NASA CR-132836

(NASA-CR-132836) STUDY OF MAGNETIC PERTURBATICNS ON SEC VIDICON TUBES Final Report (Princeton Univ.) ~~69~~ 70 p HC $5.50 CSCL 09A

N74-10201

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G3/09 20487

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STUDY OF MAGNETIC PERTURBATIONS ON SEC VIDICON TUBES

Final Report
National Aeronautics and Space Administration
Contract No. NAS-5-23254

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August 24, 1973

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I. INTRODUCTION

NASA has sponsored a program at Princeton University Observatory for the past several years to develop television sensors to meet the needs of future space astronomy missions.[8] This program has resulted in a television tube that meets many of the requirements of the LST mission. This tube, a magnetically focused SEC-vidicon, provides high sensitivity and resolution, even with exposure times of several hours. The spectral sensitivity extends from 1150A° into the near infrared. NASA Headquarters has also supported the design and fabrication of a camera to use this tube. With this camera the proper mode of operation for the TV sensor has been developed, and the system has been employed for ground based observations.

Under this contract (NAS-5-23254) Princeton has carried out a study and laboratory measurements program to determine the tolerances that must be imposed to achieve optimum performance from SEC-vidicon data sensors in the LST mission. These measurements along with other data were used to formulate recommendations regarding the necessary telemetry and remote control for the television data sensors when in orbit.

The study encompassed the following tasks:

1. Conducted laboratory measurements of the perturbations which an external magnetic field produces on a magnetically focused, SEC-vidicon. Evaluated shielding approaches.
2. Experimentally evaluated the effects produced on overall performance by variations of the tube electrode potentials, and the focus, deflection and alignment fields.
3. Recommended the extent of ground control of camera parameters and camera parameter telemetry required for optimizing the performance of the television system in orbit.

The experimental data has been summarized in a set of graphs showing the normalized spatial response at 20 cycles/mm as a function of percentage deviation in the various tube parameters.

II. LST MISSION ENVIRONMENT

The orbital environment for the instrument bay of the Large Space Telescope is generally characterized as having an ambient temperature of approximately +20°C, a magnetic field variation of ±0.35 gauss, and having a energetic particle flux due to cosmic rays and trapped charged particles.

The primary temperature effect on the television sensor is thermally induced dark current from the photocathode and walls of the image section of the tube. It is expected that most of the television tubes will require cooling to below 0°C to allow long exposures.

The earth's magnetic field at 300 nm is 0.3 to 0.4 gauss. The LST spacecraft will typically go through a reversal of this field every orbit. Negligible magnetic shielding is afforded by the spacecraft and indeed the field could be intensified by magnetic materials within the spacecraft. Therefore, it is important to determine the sensitivity of the television image sensor to external magnetic fields and to consider ways to adequately shield the sensor.

The radiation environment outside the spacecraft is reasonably well understood and documented.(9) The actual radiation environment inside the spacecraft is much less well defined and is a function of the thickness and type of materials that intercept the primary radiation. In an earlier study under NGR 31-001-276, the tube background from 42 mev protons and gamma rays was measured.(10) These measurements indicate that the tube background due to energetic particles bombardment will not be excessive and long exposures are possible.

The operational aspects of the LST mission dictate that the sensor systems require a minimum of adjustments in orbit during a design life of several years and that means be provided to make those adjustments via ground control. Accordingly, the command and telemetry required for the SEC-vidicon camera is discussed in this report.

III. LABORATORY MEASUREMENTS

Test Groups

The tests performed in this study fall into three basic groups. They are:

A) tube electrode potential and focus field perturbations,

B) external magnetic fields on an unshielded TV camera, and

C) external magnetic fields on a shielded TV camera.

TV Cameras Used

Two slow scan television systems were used for the test program. A laboratory slow scan Test Set was used for test groups A and B and the STV camera (the Stratoscope II Integrating Television Camera)[13] was used for the group C tests of shielded TV cameras.

This was done because the Test Set Camera was most suitable for electrode potential perturbation tests because of the tube electrode access and monitoring provisions inherent in a camera tube test set, while the compact STV camera head was mechanically more suitable for magnetic shielding experiments.

Figure 1 is a schematic of the SEC-vidicon tubes used for this program.

Details of the Test Set and the STV cameras used are listed in Tables 1 and 2.

Parameters Monitored

The performance parameters monitored during the testing were primarily resolution and image displacement. Resolution was monitored by measuring the response to 20 cycle/mm bar patterns. Displacement data were obtained by measuring the time displacement of the video signal step generated by the edge of low frequency bars in the test patterns.

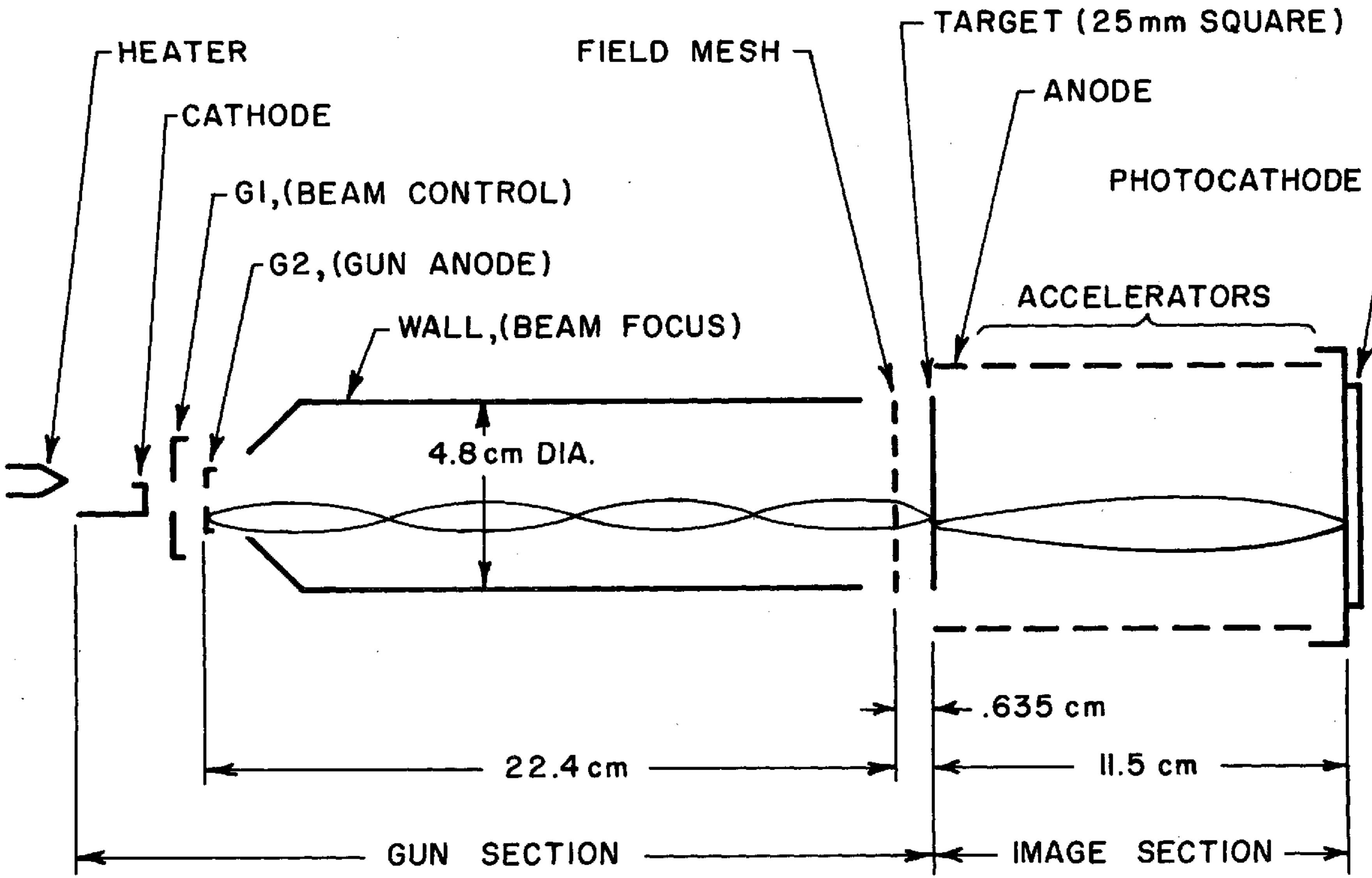


Figure 1 SEC VIDICON SCHEMATIC

TABLE 1

Test Set Camera Details

1. SEC-vidicon tube: Princeton serial No. 33, Type WX-31718, 3" all magnetic, 25 mm sq. target.

2. Lens: Canon, C16, 100 mm.

3. Light Source Filter: Corning 4-64, 525 nanometer, 50% Transmission bandwidth: ±30 nanometers.

4. Test Charts: Figure 2, used for Electrode Perturbation Tests.

   Figure 3, used for Magnetic Perturbation Tests.

5. Scan Rates: 12.5 seconds per frame

   60 lines per second

6. Video Bandwidth: 40 kHz, 4 pole Butterworth Filter

7. Video Noise Current: 3.2 pa rms

8. Video Peak White Signal:

   Electrode Perturbation Tests - 300 pa (typical)

   Magnetic Perturbation Tests - 400 pa (typical)

9. Tape Recorder: Honeywell model 7600

TABLE 2

STV Camera Details

1. SEC-vidicon tube: Princeton serial No. 34, Type WX-31718, 3" all magnetic, 25 mm sq. target.

2. Lens: NIKKOR, 85 mm.

3. Test Chart: Figure 3.

4. Scan Rates: 12.5 seconds per frame, 60 lines per seconds.

5. Video Bandwidth: 20 kHz, phase equalized, 8 pole, Butterworth Filter.

6. Video Noise Current: 2.8 pa rms

7. Video Peak White Signal: 400 pa (typical).

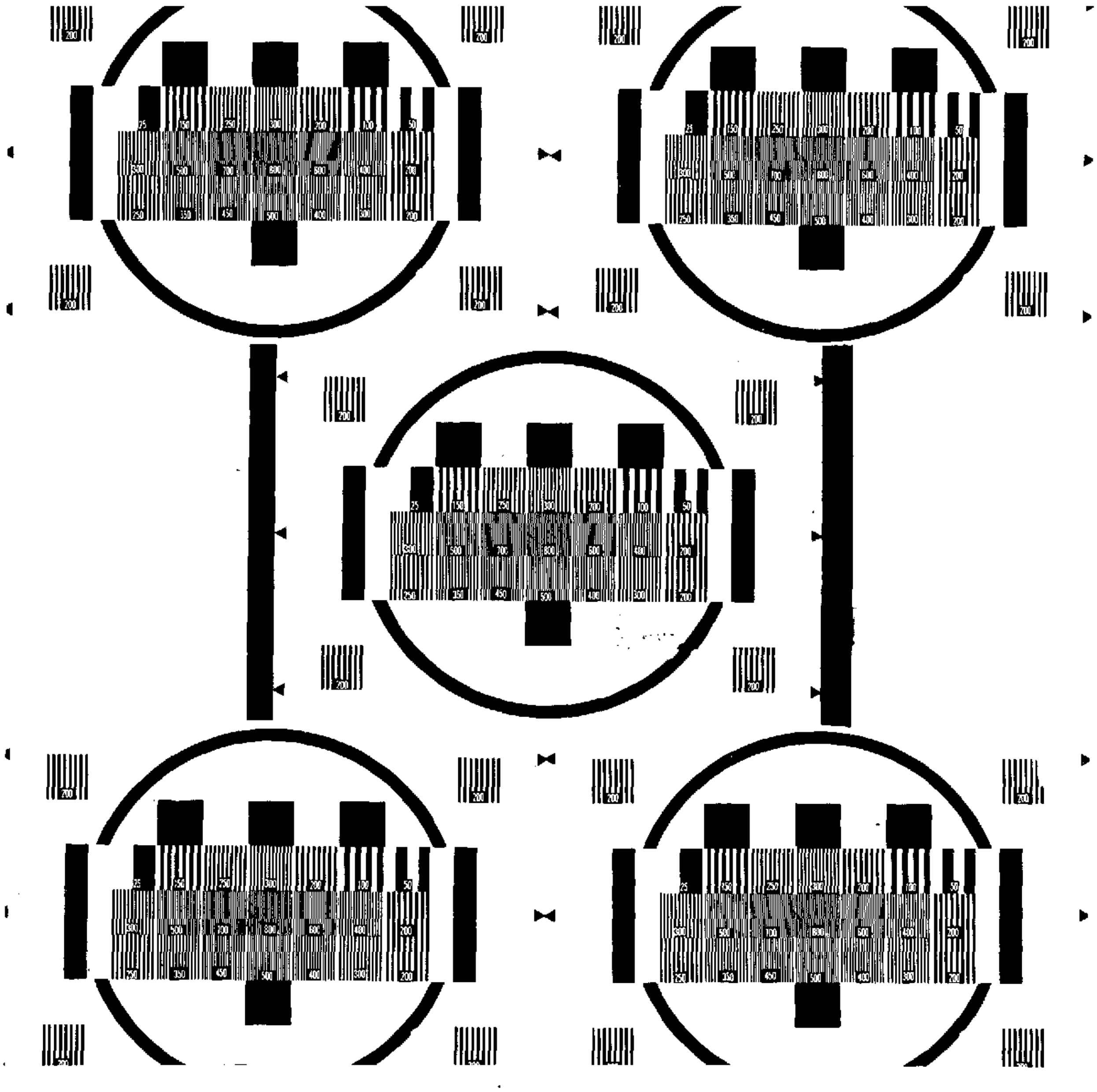


Figure 2

Figure 3

Test Patterns

Figures 2 and 3 are the test patterns employed. Figure 2 was used primarily in those tests in which corner as well as axial resolution data were gathered. Figure 3 was configured to aid in the efficient gathering of center resolution data at 10 and 20 cycles/mm and image displacement data.

Camera Operation

During all the Group A electrode perturbation tests, except for the image section focus current variation test, the camera was operated in the Continuous Scan, Mesh Hi, Mode. In this mode, the image and gun sections of the tube are operated simultaneously, i.e., the tube is continuously writing an image into the SEC storage target while the reading electron gun is continuously reading out the image that has been integrated in the frame interval since the beam last scanned its present position.

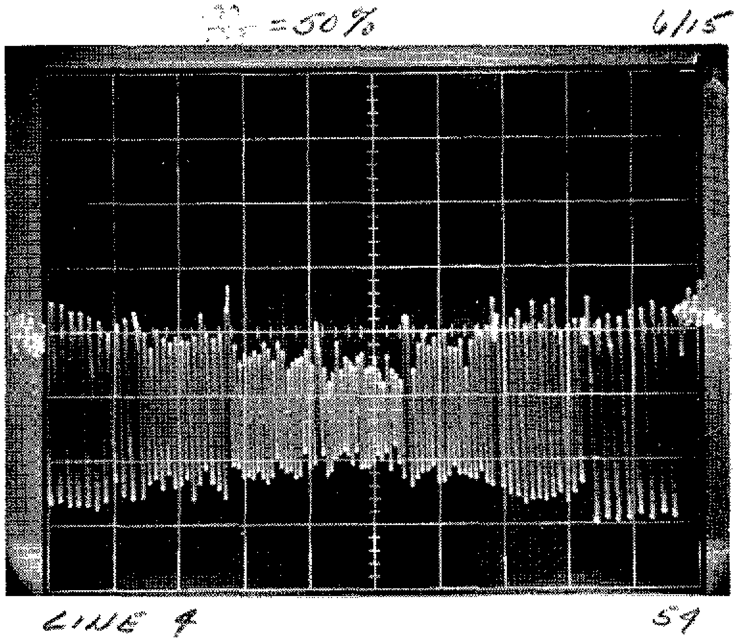
For the Group B magnetic perturbation tests and for the image section focus current variation test, the camera was operated in the sequential mode. In the sequential mode the tube is cycled through Prepare, Expose, and Readout modes. Thus the magnetic effects on the image section and the readout section of the tube could be separated.

Data Taking

During the portions of the tests where the SEC camera was operated in the continuous scan mode, a single line of camera video was recorded on Polaroid film for later data reduction.

A Honeywell 7600 tape recorder was used to store the readout frames of video during the sequential camera operation. The tape recorded data was then played back, and single lines of camera video were recorded on Polaroid film. Resolution and displacement information were then extracted from the photos.

Figure 4 shows representative Polaroid video signal photographs.



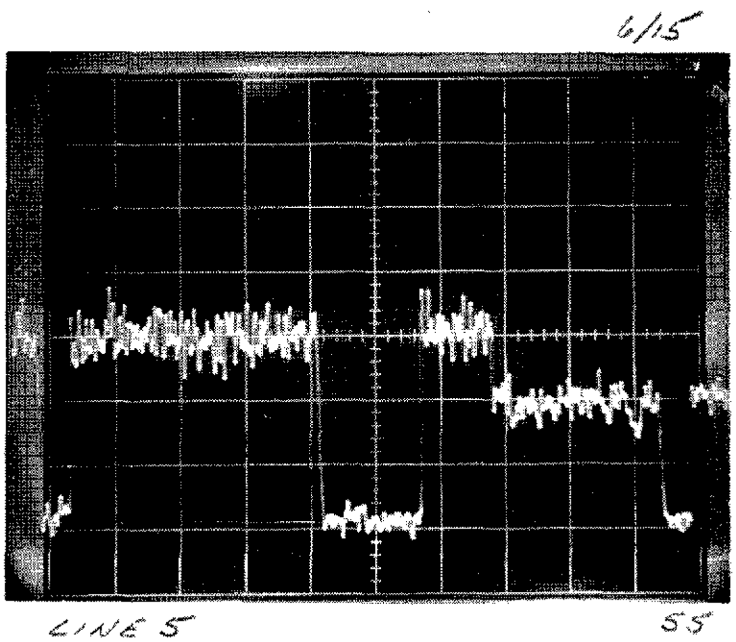


Figure 4

TYPICAL VIDEO POLAROIDS
Top Photo - Resolution Bursts, Center
Frequency burst is 20 cycles/mm

Bottom Photo - Black to White Reference

Magnetic Shielding for Group C Tests

Figures 5, 6 and 7 show the relative placements of the focus coil, magnetic shields, and the SEC tube elements for the Group C tests with STV camera head. Figures 6 and 7 show the positioning and makeup of the additional magnetic shields that were added to the basic shielding of the STV camera head.

