HIGH-PERVEANCE ELECTRON GUN

Second Quarterly Progress Report
Covering period August 1, 1959 through October 31, 1959

Contract Number DA36-039 SC-78299
DA Task Number 3-99-13-602

U. S. Army Signal Research & Development Laboratory
Fort Monmouth, New Jersey

GENERAL ELECTRIC

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HIGH-PERVEANCE ELECTRON GUN

Second Quarterly Progress Report
Covering period August 1, 1959 through October 31, 1959

Contract Number DA36-039 sc-78299
DA Task Number 3-99-13-602

To: U. S. Army Signal Research & Development Laboratory
Fort Monmouth, New Jersey

By: General Electric Company
Cathode Ray Tube Department
Industrial & Military Operation
Building 6, Electronics Park
Syracuse, New York

December 21, 1959

Electronic TUBES

HIGH-PERVEANCE ELECTRON GUN

Second Quarterly Progress Report
covering period August 1, 1959 through October 31, 1959

Objective:

To Develop an Electron Source for Electron Guns:

1. High Control Sensitivity (<8 volts)
2. High Beam Current (1000μA)
3. High Resolution (.005" final aperture)

Contract Number DA36-039 sc-78299

Technical Requirements - SCL-5655
(October 16, 1958)

DA Task Number 3-99-13-602

Prepared By: Dr. Kurt Schlesinger.
Dr. Kurt Schlesinger
Consulting Engineer

Approved By: C. Dichter
C. Dichter, Manager
Industrial & Military Operation

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Purpose

The contract calls for a research effort directed towards the development of an electron gun of an advanced nature. The gun shall deliver a strong beam (1000 microamperes) through an opening of very small size (.005") and do so under controlled divergence (within six degrees). Moreover, this beam shall be subject to modulation by weak signals (not exceeding eight volts), and beam cutoff shall be virtually complete (less than .01 microampere).

To meet these objectives it is planned to start with a large area cathode and to focus its emission upon the defining aperture under the proper angle of convergence. To minimize aberrations, the electron lens used for focusing is designed according to the theory of hyperbolic fields. It is intended to accomplish modulation within this focusing structure by electron reflexion. This will call for the development of a suitable type of electron mirror which has to be compatible with the focusing action of the lens.

The purpose of the work done during this report period was the reduction to practice of theories about gun design, as presented in the first quarterly report. For this purpose, a considerable number of experimental data have been gathered and a preferred gun design developed.

Abstract

A considerable number of experimental guns using the FRM principle (focus-reflex modulation) were built and tested during the report period. Although feasibility and efficiency of FRM were established quite early, many more tests were needed to arrive at optimum design. Some of the problems requiring solution were:

- Smallest practical aperture
- Lowest aperture voltage
- Highest control sensitivity
- Reduction of anode voltages by value and number
- Beam divergence control
- Mechanical design and alignment
- Gun structural simplifications

At the present time this effort has led to an FRM gun with a maximum observed beam current of 900μA at 20,000V (beam power = 18 watts). The gun has an aperture of .015" at 250 volts and is fully modulated by a signal drive of 11 volts. Cutoff is at -10 volts and current to the control electrode is negligible. (<20uA). Only one anode supply is needed: 500 volts at 1.5 mA; this voltage is center tapped to bias the aperture. A television display with this gun had a center resolution of at least 500 lines and produced a highlight brightness of 250 foot lamberts without tendency to saturate and with good reproduction of halftones.

Publications, Lectures, Reports and Conferences

Reports:

Reference: SIGSU-FM1b3f
Contract No. DA-36-039 SC-78299
File No. 18536-PM-59-91-91(4901)
PR&C No. 59-ELE/R-4901

Title: High Perveance Electron Gun (monthly status letters Nos. 3 and 4 covering the period August 1 through September 30.)

Author: Dr. K. Schlesinger, Consulting Engineer

Date: September 15 and October 6, 1959, respectively.

Factual Data

I. Previous Contract Effort

At the end of our first quarterly report it was found from mathematical analysis that parallel electron flow can be focused and decelerated by a short, hyperbolic lens in such a way that it passes through a small exit aperture at very low velocity. Once this is accomplished, the beam can be readily modulated by rather weak signals applied to the focusing electrode in a negative direction. This method of modulation is henceforth called "Focus-Reflex Modulation" or FRM for short.

Our first developmental gun to make use of focus-reflex modulation was type T-2 which had the apex of the focusing hyperboloid positioned at a point 83 percent down the length of the lens structure. Results with the T-2 were generally encouraging as documented at the end of our first quarterly report. Essentially, a beam of 200uA was fully modulated by a four volt drive. The main drawback of the T-2 was the low value of beam current available.

II. Gun Design Type T-2

At this point it was decided to proceed to a new gun design having the field origin coincident with and not ahead of the output aperture. Essentially, this amounts to using only one half section of a hyperbolic lens for focusing and modulation. Since this was the third type of gun design investigated under the contract, it is henceforth identified as type T-3.

This system was introduced at the end of our first quarterly report (Figures 1 through 15). It was computed as projecting an electron focus $Z_m = 1.02\ell$, or 15 mils behind the apex of the focusing cone of 109° 24'. Beam velocity at that point was predicted as 4.8 percent of input voltage or 12 volts for a 250 volt anode voltage. Hence, signal voltages of that order were expected to suffice for full modulation.

III. Early T-3 Gun Assembly

Figure II-1 shows one of the early gun assemblies of the type T-3 using focus-reflex modulation. This gun consisted of three parts:

A. Pierce Cathode.
B. Decelerating Hyperbolic Lens
C. Defining Aperture Leading into a Post-Focusing Lens.

A. The Pierce cathode section included a concave (R = .170") nickel sleeve K of 1/8" diameter having an emissive area of .060" diameter. The first anode A_1 was a plane disc at +250 volts with the same aperture as the emissive area on K. Collimation of the beam (1000uA) was accomplished by an aperture of .150" which was placed ahead of K at the critical distance (.030") such that a near zero bias on terminal C would collimate. (current to A_1 vanishing).

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TITLE: FRM - gun assembley

FIRST MADE FOR

REV NO.: Fig. II-1.

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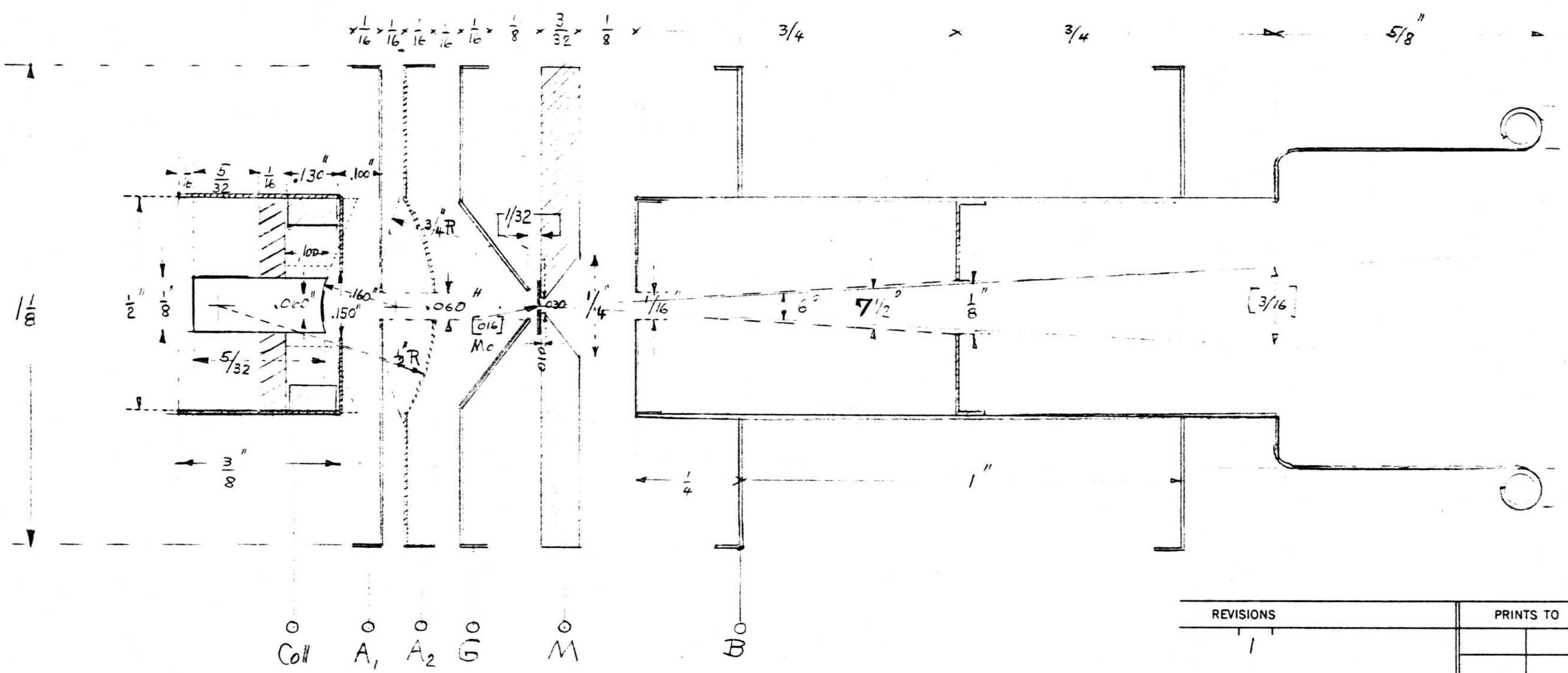

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B. The decelerating hyperbolic lens field was formed between a second anode A_2 and a conical electrode g, also called the "gate". Note that the radius of A_2 (1/2") is twice the spacing from A_2 to the aperture (1/4"). The focusing cone (g) includes an angle of 109° 24'.

C. The defining aperture in this early gun measured 22 mils punched through a thin foil of molybdenum and welded on the plane back of a "meniscus" electrode M. The latter was a thick (.100") disc of stainless steel which was carved out to form a cone of 109° 24'. This opens to a diameter of 1/4 inch in the second surface of M. This electrode which we call a "meniscus" from optical analogy, gives rise to post-focusing or condensor-action, if a subsequent anode is present at a more positive voltage than M.

In Figure II-1 an end cap of the main lens barrel, running at 2000 volts provided this converging field. A second aperture inside the barrel served to keep the beam spread within the specified upper limit of six degrees.

