WADC TECHNICAL REPORT 58-177
ASTIA DOCUMENT NO. AD 202555

DEVELOPMENT OF IMPROVED GUNS FOR CATHODE RAY TUBES

D. W. CLARK
RADIO CORPORATION OF AMERICA

OCTOBER 1958

WRIGHT AIR DEVELOPMENT CENTER

NOTICES

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ELECTRONIC COMPONENTS LABORATORY
CONTRACT NO. AF 33(600)-32608
PROJECT NO. 4156

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

McGregor & Werner Midwest Corp., Dayton, O.
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FOREWORD

This report was prepared by Mr. D. W. Clark of the Radio Corporation of America, RCA Tube Division, Harrison, New Jersey, on Air Force Contract No. AF 33(600)-32608, under Task No. 41653 of Project No. 4156, "Electronic Tubes and Transistors." This report describes work done in the Camera, Oscillograph, and Storage Tube Department of the RCA Tube Division. The work was administered under the direction of the Electronic Components Laboratory, Directorate of Laboratories, Wright Air Development Center, with Mr. Melvin St. John as the task engineer.

Included among those who cooperated in the research and the preparation of the report were Messrs. F. S. Veith, M. D. Harsh, C. R. Brackbill, N. H. Burton, and D. W. Clark.

ABSTRACT

This contract, AF33(600)-32608, calls for the development of a tube directly interchangeable with the 10UP14A, but improved with respect to focus quality and change of focus with drive. Line widths much better than those specified for the 10UP14A were attained, but difficulty was encountered in focusing screen currents of the order of one milliampere. The chief causes were focus lens distortion and space charge defocusing.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDER:

for GEORGE F. WATKINS
Lt. Colonel, USAF
Chief, Electronic Components Laboratory
Directorate of Laboratories

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INTRODUCTION

This contract is for the development of an improved gun for a cathode ray tube similar to the 10UP14A. Since the new tube must go into existing equipment, it is required to be interchangeable electrically and mechanically with the older tube.

TABLE I
Requirements Of This Contract
As Compared To Specifications For 10UP14A

	10UP14A as of 13 March 1957	Requirements of AF 33(600)- 32608
Max LWA, mm	0.68	0.33
Max LWC, mm	0.68	0.44
Min Current, μ a	200 total ultor	1000 screen
Max LW change with drive	No specifications	±0.05 mm

The required improvements are in line width "A" and line width "C". As can be seen in Table I, the new tube is required to have at least five times as much screen current, yet the line width must be reduced to approximately two-thirds of the allowable value for the existing 10UP14A. In addition, the new tube is permitted to have only a small change in line width with drive.

ANALYSIS OF REQUIREMENTS

I. Grid Modulation

A tube acceptable to this contract must meet the following cutoff and modulation requirements:

1. Screen current at least 1000 microamperes at zero bias.

2. I_{ultor} at least 200 microamperes at 32 volts E_{drive}. I_{ultor} is the total current drawn by the electrodes at the highest potential above the cathode. E_{drive} is the grid-No. 1 voltage drive from focused spot cutoff.

3. Grid. No. 1 cutoff voltage between -40 and -70 volts.

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Several tests were made on guns of typical grid-cathode donfiguration. Curve 4 of Figure 1 is an example of the results of such a test, and Figures 2 and 3 illustrate two of the general emission configurations tested. The modulation and cutoff characteristics were found to be interrelated in such a way that a tube capable of meeting the first requirement (above) could meet the second by a narrow margin at best. The generality of this finding has been reported in the literature[1] where it is shown that the relation

$$I\ \text{ultor}\ \mu a = 3E_{drive}^{7/2}\ E_{cutoff}^{-2}$$

holds with good engineering accuracy except near cutoff. This relation is a general one, being only slightly dependent on tube geometry. In Figure 1, two plots of this formula are compared with a plot of an actual tube. The agreement is very close.

Cutoff values of particular pertinence to this contract are recorded in Table 2, and the resultant drive characteristics are worked out by the formula. Table 3 contains measured data for additional comparison. The data labeled 5AZP4 were obtained from one standard RCA tube with a tetrode gun, and the cutoff was adjusted by means of the second grid voltage. Tube SN6 was one of the design evaluation series.

TABLE 2
Data From The Relations[1]
$Iu = 3\ E_d\ 7/2\ E_{co}^{-2}$
and
Iu zero bias $= 3E_{co}\ 3/2$

Grid 1 Cutoff Voltage	Grid Drive Voltage for 200 μa Iu	Zero Bias Ultor μa
40	27.3	762
44	28.8	879
48	30.2	1000
52.7	32	1147
62.5	32 + 10%	1485
70	37	1765
77	39.8	2030

TABLE 3
Measured Cutoff And
Drive Characteristics

Tube	Grid 1 Cutoff Voltage	Grid Drive Voltage for 200 μa Iu	Zero Bias Ultor μa
5AZP4	44	32	770
5AZP4	52	34	1020
SN6	63	38	1300

[1] H. Moss, The Electron Gun Of The Cathode Ray Tube - Part II. Journal of the British IRE, Volume 6, No. 2, March- May 1946, pages 99-124.