Helmholtz Coils for External Fields Tests

The magnetic fields that were used in the magnetic perturbation tests were generated with a square Helmholtz coil system.(11) Figure 8 illustrates the arrangement of the apparatus.

The field at the center of a Square Helmholtz coil system at the coil spacing for maximum field uniformity is given by:

$$B_Z\ (0,\ 0,\ 0) = 1.629\ \ NI/S$$

where:

B is the field in gauss,

N is the number of turns on each coil,

I is the current in Amperes, and

S is the length of the coil sides in centimeters.

The proper coil spacing for the Helmholtz condition of maximum field uniformity is

$$\text{Spacing (d)} = 0.5445\ S.$$

Figure 8 includes the physical data and magnetic characteristics of the coils used for the external field tests.

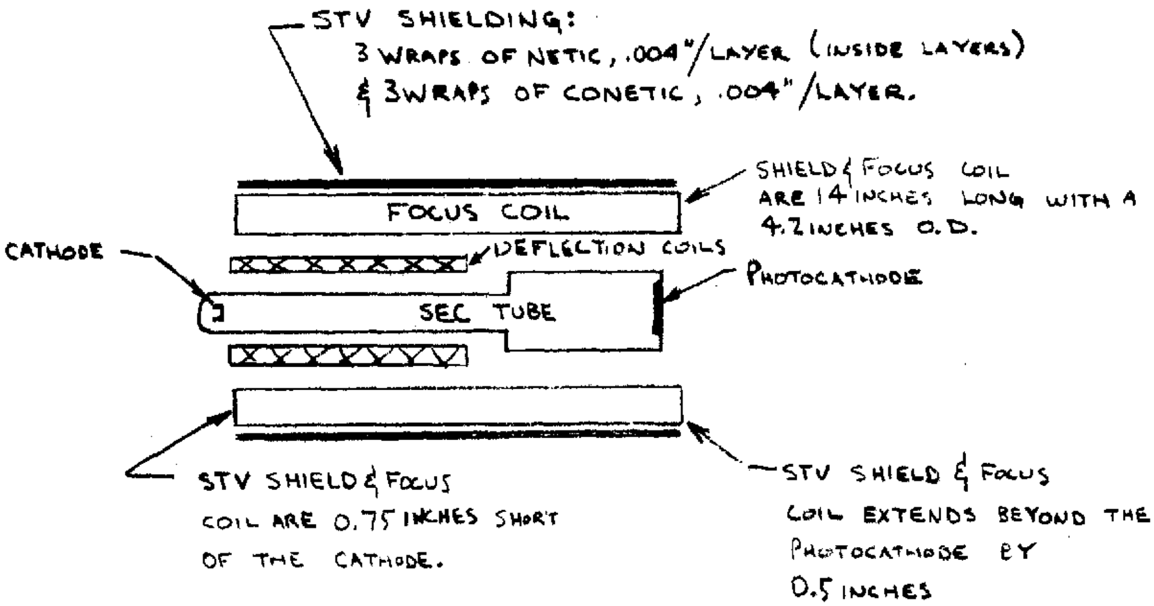


FIGURE 5: STV HEAD ASSEMBLY

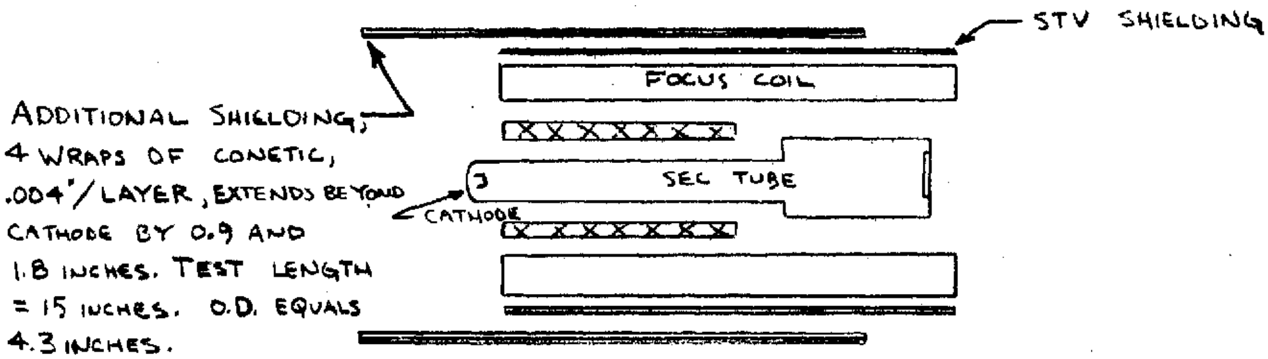


FIGURE 6: STV HEAD WITH ADDITIONAL GUN SHIELDING

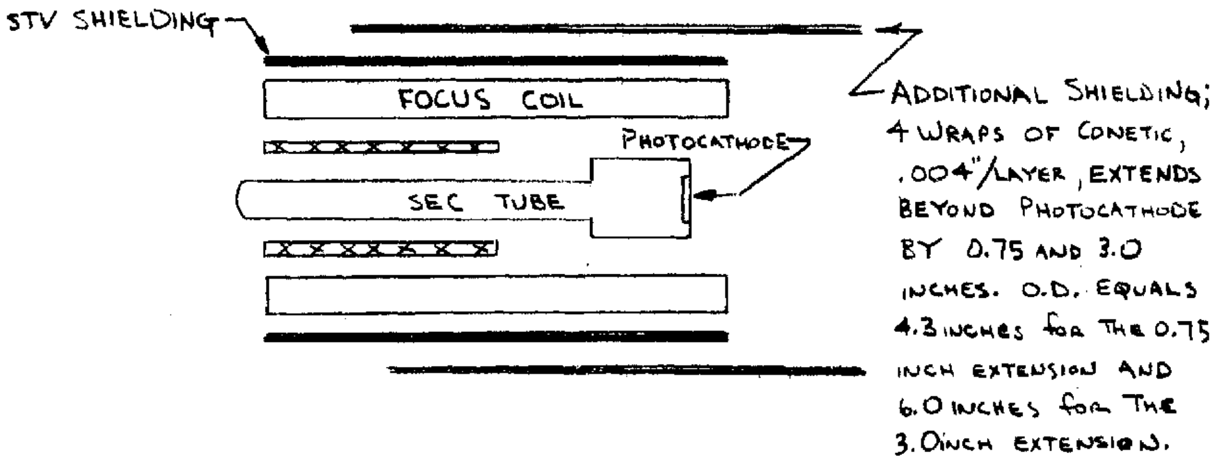
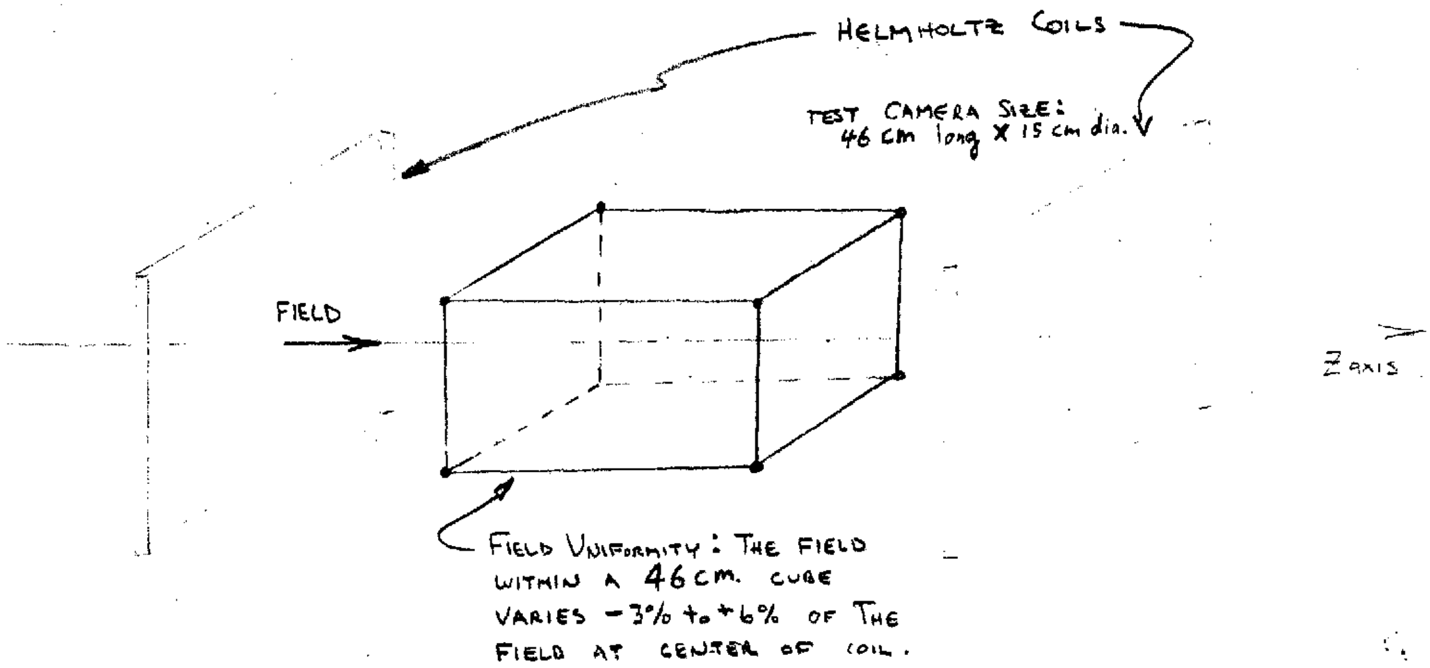


FIGURE 7: STV HEAD WITH ADDITIONAL IMAGE SECTION SHIELDING



Coil data:	length:	118 cm (46-5")
	Spacing:	64 cm. (25.25")
	Windings:	20 turns, No. 10 Copper formular

Central field sensitivity: 0.276 Gauss/Ampere

Figure 8: Square Helmholtz Coils used for External Magnetic Field Tests.

IV. TEST RESULTS

In this section the results of the laboratory measurements are presented in the form of graphs showing the effects on the spatial frequency response of the SEC-vidicon for perturbations in electrode potentials, focus field, and external magnetic fields.

Table 3(A-D) lists the tests performed according to the groups defined in the previous section and stated in the table headings. Table 3 also serves as the index to the twenty-five data graphs presented.

Following the data graphs there is a brief discussion of the data presented with the discussion paragraphs keyed to the graph designations. The impact of these data on a camera design for the LST is the topic of section V.

In general these test results on the WX-31718 (25mm square target) should hold for the larger WX-31958 and smaller WX-32335 SEC-vidicons.

There are some factors that must be scaled. For example, the magnetic shielding effectiveness was found to be strongly dependent on the distance which the cylindrical shields extended past the photocathode and electron gun. With a larger diameter cylinder the proportional overlap should be maintained, i.e., the shields will extend further in absolute dimensions.

The effect of external magnetic fields on the electron gun will depend on the distance from the gun to the target and the potentials on the electrodes. To a first approximation the effect will be proportional to the distance. It is also inversely proportional to the axial magnetic focus field since the two fields are added vectorially.

It should be noted that there is not a unique optimum setting for each individual tube parameter. On the contrary, most of the parameters are strongly related in a continuum of substantially optimum values. For example, if all of the positive electrode potentials in the readout (gun) section of the tube are scaled upward proportional to the square of an upward increase in axial focus field, the readout section will stay substantially in focus.

In addition to the continuum of values for readout section focus described above, there are discrete different focus continuum families because of the multi-loop nature of the readout section focus (refer to Figure 1). Although the readout section can in principle be focused with any positive non-zero integral number of loops, there are practical constraints, such as the configuration of the deflection coils, that tend to favor operation at four loops.[12]

The present 80 gauss axial focus field is a value chosen by the SEC-vidicon tube designers to provide a reasonably compact one loop image section. Lower axial focus field would increase the length of the image section which is inversely proportional to the field strength. Higher axial fields would result in a more compact tube, but would require more deflection power in the readout section and would increase the thermal dissipation in the usual case of a solenoid electromagnet being used to generate the focus field.

TABLE 3

Tests Performed and Data Graph Index

Group A - Tube Electrode Potential and Focus Field Perturbation

Test	Graph
A1. Focus Current Perturbation	
a. Entire tube	
1. Center resolution	A1-1
2. Corner resolution	A1-2
b. Image section, center resolution	A1-3
A2. Photocathode Potential Perturbation	
a. Center resolution	A2-1
b. Corner resolution	A2-2
A3. Wall (beam focus) Potential Perturbation	
a. Center resolution	A3-1
b. Corner resolution	A3-2
A4. Field Mesh Potential Perturbation	
a. Center resolution	A4-1
b. Corner resolution	A4-2
A5. G2 (Gun Anode) Potential Perturbation	
a. With constant gun current	
1. Center resolution	A5-1
2. Corner resolution	A5-2
b. With constant gun bias, center resolution	A5-3
A6. Beam Current (total gun cathode current) Perturbation	
a. Center resolution and black level shift	A6-1
b. Corner resolution	A6-2
A7. Alignment Current Perturbation	
a. Center resolution	
1. Coil A1	A7-1
2. Coil A2	A7-2

TABLE 3

Tests Performed and Data Graph Index

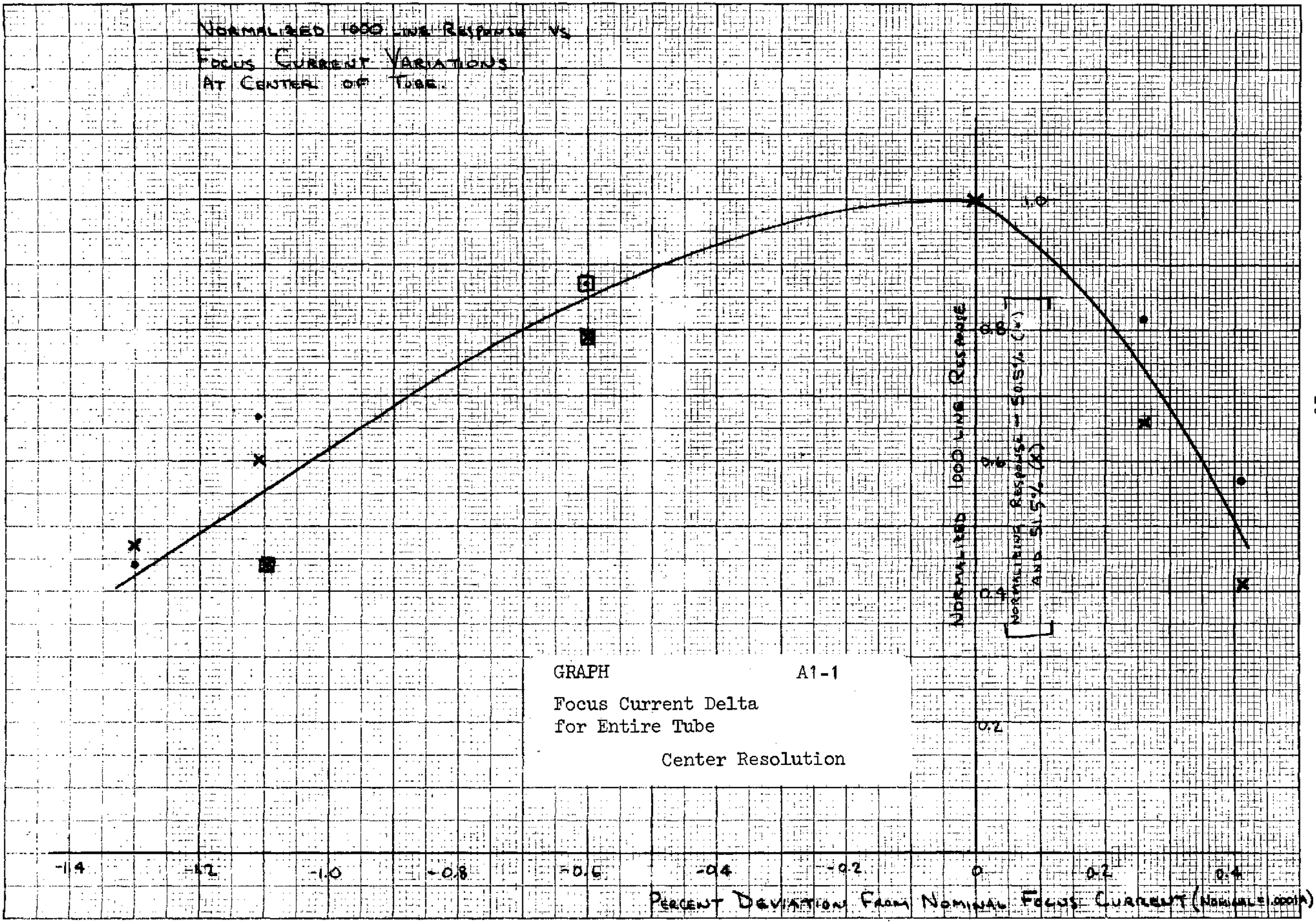
Group B - External Magnetic Fields on Unshielded TV Camera