IV. Results of Tests with T-3

Figure II-2A shows a family of curves obtained with this gun. Heavy solid lines show forward current I_b as collected at a collector anode held 50 volts above the potential of the 22 mil aperture. (In this case the lens barrel itself was used as a collector). Light solid lines show the backward current I_{A_2} collected by the booster anode A_2

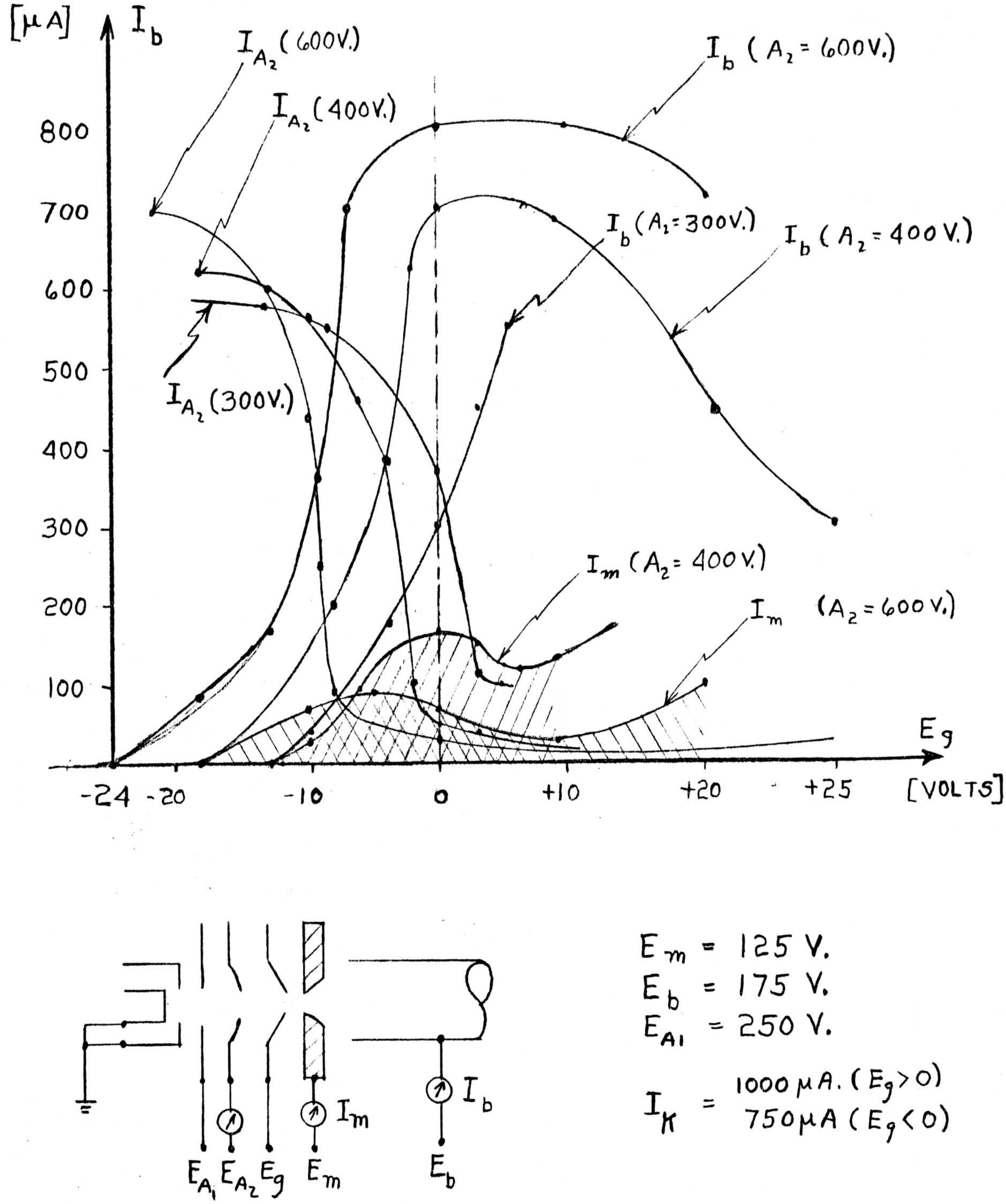


Fig II-2A: Current Distribution in Focus-Reflex Gun at the entrance to the hyperbolic field. The current to A_1 was found to be negligible. Shaded areas show the current I_m as intercepted by the miniscus electrode M, supporting the aperture.

V. Complementary Symmetry of Currents

It is found that forward current I_b and backward current I_{A2} to the second anode A_2 supplement each other to add up approximately to the constant value of cathode current I_k (1000uA) minus losses. This complementary symmetry of I_b and I_{A2} is typical for focus reflex modulation. It becomes quantitatively more complete as the booster voltage A_2 is raised and with it the peak beam current I_b. At A_2 = 600 volts, there is almost perfect mirror symmetry between I_b and I_{A2}, whose curves intersect at 400uA, or one half of the forward current amplitude. The existence in an FRM gun of a conjugate current I_{A2} at high transconductance ($-g_m$) can conceivably be utilized for positive feedback to the gate. This would further increase the effective g_m of the tube, thus greatly reducing the signal drive. One can also design circuits using the A_2 current for signal processing such as amplification and sync separation.

VI. Effects of the Anode Voltage

Raising the anode voltage boundary A_2 in the hyperbolic lens was found to have four effects. It:

A) Raises the beam cutoff voltage
B) Boosts the beam current
C) Reduces losses to the defining aperture
D) Reduces losses to the lens barrel

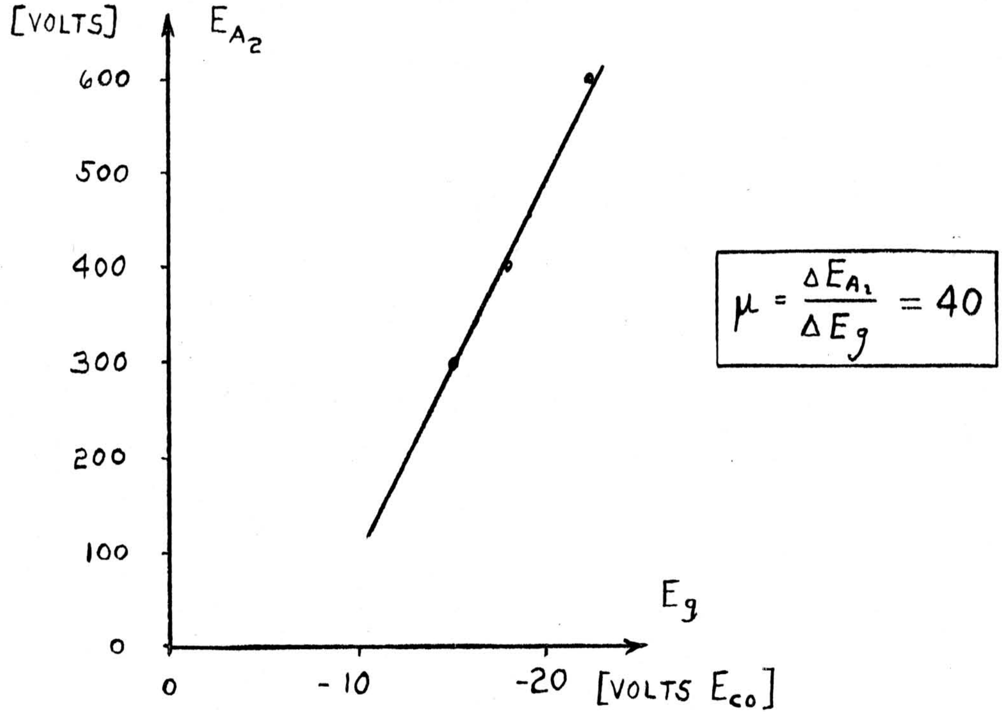


FIG II-2B: CUT-OFF VOLTAGE AS A FUNCTION OF "BOOSTER" ANODE

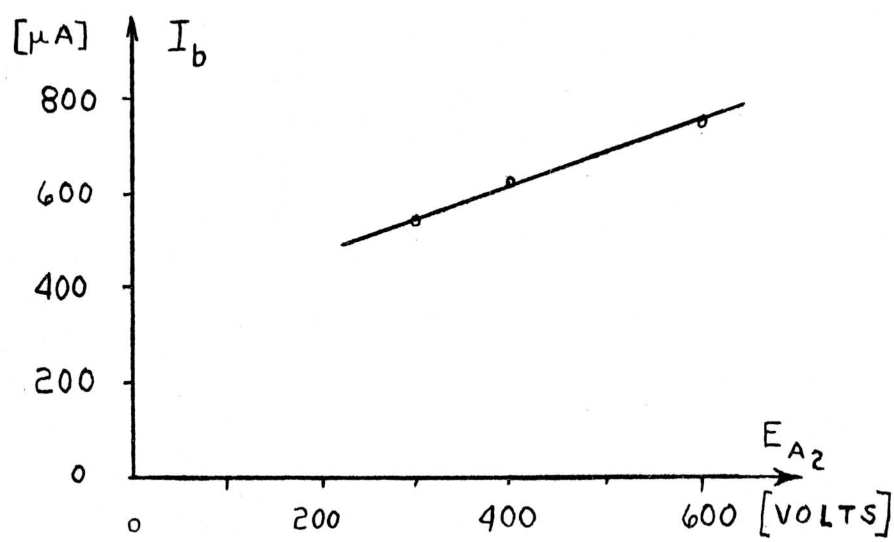


FIG. II-2C: FORWARD CURRENT AS A FUNCTION OF "BOOSTER" ANODE

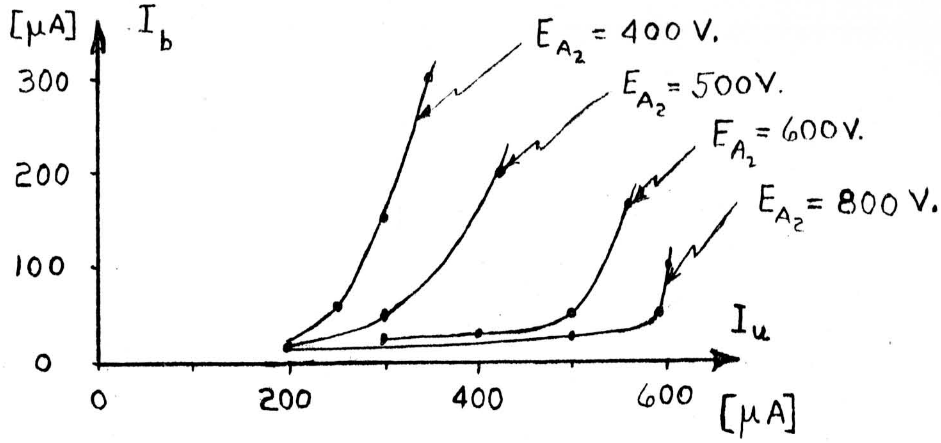
It was further found that the booster anode voltage has no effect at all on the signal drive required for full modulation! We are now referring to the four above points in more detail:

A. The relation between cutoff voltage and A_2 voltage is shown in Figure II-2B. The function is linear and can be described by a constant μ factor ($\mu = 40$ in this case). This relationship permits, in practice, to shift the characteristic of an FRM gun into an all-negative voltage range where current drawn to the gate is practically zero.

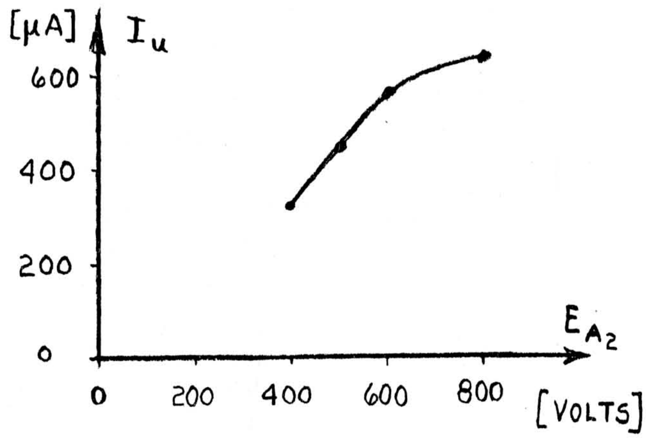
B. The booster effect of A_2 on forward current follows generally from the theory of scaling voltages in space charge limited systems. This theory predicts both current and current density to increase with $M^{3/2}$ and space charge density to increase with M, where M is the voltage scaling factor.

The beam current boost observed in this early gun is shown in Figure II-2c. It rises more slowly than expected, probably because A_1 was not included in the voltage rise. However, a later test reported under Figure II-5, has fully confirmed the 3/2-power gain in beam current as expected from the theory of voltage scaling.