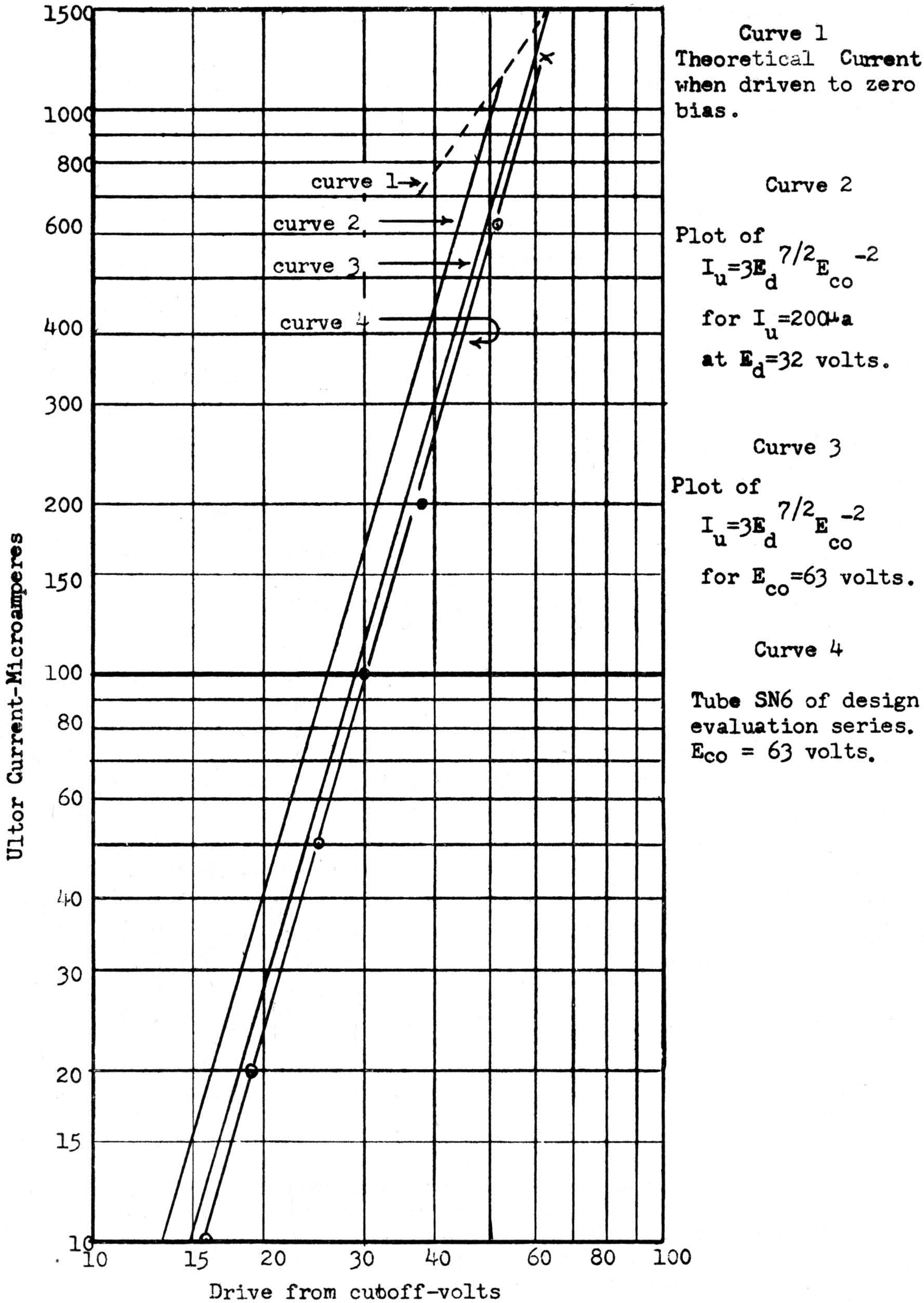


Figure 1. Drive Characteristics

Figure 1 and Tables 2 and 3 indicate that the empirical relation gives a very useful, but somewhat optimistic approximation to the performance of an actual tube.

It can be seen from Table 2 that a gun capable of delivering 200 microamperes of beam current at 32 volts modulation could not greatly exceed the requirement of 1000 microamperes of screen current at zero bias. To be within contract limits, a tube would need the following characteristics:

1. A uniform and highly active cathode (to operate as well as the formula predicts).

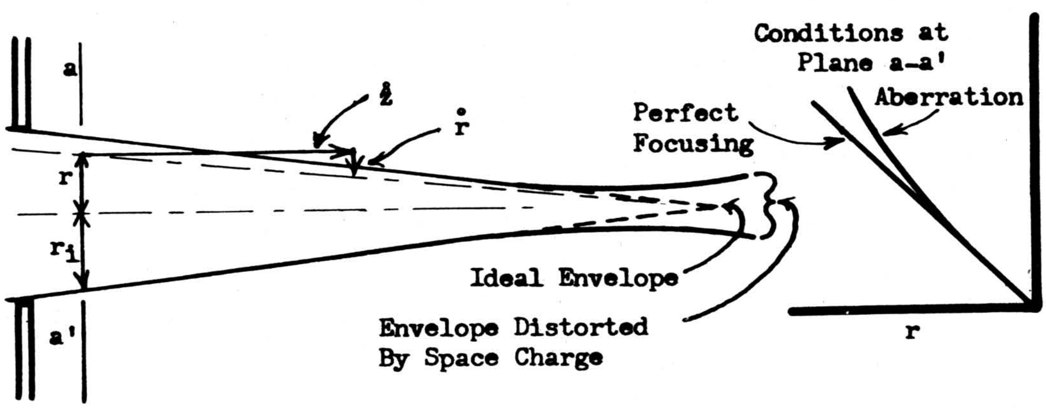
2. A cutoff voltage controlled within rather narrow limits.

3. A current efficiency of nearly 100 per cent.

Although the first two requirements can be met in practice, space charge and focus lens considerations prevent realizing the third.

II. Space Charge Defocusing

The screen current and voltage specified by this contract are such that space charge repulsion is a significant factor affecting spot size. Space charge effects can be conveniently analyzed by the method of Schwartz.[2] Throughout a given beam cross section, the electrons are assumed to be uniformly distributed, and to have inward radial velocities proportional to their respective radial distances from the beam axis. This ideal relationship between radial velocities and distances is illustrated in Figure 2, but it cannot be perfectly satisfied in practice. The radial velocity requirement cannot be realized because all practical focusing systems have positive spherical aberration. Furthermore, the current density across an electron beam is not constant, but decreases away from the axis. The requirement of high current efficiency prevents masking out the low-density part of the beam. The above deviations from assumed conditions will cause the computed spot size to be smaller than that attainable with an actual tube.



