). Upon the completion of this test, the remaining evaluation of test specimen No. 4 was terminated due to the random internal shorting of the test specimen. This also terminated the test and evaluation of high resolution tubes utilizing the test fixture described in the Appendix of this report. However, a fifth specimen was then evaluated at WADD using their Cathode Display Unit. The results of these tests are shown below:

V The Results of the Evaluation of Test Specimen No. 5

a. The Shrinking Raster Test

Horizontal Sweep Frequency Vertical Sweep Frequency Blanking (percent) Number of Lines (total) Number of Visible Lines Height of Vertical Raster Line Width Spatial Frequency

60 cycles/sec 10 percent 262.5 Lines (optical) 473 Lines (TV lines) .250 inches .53 mils/TV Line 1886 TV Lines/inch

15.75 Kilocycles/sec

b. The Aperture Response Method Horizontal Sweep Frequency

Vertical Sweep Frequency Blanking (percent) Vertical Height of Raster Drift Rate 31.5 Kilocycles/sec 60 cycles/sec 10 percent .1875 inches 10 cycles/sec









Spatial Frequency TV Lines/Inch	Relative Amplitude	Relative Amplitude
100	1.00	1.00
140	. 99	.980
170	.98	.960
200	. 97	. 941
280	.95	.902
375	.90	.810
460	.85	.723
510	.80	.640
630	.75	.562
700	.70	.490
770	. 65	. 423
860	.60	.360
900	. 55	. 302
1000	.50	.250
1100	. 45	.202
1200	.40	.160
1250	. 35	.1225
1350	. 30	.09
1450	. 25	.0625
1600	. 20	. 04
1700	. 15	.0225
1900	.10	. 01

Figure 35 is a log-log plot of spatial frequency characteristics of this test specimen. The value of N_S has been evaluated as 480 TV lines/inch. Therefore, the spot profile can be approximated by the equation $y = e^{-\left[(920 \times 7)^2\right]^2}$. Figure 36 is a graph of this function, it can be seen that the half amplitude point occurs at a diameter of .852 mils.

The double line method and the single line method of tests were not performed on this test since it would require considerable modification of the WADD test console.

Close examination of the test results show that a correlation does exist between the aperture response method, single line trace, and double line trace methods. The shrinking raster technique appears to give a resolution of twice the actual spot diameter based on the half amplitude point of the intensity distribution curve. Since it was pointed out in the first portion of this report that the beam profile was a function of the beam





current density, the control grid bias was determined in the following manner. Prior to each test, the slit and photomultiplier assembly was rotated until the slit was precisely parallel to line trace. Then the line trace was moved relative to the slit until the peak amplitude point of line profile and the slit coincided. The trace brightness was then adjusted to give the same photomultiplier tube output for each test of the specimen for it is impossible to accurately relate the beam current density of each test accurately. This gave the best correlation of the various tests. It should be pointed out that this is a basic criterion if one wishes to specify to resolution.

APPENDIX "A" DETAILED DESCRIPTION OF THE TEST RACK

1. Power Supply Assembly

The function of the Power Supply Assembly is to provide the required power to the various cathode ray tube elements at the desired voltages and currents. There are essentially two types of magnetic deflection cathode ray tubes, the electrostatic focus type and the magnetic focus type. Figure II illustrates the circuit diagram of the electrostatic focus tube. From this illustration, it can be seen that in addition to the control grid bias supply, three other power supplies are required; one power supply for the accelerating anode, a voltage supply for the focusing grid, and also a supply for the screen grid. Figure III shows the electrical connection of the magnetic focus cathode ray tube. This type of cathode ray tube requires two constant voltage power supplies and a constant current supply in addition to the control grid bias supply for normal operation.

It is of prime importance that all these power supplies be "ripple free", and also these supplies should be essentially "drift free". If the power supplies exhibit "drift" or "ripple" qualities, they will be reflected in modulation patterns on the line or raster scan with defocusing effects across the face of the tube and in some cases will cause variations in spot brightness.