C. Current loss I_m to the defining aperture is shown in Figure II-2a in shaded areas. It is measured with booster voltages of 400 and



BARREL INTERCEPTION VS.
ULTOR CURRENT FOR
VARIOUS "BOOSTER" VOLTAGES



ULTOR CURRENT VS. "BOOSTER" ANODE

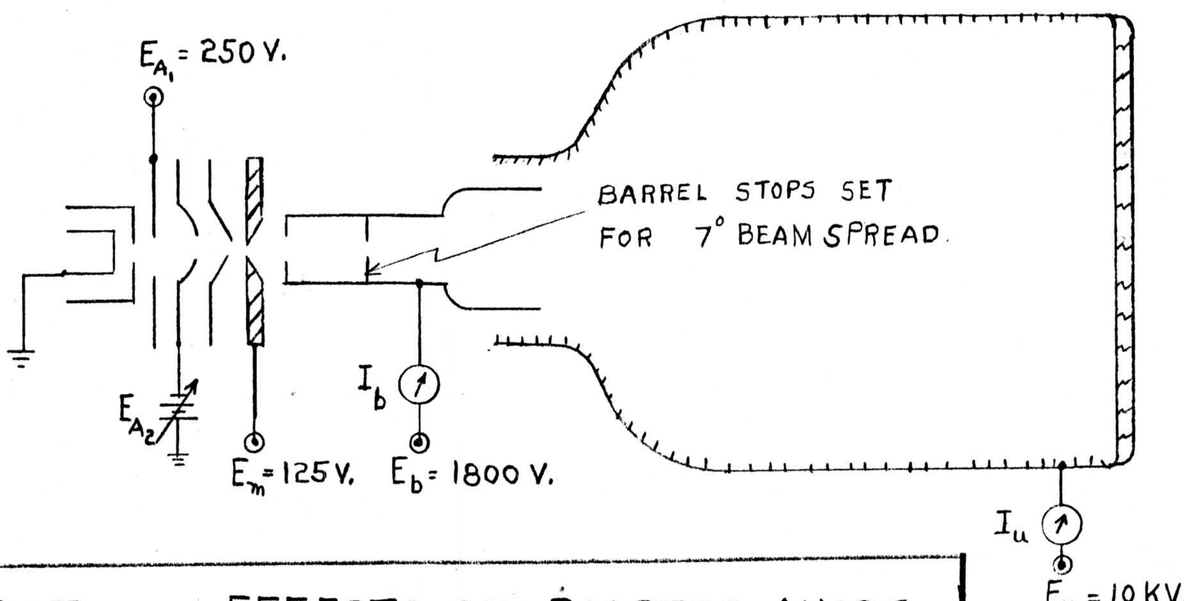


FIG. II-2D: EFFECTS OF BOOSTER ANODE

600 volts. It is found that I_m is at a minimum if the forward transmission is at its peak and that it increases on both sides of this setting. This fact indicates that the gate voltage variation causes concomitant focus variations in the hyperbolic lens. This focus modulation seems to be adjusted properly so that focus falls into the defining aperture when transmission through the gate is at its maximum.

D. Figure II-2d shows the influence of booster voltage on the current loss to the main lens barrel following the aperture. This has been measured with 10KV on the screen and in a focused condition obtained with the lens barrel at 18 percent of ultor voltage. The barrel was stopped down to pass a maximum beam spread of 7.5°.

It is seen that losses to the barrel decrease rapidly for any given beam current as the A_2 voltage is raised. At the same time the ultor current rises as shown, thus lifting the overall transmission of the tube to a high level. (In later guns overall transmission runs as high as 75 percent).

Both effects indicate that the primary beam spread at the aperture, i.e. before post-focusing, decreases with the increasing booster voltage.

VII. Signal Drive Requirements

A glance at Figure II-2a shows a definite need for improvement in signal sensitivity. The drive requirement of this gun runs twice as high as desired by contract specifications. (16 volts, as compared to eight volts as specified.) To solve this problem, two approaches were tried:

A. Reduction of the gate aperture.
B. Increase of the depth of the gate.

Of these steps only the second one was successful. However, because of its general interest, a report on step A is also included here.

A. Influence of gate diameter

An attempt was made to improve cutoff by reducing the opening at the apex of the focusing cone. Figure II-3 and II-4 show test results from guns with gate apertures of 20 mils and 40 mils, respectively.

The 20 mil gate aperture is definitely too small! As Figure II-3 shows, gate current has become four times stronger than forward current. (400 and 100μA, respectively.) This heavy interception of beam current is caused not only by the small size of the gate aperture, but also by the fact that the gate is now operating in the positive region.

Data for a 40 mil gate are shown in Figure II-4. This tube operates entirely in the negative voltage region if the booster anode is raised to 800 volts. But even at lesser A_2 voltages where the gate goes partly positive, the gate current stays small (less than 15μA for A_2 = 500 volts).

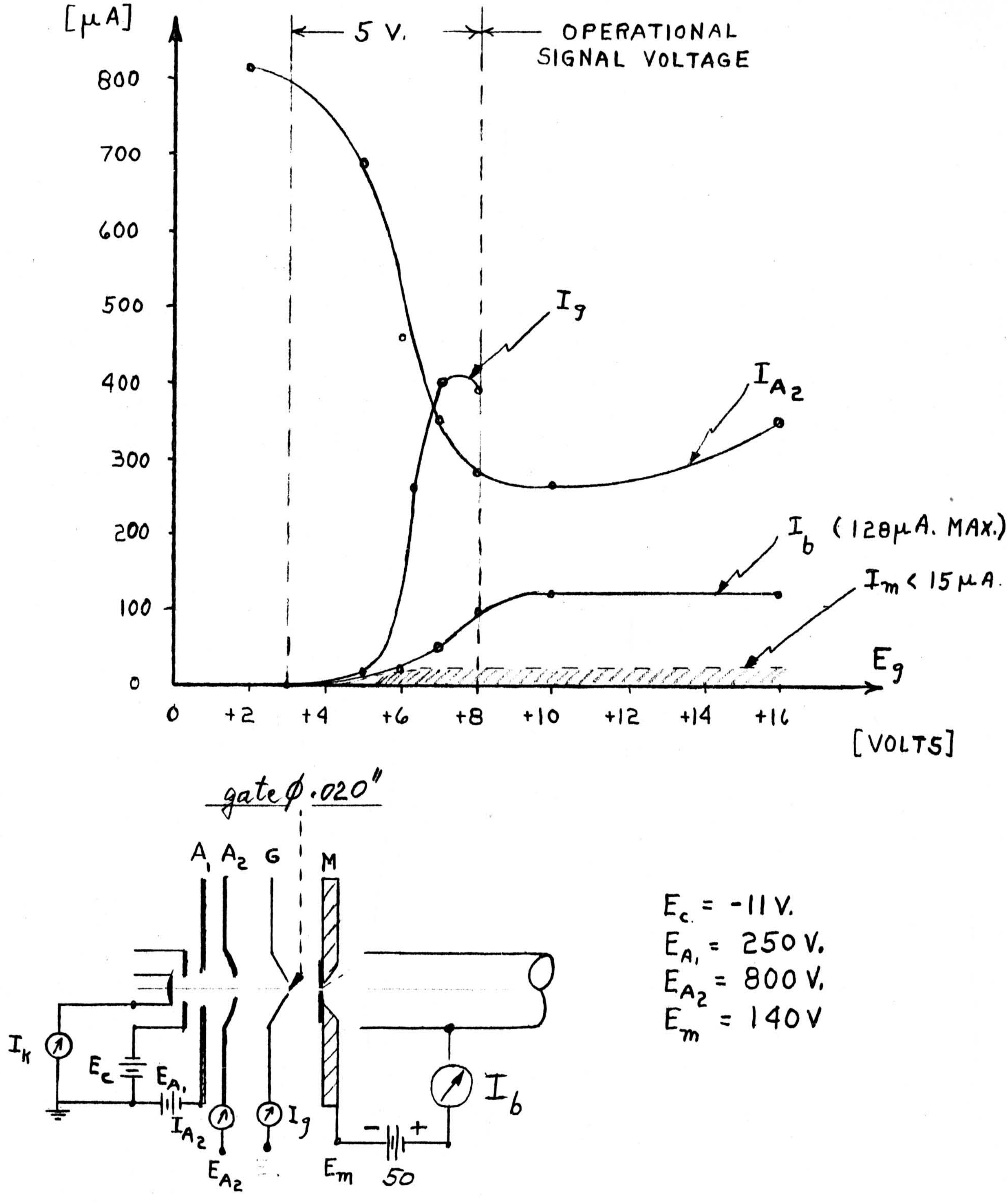
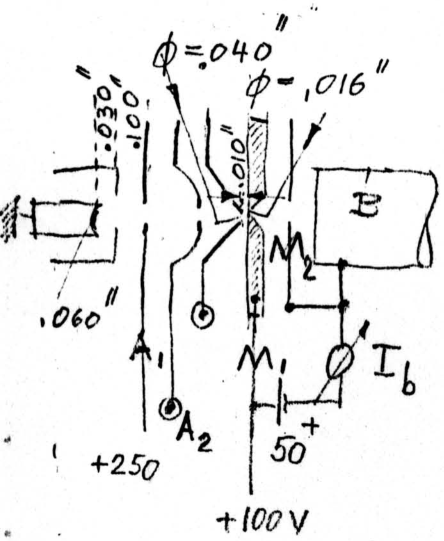
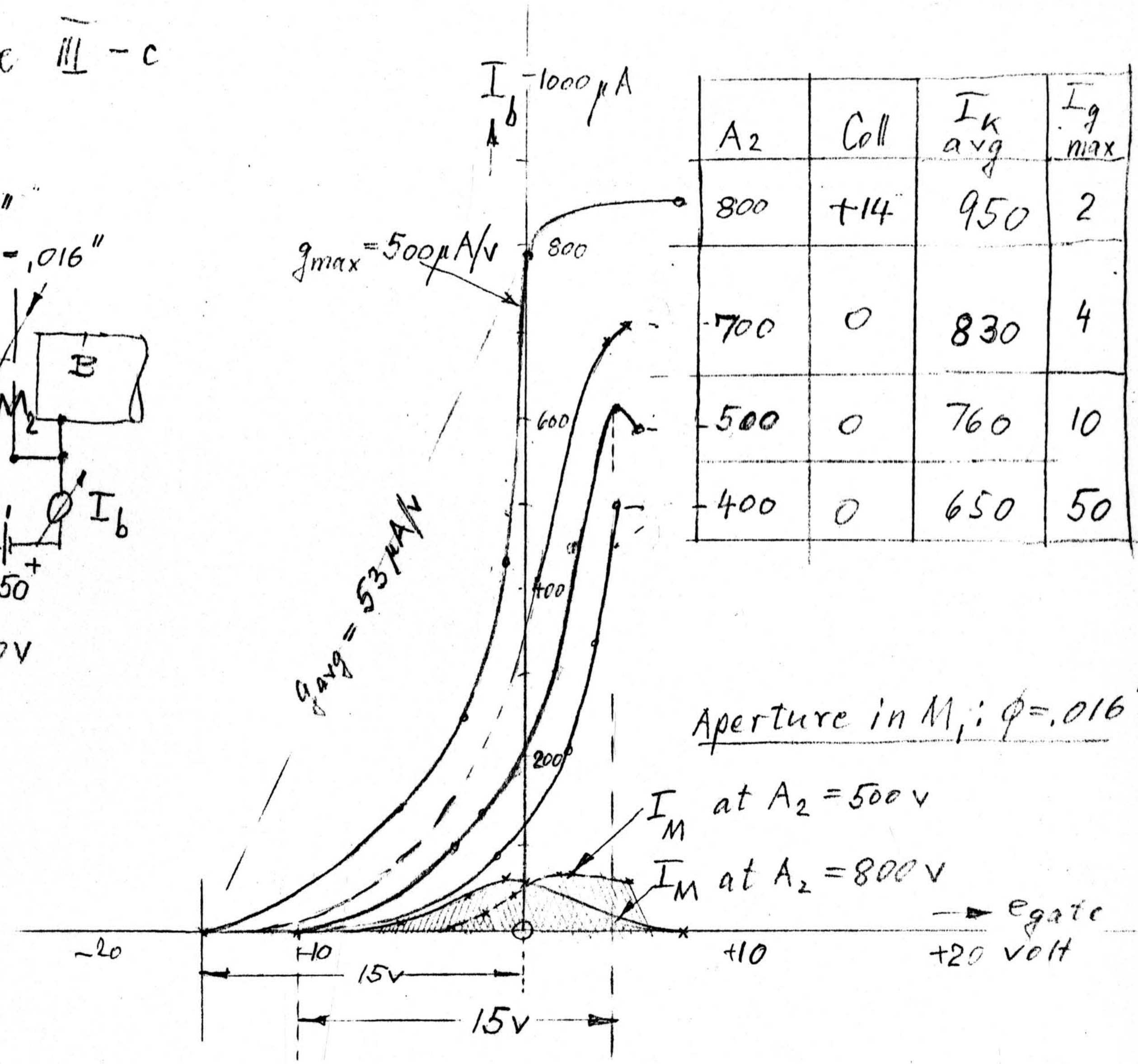