Axial position of plane a-a' taken near the limiting aperture
r = radial distance to some part of beam at plane a-a'
$\dot{r}$ = radial velocity at plane a-a'
r_1 = envelope radius at plane a-a'
$\dot{z}$ = axial velocity at a-a'

Figure 2. Conditions for Perfect Focusing

[2] Schwartz, J. W. Space-Charge Limitation on the Focus of Electron Beams. RCA Review, Volume 18, No. 1. March 1957 pages 3-11.

According to Schwartz (ibid), the ratio of spot diameter to limiting aperture diameter is a function of the parameter

$$\frac{I^{1/2}}{V^{3/4}} \frac{Z}{r_i}$$

and a curve of the functional relationship is given in Figure 3.

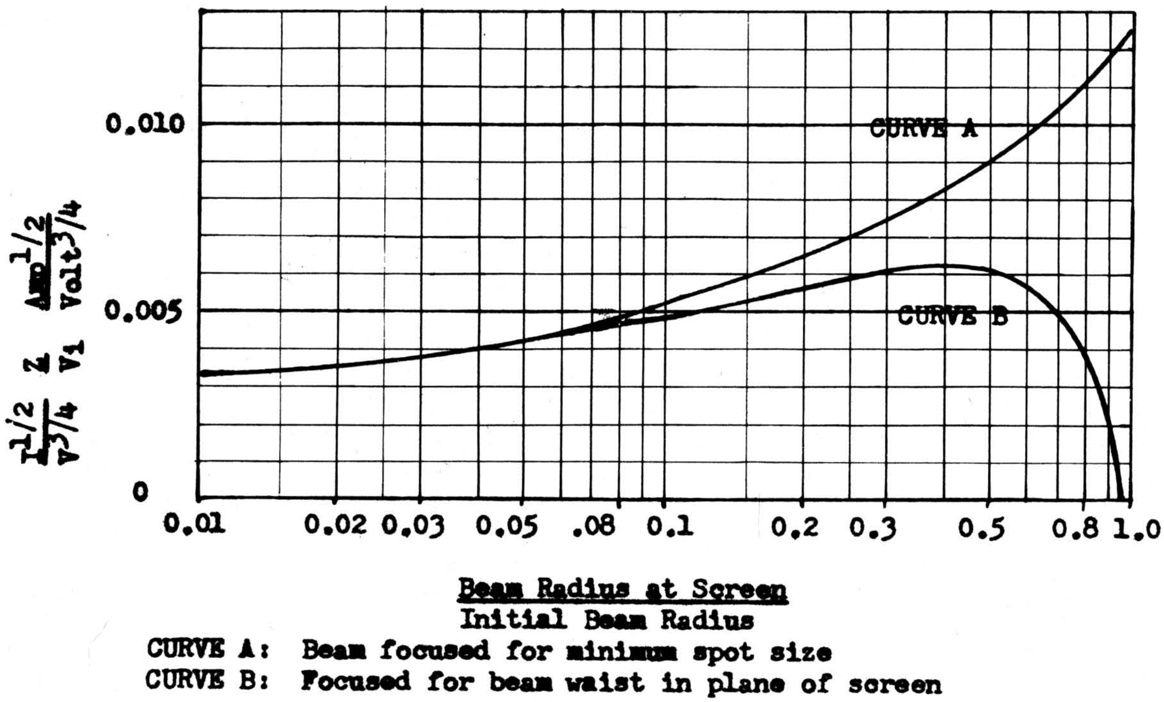


Figure 3. Spot Size Relationship

The effect of space charge defocusing can easily be ascertained from Figure 3, where I ranges up to 0.001 amperes, V is 10,000 volts, Z is the axial distance from the limiting aperture to the screen, and r_i is the initial beam radius. Bulb dimensions and other considerations dictate that Z be approximately 12.6 inches. The only item that can be adjusted at will is r_i. Table 4 indicates several possible choices of limiting aperture diameter, and the spot size which would follow each choice if space charge were the only limiting factor.

TABLE 4

Theoretical Minimum Spot Size As A Function Of Aperture Diameter

Aperture Dia. inches	Spot Dia. inches
.140	.0196
.160	.0152
.180	.0116
.200	.0086

Thus, even with a uniform perfectly focused beam, a limiting aperture smaller than 0.160 inches would certainly result in excessive spot size. Since spherical aberration, beam non-uniformity, and light scattering all tend to make the spot bigger than the computed value, a larger limiting aperture is indicated.

PRELIMINARY DESIGNS

I. Monitor and Radar Tubes

At the time this contract was first considered, it was felt that the requirements could be met with the least difficulty by modifying the design of a high-resolution monitor kinescope. Particularly attractive was the basic design of the RCA Developmental Type C73681. This is a fourteen-inch rectangular tube, magnetically focused and deflected, and intended for service as a television studio monitor. It employes a triode gun, and it is characterized by low current efficiency and a very small spot. The following comments summarize the performance of a sample C73681:

> With ultor voltage fixed at 10 kilovolts and focus current fixed at that value which gave best overall focus at 100 μamperes ultor current, the ultor current was varied from 50 to 1500 μamperes. Over this range the average line width (measured by the shrinking raster technique) at the tube center was approximately 0.18 mm and the range of line width from 0.165 mm to 0.2 mm, approximately. The average line width at a point corresponding to the point of measurement of Line Width C on a ten-inch indicator was 0.26 mm and the range of line widths from 0.21 mm to 0.3 mm, approximately.

To meet this contract, however, the gun of the C73681 would have to be provided with a screen grid and an electrostatic focusing structure. It would also have to be improved with respect to current efficiency.

