TECHNICAL PROPOSAL

IMPROVED CATHODE-RAY
GUN DESIGN

AMC PR-1008 (R&D EXHIBIT WCRE 55-37)

GENERAL ELECTRIC

TECHNICAL PROPOSAL

IMPROVED CATHODE-RAY GUN DESIGN

AIR MATERIEL COMMAND PR-1008

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SYRACUSE, NEW YORK

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I. INTRODUCTION

This technical proposal describes how the General Electric Company proposes to meet the requirements of the Wright Air Development Center for an improved electron gun as requested in AMC PR-1008 and R & D Exhibit WCRE 55-37, as ammended on September 15, 1955. The analysis of the requirements, the determination of the best approach, the establishment of design parameters and several methods of attack are described in detail. Although cathode-ray tube experience at General Electric indicates some doubt that all the requirements of the request can be met on a 10UP14A retrofit basis, a proposal is included complying so far as is deemed possible to the contract requirements. Also discussed are non-compliance counter proposals along lines deemed more likely to ultimately meet the application, and more likely to be achieved within the scope of the program outlined.

The General Electric Company has already given extensive consideration to the problem of high current, small spot size electron guns in both the industrial and commercial cathode-ray tube fields. This experience has been of great value in understanding the requirements and in part, explains the beliefs expressed in the preceding paragraph.

II. TECHNICAL APPROACH

A. Analysis of Requirements

The problem is one of creating an electron gun with an exceedingly small round spot, which changes size very little over a wide beam current range. This gun must operate at a relatively low anode voltage.

Listed are the limiting design considerations:

Anode voltage - 10,000 Vdc

Focus voltage - -150 to +150 Vdc

Line width "A" at 1,000 uamp - .30 mm

Line width "C" at 1,000 uamp - .40 mm

Max. line width variation from 10 uamp to 1,000 uamp - ±.05 mm

All additional specifications are the same as those proposed for tube type 10UP14A. The tube is to be mechanically interchangeable with the 10UP14A.

The requirement of maintaining spot size at currents in excess of 200 uamperes using conventional immersion lens structures is problematical for several reasons: (Also please see Appendix)

(1) As the control grid is modulated, the cathode loading varies as the 3/2 power of the grid drive

$$Dc = 1 < E_d^{3/2} \text{ (for constant geometry)}$$

furthermore, the sine of the beam angle varies as the ratio of the grid drive voltage to the cut-off voltage.

$$\sin\alpha = \frac{Ed}{Ec}$$

α = Beam 1/2 angle
Ed = Drive voltage
Ec = Cut-off voltage

It can be shown* that for the space charge free case, and for no aberration, the area of the crossover remains constant for constant geometry and anode voltage, even though the drive is varied.

Since the beam angle varies with drive, however, the apparent location of this crossover with respect to the focus lens also varies, thus causing a change in the lens focal distance with an accompanying change in spot size.

$$Y_2 = .8 \frac{\text{image distance}}{\text{object distance}} Y_1^{**}$$

Y_2 = Spot radius
Y_1 = Crossover radius

Furthermore, since space charge and aberration cannot be neglected and vary with cathode loading, the spot will vary even further in size with drive.

(2) The change in beam angle with drive places a further burden on the focus lens system. Most lenses are badly aberrated when more than about 20% of the cross-sectional area of the lens is utilized. As the beam angle varies, a greater or lesser part of the lens area is used and the spot will once again suffer from spherical aberration and a variation in spot size with both beam current and drive will be observed. Note in Appendix 1, the relation between spot size and beam diameter at the lens.

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* Moss, Hilary, "The Electron Gun of the CRT Tube", Journal of Brit. IRE, Nov., 1945.

** Spanginburg, Karl, "Vacuum Tubes"

B. Objectives to be Realized

(1) An immersion lens (cathode, modulating electrode and accelerating system) must be designed with little change in crossover area or beam angle with drive. It is thought that an approach using a narrow divergence angle would be most fruitful.

(2) The crossover must be made as small as possible either by increasing cathode loading or using spherical immersion lens focusing methods.

(3) If loading is increased, an improved cathode will be necessary to insure good life.

(4) Immersion lens aberration must be reduced by elegant assembly techniques.