Test	Graph
B1. Image Section - External axial field Center resolution	B1
B2. Image Section - External transverse field	
a. Center resolution	B2-1
b. Image displacement	B2-2
B3. Readout Section - External axial field Center resolution	B3
B4. Readout Section - External transverse field	
a. Center resolution	B4-1
b. Image displacement	B4-2

Group C - External Magnetic Fields on Shielded TV Cameras

Test	Graph
C1. Image Section - External transverse field. Image displacement with various shield configurations, reference Figures 5 and 7.	C1
C2. Readout Section - External transverse field. Image displacement with various shield configurations, reference Figures 5 and 6.	C2

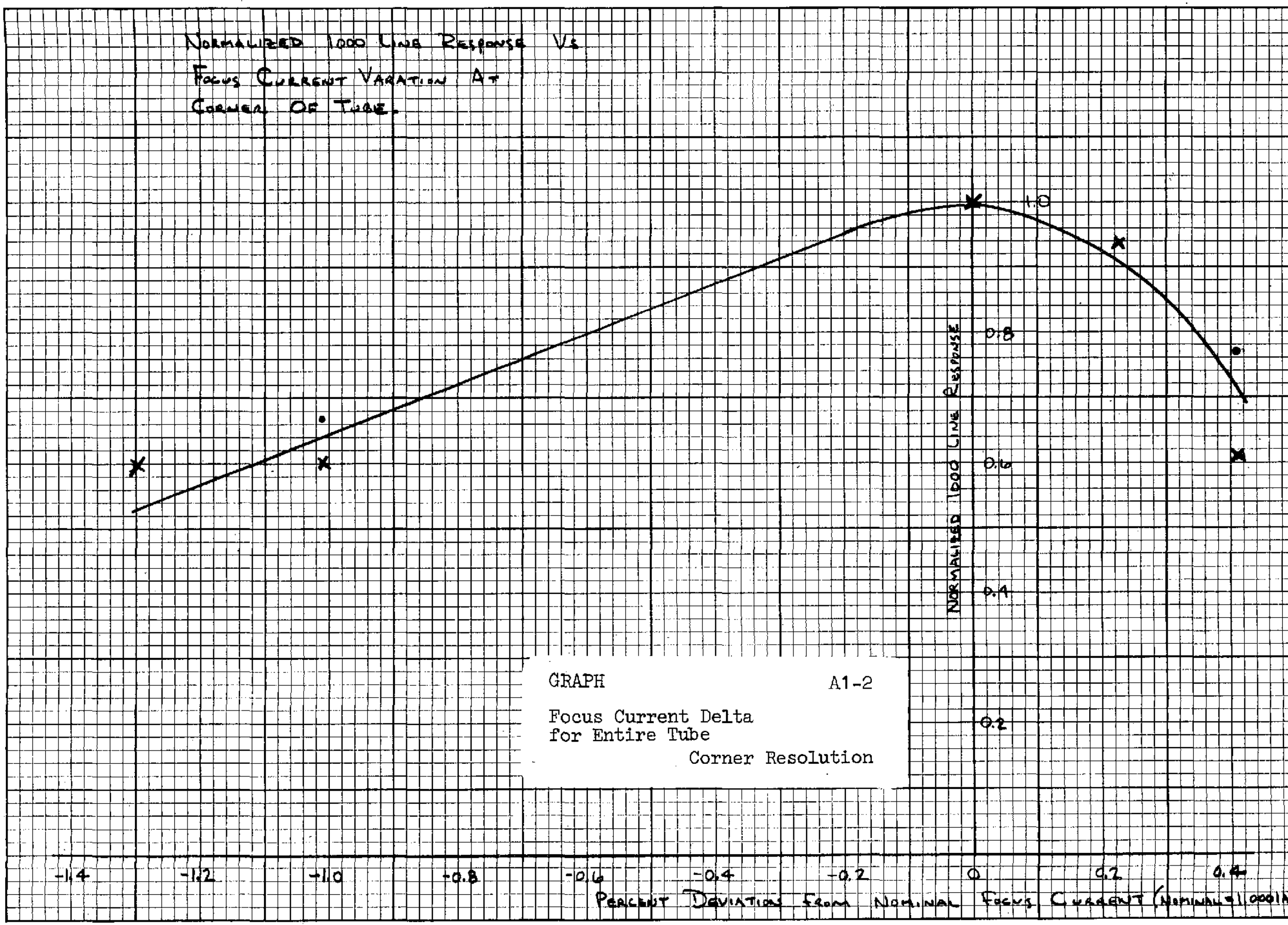
Test	Graph
D1. Measured square wave MTF of the tube used in the Test Set Camera for group A and B tests.	D1



GRAPH A1-1

Focus Current Delta
for Entire Tube

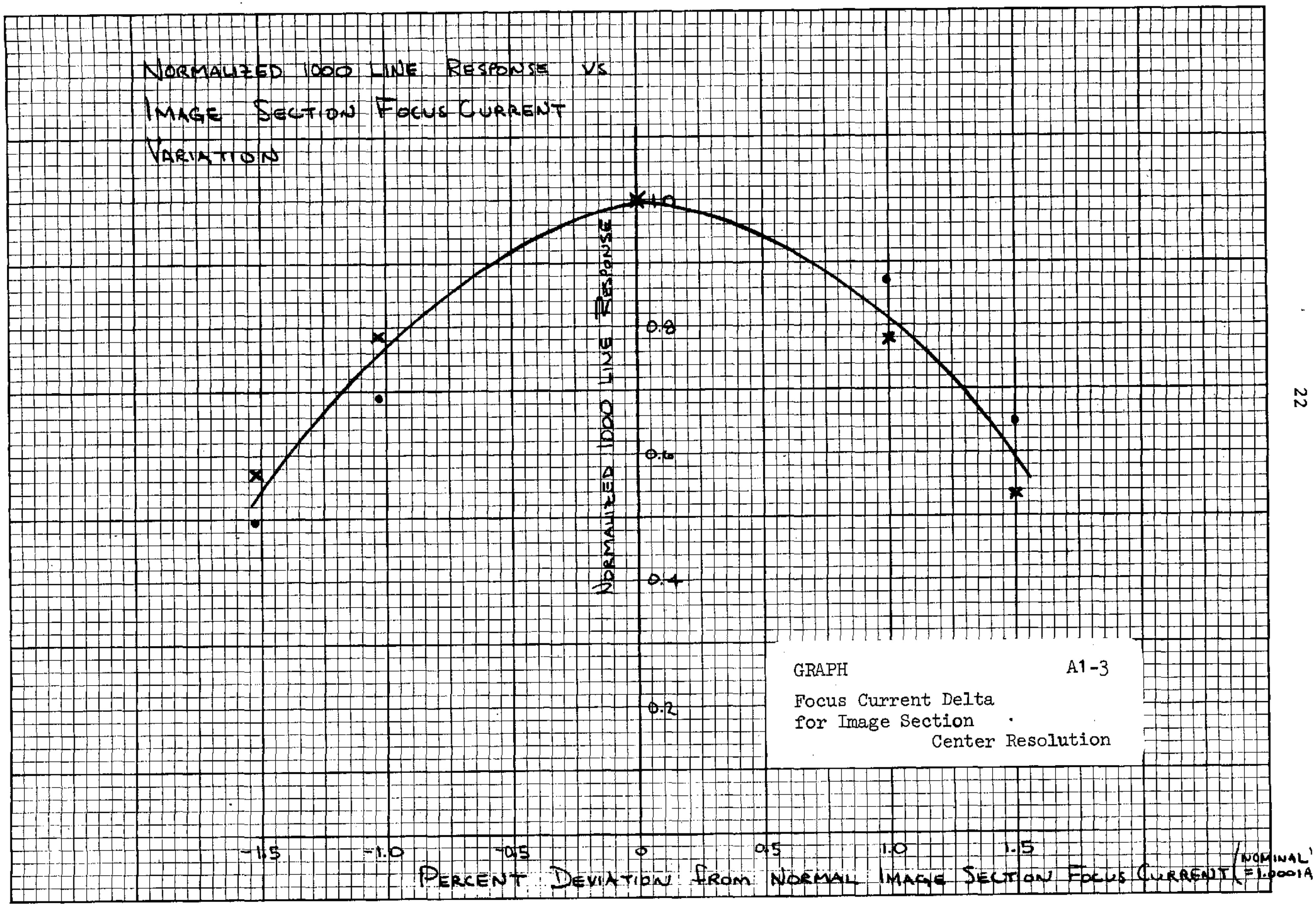
Center Resolution



GRAPH A1-2

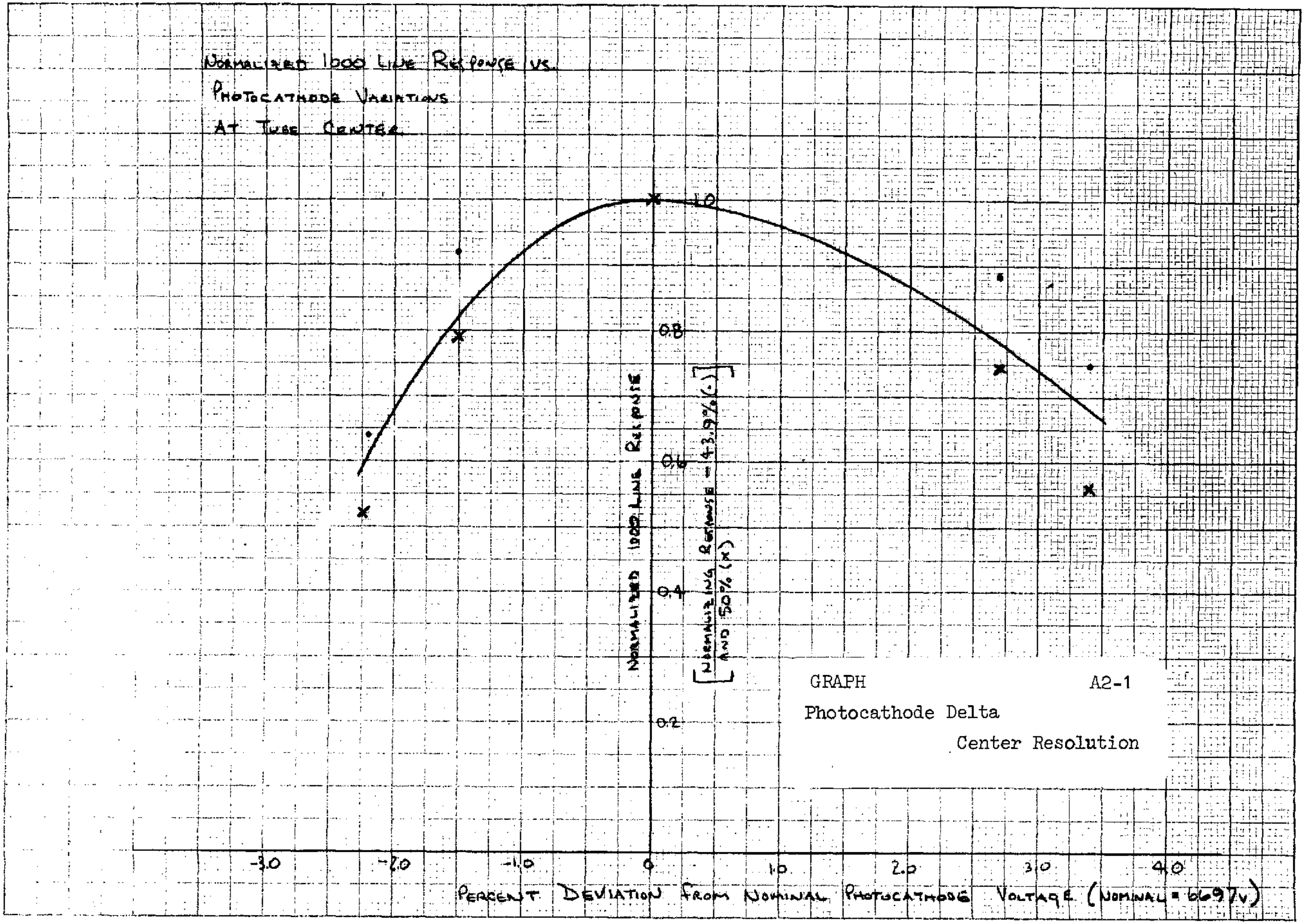
Focus Current Delta for Entire Tube

Corner Resolution



GRAPH A1-3

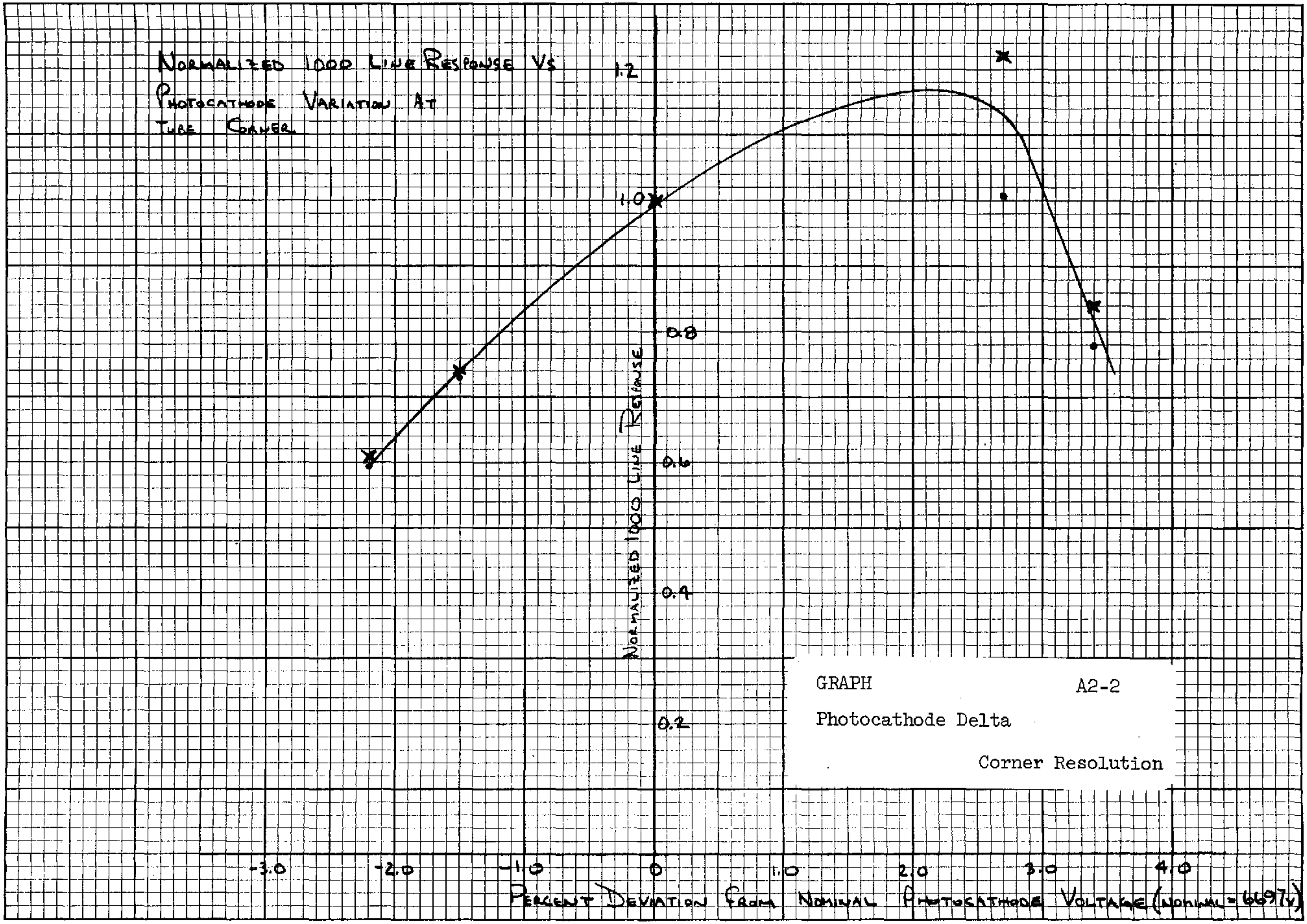
Focus Current Delta
for Image Section
Center Resolution