By the time work was started on this contract, RCA had gained new experience in the design of high-resolution radar tubes. The RCA 5AHP7 was felt to be especially pertinent. This tube employs a tetrode gun structure and an electrostatic focusing element. It is characterized by high resolution and by a current efficiency higher than that of the RCA C73681 monitor kinescope (although still not high enough for this contract). These factors made the RCA 5AHP7 gun more suitable than the C73681 for initial investigations on this contract.

II. Early Tetrode Tests

A. 5AHP7 Gun Structure. Of the first four tubes constructed for this contract, two had guns identical to those used in the RCA 5AHP7 radar indicator, and two had guns without electrostatic focusing elements, but otherwise similar to the 5AHP7. All four tubes had P14 screens, ten-inch bulbs, and dimensions according to specifications for the 10UP14A radar indicator. See Figure 4 for a diagram of the 5AHP7 gun. Test results on these and other tubes are summarized in Figures 5, 6, and 7.

The two electrostatically focused tubes were found to have focus quality approaching contract requirements up to a screen current of approximately 300 microamperes. The masking characteristics of these guns did not permit higher screen currents. Furthermore, these two tubes were tested in comparison to the two magnetically focused tubes, and it was found that the electrostatic focusing structure did not introduce appreciable spot deterioration. It should be noted, however, that the beam diameter through the lens during these tests was 0.100" and the conclusions regarding the quality of this lens would not necessarily apply to structures permitting a larger beam.

B. Prefocusing Lens Characteristics. The RCA kinescope gun FM 80856 is characterized by strong prefocusing, and consequently by high crossover magnification, high current efficiency, and small beam diameter through the focusing and deflection fields. In view of the desirability of the latter two features, tests were made on one of these guns in comparison with a standard 5AHP7 gun. The guns were operated in standard five-inch bulbs. With both guns delivering comparable screen currents, the 5AHP7 gun was found to produce a narrower trace. Comparative results are given in Figures 5 and 6.

C. Shaved Cathodes. The roughness of an ordinary sprayed oxide cathode surface is known to increase the distortion of the object forming lens, with consequent increase in spot size. This factor has been considered theoretically in the literature[3] and found, under certain conditions, to be more significant than cathode temperature or accelerating potential in limiting the maximum attainable spot current density.

One ten-inch tube was built which had a gun similar in structure to the 5AHP7 gun, except that it had a shaved cathode. This tube was tested in comparison with a similar tube having an unshaved cathode, and an improvement in focus quality was noted as indicated in figure 7. In view of this finding, several of the design evaluation tubes were fitted with shaved cathodes. An advantage was again noted, particularly at low currents. At higher screen currents, however, additional factors contributed significantly to the spot size, and the relative advantage of shaved cathodes became less significant.

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[3] Preston, Glenn W., Effect of Cathode Roughness on the Maximum Current Density in an Electron Beam. Journal of Applied Physics, Volume 27, Number 6, June 1956, pages 627-630.