(5) An improved focus lens must be designed which will have less aberration (spherical in particular). This can be achieved by:

   a) Making the lens larger
   b) Improving electrode shaping and assembly techniques
   c) Using a combination of weak lenses rather than one strong one.

(6) Excessive use of limiting apertures will necessarily be avoided because of the great range of currents over which the gun will be required to operate.

III. DISCUSSION OF APPROACHES (Proposed Systems)

A. Improve the 10UP14A gun by redesigning the conventional immersion lens and improving the final lens. (Complete compliance with contract requirements.)

(1) Immersion Lens

The cathode loading will be increased by decreasing G1 hole size and the other geometry will be adjusted to give an extremely small beam diameter. At the same time, the parts will be designed to enhance accurate assembly so that the line-up will be improved and aberration reduced. Every effort will be made to keep the beam angle as small as possible. It is possible that the cathode construction and/or processing will be changed to insure good life.

(2) Final Lens (Focus Structure)

This lens will be increased in diameter, the parts will be designed to improve mechanical accuracy. The applied voltages must remain the same, so that the approach is severely restricted so far as fundamental design change is concerned. Since the beam angle is narrow, no limiting aperture will be used.

In general, it is believed that this gun could meet the spot size requirements to about 300 uamperes. Since no limiting is used, and the spot ovality will be controlled by the excellence of the construction, no current will be drawn by any part other than the screen and equal display brightness will be achieved at lower drive voltages. Thus, the gun will behave similar to a 10UP14A gun operating at 400 uamperes.

B. Use the immersion lens described in Part II,A, 1 above, but increase the focus voltage from -150 to +150 to 2,000 volts ± 150.

This plan will allow for a multiplicity of electrodes to form a focus lens with which the General Electric Company has had favorable experience in commercial application. The focus lens becomes:

(1) a series of short coaxial cylinders

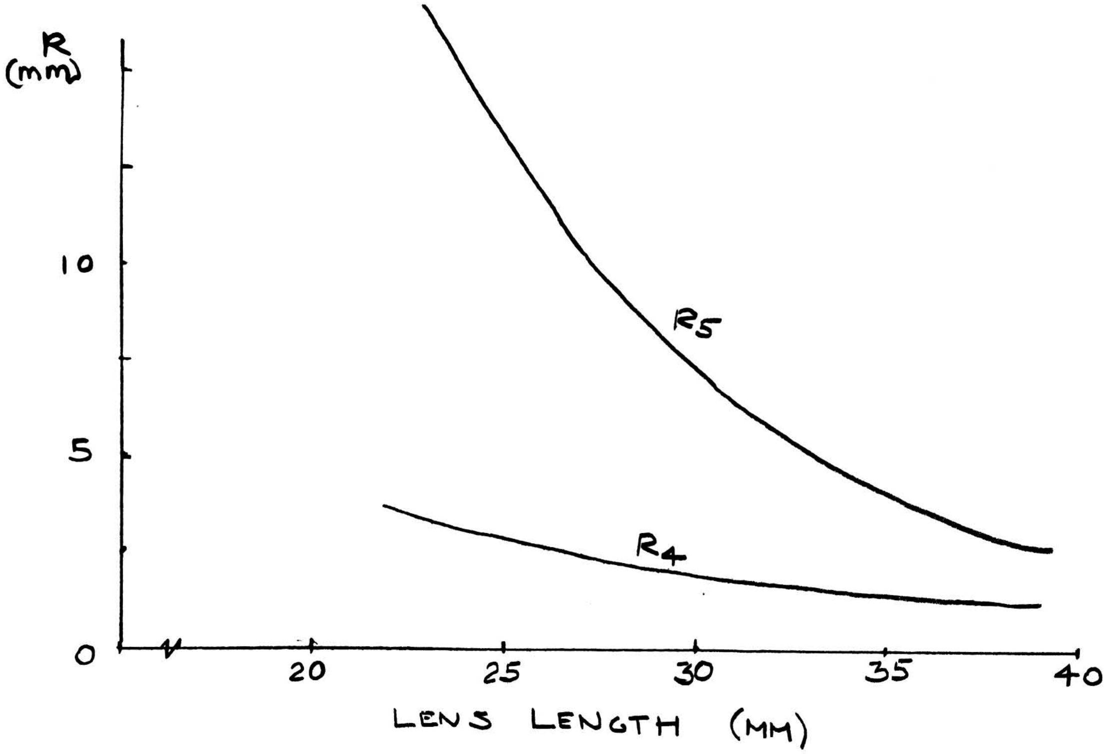
or

(2) apertured disks

spaced and held at voltages to become the boundary conditions for a long focusing field. This lens commences operation on the beam before the diameter is very large.