FIG. II-3 *Narrow-gate tube*

Gun type III - c





A_2	Coll	I_K avg	I_g max
800	+14	950	2
700	0	830	4
500	0	760	10
400	0	650	50

data taken:

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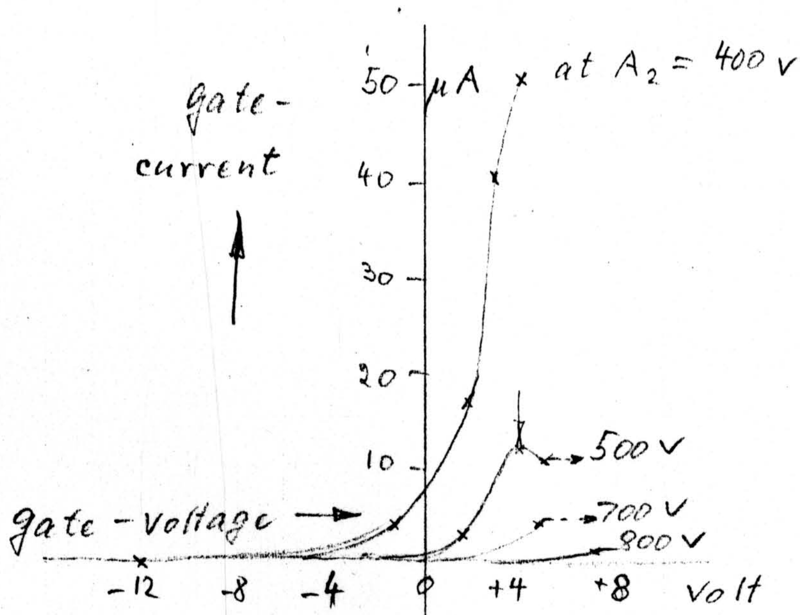

Fig. II - 4: Thin 40-mil gate

Figure II-5 shows the control characteristics of the same gun taken for various booster anode voltages A_2, but with the maximum beam current "optimized" by readjusting voltage at the first anode A_1 for every setting of the booster voltage A_2. This plot shows the interesting result that these "optimized" I_b (e_g) curves seem to be almost identical in shape. The only major difference between them is the amplitude of maximum forward current. The latter now seems to fall in line with a 3/2 power function of the booster voltage. Incidentally, at A_2 = 800 volts, this gun was putting as much as 1200uA through an aperture of 17 mils.

Returning now to the problem of drive signal demand, Fig.II-4 indicates that the desired improvement in control sensitivity has not been achieved by the reduction of the gate aperture from 60 to 40 mils. A drive signal of 15 volts is still needed for full modulation and this figure is practically unaffected by any changes in d-c voltages.

B. The "Tunnel Gate"

A different approach was tried and this one was more successful. It consisted of an increase of the axial length of the control electrode. Figure II-6 shows how the original focusing cone (a) was modified by welding into it an insert (b). This produces at the apex an effective axial depth of 1/32" which is the equivalent of an equipotential

10-12-59

η %	A_2	A_1	I_K	Gate √max	peak output	η
76	500	220	330–630	30	69	76%
78	600	285	1130–800	70	75	78%
76	700	325	1350–1000	90	69	76%
85	800	330	1420–1000	40	30	85%

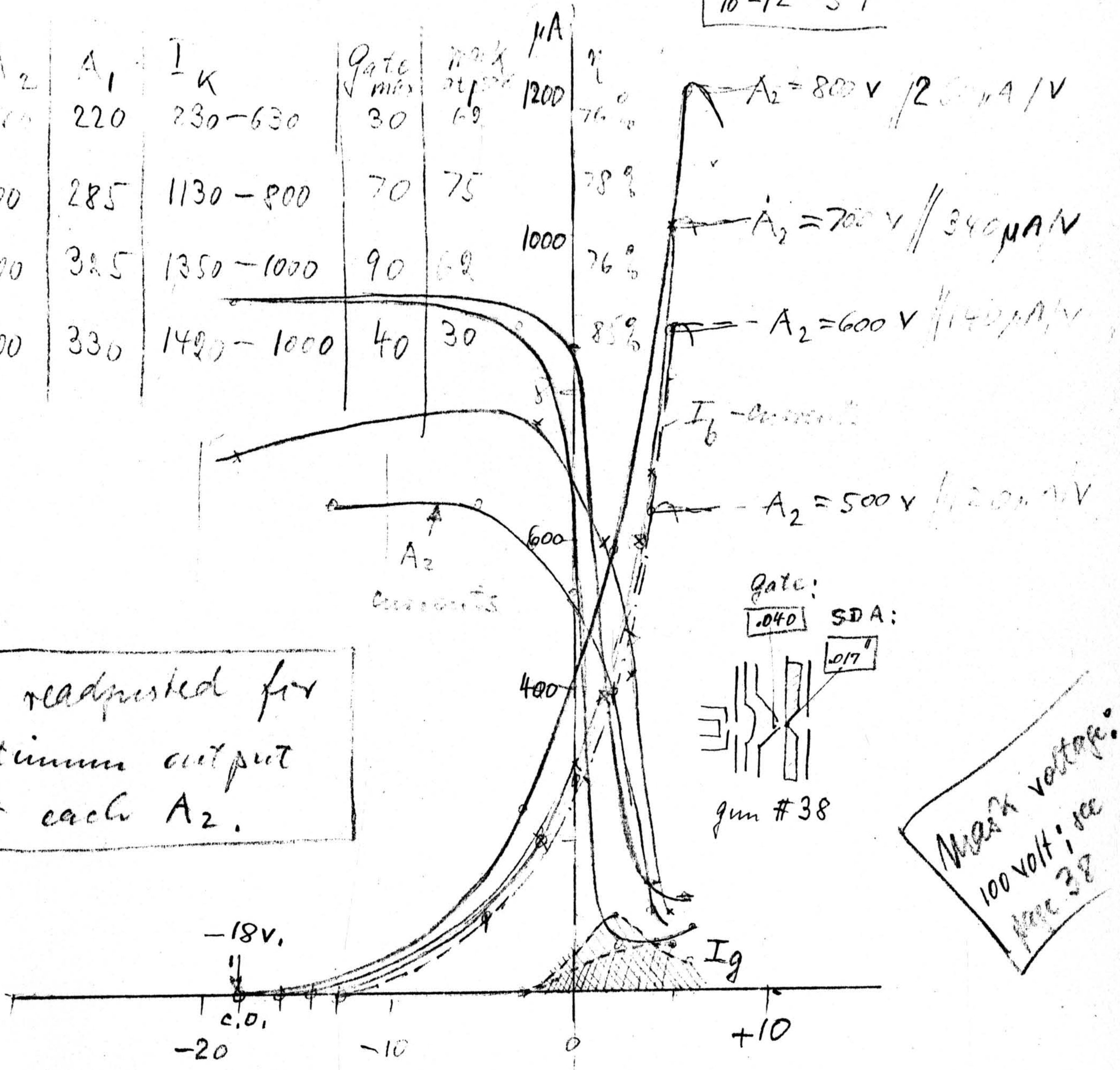

Fig. II–5: Voltage scaling in FRM-gun.

I_m only about 75 μA.

mesh dia = .016"

gate φ = .040"

Gun type IIIc; #38.

same system as shown p 39

and measured (p. 38).

Note: if A_1 is optimized for each A_2-value, all curves seem to coincide. However, the peak-value on each follow a 3/2-power law with voltage on booster anode A_2.

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Fig. II – 6	Tunnel gate insert	
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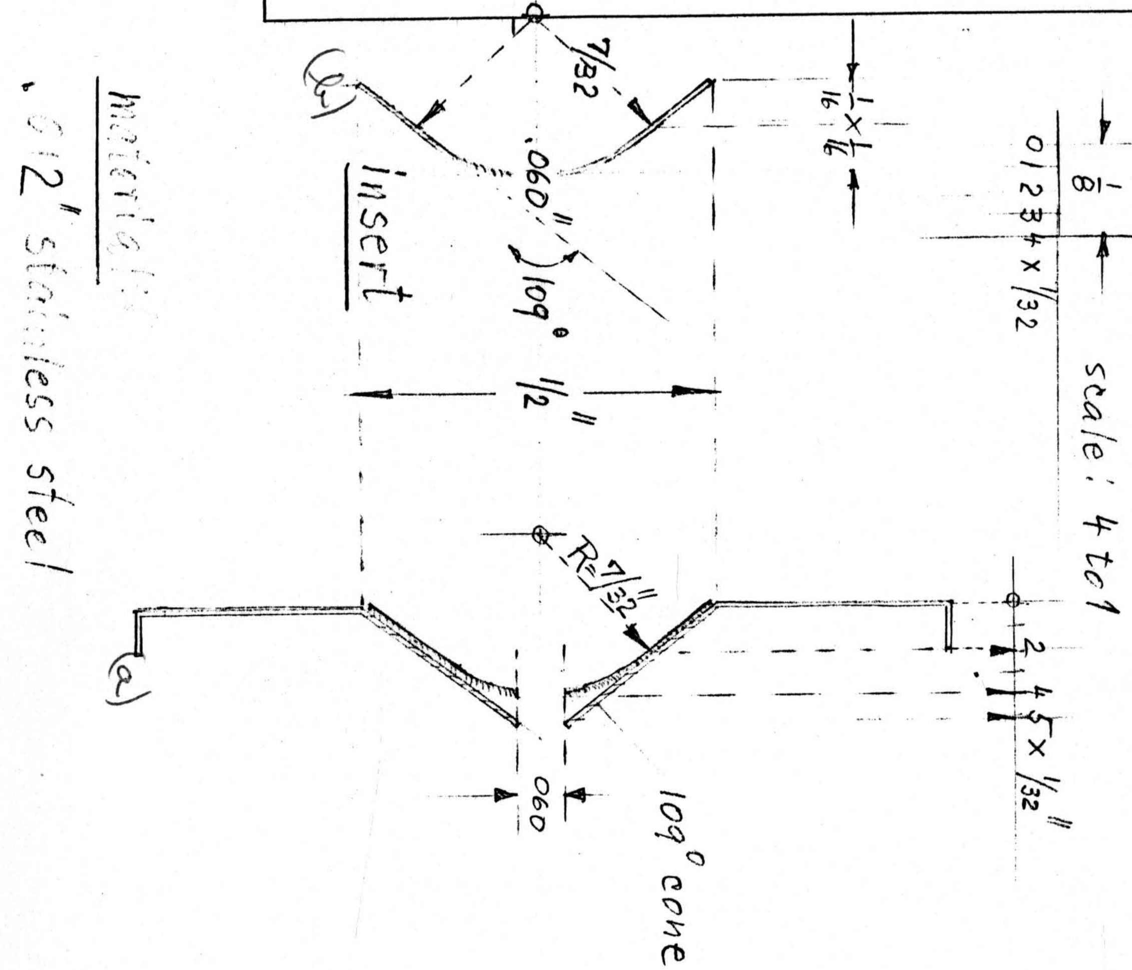