GRAPH A2-1

Photocathode Delta

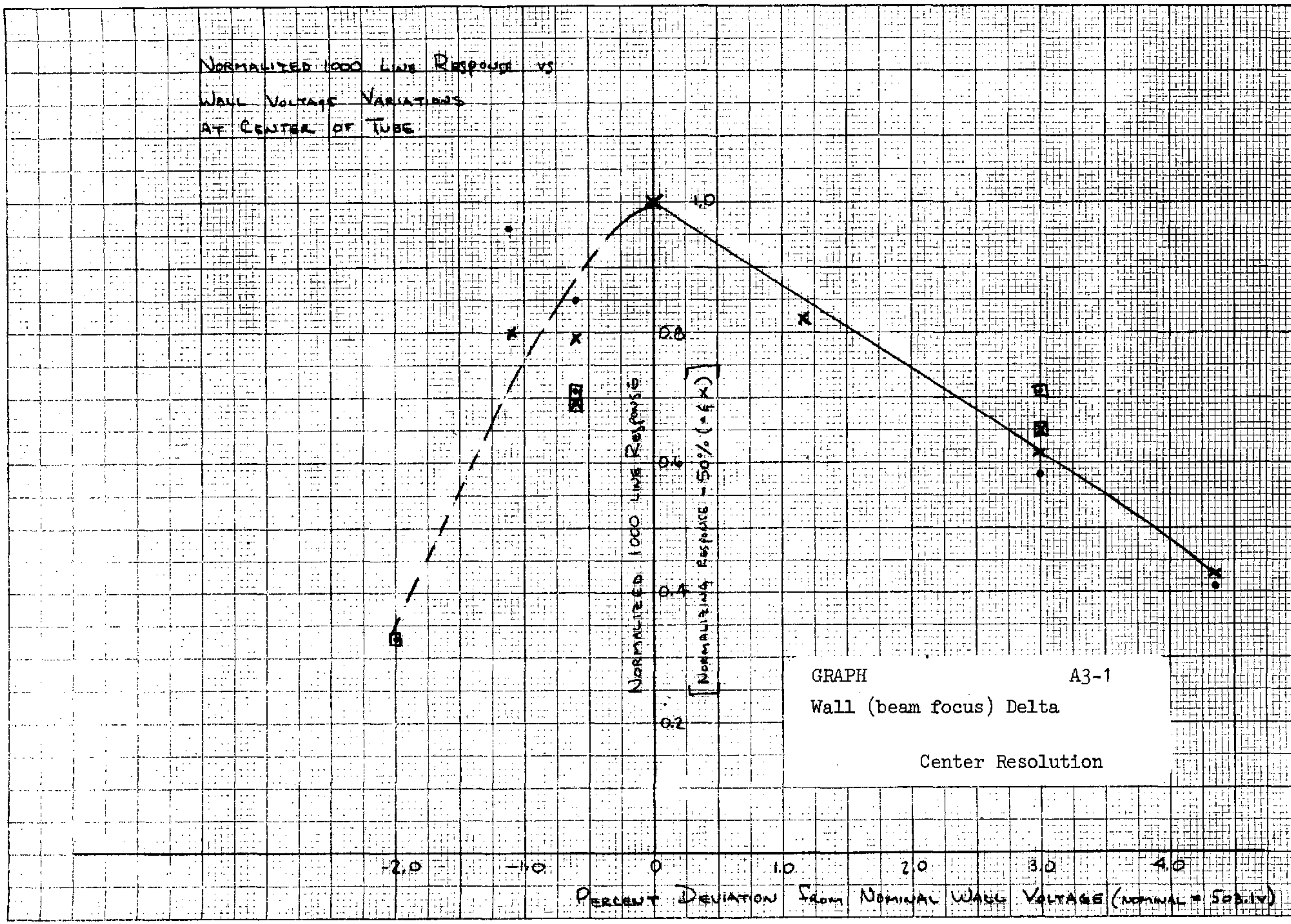
Center Resolution



GRAPH A2-2

Photocathode Delta

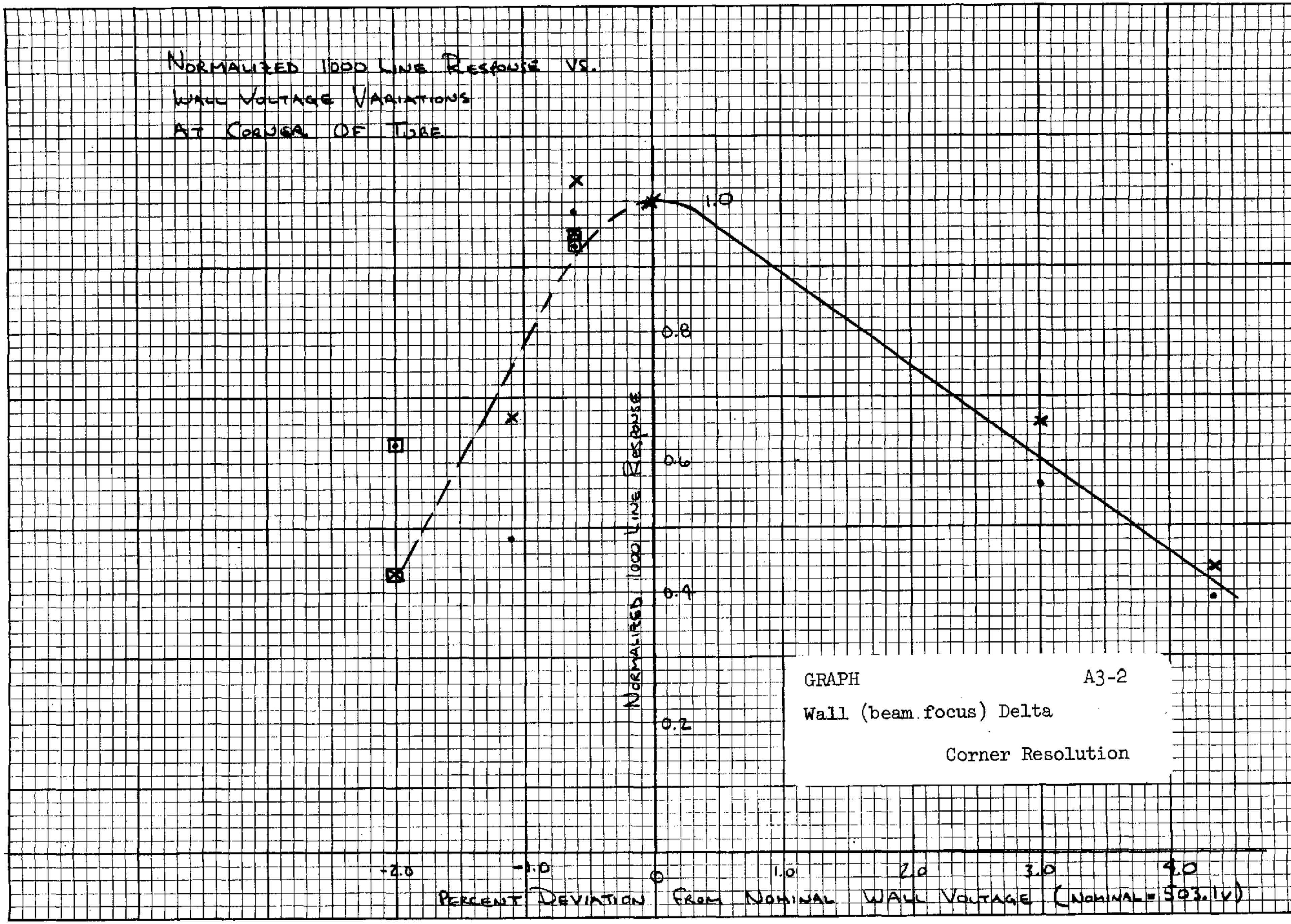
Corner Resolution



GRAPH A3-1

Wall (beam focus) Delta

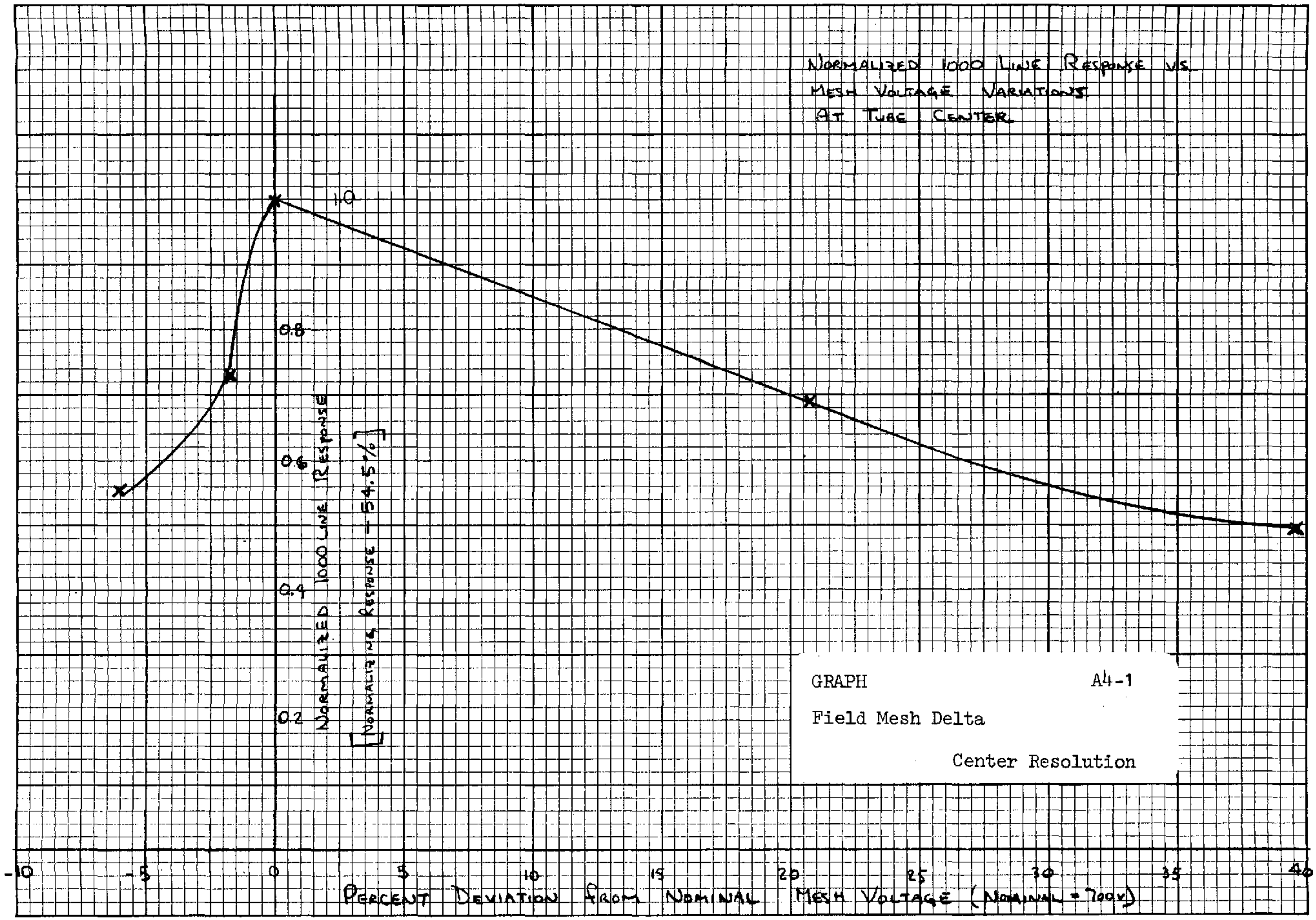
Center Resolution



GRAPH A3-2

Wall (beam focus) Delta

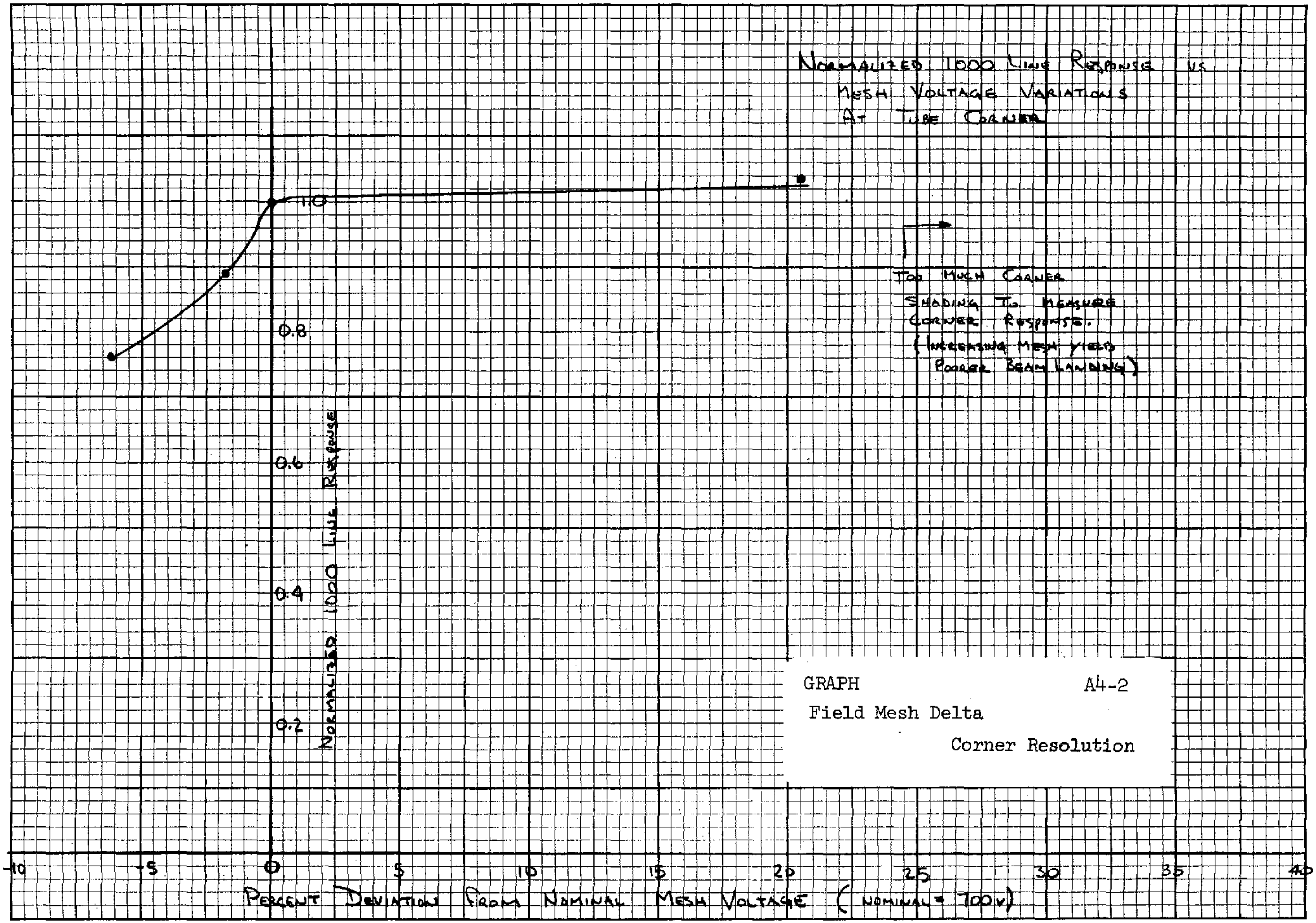
Corner Resolution



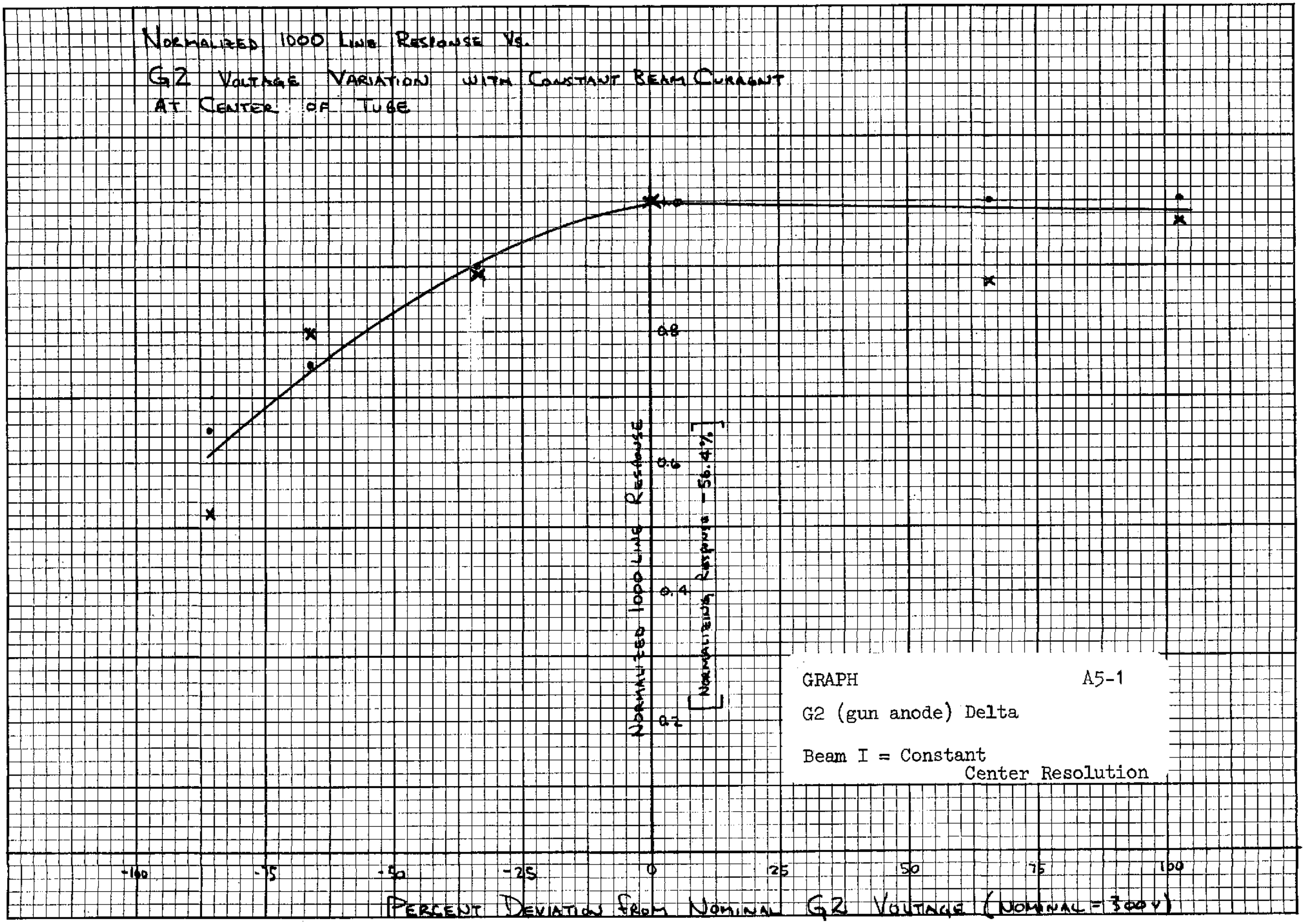
GRAPH A4-1

Field Mesh Delta

Center Resolution



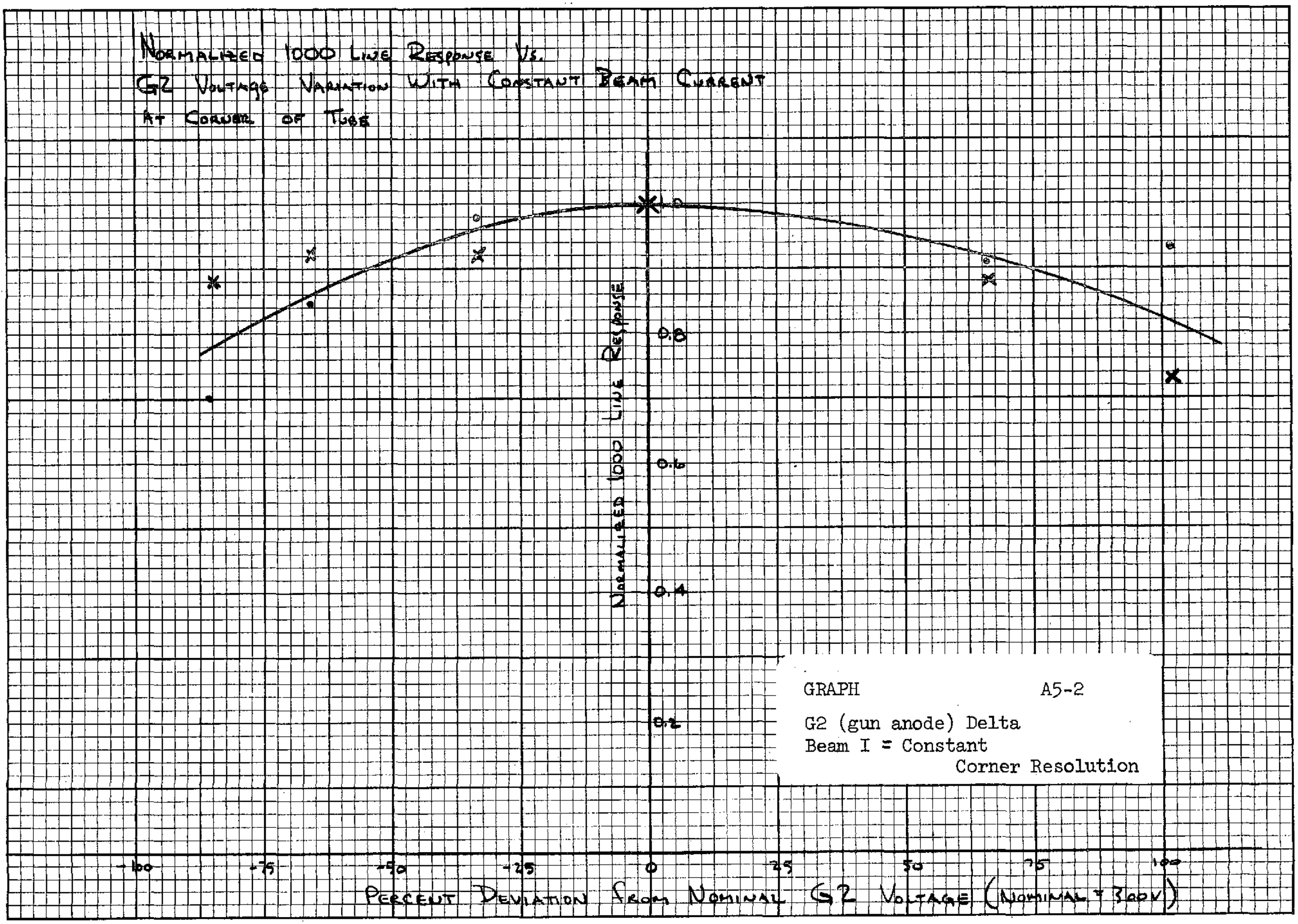