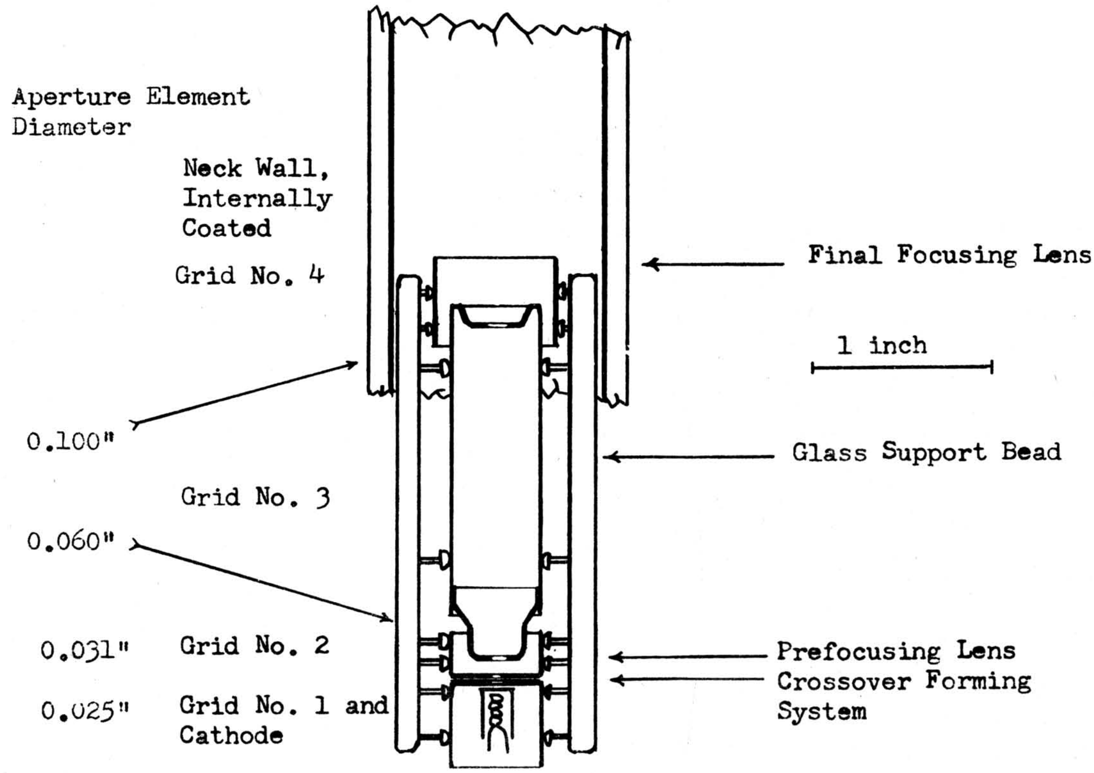

FIGURE 4. DIAGRAM OF RCA 5AHP7 GUN

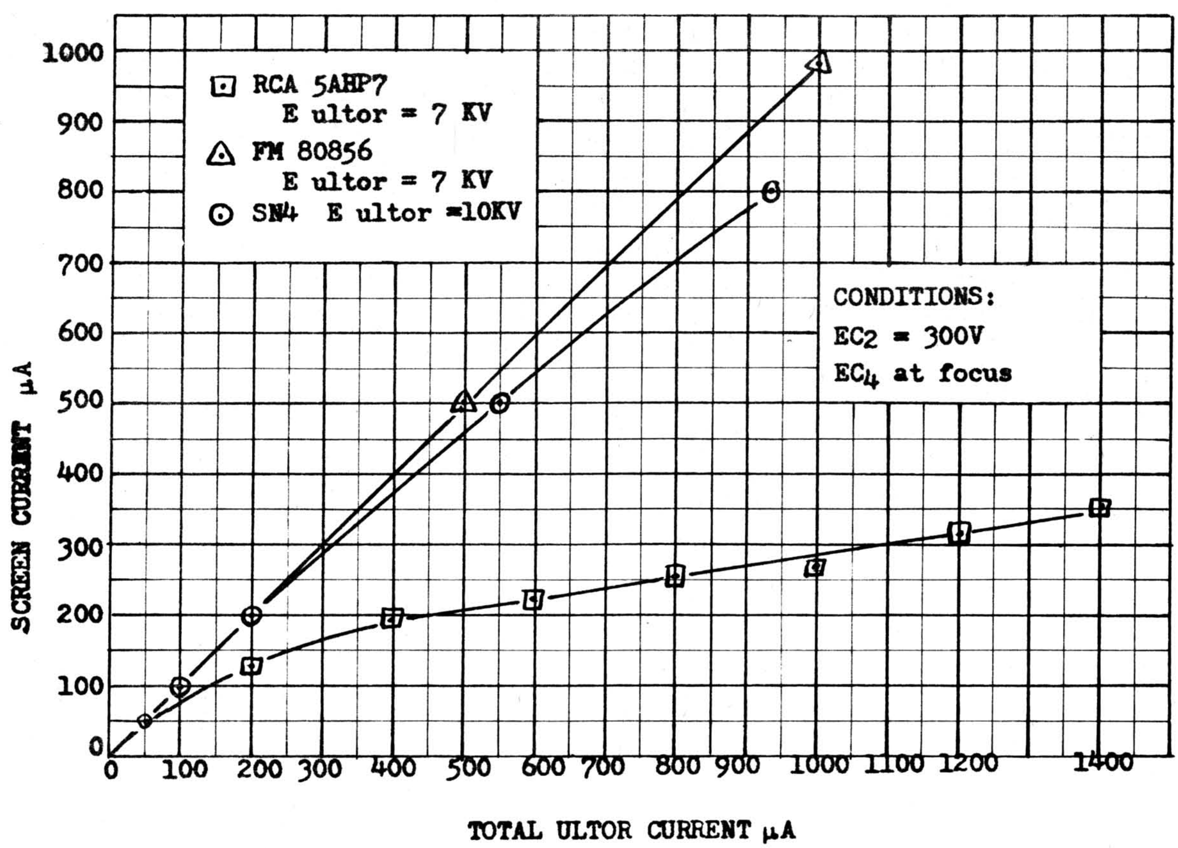

FIGURE 5. SCREEN CURRENT CURVES

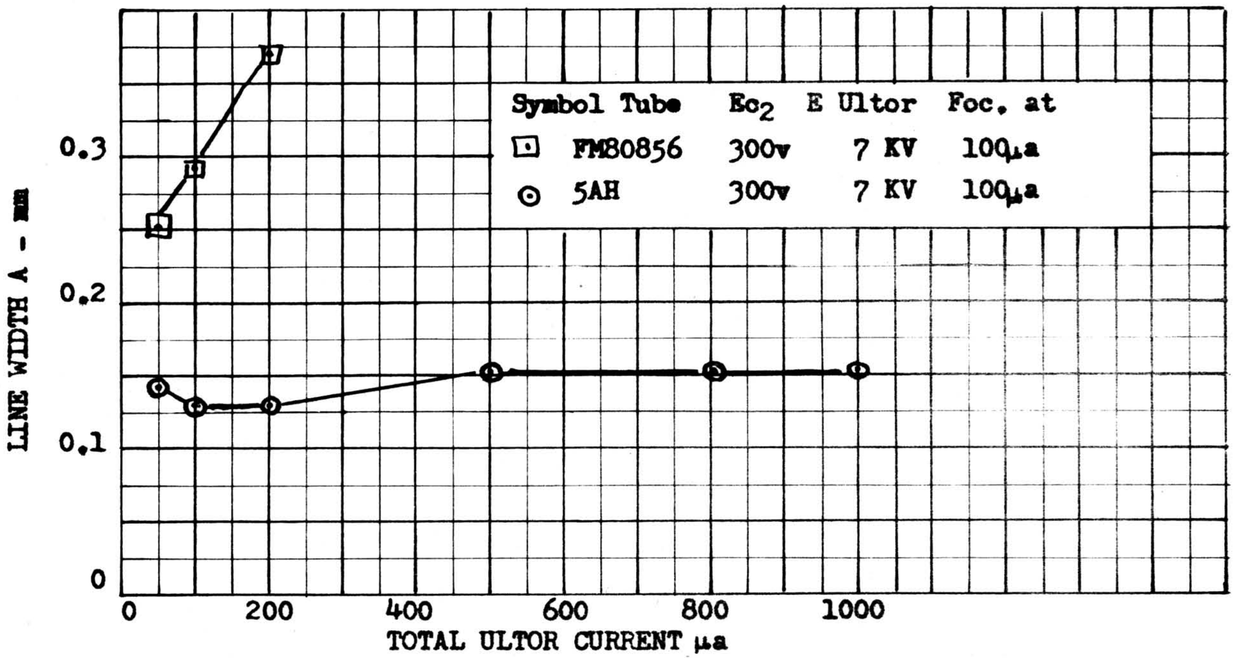

FIGURE 6. PERFORMANCE OF EARLY 5 INCH TUBES

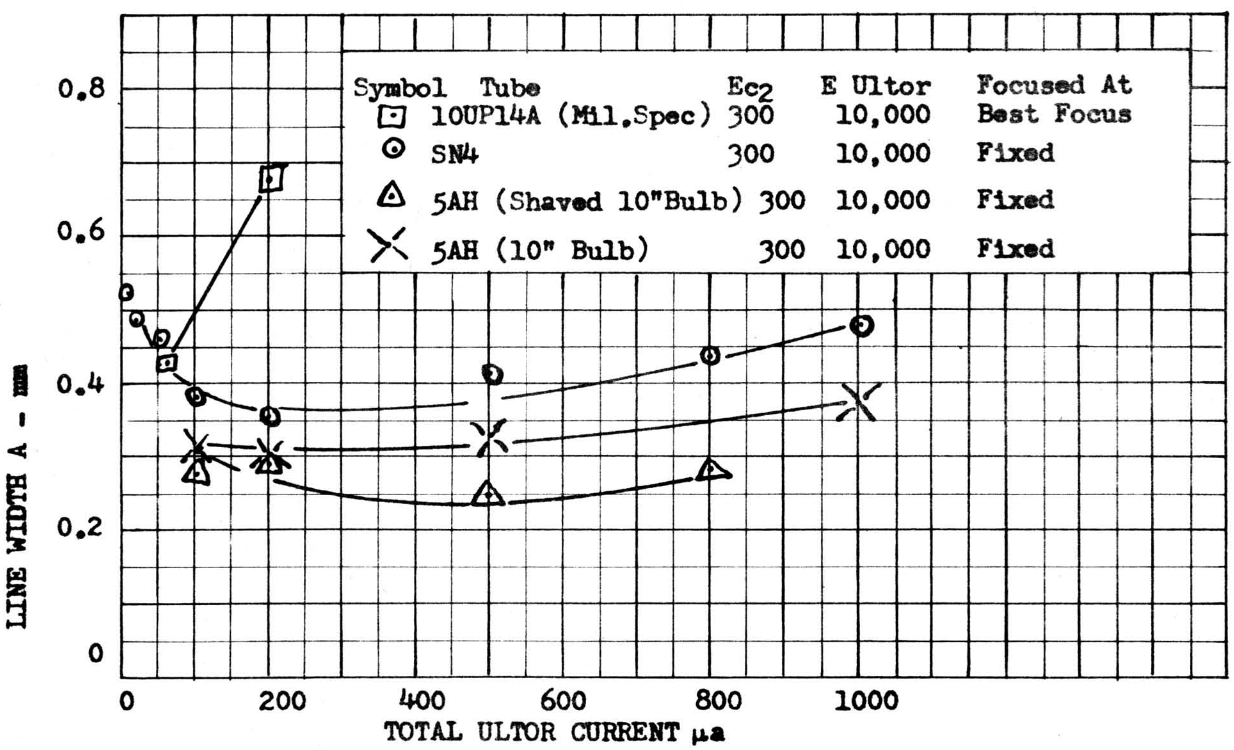

FIGURE 7. PERFORMANCE OF 10 INCH TUBES

DESIGN EVALUATION TUBES

Figure 8 illustrates some features of the tubes submitted for design evaluation purposes. Although not shown in the figure, the following items are also important:

1. Three of the tubes had shaved cathode surfaces. Given no other limiting factors such as space charge, a smoother cathode surface causes less distortion in the crossover-forming region and consequently a smaller spot size.

2. The thickness of the material immediately around the control grid aperture was reduced by coining. This results in a cleaner aperture, improved electron-optical characteristics, and better control over the cutoff voltage.

3. A prefocusing system was used which had previously given very good results with other tube types. It permitted very little current to be masked except when the tube was operated near zero bias.

4. The masking electrode was placed well within the third grid structure, in a region shielded from electrostatic fields. It limited the beam diameter in the focusing field to 0.225 inches.

These tubes were tested at Lancaster with a 210 line raster. Supplimentary checks were made with a 105 line raster and a 42 line raster, but no significant differences were found. Aside from the number of lines used, the tests were made in accordance with MIL-E-1c specifications, which permit the focus voltage to be adjusted with the lines just far enough apart to make the line structure clearly visible. The 10UP14A specifications, however, call for a raster expanded to one centimeter between lines, and focusing for minimum line width and no background smear. The former procedure generally results in best focus for the most dense portion of the beam near the axis, but the peripheral electrons are overfocused due to positive spherical aberration of the lens. The latter procedure avoids spot flare from the outermost electrons, but results in a higher focus voltage and a larger line width measurement. The above procedural differences could account for the discrepencies noted between the readings taken at Lancaster and at Dayton. However, the measurements taken at both places indicated that further improvements were needed to meet contract requirements.