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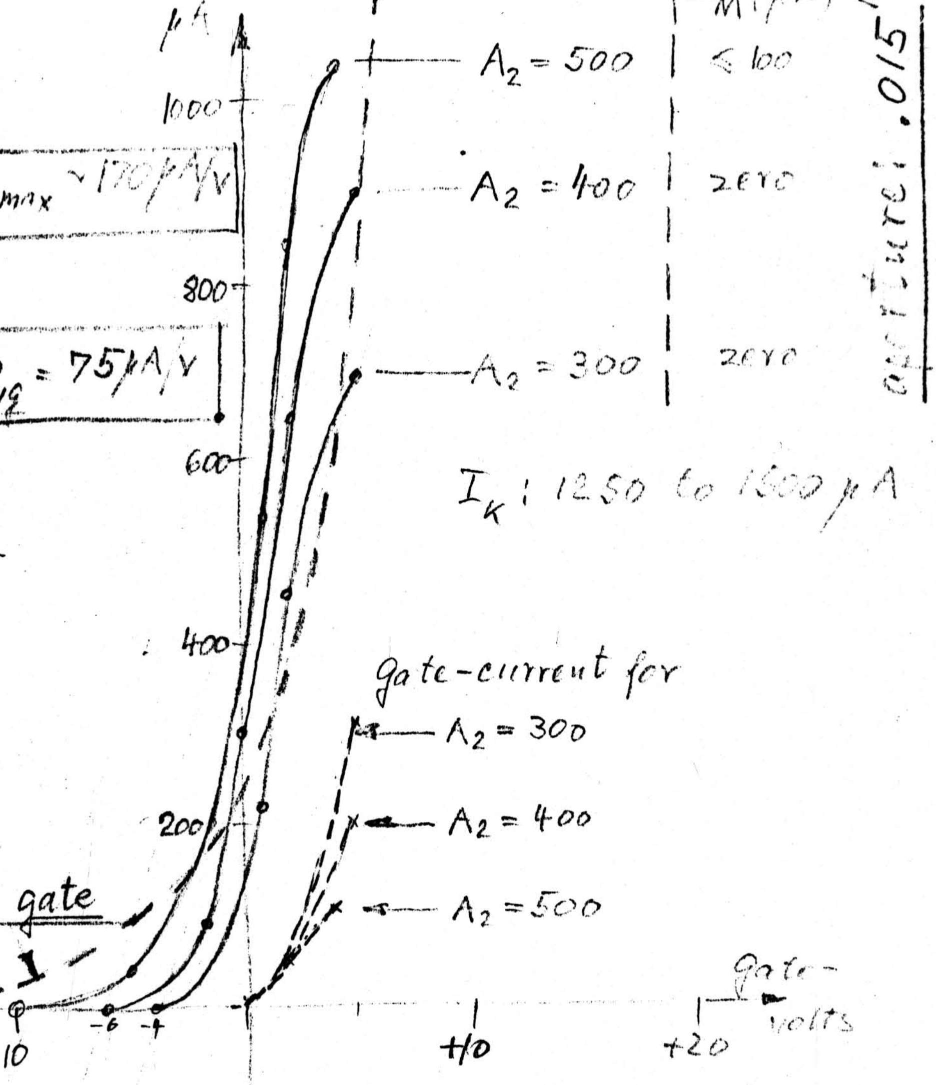
dotted curve: type III-C #38[x1] p.44

Tunnel-gate

gun type II-D

tube # 46



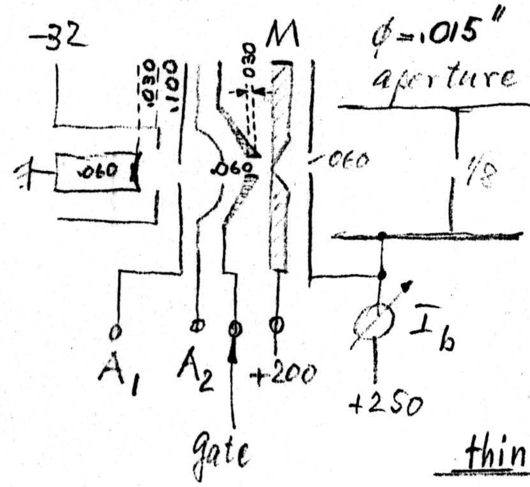
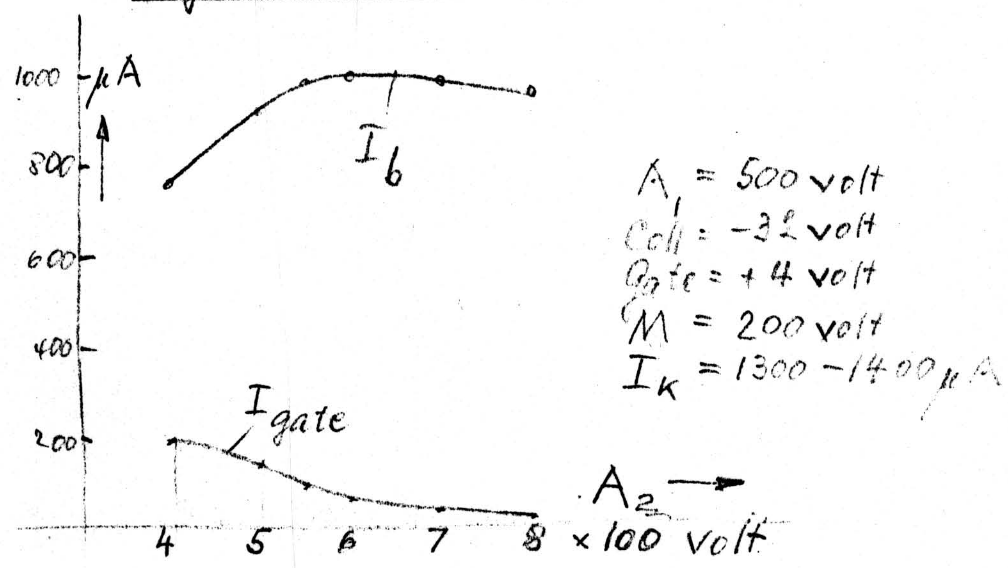


Fig. II-7: Tunnel-gate characteristic



[x1] Comparison-gun #38 had an aperture of .017"

cylindrical throat. At a later stage of this development, this throat is realized by boring a 60 mil "tunnel" through a thick piece of material (See Figure II-10).

The performance of this "tunnel gate" is shown in Figure II-7. This plot shows a family of I_b vs. e_g curves measured with the tunnel gate (solid lines). For comparison, the characteristic of a "thin" gate is shown in a dotted line as reproduced from Figure II-5.

It will be noticed that the cutoff voltage has been moved closer, from -18 volts to -10 volts. The average slope has been increased from 50 to 80uA/volt, whereas the maximum slope at peak current and also the value of the latter have remained unchanged (approx. 180uA/volt and 1000uA, respectively).

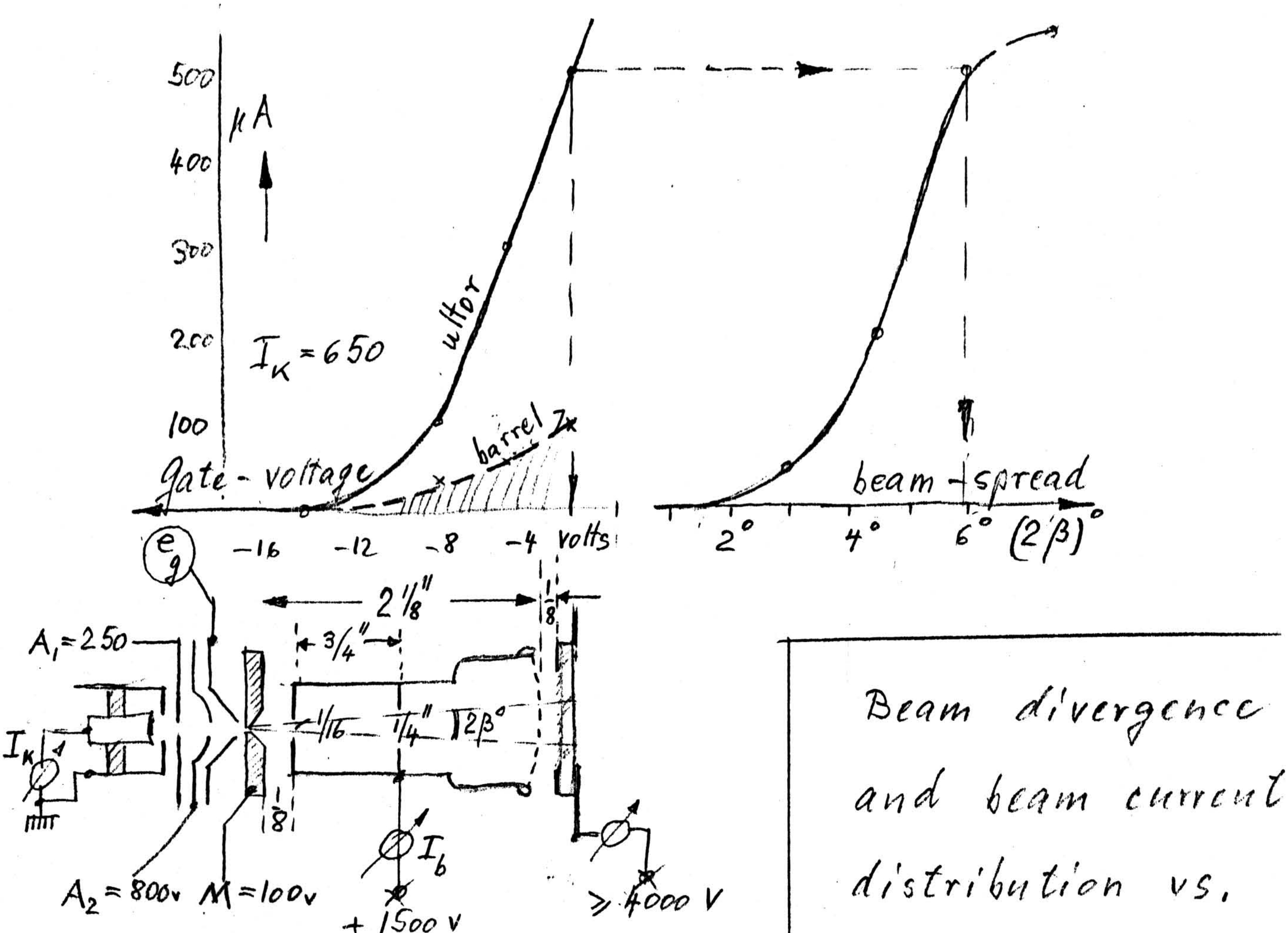
As an average of many tests, the drive demand for a 900uA beam has been reduced by the tunnel gate from 16volts to 11volts.

VIII. Beam Divergence Tests

To check the performance of the post focusing system, formed by the meniscus and a subsequent anode, a series of measurements were made using a specially constructed tube as seen in Figures II-8 and II-9. This tube had a two-inch lens barrel without stops, terminated in a wire mesh of known resolution (16 mesh).

A small aluminized screen at 4000 volts was mounted closely behind the mesh, thus displaying a bright and sharp shadow-image of it.

gun type III – c.   Test of 10 – 2 – 58



Barrel-system used
[see Fig. II-1 of entire gun]

Beam divergence and beam current distribution vs. gate-voltage.

Fig. II – 8

In this manner beam divergence in the barrel could be measured under a wide range of operating conditions. Figure II-8 shows beam spread as a function of beam current in an early FRM gun using a barrel with an input shield. The voltage step up from meniscus to barrel was 15 to 1. (More recent tubes use M = 200V and B = 3000V, i.e. the same voltage ratio.)

The beam spread is found to increase with beam current, but it does not exceed six degrees up to and including 500uA. For higher currents, beam spread increases at a somewhat slower rate.

Figure II-9 shows a gun with a separate shield electrode M_2 between the meniscus M and an open two-inch barrel B. This gun was studied under two conditions:

A. with shield M_2 on booster anode A_2 voltage
B. with shield M_2 on lens barrel B voltage

Beam spread was measured in both circuit connections, with the control gate adjusted for peak beam current and with booster anode voltage variable. In both cases, ultor current increases with booster voltage. Overall transmission is better in condition (b) than (a).

Beam spread in connection (a)is found to be a function of the booster voltage, whereas it stays practically constant in connection (b). This implies that the post focusing field is strong enough to override any influence of the A_2 voltage on primary beam spread at the aperture.