GRAPH A4-2
Field Mesh Delta
Corner Resolution



GRAPH A5-1

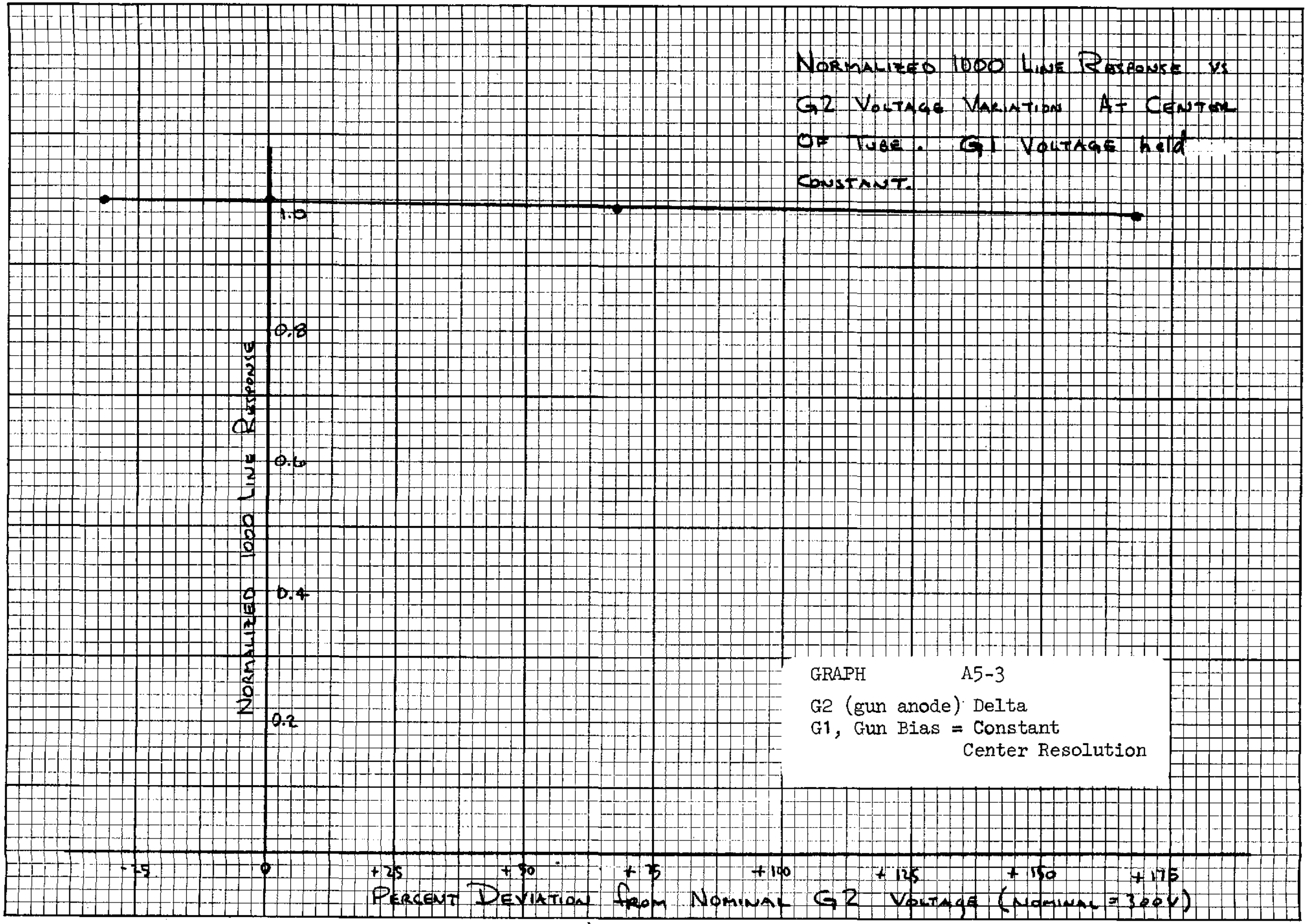
G2 (gun anode) Delta

Beam I = Constant
Center Resolution



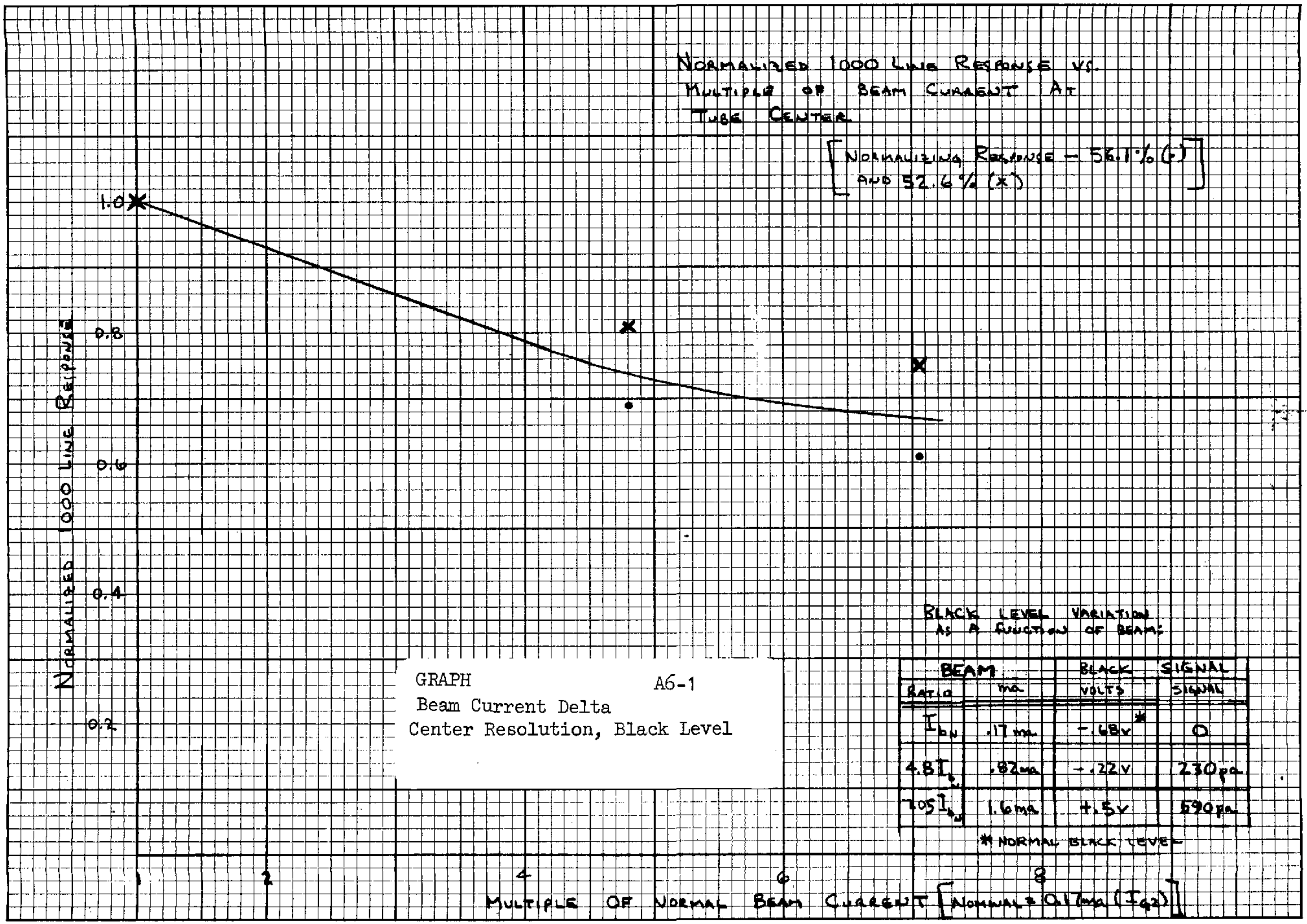
GRAPH A5-2

G2 (gun anode) Delta
Beam I = Constant
Corner Resolution



GRAPH A5-3

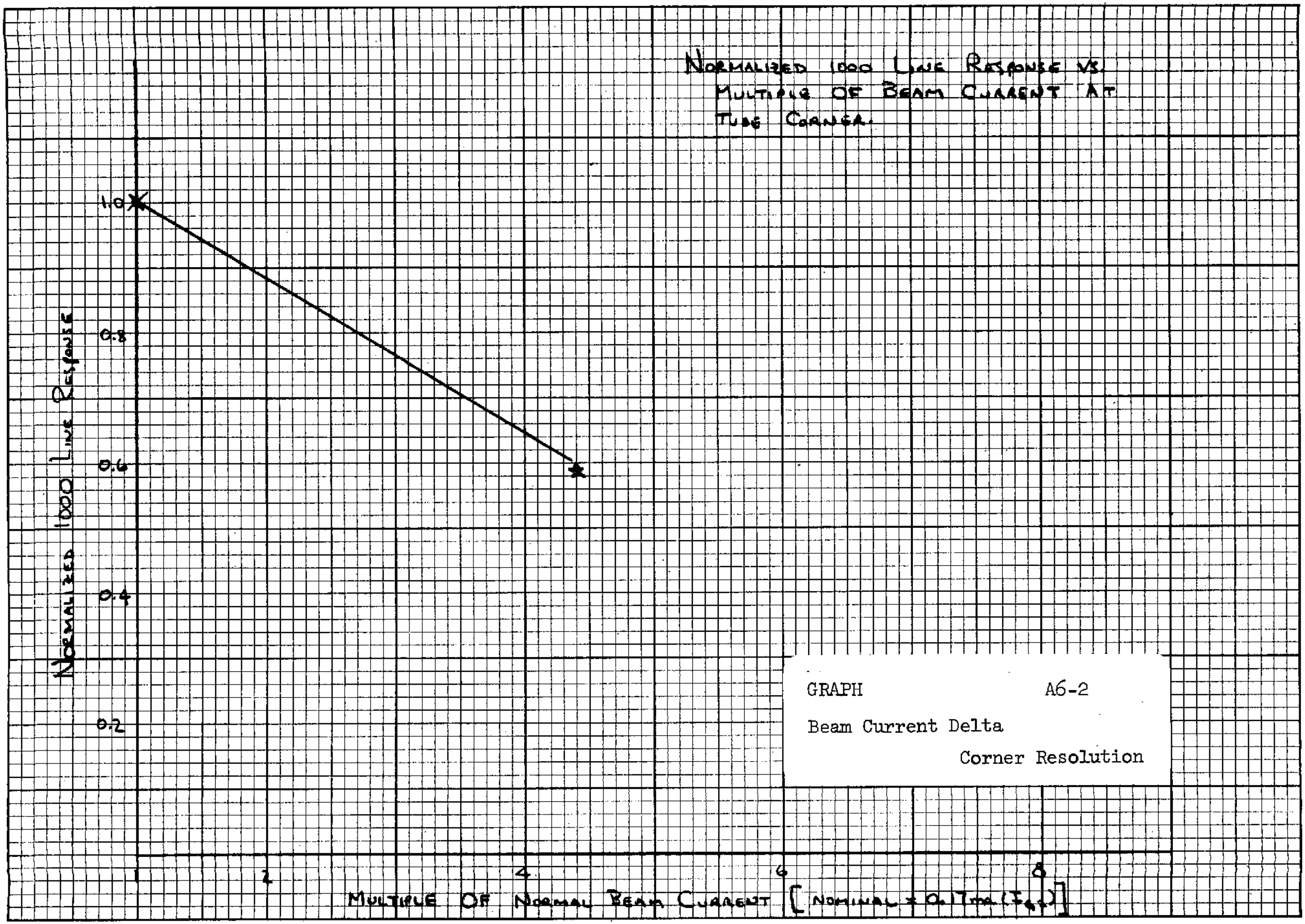
G2 (gun anode) Delta
G1, Gun Bias = Constant
Center Resolution



BEAM		BLACK	SIGNAL
RATIO	ma	VOLTS	SIGNAL
I_{bN}	.17 ma	-.68v*	0
$4.8 I_{bN}$	.82ma	+.22v	230pa
$7.05 I_{bN}$	1.6ma	+.5v	590pa