If R_4 is defined as the true beam radius, and R_5 is the radial distance to the aberrated electron, experience has shown that the aberration ratio R_5/R_4 is a function of lens length as shown on page 7.

Note the marked reductions in the ratio R_5 to R_4 as the beam length increases, and the number of contributing electrodes increases.



Since the action of each individual element is small, little aberration is introduced by misalignment or malformation of any individual part. The combination of these two effects results in an aberration free lens operating on a narrow beam and excellent focusing characteristics have been obtained.

This lens, properly adapted, should meet the spot size requirements to 500 uamperes. Since it also will draw no current, it will behave similar to a 10UP14A lens at 600 microamperes.

A further refinement in this type lens may make it possible to operate the lens at substantially the same voltages as the 10UP14A. This, however, would greatly increase the complexity of the task.

In order that spot ovality may be decreased to a minimum, an astigmatism control can be incorporated in this lens. This will require the addition of one extra voltage lead through the base. It is probable that this voltage would need only be d.c. and would not require modulation over the ranges desired.

C. Use final lens described in III,B above, with an improved immersion lens:

(1) Ideally speaking, it would be desirable to have the immersion lens provide a stream of closely bundled paraxial electrons to the focus lens. This may be accomplished by shaping the immersion lens electrodes in a manner described by Pierce.* This arrangement would have several advantages:

a) The cathode loading is reduced.

b) The crossover may be compromised into an optimum position with drive.

c) The beam angle may be adjusted.

d) Use of a limiting aperture is possible.

Since the beam crossover is formed after it is modulated, this immersion lens has little change in beam angle with drive.

(2) Another arrangement with which General Electric has some experience is one in which the beam is focused by an auxiliary lens immediately coupled to the immersion lens which

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* Pierce, J. R., "Electron Beam".

acts in a sense opposite to that of the immersion lens. Thus, when the beam is diverging from the immersion lens, the auxiliary lens will be increasing in strength to reconverge it. This effect tends to keep the beam angle constant with drive. This lens may or may not be electrically identical to the 10UP14A.

IV. SUMMARY OF TECHNICAL PROPOSAL (Sections I-III)

Section III of this proposal details the following possible approaches:

- III A 1. Improved immersion lens (compliance)
  - 2. Improved final lens (compliance)
- B 1. Multi-element periodic lens (non-compliance)
  - 2. Multi-element long field lens (non-compliance)
- C 1. Pre-focused immersion lens (non-compliance)
  - 2. Double crossover immersion lens (non-compliance)

It should be noted that B 1 and C 2 can be designed so as to be electrically retrofit for the 10UP14A. However, in that instance, it is probable that spot size deterioration will take place.

The chart below states the advantages and disadvantages to the best combinations of the above approaches. Disadvantages are stated as additional voltages required beyond those available for the 10UP14A and advantages are stated in terms of probable maximum beam current within the line width requirement of the P.R. Probability refers to the probability of success of meeting the beam currents stated in the advantages column.

APPROACH	ADVANTAGES	PROBABILITY	DISADVANTAGES
A_1 with A_2	400 - 500 uA	.9	-----
A_1 with B_1	650 uA	.6	Focus Voltage + 2000V
A_1 with B_2	650 - 700 uA	.6	Focus Voltage + 2000V and + 1000V and astigmatism control
C_1 with B_1	600 - 700 uA	.3	Focus Voltage + 2000V pre-focus voltage + 300V
C_1 with B_2	700 - 800 uA	.3	Focus Voltage + 2000V and + 1000V and astigmatism control, pre-focus voltage + 300V
C_2 with B_1	700 - 1000 uA	.7	(Same as C_1 with B_1)
C_2 with B_2	700 - 1000 uA	.7	(Same as C_1 with B_2)

It is our recommendation that the above approaches should all be explored during the first phase of the development and that the most promising of these approaches be used during the second phase for the final prototype development. If a more concise approach is desired, then the combinations C_1 with either B_1 or B_2 should be eliminated. Cost analysis information is submitted on two different tasks; one including all approaches and the second eliminating C_1 combinations. If it is the desire of the contracting agency to have cost information based on pursuing only one of the several recommended approaches, this can be supplied.