Because of these requirements, the following power supplies were incorporated in the test rack as the power supply assembly.

They are:

- 1. "eg," Supply (John Fluke Model 406)
 - a) Voltage Range 0-500 volts continuously variable
 - b) Current Capacity 100 ma dc
 - c) Line and Load Regulation . 01% to 50 mv whichever is greater
 - d) Ripple less than 1 mv rms
 - e) Voltage Polarity reversible



Figure I. Power Supply Assembly





Figure III. Magnetic Focus CRT Gun

- 2. "eg," Supply (John Fluke Model 400 BDA)
 - a) Voltage Range 500 to 5100 volts continuously variable
 - b) Current Capacity 1 ma dc max
 - c) Line and Load Regulation .01%
 - d) Ripple less than 5 mv rms
 - e) Voltage Polarity reversible
- 3. High Voltage Anode Supply (Spellman High Voltage Co.)
 - a) Voltage Range 1-30 kilovolt
 - b) Current Capacity 1 ma capacity
 - c) Line Regulation 0.1% No Load to Full Load
 - d) Ripple less than 100 mv rms
 - e) Voltage Polarity reversible
- 4. Constant Current Supply (Magnetic Focusing)
 - a) Current Range 5 to 85 ma dc
 - b) Regulation .1%
 - c) Ripple less than 5 mv across coil

The power supply assembly also incorporates a John Fluke Model 405 high voltage supply for the Photomultiplier tube. This supply has the following characteristics:

- 1) Voltage Range 600 3000 volts D. C.
- 2) Current Capacity 15 ma max
- 3) Line and Load Regulation 0.01%
- 4) Ripple Output less than 5 mv rms
- 5) Calibration Error-less than 0.5%

The control grid bias is obtained from the scanning generator supply. This is part of the blanking and unblanking circuit. The ripple output of this circuit is less than 10 millivolts measured from the grid of CRT to cathode,

2. <u>Scanning Generator Assembly</u>

The various resolution tests require one of two types of scans on the face of the cathode ray tube. Essentially, these scans are the line scan and raster scan. The line scan appears as a single line trace on the face of the cathode ray tube. The raster scan results in a series of parallel lines in rectangular form appearing on the face of the CRT.

The scanning generator supplies power to the deflection coils of the proper wave form. If one wishes to employ a line trace, the scanning generator supplies a current of sawtooth wave form to either deflection coil. When a raster pattern is required, the scanning generator supplies power to both sets of deflection coils. The current supplied to these coils are of a sawtooth nature where the repetition rate of the horizontal sweep rate is greater than the vertical sweep speed. Since in most cases, it is necessary that the raster pattern be stationary, the vertical and horizontal sawtooth generator must be synchronized. The scanning generator also provides an unblanking signal during the forward trace time so that the spot occurs on the face of the cathode ray tube only during the actual forward scan period. This blanks out the spot during the retrace.

Figure IV is a functional block diagram of the scanning generator incorporated in the test rack. The theory of operation of this assembly will be described with the aid of Figure IV.

The oscillator (shown in the upper left hand corner of the diagram) provides a very stable sine wave output signal at a frequency of 25 kilocycles. The output of this oscillator is used to drive the Schmitt Trigger. The Schmitt Trigger produces a square wave output in place of the sine wave input (at the same frequency).

The output of the Schmitt Trigger in turn drives the divider. The divider consists of a group of 10 binary counters connected in series which provides an output of both positive and negative square wave pulses. Each binary counter output yields a frequency division of two of the preceding stage. Obviously, the total division of the divider is 2^{10} or 1024. These outputs provide the various sweep frequencies of both horizontal and vertical systems by actuating both delayed multi's. The binary counter output pulses cause the delayed multi to change state (flip up), and it remains in this state for the period predetermined by the associated time constant. The delayed multi output, in turn, does two things: They are.