* NORMAL BLACK LEVEL

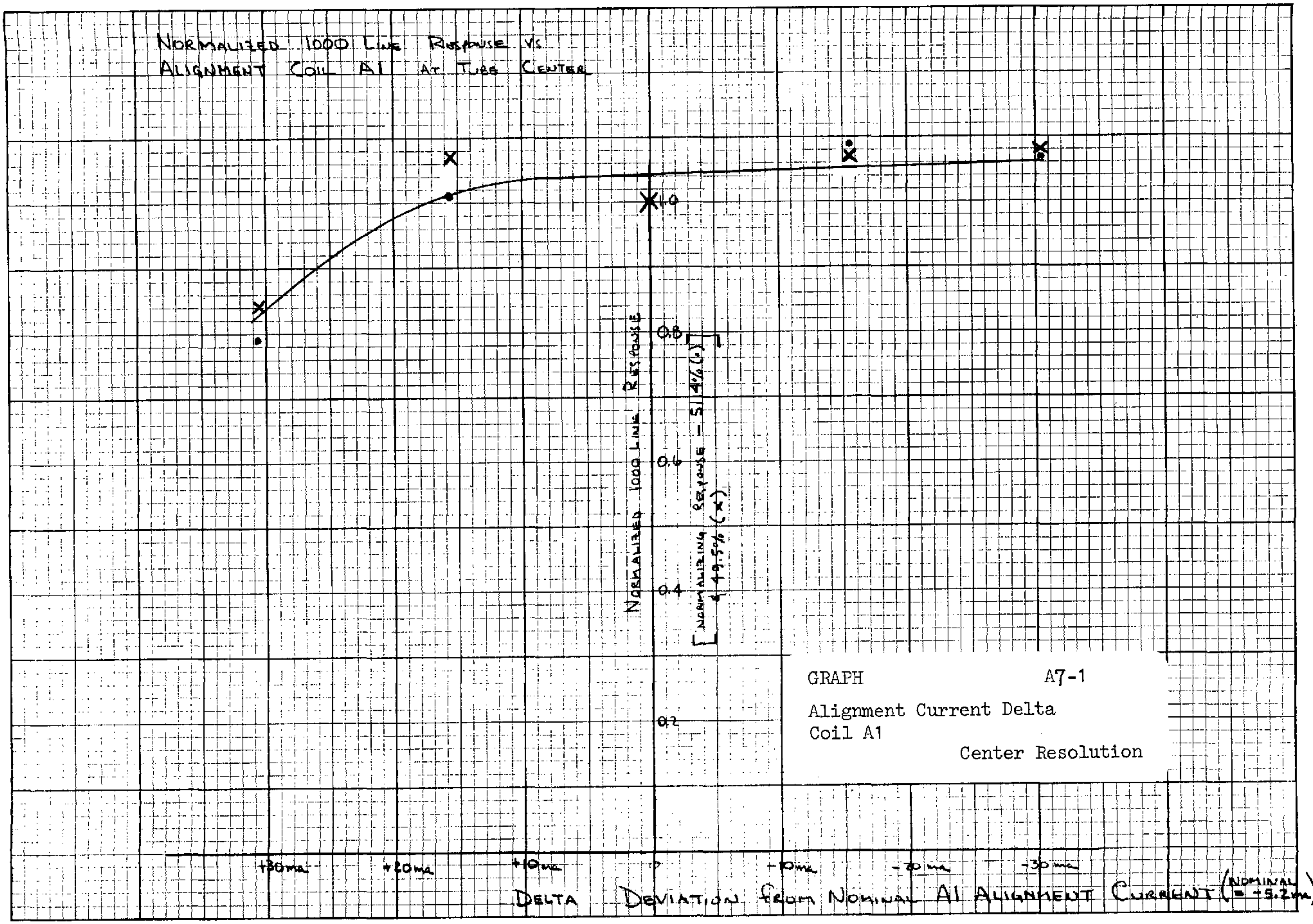
GRAPH A6-1
Beam Current Delta
Center Resolution, Black Level