Nowhere in this proposal was mention made of the use of a magnetic focus lens. It is quite possible that the combination of an improved immersion lens in conjunction with a magnetic focus lens will give the best results. In studying immersion lens characteristics, however, magnetic focus lenses will be used. Therefore, inherent in this technical proposal, regardless of the specific approach taken, will be the examination of magnetic focus guns. For this reason, no specific technical proposal is made concerning the use of magnetic lenses.

V. PERSONNEL

The engineering effort will be carried on by the engineering staff of the Industrial and Military Product Engineering Sub-Section of the Cathode-Ray Tube Sub-Department with the extensive help of the Thermionics Section of the Electronics Laboratory. Key personnel directly responsible for carrying out the task of the P.R. will be:

Dr. Paul H. Gleichauf - Electronics Laboratory

F. J. Mayer - CRT

K. J. Burnett - CRT

C. Dichter - CRT

Personnel resumés are as follows:

Paul H. Gleichauf

Born at Brno, Czechoslovakia on August 27, 1916. He received his doctor's degree in physics from the Masaryk University at Brno, Czeckoslovakia in 1939. His thesis was on residual charges in semiconductors. During his studies he worked part time with "Iron" radio factory. After obtaining his degree, he joined the "Electrum" radio factory where he worked on design of radio receivers in the development laboratory and in production.

In October 1946, he emigrated to the United States of America and joined the same year the Westinghouse Research Laboratories at Pittsburgh, Pennsylvania. He worked there until 1952. The work was mainly basic research on electrical breakdown in high vacuum. Two papers on this subject were published in the Journal of Applied Physics. Other work was carried out on lightning arresters using gas mixtures.

He joined the General Electric Company, Electronics Laboratory at Syracuse, New York in February 1952, where he is working on tube development. His main activity is presently in the field of electron gun development and gas discharge studies. He developed the multi-element focus lens used in the General Electric tri-color tube.

He is a member of the American Physical Society and an associate member of the American Institute of Electrical Engineers.

F. J. Mayer, Jr.

Graduated from the Michigan College of Mining and Technology in 1948 with the B.S. degree in Electrical Engineering. Mr. Mayer joined the General Electric Company in the same year. In 1949, he became associated with its Cathode-Ray Tube Sub-Department. He has had six years' experience in engineering and engineering supervision in design engineering, planning, and manufacturing of cathode-ray tubes of both the Industrial and Military or Commercial types.

For two years he has been active in engineering and liaison work on the specific guns discussed in this report.

K. J. Burnett

Graduated from the University of Missouri School of Mines and Metallurgy, B.S.E.E. in 1952. Mr. Burnett joined the General Electric Company as a test engineer in February, 1952. He entered the Cathode-Ray Tube Sub-Department of this company in 1953 and has done gun design and development work on Monochrome, Tri-Color, and Industrial and Military type tubes.

For the past year he has had the responsibility for the design of low voltage electrostatic focus guns for radar indicator tubes.

Channing Dichter

A.B. and M.S. in Physics from Syracuse University. Prior to his employment at General Electric in 1951 as a physicist, he had three years' experience as a research assistant and as a research associate at the Institute of Industrial Research, Syracuse University, in the investigation of semiconductors for detectors, storage surfaces, and filters.

Since his association with the Tube Department, he has had responsibility for developing new tube types and has held supervisory positions in Monochrome Engineering and Development Engineering. He is currently Manager-Industrial and Military Product Engineering.

VI. FACILITIES

The development will be carried out in the Cathode-Ray Tube Sub-Department at Electronics Park, Syracuse, New York. Complete

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laboratory facilities exist that will enable us to carry out this task. No additional special facilities are anticipated.

Specific tools, jigs and fixtures for assembly of guns will be constructed as required. Details of these will be included in the quarterly Scientific Reports.

VII. ENGINEERING AND DEVELOPMENT TIME

It is estimated that the proposed program will require one year to complete and that for a complete attack, the equivalent of thirty man-months will be spent on the project. For a reduced effort (see Section IV), twenty-four man-months will be required. It is estimated that delivery of tubes required under phase I of P.R.-1008 will be made eight months after the start of the development.