Figure IV. Scanning Generator Incorporated in the Test Rack

- 1. Actuates the sawtooth generator during the time the delayed multi remains high.
- 2. Provides an unblanking signal during trace time.

It can be seen that the counter output determines the repetition rates of the sweep circuits whereas the delayed multi's determine the trace time.

Continuing the signal path, the output of the delayed multi actuates the sawtooth generator (the slope of the sawtooth generator is controlled by its associated time constant). Next the sawtooth is direct coupled to the deflection amplifier which, in turn, drives the deflection coils.

As previously mentioned, one of the purposes of the delayed multi's is to provide an unblanking signal during the trace. Referring to Figure IV, the output of each multi is fed into a common coincidence gate. At the time when there is a signal output from each multi (this occurs during the forward vertical and horizontal sweep periods), that signal will be present at the output of the coincidence gate. This signal is then fed to the grid of the cathode ray tube, thus causing the tube to unblank. If either or both output of the delayed multi's should fail to be present at the gate, then the trace will not appear on the tube under test since the tube remains blanked. This is a safety feature incorporated to protect the tube so that a dot does not appear unless it is being swept thus eliminating the possibility of burning the face of the cathode ray tube.

It should be noted that the test rack is extremely flexible and will accommodate almost any method of test required. When the rack is operated with the fixed frequency oscillator, a choice of six sweep speeds for the horizontal deflection and vertical system is available by merely rotating the switches on the front panel. When the switch is rotated, it automatically sets in the proper time constants for the delayed multi and sawtooth generator. If one wishes to use a specific set of sweep speeds and durations, it may be accomplished by using the divider with external trigger. The proper time constants required for the delayed multi and sweep generators are inserted on the test panel. The rack may be also used to obtain a single line recurring in either horizontal or vertical direction. In addition to the normal line and raster patterns, the test rack

can be used to obtain triggered single line traces in either direction. This is accomplished by switching the delayed multi input to external sweep trigger and utilizing one of six of the sweep speed positions. If the sweep speeds do not meet the requirements, the exact sweep speed can be accomplished utilizing the external time constant provisions of the rack (as previously described). Figure V shows this basic circuit of the deflection amplifier incorporated in the test rack. From this diagram, it can be seen that the amplifiers are direct coupled push-pull circuits incorporating current feedback to linearize the output current of the deflection amplifier. The input stage of this amplifier is a cathode coupled amplifier. The output of the cathode coupled stage provides a phase inverted and amplified signal to the push-pull connected current drivers. The current feedback signal is provided by the cathode resistors \mathbf{R}_1 and \mathbf{R}_2 .

The feedback signal is fed to the amplifier input by means of resistors R_3 and R_4 . The use of this type of circuit has two important distinct advantages over an A.C. coupled deflection amplifier. They are:

- 1. The raster pattern may be positioned any place on the face of the CRT by merely altering the D. C. component of the sawtooth wave. This is accomplished by adding a positive or negative D. C. signal with sawtooth input.
- 2. The linearity is not appreciably effected as the frequency of the sawtooth wave is varied. Therefore, no linearity adjustments are required when the raster scan is changed.

The horizontal deflection amplifier is capable of supplying a differential current output of 300 ma. This amplifier may be used from D.C. to 20 kc without any appreciable change in quality.

The vertical deflection amplifier is capable of providing a differential current of 120 ma. This amplifier will function properly from D.C. to 5 kilocycles.

These deflection amplifiers are used to drive a set of square core high quality deflection coils. The horizontal coil is critically damped while the vertical coil has been heavily damped to minimize the cross coupling of both coils.



Figures VI and VII are the circuit diagrams of the vertical and horizontal deflection amplifier and drives.

This then completes the description of the scanning generator and its capabilities. However, it should be noted that various power supplies that are required to operate the scanning generator are essentially filtered ripple free and regulated. This is a basic requirement of the deflection amplifier power supplies.