GRAPH A6-2

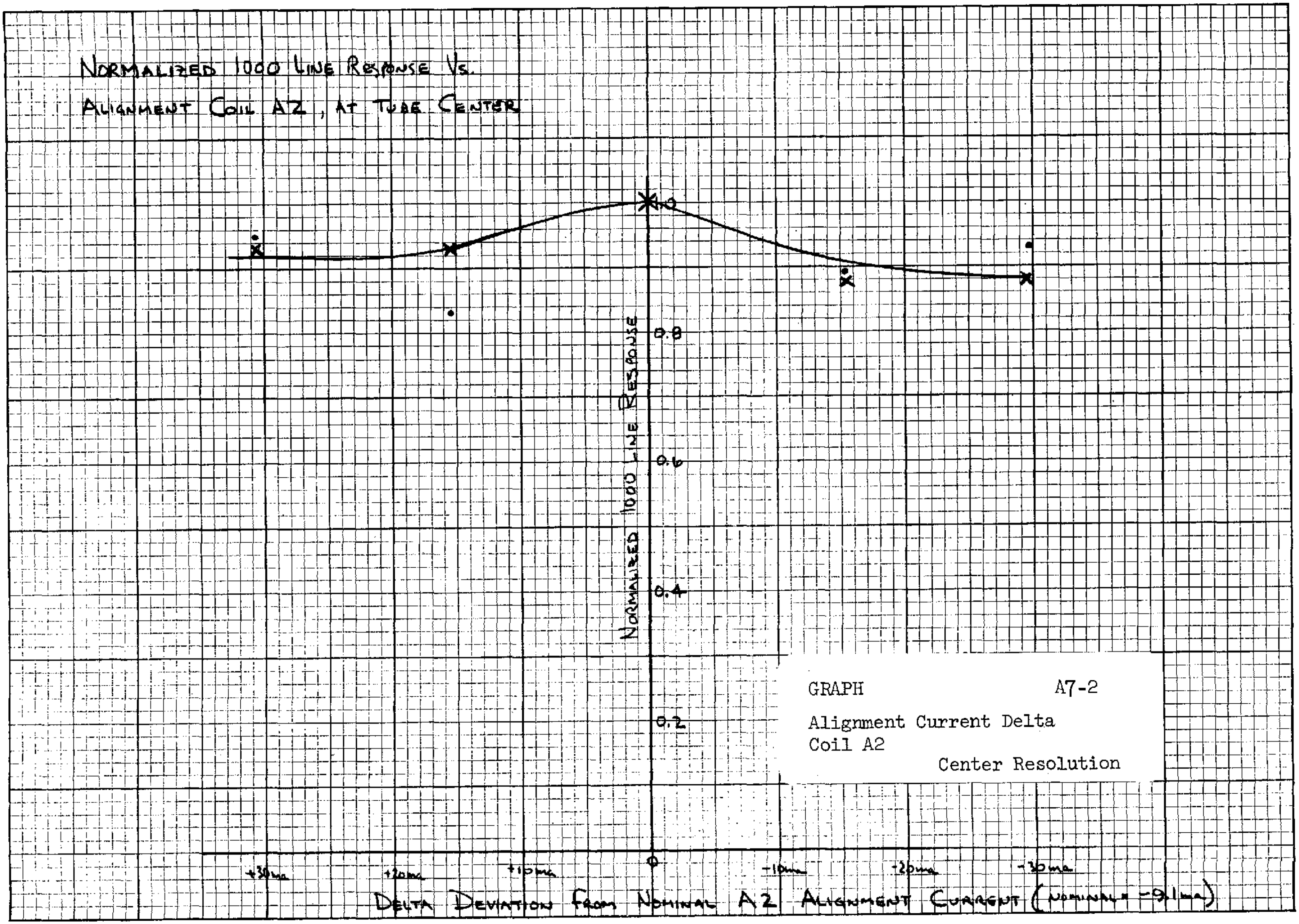
Beam Current Delta

Corner Resolution



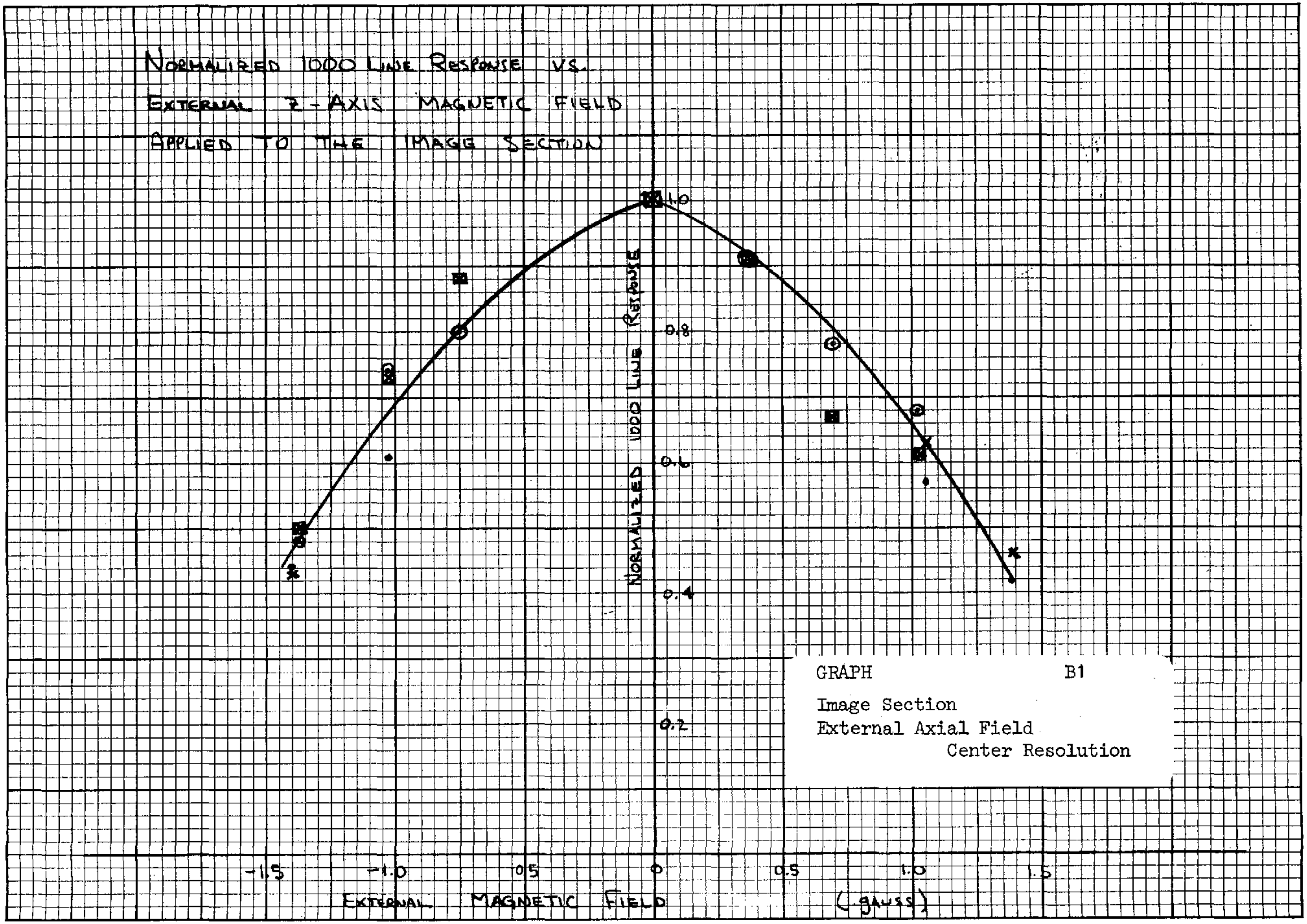
GRAPH A7-1

Alignment Current Delta
Coil A1
Center Resolution



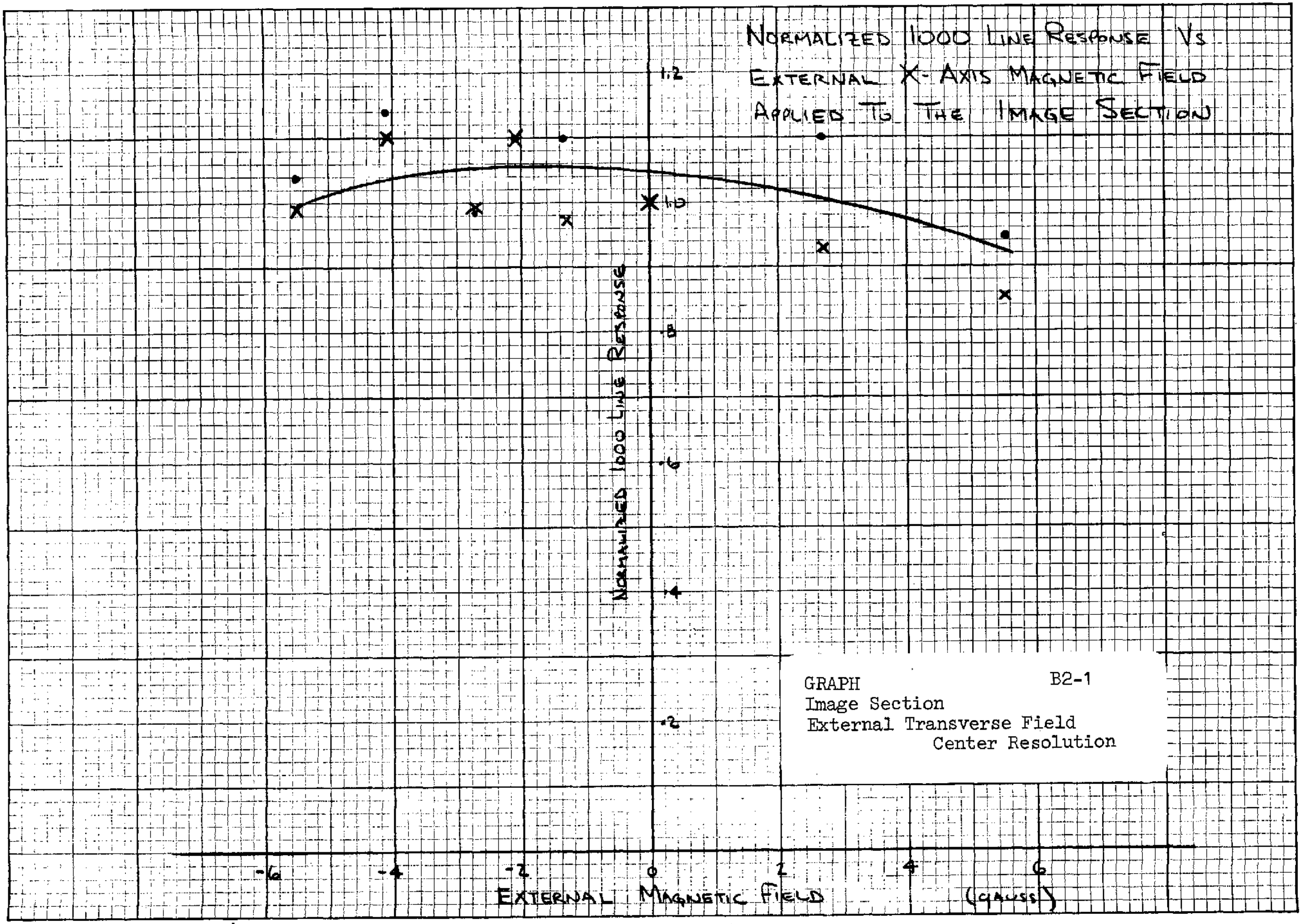
GRAPH A7-2

Alignment Current Delta
Coil A2
Center Resolution

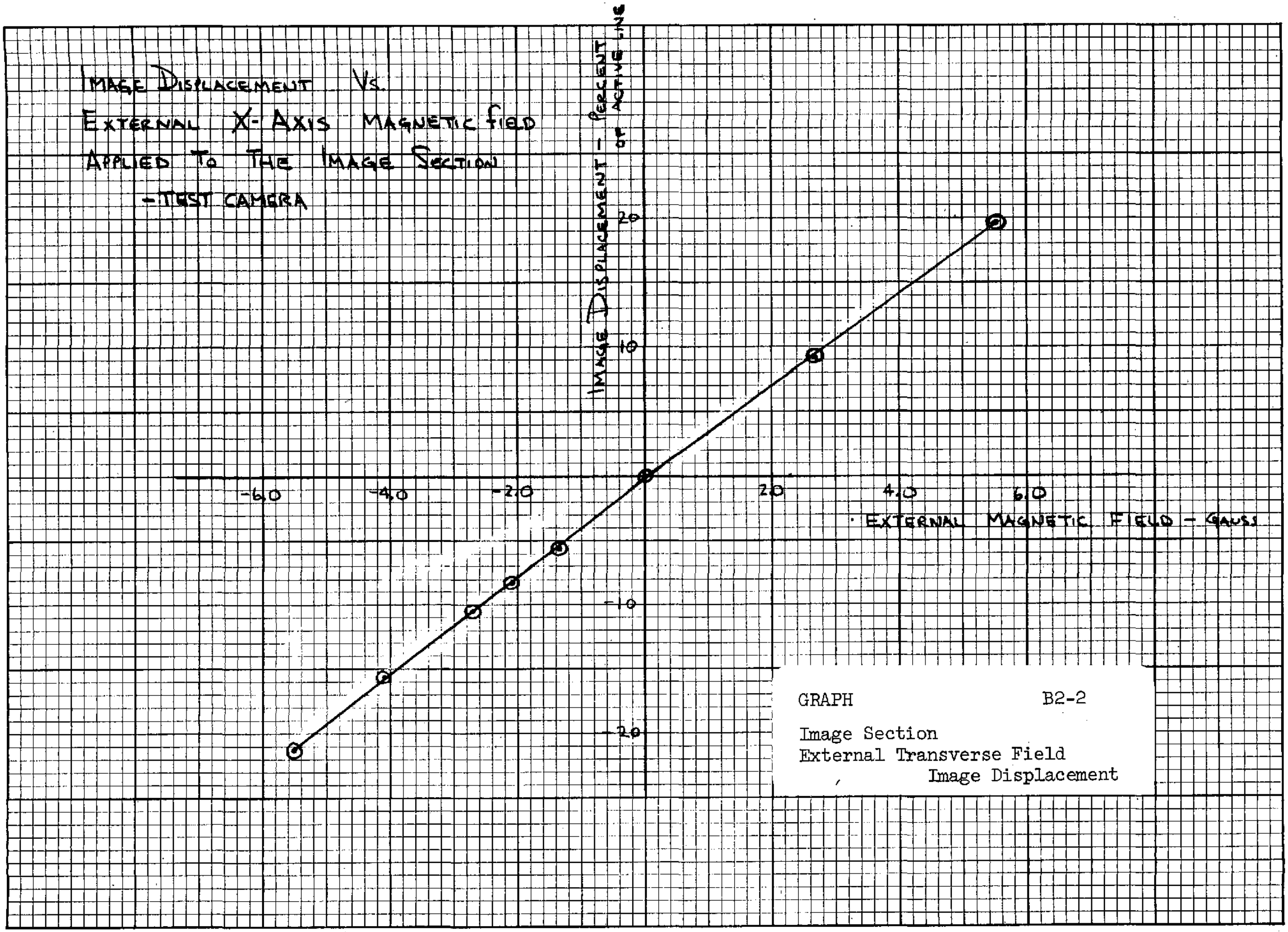


GRAPH B1

Image Section
External Axial Field
Center Resolution

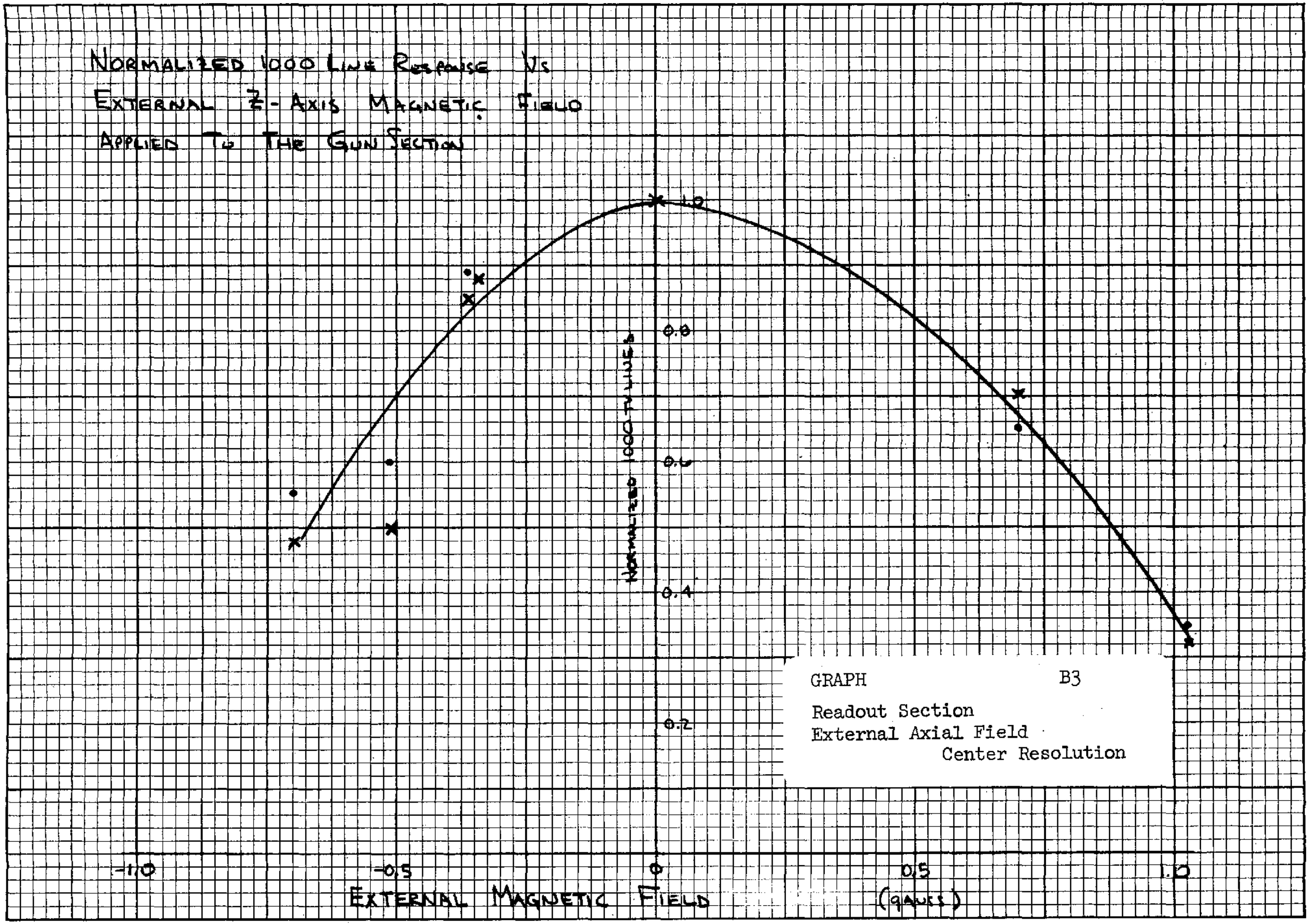


GRAPH B2-1
Image Section
External Transverse Field
Center Resolution



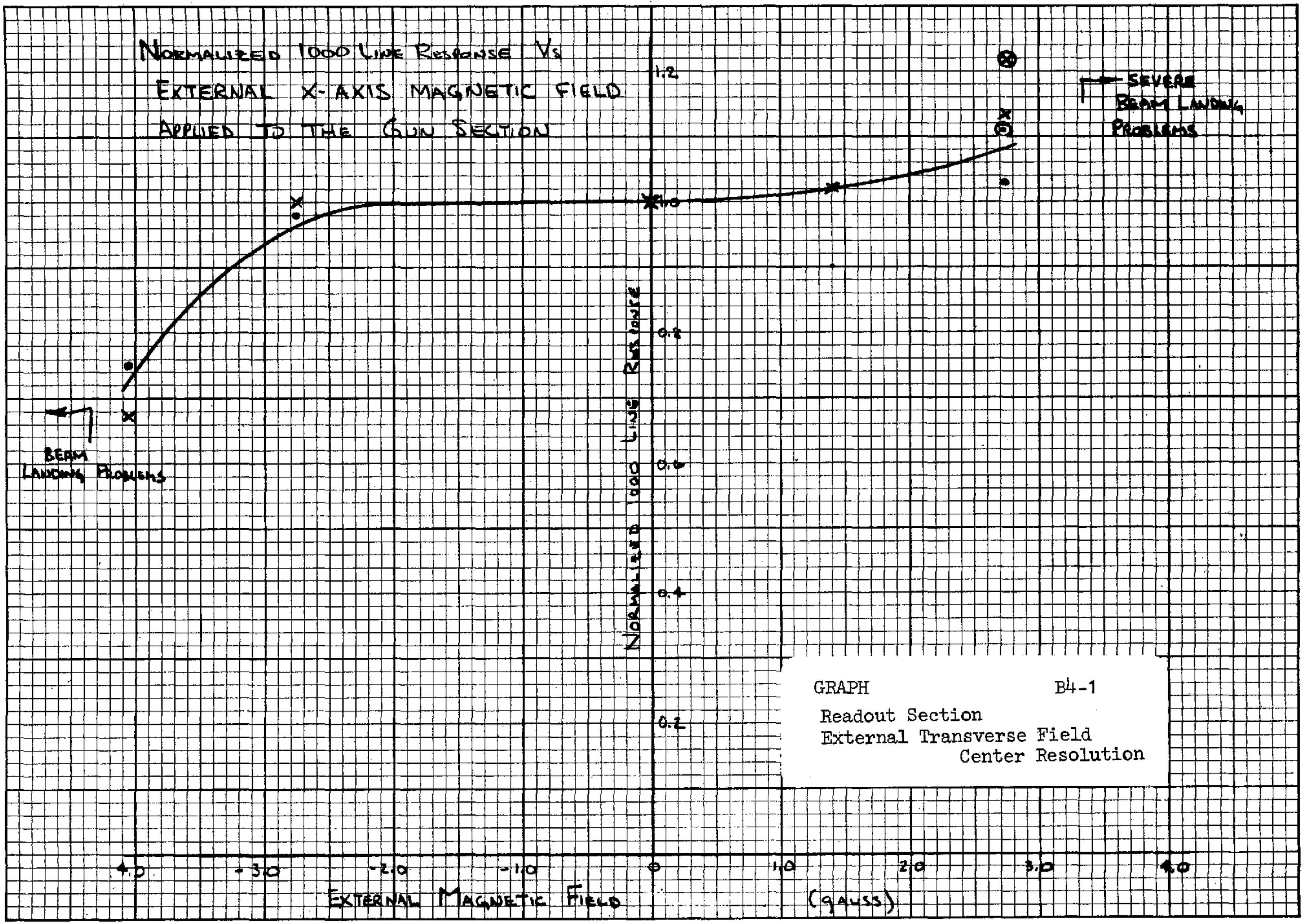
GRAPH B2-2

Image Section
External Transverse Field
Image Displacement



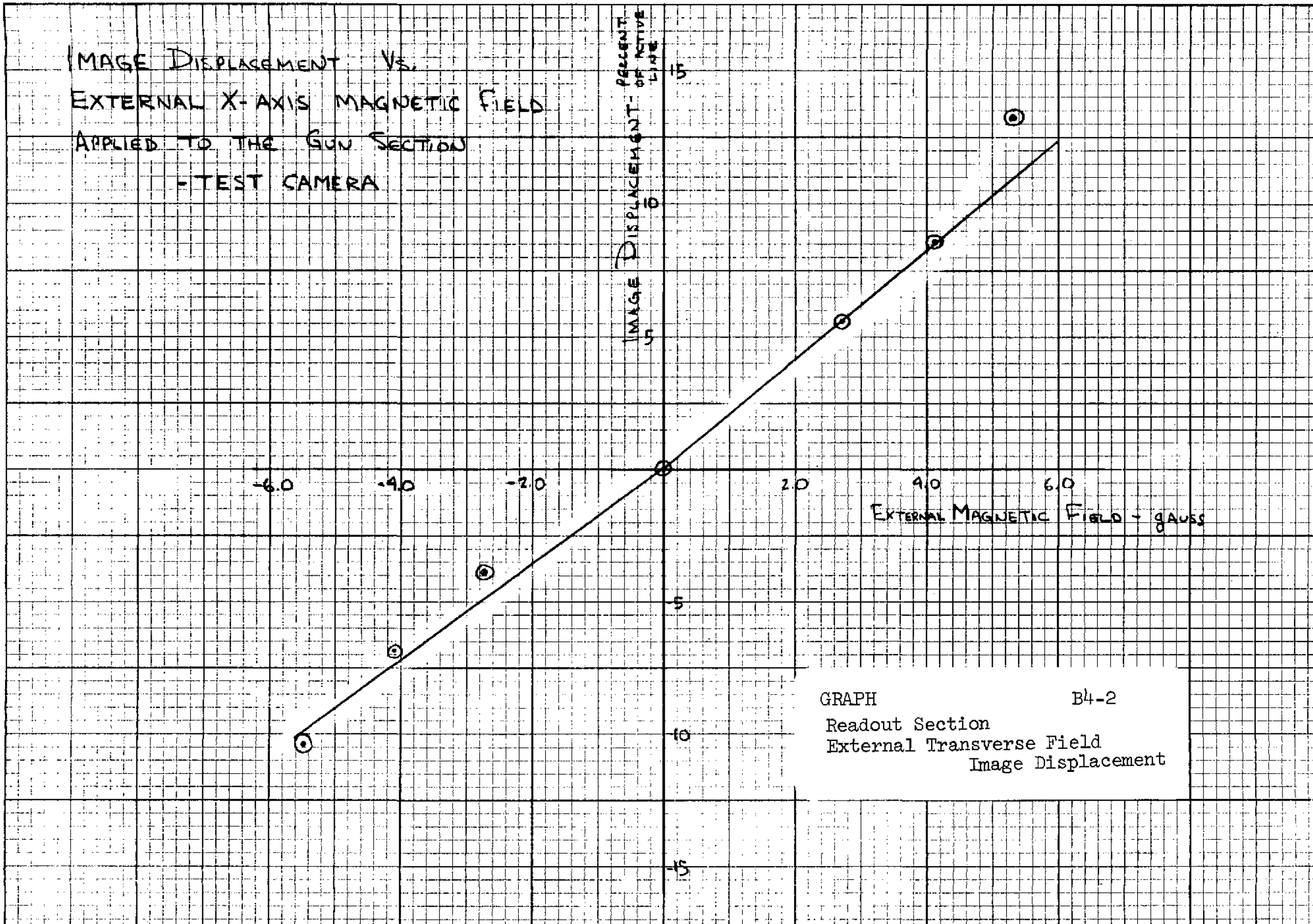
GRAPH B3

Readout Section
External Axial Field
Center Resolution

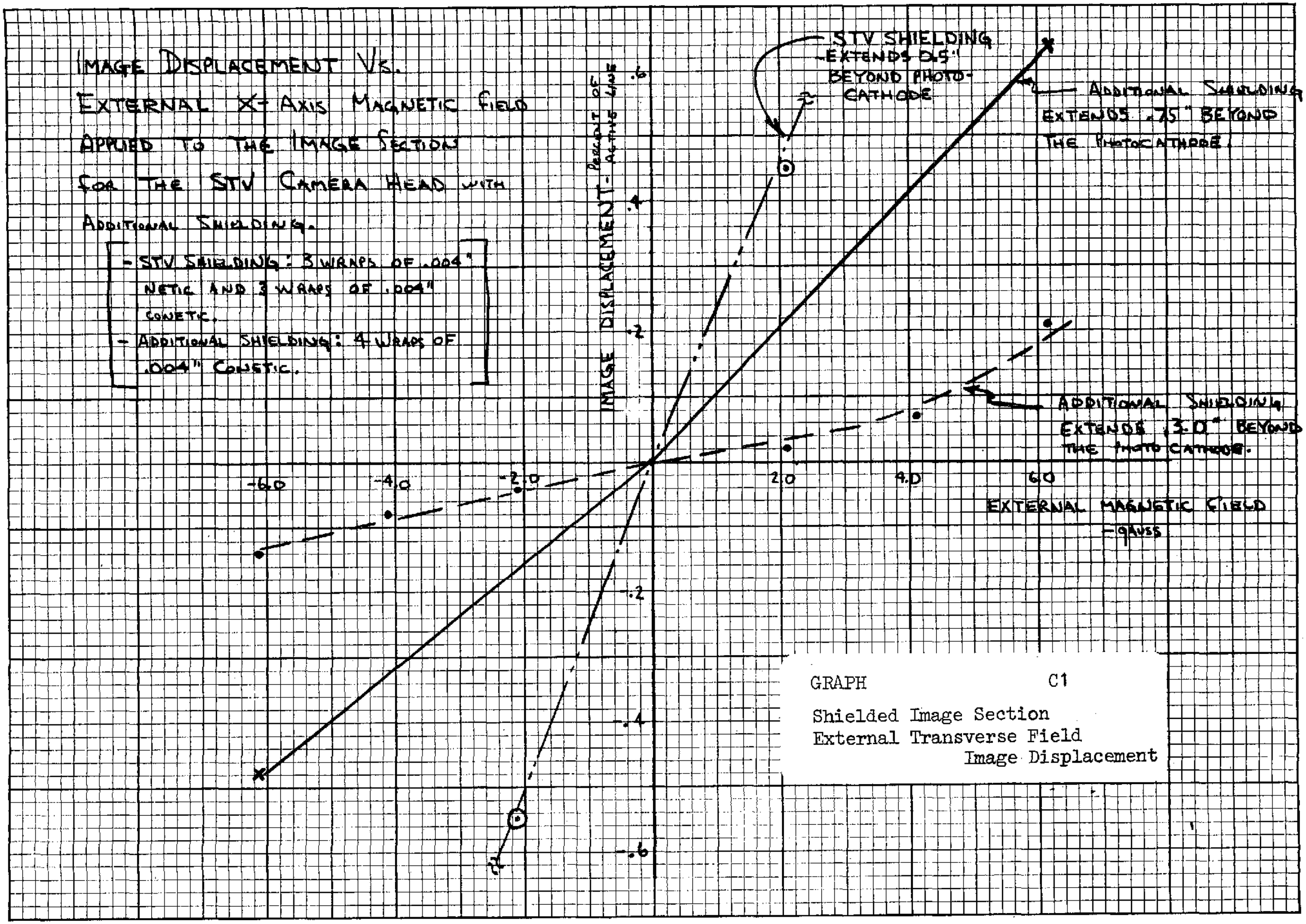


GRAPH B4-1

Readout Section
External Transverse Field
Center Resolution

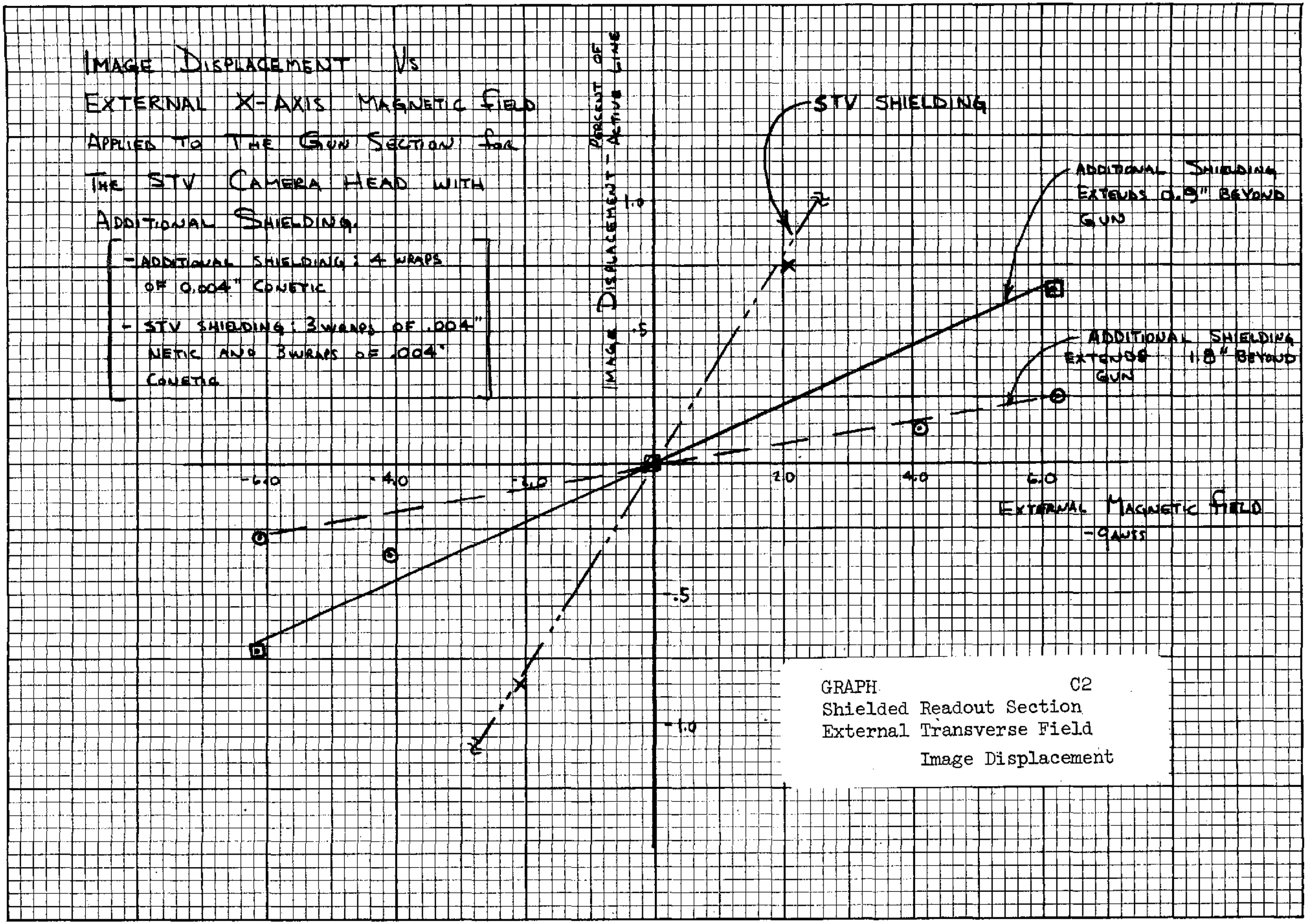


GRAPH B4-2
Readout Section
External Transverse Field
Image Displacement

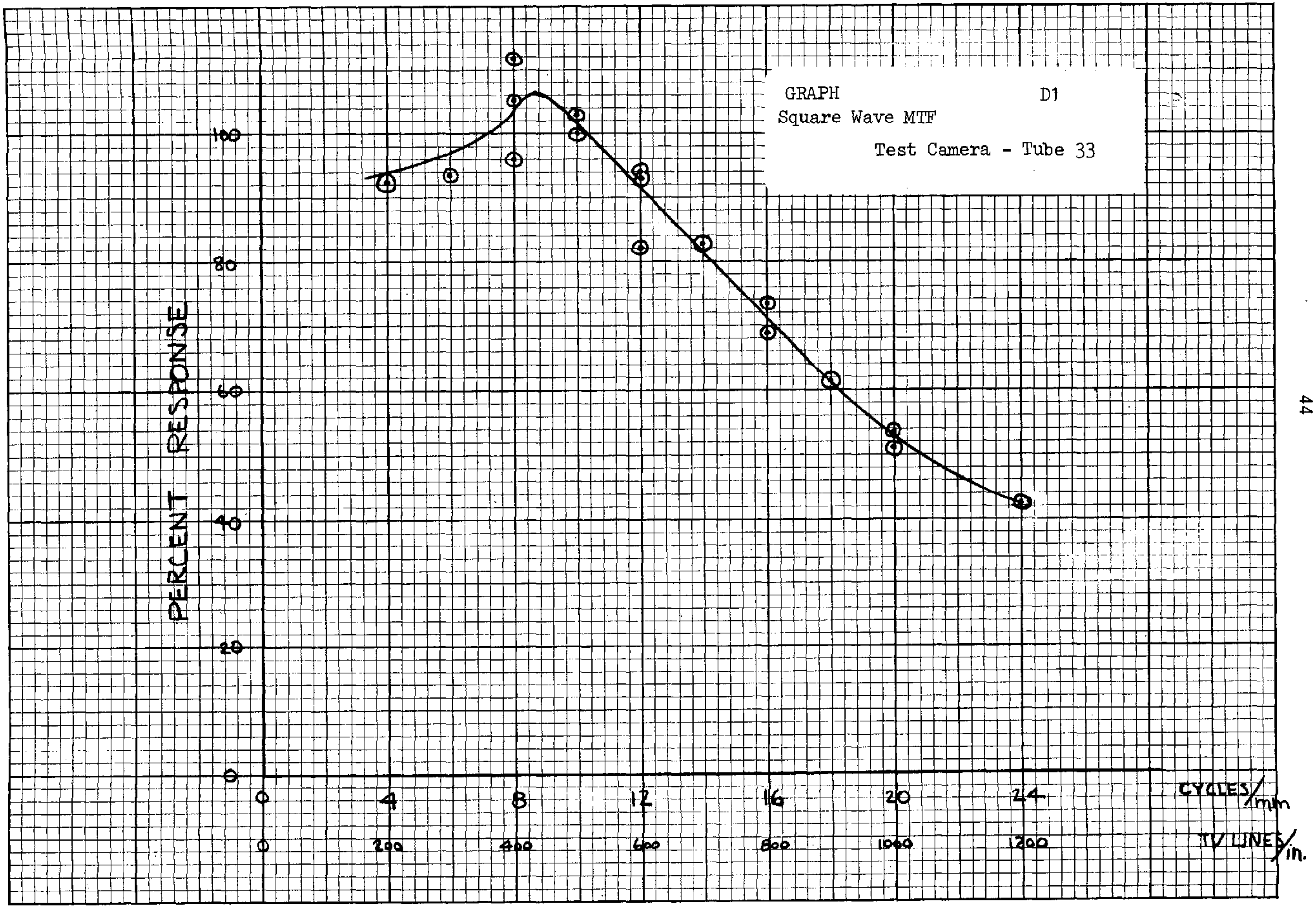


GRAPH C1

Shielded Image Section
External Transverse Field
Image Displacement



GRAPH C2
Shielded Readout Section
External Transverse Field
Image Displacement



GRAPH D1
Square Wave MTF
Test Camera - Tube 33

Discussion of the Data Graphs

Graphs A1 - 1,2 Focus current perturbation, entire tube

This test combines the defocussing effect in both the image and readout sections as the axial magnetic focus field is moved off optimum. Note the criticality of the focus field since an increase of only 0.4 percent halves the response at 20 cycles/mm.

Graph A1 - 3 Focus current perturbation, image section only

Comparing this graph with A1 - 1 and 2 shows that the readout section focus is more critical than the image section which operates at higher electron velocities and one loop focus.

Graphs A2-1, 2 Photocathode potential perturbation

A2-1 shows that the criticality of photocathode voltage is about half that of the magnetic field. This is consistent with theory.

Comparison of A2-1 and A2-2 implies a slight curvature of the image section focal plane in the Test Set camera which is probably caused by flaring of the axial focus field at the end of the simple focus coil used in the Test Set Camera head.

Graphs A3-1, 2 Wall (beam focus) perturbations

These curves show the extreme criticality of the readout beam focus condition, particularly on the low side. Note that the agreement between A3-1 and A3-2 indicates that the readout section focus plane is properly flat with the beam coming into focus in the corner of the format at the same focus settings as the center.

Graphs A4-1, 2 Field Mesh potential perturbations

The criticality of focus with respect to mesh voltage is about as anticipated on the low voltage side, but the large insensitivity of focus to higher mesh voltages was a surprising result. This is probably because the higher mesh voltages reduce the diameter of the out of focus beam, somewhat offsetting the defocus effect for higher than optimum mesh voltages.

Graphs A5-1, 2, 3 G2 (gun anode) potential perturbations

These curves show the insensitivity of focus related to G2 voltage variations.

Graphs A6-1, 2 Beam current perturbations

These curves indicate a moderate criticality of beam current with regard to resolution, particularly in the corners. But it is clear that other beam current related effects are more important. Tabulated on Graph A6-1 is the effect very high beam current has on the tubes black level. This is probably the result of gas ions generated in the field mesh - target space. Another possibility is soft X-ray induced signal caused by the beam striking the field mesh.

Graphs A7-1, 2 Alignment current perturbations

These curves show that the alignment fields do not have any first-order effects on resolution.

Graph B1 Image Section - External axial magnetic field

When normalized to the 80 Gauss axial focus field, the effects of external axial fields on the focus of an unshielded image section are consistent with the results of Graph A1-3, where the focus current was varied.

Graphs B2-1, 2 Image Section - External transverse magnetic field

Graph B2-1 confirms the expectation that transverse fields do not affect image section resolution, while B2-2 shows the magnitude of the image displacement caused by transverse external fields on an unshielded image section.

Graph B3 Readout Section - External axial magnetic field

As in the case of the image section (Graph B1) the effects of external axial fields on the readout section are consistent with the effect caused by a comparable change in the focus field by a perturbation in the focus current.

Graphs B4-1, 2 Readout Section - External transverse magnetic field

B4-1 shows that transverse fields have virtually no effect on readout section resolution. Strong transverse fields (greater than ±3 gauss), however do interfere with proper beam landing.

B4-2 shows the image displacement effects of transverse field on the readout section.

Graphs C1 and C2 Transverse magnetic field effects on shielded cameras

These graphs are to be interpreted with the aid of Figures 5, 6, and 7 which show the arrangement of the various shields. The data of graphs C1 and C2 show that the effectiveness of simple open cylindrical shields depends very much on the extent to which the shields overhang the photocathode and electron gun locations.

Graph D1 Square Wave MTF

The measured square wave response of the tube used in the Test Set Camera for test groups A and B. The less than unity response below 5 cycles/mm is an artifact in the plotted data caused by regional shading in the tube. The above unity response near 8 cycles/mm is the effect of the fundamental component of a square wave having a peak amplitude 27 percent above the square wave amplitude. The highest frequency data point, 24 cycles/mm, has been corrected for the video filter attenuation.

V. IMPACT ON LST CAMERA DESIGN

Electronic Stability Requirements

Available electronic technology is such that the performance of the TV camera should be limited by the television tube capabilities and not by the electronic circuits. This is particularly pertinent in the focus and resolution performance areas.

The purpose of many of the tests conducted during this study was to determine or confirm the tolerance levels required on the various tube electrode potentials and magnetic fields.

Table 4 lists the tolerances required to limit to less than 10 percent the loss of spatial frequency response at 20 cycles/mm for each individual parameter, and proposes worst case tolerances for the parameters so that the combined effect will result in no more than 10 percent loss in resolution.

Image Deflection Considerations