APPENDIX

A. From optical considerations only, the optimum spot diameter can be expressed:

$$d \text{ optimum} = K \frac{L}{d_L} \sqrt{\frac{J_a U_o}{\bar{j}_k U_a} \ln \frac{1}{p}}$$

where:

d_L = Diameter of beam at lens center plane

L = Distance from beam center plane to screen

J_a = Beam current (Amp.)

$\bar{j}_k$ = Average cathode loading (Amp/cm^2)

U_o = Electron energy at cathode

U_a = Anode voltage

P = 0.5

$K = \frac{4}{\sqrt{\pi}}$

B. For 10UP14A:

L = 33.7 cm

J_a = 300 uamperes

$\bar{j}_k$ = .15 Amp/cm^2

U_o = .1 volt (assumed)

U_a = 10,000 volts

d_L = 3 mm (practical value)

$$d_L = \frac{4}{\sqrt{\pi}} \frac{33.7}{d \text{ optimum}} \sqrt{\frac{3 \times 10^{-4} \times .1 \times 0.7}{.15 \times 10^4}}$$

$$d_L = \frac{.009}{d \text{ optimum}} \qquad \text{(Equation 1)}$$

(Where d opt. and d_L are in cm.)

This relation considers no space charge. It would appear that the spot size were irrevocably related to beam current J_a. This is not true, however, since $\bar{j}_k \sim J_a^{3/5}$ and $d_L \sim J_a^{1/5}$. (For a system with no limiting aperture.) The plot of lens beam diameter vs. spot size appears below:

d_L	(mm)	2	3	4	5
d opt.	(mm)	.45	.3	.225	.18

C. Since the electrons in the beam cause space charge, the beam diameter is always greater than d optimum (above) and is increased to d_R where:

$$d_R \cong 0.14\,(KL)^{2.6} d_L$$

K is a space charge constant such that:

$$K = 308\,\frac{j_o^{1/2}}{U_a^{3/4}} \quad (\text{cm}^{-1})$$

and

$$j_o = \frac{4}{\pi}\,\frac{J_a}{d_L^2}$$

so:

$$KL = 349\,\frac{J_a^{1/2} L}{d_L\, U_a^{3/4}} = \frac{.204}{d_L}$$

and:

$$d_R \cong .14\left(\frac{.204}{d_L}\right)^{2.6} d_L$$

$$d_R \cong \frac{.0074}{d_L^{1.6}} \quad \text{(Equation 2)}$$

so:

d_L =	2	3	4	mm
d_R =	.86	.80	.785	

Unfortunately, these values are even optimistic as:

1. The beam is not concentric with the axis.
2. The beam current distribution is not uniform.

An impirical relationship can be written assuming that the peak current density is used rather than the average. (Once again we assume no aperture limiting.)

$$d_R \cong \frac{.0224}{d_L^{1.6}} \quad \text{(Equation 3)}$$

and:

d_L	2	3	4
d_R	.916	.91	.88

These calculations all assume no beam aberration and are meant to explore the theoretical beam diameter necessary in the lens to achieve various spot diameters. Aberration can be taken into account after some empirical data are collected.

A cursory estimate of the space charge magnitude indicates that the results are in the order of possibility.

The relations are plotted in Figure II. (Please see next page.)