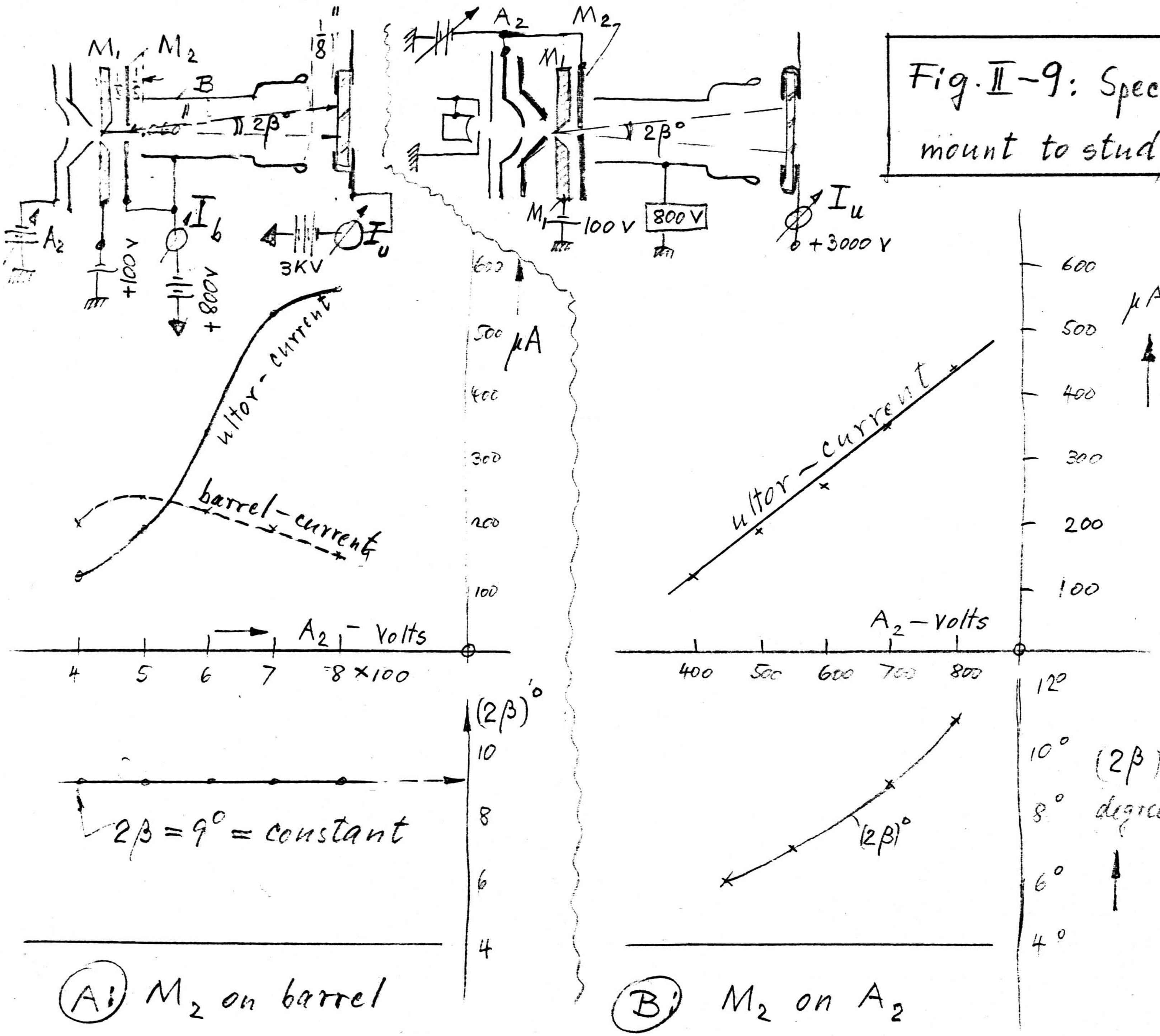


Fig. II-9: Special gun-mount to study beam-spread

test of 10-2-59

gun type III-c

Barrel interception is quite small in connection (a) (less than 20ua); it is five to ten times larger in connection (b). Hence, (a) seems more suited for bleeder circuits, offering focus protection from changes of ultor voltage.

Resolution tests seemed to favor condition (a) slightly over condition (b), also.

The above observations, as well as a theoretical analysis made of the post-focusing structure, have demonstrated the feasibility of reducing excessive beam divergence at the aperture by post focusing without loss of resolution.

IX. Final Form of Tube

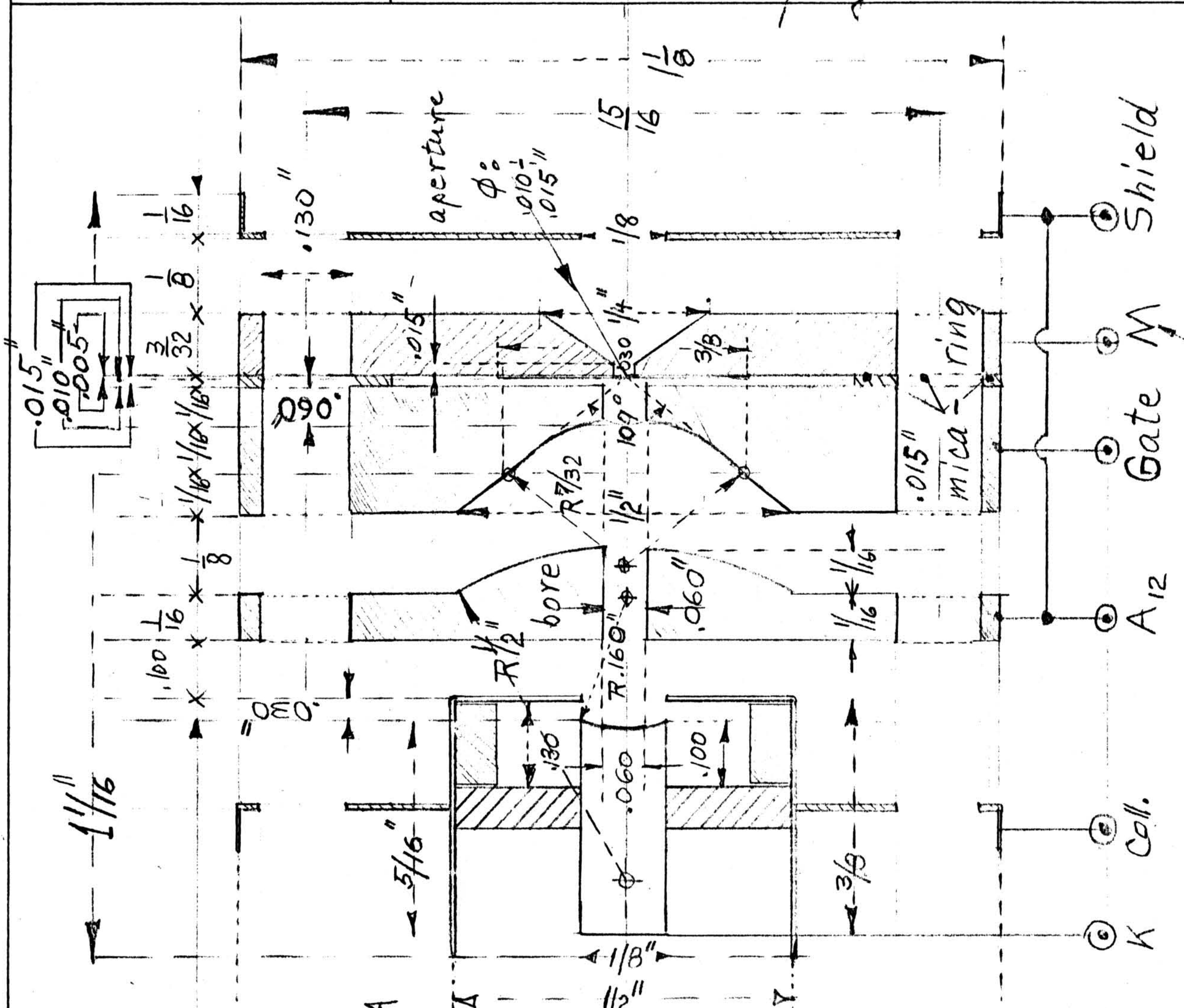
Figure II-10 shows the gun structure as developed at the end of this report period. The "tunnel gate" is now machined from a solid piece of aluminum. The depth of the throat has been increased to .060". Distance to the meniscus aperture is reduced to 10 mils and this is secured by a spacer ring of 15 mils mica. The aperture is etched through five mil stainless steel and then welded on a meniscus held at 250 volts.

The post-focusing field behind M is obtained by use of a plane shield with 1/8" opening, mounted 1/8" behind the meniscus. This shield is permanently connected back to the booster anode A_{12}. (500 volts). The anode A_{12} is also machined from a 1/8" disc of aluminum. It

GENERAL ELECTRIC

REV NO. Fig. II-10.	TITLE Focus-Reflex-gun
CONT ON SHEET / SH NO.	FIRST MADE FOR SCEL-project #552.457

REVISIONS: #1 / 11-12-59 meniscus



Scale: 4 to 1 (1/32")

typical operation:
cathode K: grounded
cathode-current: 1500 μA
Anode A_{12}: 500 V
A_{12}-current: 200 μA
Collimator C: 0 ÷ +5 V
Gate: -9 to +3 volt
Gate current, 50 μA above +2 volt
zero from -9 to +1 V
Meniscus M: +250
I_M (avg) 200 μA
Peak beam output: 1000 μA

PRINTS TO

MADE BY K. Schlesinger	APPROVALS	CRT	DIV OR DEPT.
ISSUED 11-12-59	K S	Bld. 6 - Rm 304	LOCATION

CONT ON SHEET / SH NO.

FF-803-W2-P (8-55)
PRINTED IN U.S.A.

forms a plano-convex lens whose curved surface is one of the two boundaries of the retarding hyperbolic lens.

The plane, first surface of A_{12} faces a Pierce cathode with 60 mils emissive diameter. The collimating aperture has been reduced to .125" at 30 mils distance, resulting in zero-bias operation.

X. Performance Test

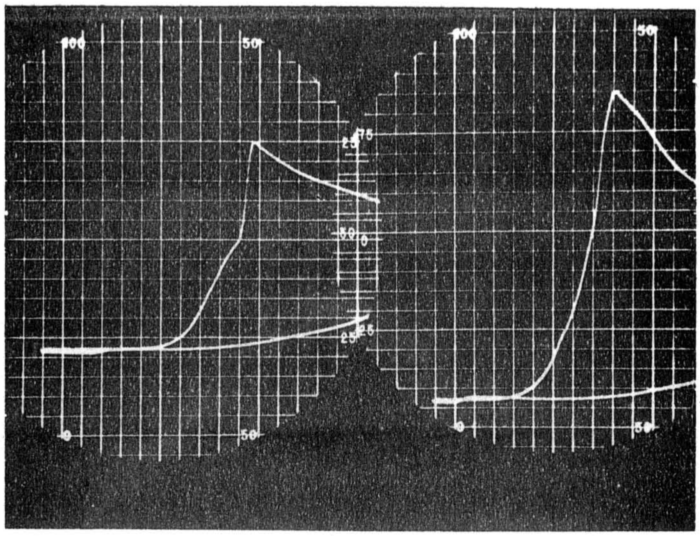
A. Curve Tracer

The performance of this gun is best illustrated by Figure II-11, showing photographs taken from a curve-tracing scope at 60 cycle rate. The four curves shown are taken at different values of meniscus voltage as indicated. The recommended operation is marked as M = 250V. At this meniscus voltage, the peak current found past the .015" aperture was 900uA, or 85 percent of the cathode current (1050uA). Drive voltage to cutoff was 11 volts peak to peak.

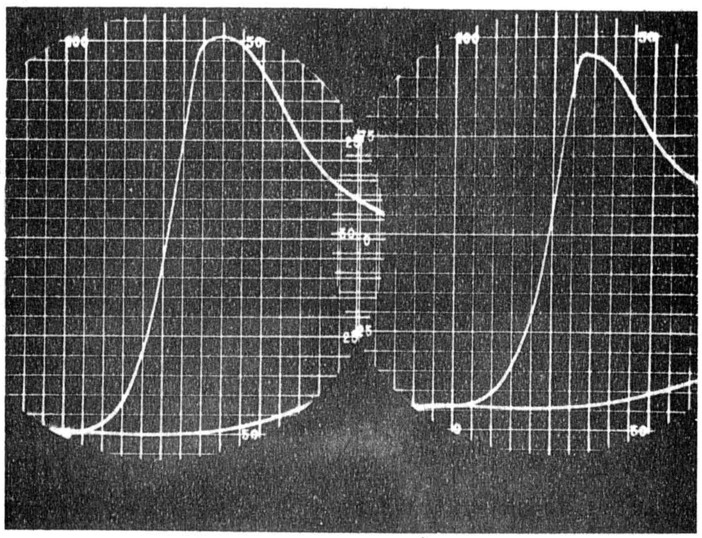
B. Space Charge Instabilities

Inspection of Figure II-11 shows an interesting effect--at low values of aperture voltage there is found to occur a sharp discontinuity near the peak of the characteristic. This jump may cause "streaking" in the display which gets worse with reduced aperture voltage but clears up completely at voltages of 250V or beyond.