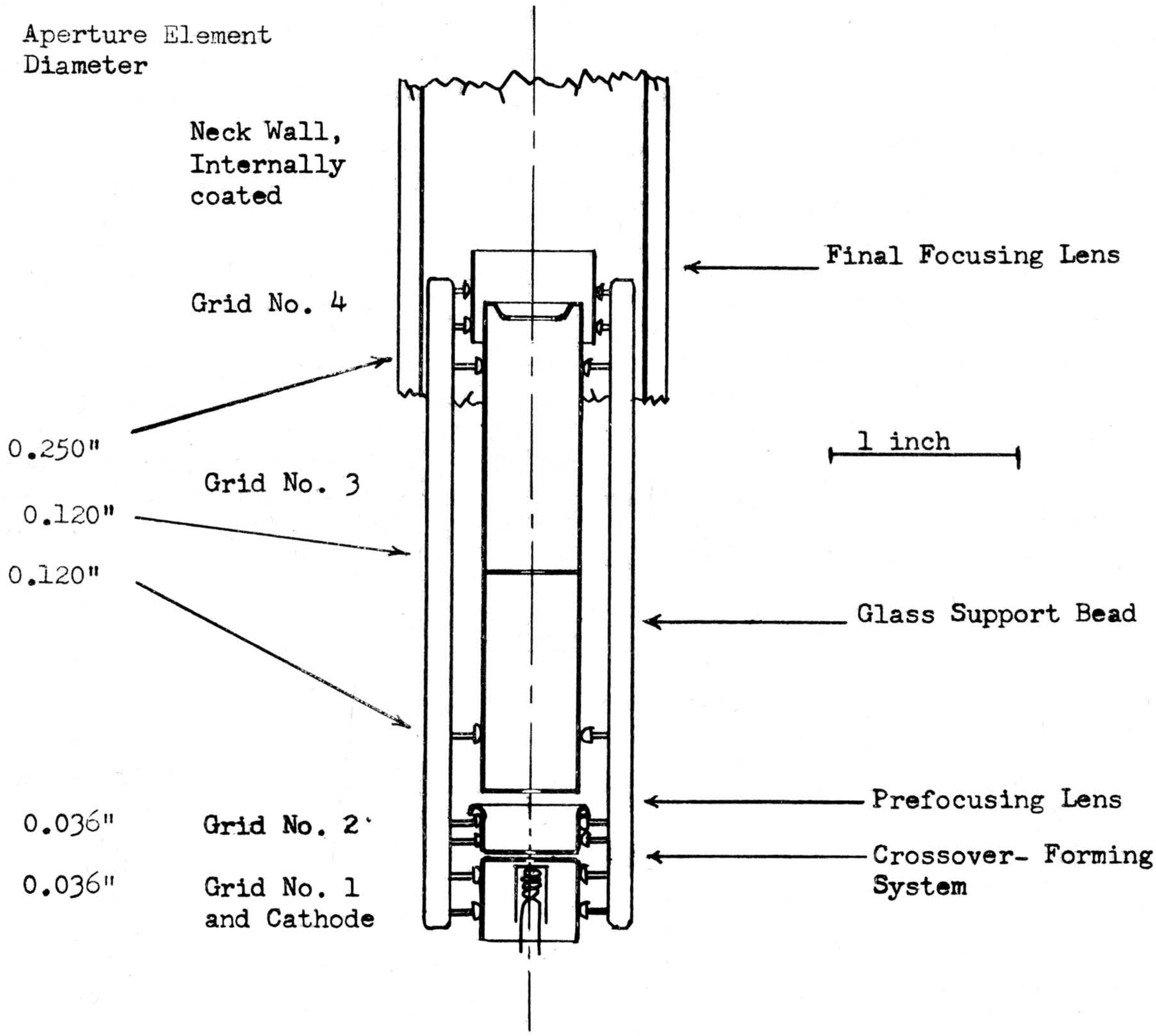

Figure 8

Diagram of Design Evaluation Gun

FINAL MODIFICATIONS

Tests on the original set of design evaluation tubes indicated that several changes were needed to bring the operating voltages into the specified range, and to improve the performance in general. The earlier tubes were characterized by high cutoff voltage, high focus voltage, and poor focus due in part to space charge. A modified gun design was worked out having reduced magnification, increased masking, and some minor changes in spacing. The gun beading jig was improved to achieve better alignment of parts. The gun is illustrated in Figure 9.

Upon testing the tubes it was found that the magnitude of the cutoff voltage was reduced, the focus voltage was reduced, and the masking was increased, all as desired, but the focus quality was no better than that of previous tubes. The changes in magnification and masking, being so chosen to concentrate more of the beam current farther from the axis to reduce space charge effects, served also to bring out the defects in the focusing lens. To determine the effect of focus defects on line width, special measurements were made on one of the final tubes and the results are recorded in Table 5. The line width was first measured with the tube focused by a magnetic coil considered to have small aberrations in the zone occupied by the electron beam. During this test the focusing electrode was held at full ultor potential, and therefore contributed no focusing effect. The tube was then operated using electrostatic focus, and a corresponding line width measurement was taken. Focus was adjusted for minimum line width with a line separation of one millimeter.

TABLE 5

Magnetic vs. Electrostatic Focus

					Normal Operation
Eultor KV	4	4	5	5	10
EC1, volts	-10	-11	-7.5	-7.5	-45
EC2, volts	120	125	125	125	440
I screen, μa	187	187	261	261	740
I total, μa	253	253	353	353	1000
Current Efficiency	.74	.74	.74	.74	.74
E focus, volts	___	-90	___	-175	-480
I focus, ma	73	___	80	___	___
LWA, mm	.72	.66	.78	.68	.60
Corrected LWA, mm	.605	.66	.655	.68	.60

Since the focusing electrode lead would not stand full ultor potential, it was necessary to make the test with reduced ultor voltage. The screen current was also reduced by an amount appropriate to hold the space charge parameter