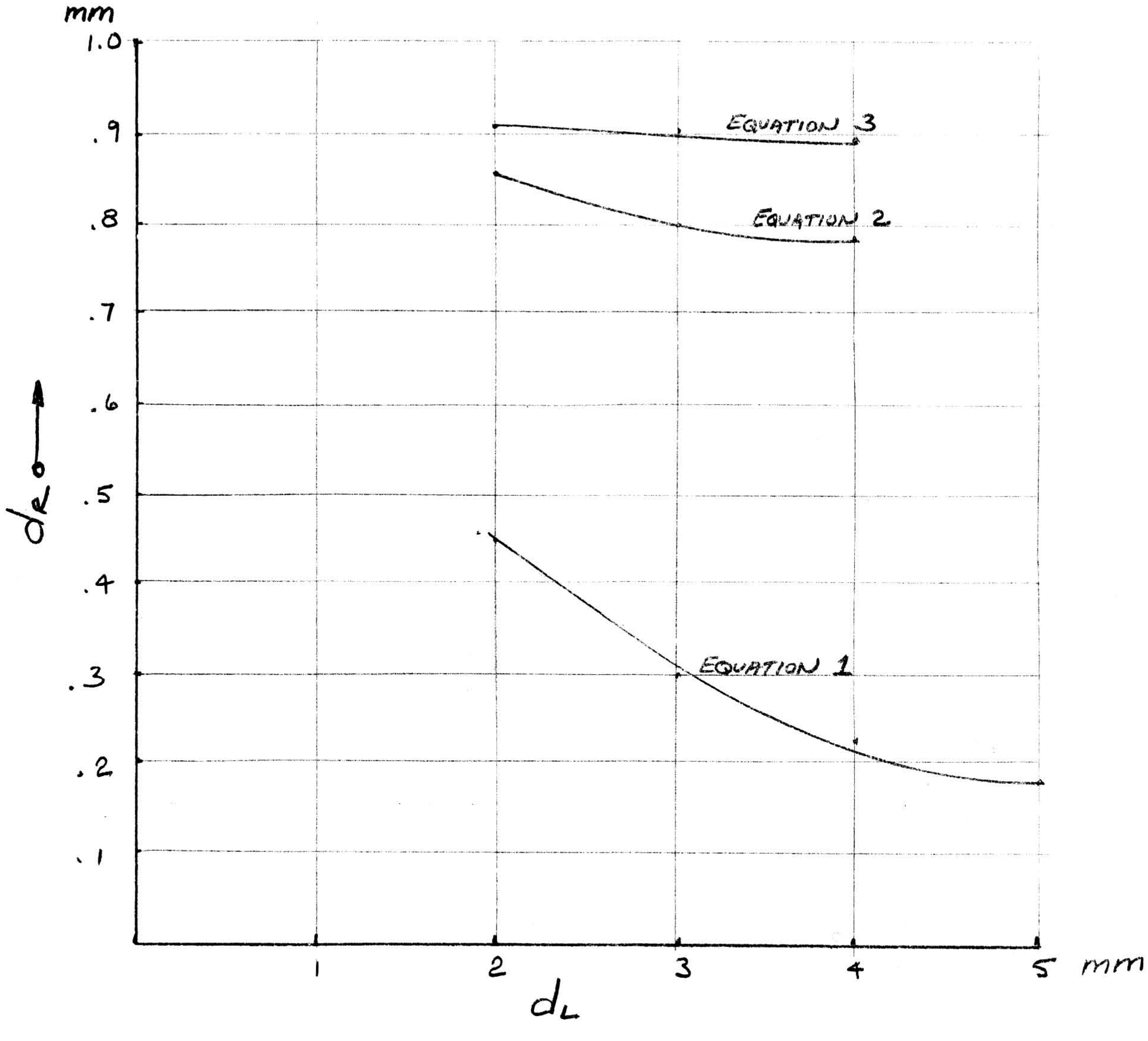
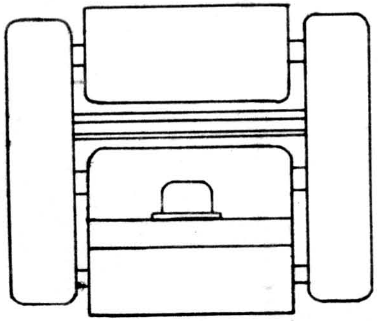
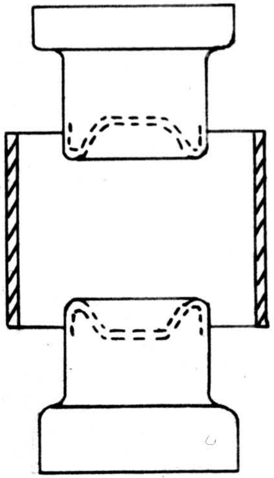


Figure 2

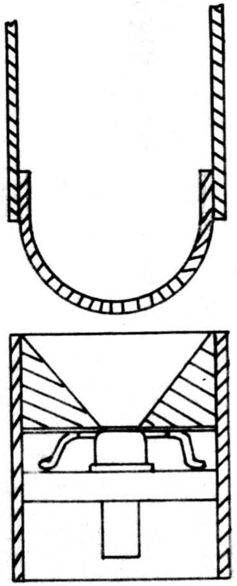
Spot Diameter d_R vs. Beam Diameter in lens d_L