We believe that this effect is due to space charge loading in the throat of the control grid where the electron velocity is at a



M = 150 V.　　　　M = 200 V.



M = 300 V.　　　　M = 250 V.

Fig. 2-11 BEAM CURRENT vs. GATE VOLTAGE

Vertical Scale: 1 Div. = 50 μA
Horizontal Scale: 1 Div. = 2 Volts

minimum. This assumption is supported by an accepted expression for maximum current transmission through a drift tube of length ℓ and diameter d:

$$I_{max} = 1230 \left(V_{KV}\right)^{3/2} \cdot \left(\frac{d}{\ell}\right)^{2} \; [mA]$$

For ten volt electrons going through a throat section of 60 X 60 mil the above equation yields an upper bound of 1240uA. This space charge repulsion thus seems to establish a limit for further exploitation of the tunnel gate technique.

C. Television Picture Test

A first sealed off 14-inch tube was built and tested by the end of November. The tube used an FRM gun of the latest type. The results are reported below.*

Figure II-12 shows all currents in the gun as functions of gate voltage. Note the remarkably small current interception by the gate ($\lessapprox$20uA) and by the aperture ($<$100uA) over the working range of signal voltages (nine volts drive). Figure II-13 shows the improvement in gun efficiency resulting from an increase in ultor voltage. In this test the FRM gun structure itself was running under constant conditions as follows:

A_{12} = 500V; M = 250V; Collimator at zero.

*These data were made available by the courtesy of Mr. E. Schilling of our Monochrome Tube Section.

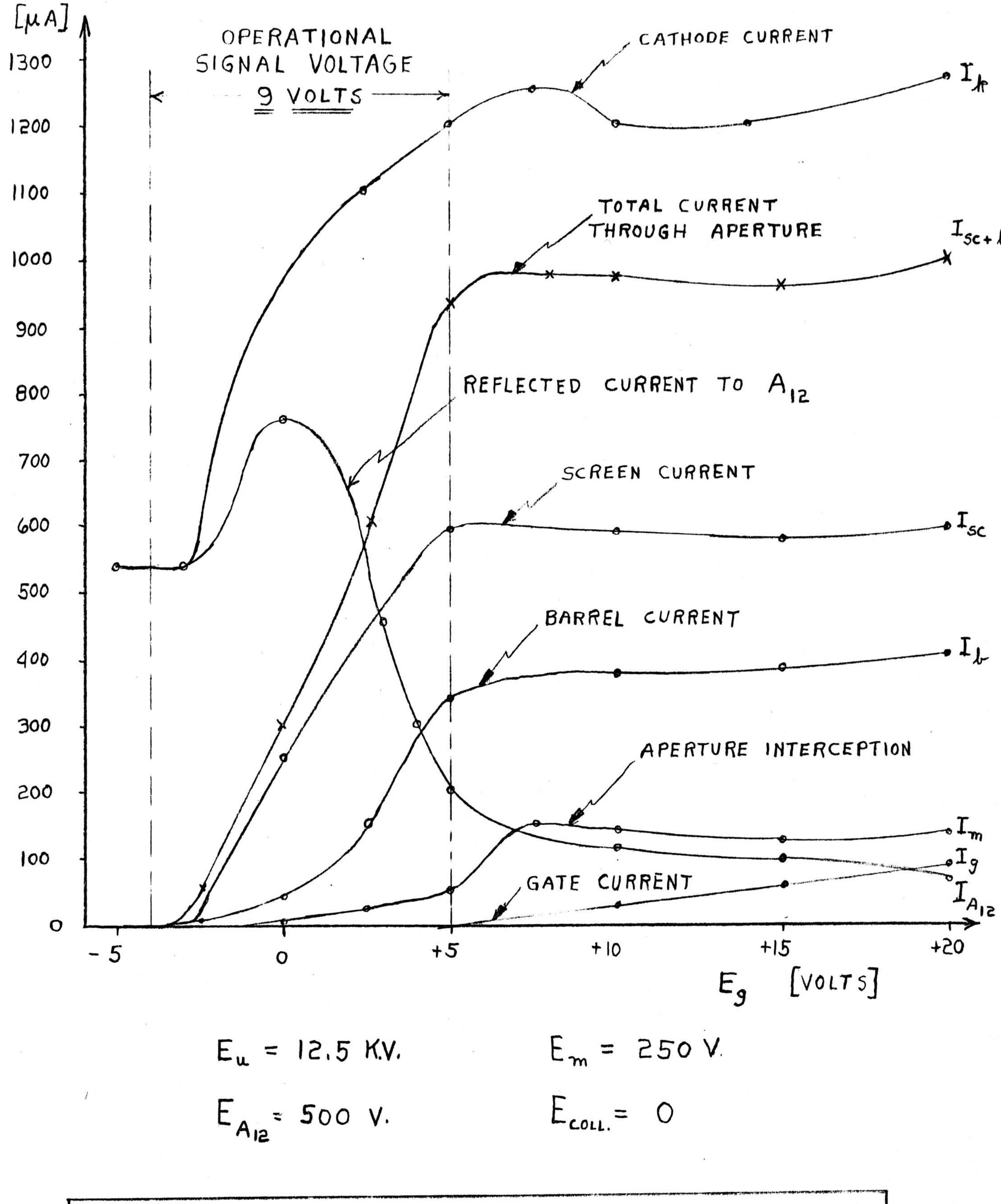


FIG. II-12: Current distribution in sealed-off 14"-Focus-Reflex tube

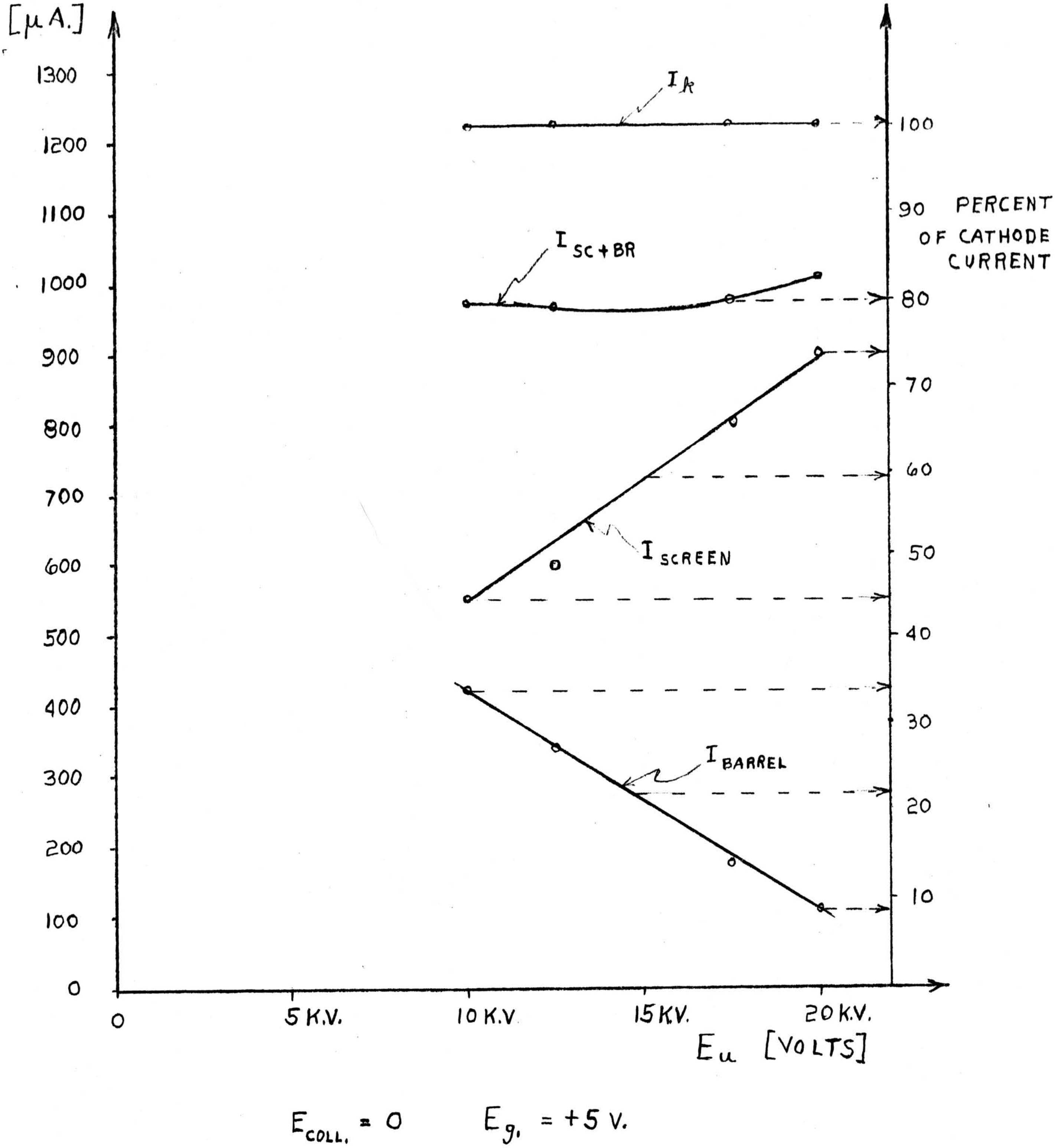


FIG. II-13 GUN EFFECIENCY VS. ULTOR VOLTAGE

As the ultor voltage is raised from 10KV through 15KV to 20KV the focused screen current rises from 550uA through 750uA to 900uA. This means an overall transmission of 45 percent, 60 percent and 75 percent, respectively, in terms of cathode current (1220uA = const).

In the process, current losses to the focusing barrel decrease from 35 percent to less than ten percent.

Figure II-14 shows the light output measured with a calibrated Weston photometer. The tube had a standard aluminized television screen with P-4 phosphor. It is seen that the light output is a fairly linear function of signal input and shows no signs of saturation up to, and beyond 200 foot lamberts. The highest light level measured was 250 foot lamberts. This occurred with a beam current of 550uA at 17.5KV, i.e. a beam power of 9.6 watts. At this brightness level, the spot was still well focused. By comparison, a conventional picture tube runs at an average beam current of 200uA and gives a highlight brightness of 90 to 100 foot lamberts. At higher light levels the spot defocuses badly ("blooming") since standard picture tubes do not use a defining aperture. In these television tests the picture resolution was at least 500 lines as evidenced by the enclosed photographs Figures II-15 and II-16. These pictures show the display of a