3. The Optical Bench Assembly

Once the proper raster or line scan is present on the face of the cathode ray tube, it is necessary to inspect the pattern visibly either with the naked eye or with the aid of a magnifier for resolution tests. Other test methods require that the raster pattern be viewed by a sensor such as a photomultiplier or that the pattern be photographed. For these tests, the cathode ray tube mount and the camera mount must be capable of

- 1. Positioning the camera relative to the cathode ray tube anywhere across the face of the cathode ray tube.
- 2. Positioning the deflection coils relative to the CRT in the "x" and "y" direction also aligning the electrical axis of the coil with the axis of the electron gun of the tube.
- 3. Positioning the focus coil relative to the CRT in the "x", "y", and "z" directions and also aligning the electrical axis of the coil so that it coincides with the axis of the electron gun of the CRT.

The optical bench assembly is composed of two individual units mounted on a track similar to the lathe bed. This permits adjustments in the "z" axis of the CRT relative to the camera without altering the "x" and "y" alignment. The two units mounted on the optical bench are:

- 1. The Cathode Ray Tube Mount Subassembly
- 2. The Camera Mount Subassembly

The cathode ray tube mount provides the mounting for the cathode ray tube itself, the deflection coil, and the focus coil. Figure VIII shows a view of the mount without a cathode ray tube.



Figure VI. Vertical Deflection Driver



Figure VII. Horizontal Deflection Driver



Figure IX shows a view of the mount with a magnetic deflection type cathode ray tube (Dumont K1725) installed in the mount. Inspection of these Figures reveal that the cathode ray tube is rigidly clamped to the unit by two brackets. The deflection coil can be adjusted in the "x" direction by its associated adjustment knob. It can also be adjusted in the "y" direction by the respective adjustment knob. The "B" and "D" knobs (See Figures VIII and IX) are used to tilt the deflection coil so that the electrical center of the coil will coincide with electrical axis of the CRT electron gun. Therefore, the deflection coil mount fulfills requirement #2 given on the previous page.

The focus coil subassembly has a mount that is similar in construction to the deflection coil subassembly mount, however, it has one more degree of freedom. In addition to the "x" and "y", it is possible to move the focus coil subassembly in the "z" direction thereby making it possible to adjust the focus coil in any of the three rectangular coordinate axes. The plane of the focus coil can be tilted in any direction by the "C" and "E" knobs (See Figures VII and IX) so that the electrical axis of the focus coil may be precisely aligned with axis of the electron gun of the cathode ray tube. It is obvious that this arrangement of the focus coil mount meets the third basic requirement enumerated on the previous pages. (The mount must be capable of positioning the focus coil relative to the CRT in the "x", "y", and "z" directions and also the alignment of the electrical axis with the electron gun of the cathode ray tube).

The first requirement enumerated, that of being able to position the camera relative to the cathode ray tube face, is accomplished by the camera subassembly mount. Figure X is a photograph of the camera subassembly mounted on the optical bench track. The camera mount subassembly provides mounting for the camera lens, the camera body, and the photomultiplier. From this view, it can be seen that the camera subassembly allows the camera (with the lens and photomultiplier) to be moved in both the "x" and "z" directions. Figures VIII and IX indicate the direction of motions. This arrangement permits photographing the CRT pattern or using the photomultiplier mounted in the film plane of the camera. Figure XI shows a detailed view of the photomultiplier mounted in its holder. It should be noted that this holder will accommodate any sort of



Figure IX. CRT Mount With Magnetic Deflection Type CRT Installed



Figure X. The Camera Mount Subassembly



Figure XI. Photomultiplier Subassembly

window or restrictions in front of the photomultiplier's face. With this mechanical design, the desired slit or line patterns are vacuum plated on glass blanks. These windows are then mounted in the retainer ring which, in turn, mounts in the photomultiplier holder. Figure XI shows both types of retainer rings. The retainer ring having a rectangular window is mounted in the photomultiplier holder, while the retainer ring having a circular window is shown by itself. The slit pattern used to perform the spot dissection method is shown in this Figure.