$$\frac{I^{1/2}}{V^{3/4}} \quad \frac{Z}{V_i}$$

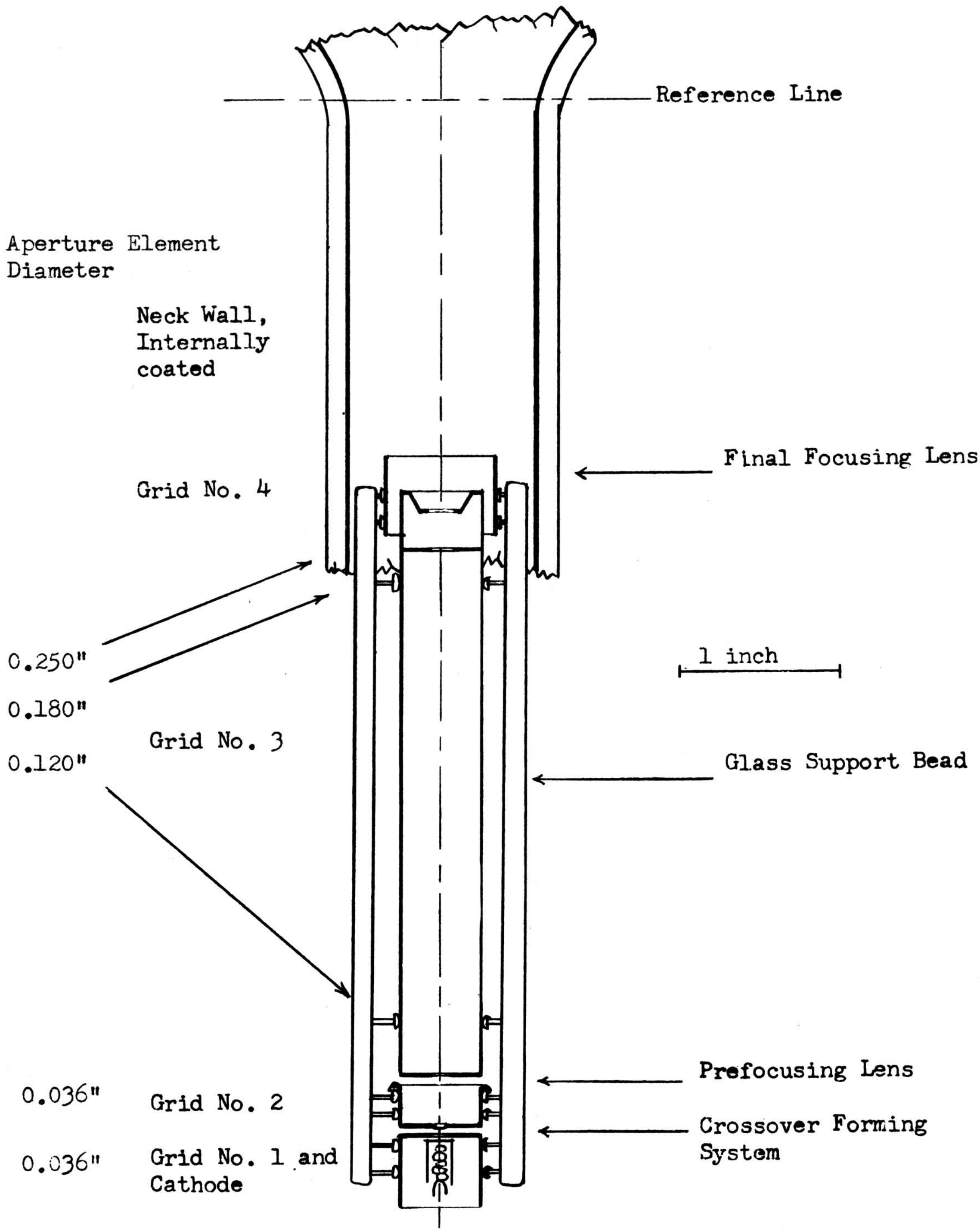

Figure 9
Diagram of Final Gun Design

constant at a level comparable to typical ten killovolt operation. The current efficiency was also held constant. Due to deflection yoke interference, it was not possible to place the magnetic focusing coil in the exact axial position of the electrostatic focusing element, but this displacement was corrected for in the bottom row of data. The corrected line widths are seen to be greater with electrostatic focus. Furthermore, it was noticed that electrostatic focusing caused in a large **halo,** while magnetic focusing did not. Spherical aberration in the focusing lens is thus seen to be a factor contributing to the excessive spot size.

Additional tests were performed to determine the significance of space charge. During these measurements the space charge parameter was changed by changing the ultor voltage. The total current and current efficiency were held constant, and in this way changes in effective cathode area, prefocusing lens strength, and main lens aberration were all kept small.

TABLE 6

Effect Of Ultor Voltage On Line Width

Eultor, KV	8	10	12
EC1, volts	-18	-45	-71
EC2, volts	282	440	580
E focus, volts	420	480	600
I screen, μa	740	740	740
I total, μa	1000	1000	1000
Current Efficiency	.74	.74	.74
LWA, mm	.80	.60	.53

Table 6 indicates that an increase in ultor voltage results in reduced line width, even when the other main operating parameters are held constant. Space charge defocusing is seen to be an additional factor contributimg to excessive spot size even when the tube is operated at somewhat less than the required current. Note also that the design of this tube was so chosen to minimize space charge effects, even to the extent of causing excessive beam diameter in the focusing field.

CONCLUSIONS

The requirements of this contract were found to necessitate the use of the lowest possible magnification, the largest limiting aperture consistent with focusing lens characteristics, a rather high current efficiency, and a very tightly controlled cutoff voltage. With close attention to the above details, and with such innovations as shaved cathodes and coined grid apertures, it was possible to attain good line width over a much wider screen current range than required of the standard 10UP14A. Tube SN4 of the design evaluation series· is an excellent illustration of success along these lines. Readings taken on this tube at WADC are plotted in Figure 7 and summarized in Table 7. These data show that the new tube can be operated at five times the ultor current required of the 10UP14A and still have appreciably smaller line width. Furthermore the new tube has a current efficiency of nearly 100 per cent, and the change in line width with drive is very slight.

TABLE 7
Performance of Tube SN4
As Compared To Specifications For 10UP14A

	10UP14A MIL SPEC as of 13 March 1957	Performance of SN4
Max. LWA, mm	0.68	0.525
Ultor Current, μa	200	from 10 to 1000 fixed focus conditions
Max. LW change with drive	none specified	± .086 mm

If further improvements are to be attempted, the Design Evaluation gun could well be taken as the starting point. A final focusing lens of larger diameter should be considered, as a carefully designed one would have reduced spherical aberration over the large beam diameter. The effect of space charge will, however, remain as a factor limiting the maximum achievable current density in the spot.

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