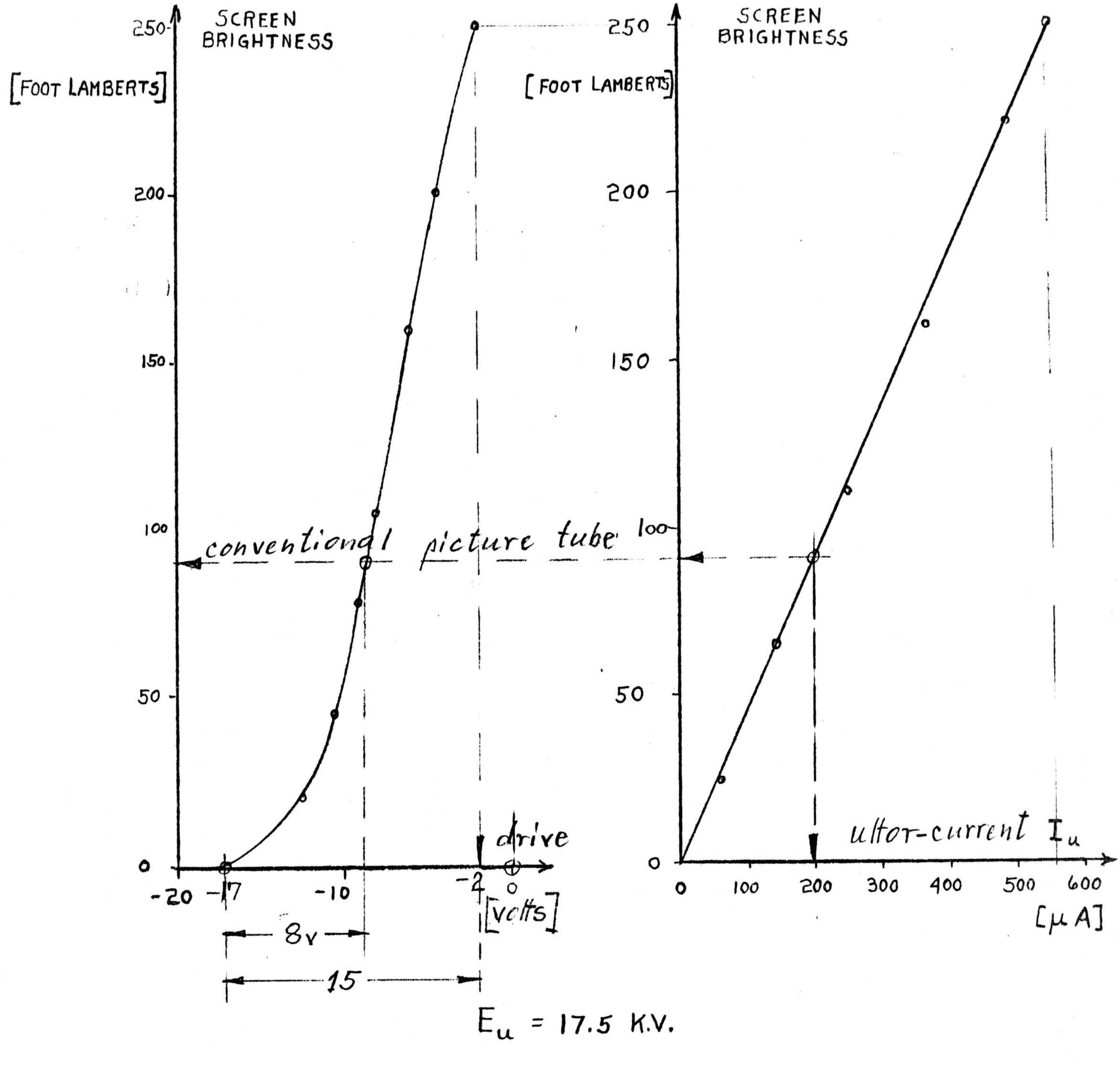


Fig II-14: Light Output Curves, FRM Gun.

standard television test pattern with the FRM gun handling a video signal of 11 volts peak to peak. The center resolution is seen more clearly in Figure II-16 which is a photographic enlargement of Figure II-14.

From Figure II-15, one can guage the relative corner resolution obtained with a conventional 90^{o} deflection yoke. The small degree of deflection defocusing is an indication that the beam diameter at the site of the yoke was comparable with standard practice.

Summarizing the above tests, it appears that the FRM tube as a television display offers 2-1/2 times the light output of a conventional picture tube, has better resolution and focus stability and requires only 11 volts or 1/5 of the signal drive currently in use.

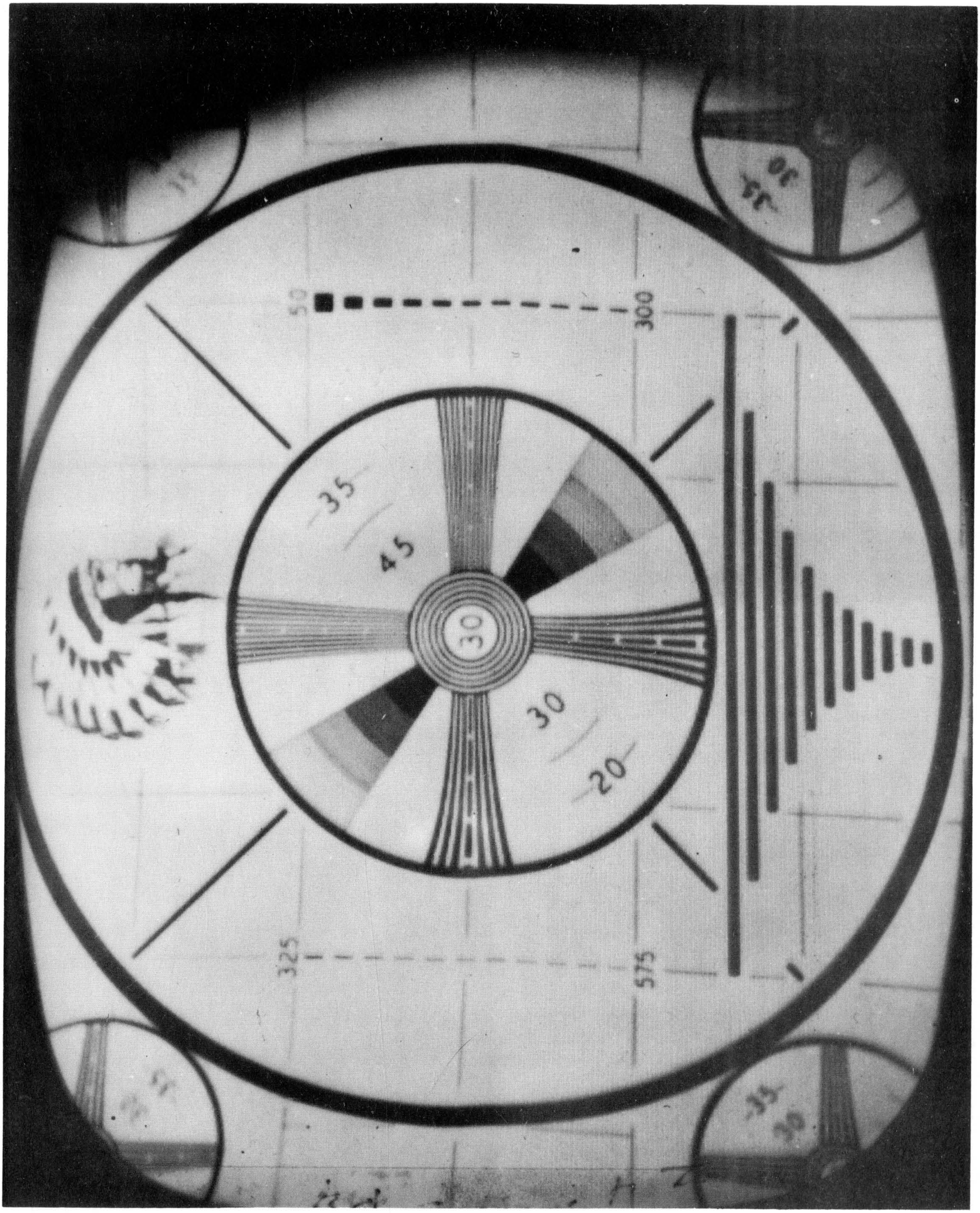


Fig. II-15: RESOLUTION TEST OF FOCUS REFLEX GUN

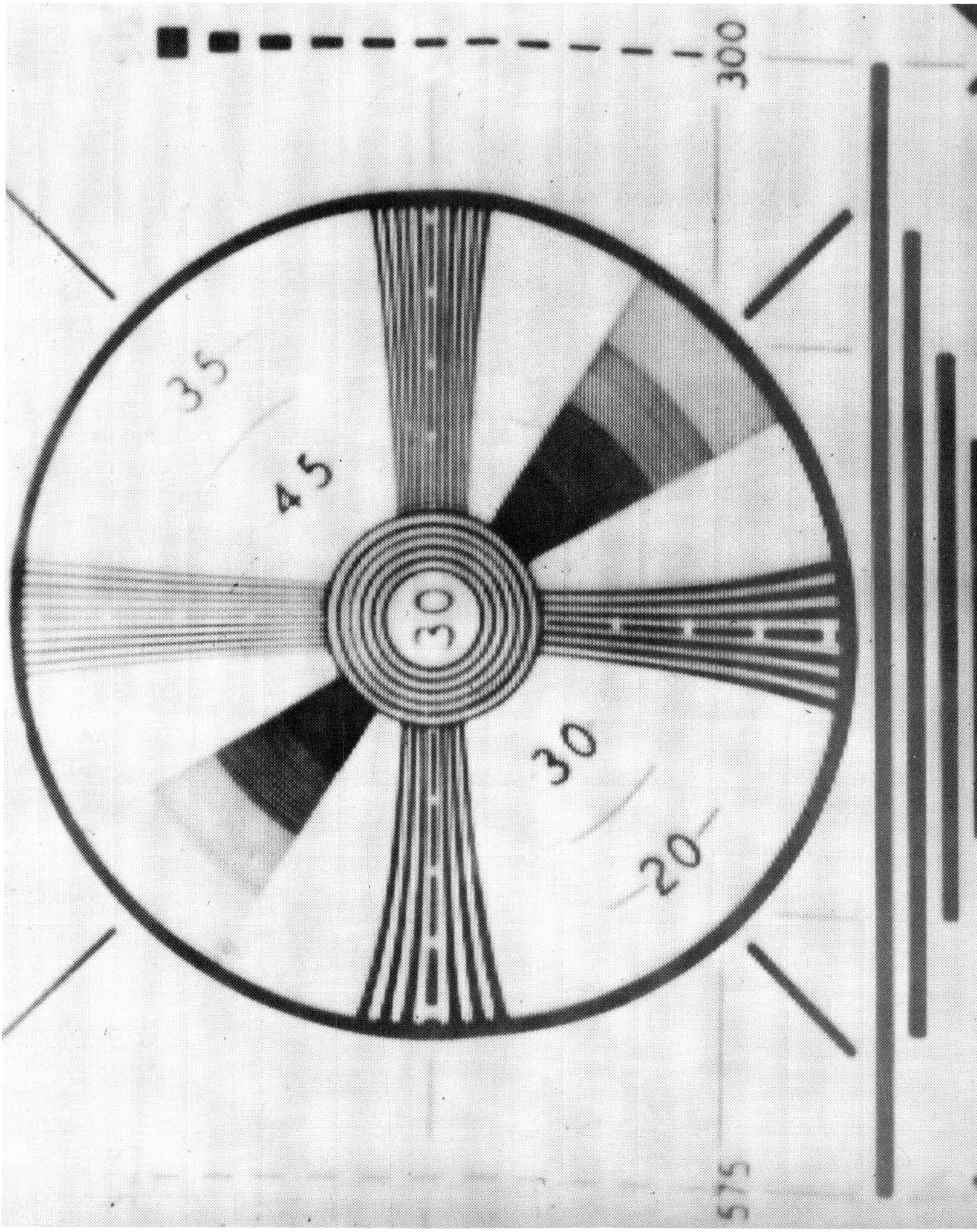


Fig. II-16: CENTER SECTION OF FIG. II-15 OPTICALLY ENLARGED

Conclusions

When surveying the results achieved so far, the largest departure from specifications is the size of the object aperture now in use (.015"). This is three times as big as required. In many other respects we are coming close to meeting the specifications. These include beam current (900uA), control sensitivity (11 volts), low power input ($<$20uA), and beam divergence (approximately 7^{o}).

Moreover, the present value of cathode current density is now abnormally low ($0.1 Amp \cdot cm^{-2}$) and can be traded for a gain elsewhere.

Program for Next Interval

It is therefore intended to reduce the size of the present gun structure by a factor of two in all dimensions, while keeping all voltages unchanged. This should leave the beam current unchanged, raise the cathode loading to 0.4Amp·cm^{-2}, which is still practical, and reduce the aperture to .007" for full transmission.

We are presently engaged in redesigning jigs and fixtures to build such guns whose overall dimensions will be approximately 1/2" by 3/4". Glass beading techniques will replace cemented ceramic supports now employed.

Further refinement work is still needed in the post-focusing section and main lens. However, these problems will be greatly simplified if the above mentioned scaling operation is successful. It is therefore suggested to postpone final work on the main lens system until the 1/2" gun with .007" aperture is an accomplished fact.

Identification of Personnel

	Approx. Man-Hours
P. P. Coppola, Physicist	11
K. Schlesinger, Consulting Engineer	280
Engineering Assistants (3)	725