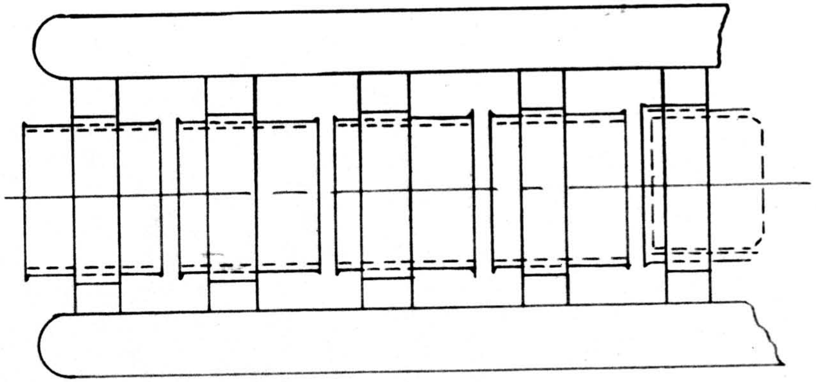
III C2 IMMERSION AND AUXILIARY LENS



III A2 STANDARD FOCUS LENS



III C1 PIERCE IMMERSION LENS



III B1 MULTI – ELEMENT FOCUS LENS

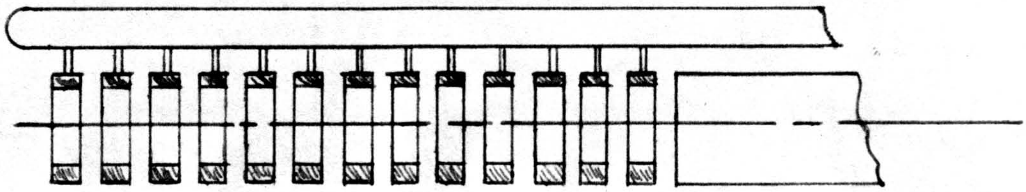
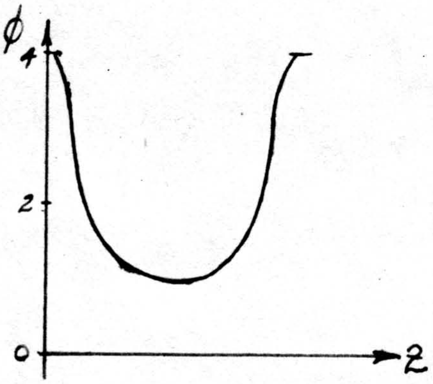
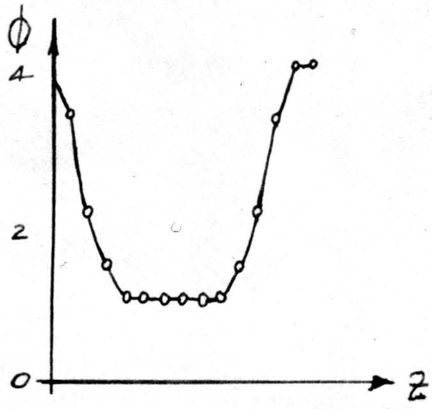


FIG. III B_2 MULTI-ELEMENT EINZEL LENS

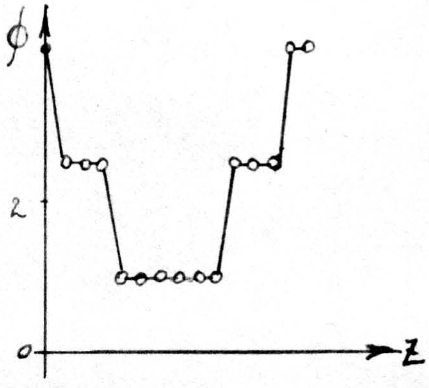
THE FOLLOWING ILLUSTRATION SHOWS AN IDEALIZED AXIAL VOLTAGE DISTRIBUTION ① WHICH YIELDS MINIMUM ABERRATION, ALONG WITH A CLOSE APPROXIMATION ② WHICH USES LENS III B_2. THE MORE PRACTICAL DISTRIBUTION ③ SHOWN, USES FEWER ELEMENTS, BUT INCREASES ABERRATION 20%



(1)



(2)



(3)