Deflection of the image during exposure by the earth's magnetic field is an important consideration because of the long exposures expected in the LST mission. The image section deflection transfer function is 0.9 mm per gauss (Graph B2-2). In order to keep the loss in spatial frequency response caused by smearing of the image during exposure to less than 10 percent, the image shift must be less than 1/2 of a picture element. At 20 cycles/mm this is a shift of 12.5 microns which corresponds to a transverse field of 0.014 gauss. Since the orbital change in the earth's magnetic is 0.7 gauss peak to peak, a magnetic shield with an attenuation factor of 50 is required.

Deflection in the gun section is not as serious since the readout occurs in less than a minute, too short a time for the earth's field to change significantly. Of course, on board sources of magnetic fields, such as other television cameras, must also be considered.

TABLE 4

SEC-Vidicon Parameter Tolerances

Tube Parameter	Single variable deviation corresponding to 10% loss at 20 cycles/mm	Recommend worst case tolerance for overall less than 10% loss at 20 cycles/mm	Percent of error budget
Focus Current	±0.1%	±0.035%	35
Photocathode Voltage	±1.0%	±0.15%	15
Wall Voltage (beam focus)	±0.25%	±0.05%	20
Field Mesh Voltage	±0.5%	±0.10%	20
G2 Voltage (gun anode)	±30%	±1.5%	5
Beam Current*	±80%	±4%	5
			100
Alignment Current*	*	*	

*Considerations other than resolution may dictate the tolerances on these items.

Magnetic Shielding

The magnetic shielding problem is accentuated by the fact that the shield must accomodate the 80 gauss axial focus field generated by a solenoid or perhaps a permanent magnet assembly. The shield must absorb the external field of the focus magnet without saturating and still provide the required factor of 50 attenuation of external transverse fields. The axial external field variation caused by the earth, if uncompensated, would cause a less than 10% loss in MTF at 20 cycles/mm. See Graph B1. If necessary, the external axial field could be measured or predicted and compensated with adjustment of the focus parameters of the tube.

Magnetic Shielding-Thermal Design

It is important that the photocathode and image section of the television tube be at a temperature below 0°C to limit the internal background due to dark current from the photocathode and emission from the walls of the image section. A nominal temperature of -10°C is recommended. The field emission from the electrodes and the wall of the image section is enhanced by the photocathode materials that are deposited on these surfaces as well as on the window during the evaporation of the photocathode. This enhancement is caused by the lowering of the work function of these surfaces. This effect has a strong temperature coefficient as does the photocathode dark current.

Most of Princeton's experience to date has been with bi-alkali and tri-alkali photocathodes that are sensitive in the visible and ultraviolet. There is limited experience with solar blind photocathodes such as CsTe. From limited testing of IUE tubes, it appears that these tubes also have a temperature dependent dark current.

Since the ambient temperature of the instrument compartment is to be approximately +20°C, the image section must be cooled. The heat from the focus coil must be dissipated as well. Therefore, there is a close relationship between the thermal and magnetic design of the front end of the camera head.

The problem is to not only cool the window but also the walls of the image section. Furthermore, it is important that the window not be heated by radiation coupling to warmer parts of the tube or instrument compartment. This is another reason for cooling the walls of the image section of the tube. In the forward direction, it would be desirable to provide a cool cylinder that would intercept most of the solid angle seen by the window in that direction. This cylinder, if magnetic, could also serve as part of the magnetic shield. Unfortunately the thermal conductivity of magnetic metals is far less than that of copper. A laminated tube of both copper and magnetic material may be a good compromise. If the cylinder extends one diameter in front of the window the solid angle occulted would be approximately 5 steradians.

Another thermal consideration for an SEC-vidicon integrating TV camera is that the best noise performance of the video preamplifiers can be obtained if they are cooled to about the same extent as the photocathodes, i.e., to approximately -10°C.

VI. LST CAMERA GROUND COMMANDS AND TELEMETRY

Camera Optimizing Ground Commands

The following primary and secondary ground controls for the camera's operating parameters are recommended for optimizing the camera's performance on the LST mission. The primary controls are the Increment and Decrement of the Wall Voltage and the Photocathode Voltage. These primary commands are the functions that have a higher probability of being used if the camera requires optimization. The secondary ground controls, which are envisioned to be used infrequently, are the Increment and Decrement of the Beam Current, the Focus Current, and the Gun Heater Voltage.

The total range for the Wall, Photocathode, Beam Current, and Focus Current adjustments should be 8 bits or 256 levels with the quiescent level being at level 128 (binary 10000000). 6 bits, 64 levels are sufficient for the Gun Heater admustment. Each Increment or Decrement command should step the adjustment by one level. When the camera power is applied, an internally generated reset function should reset each adjustment to its quiescent level; also, a ground command could perform this resetting function.

Table 5 lists the recommended optimizing ground commands, the total adjustment ranges and step sizes.

The adjustment signals for the wall, photocathode,beam, focus current and gun heater should be telemetered back to the ground as an aid in the optimizing process. The accuracy and bandwidth requirements of the adjustment signals are listed later in this section under camera telemetry requirements.

TABLE 5

Camera Optimizing Commands

Commands	Total Adjustment Range	Single Step
1. Wall Voltage Increment	±2.56%	0.02%
2. Wall Voltage Decrement	(±13V typical)	
3. Photocathode Voltage Increment	±8.96%	0.07%
4. Photocathode Voltage Decrement	(±700V typical)	
5. Beam Current Increment	+256 %	2%
6. Beam Current Decrement	-100	
7. Focus Current Increment	±1.024%	0.008%
8. Focus Current Decrement	(±0.8 gauss typical)	
9. Gun Heater Increment	±64%	2%
10. Gun Heater Decrement		

Camera Test Image

The projection upon ground command of a test image onto a photocathode is recommended for camera evaluation and optimization. As a minimum, the projection system should be capable of producing both a uniform field and a resolution test pattern. It is desirable to have the uniform field illumination from the projector to be settable to a level such that several minutes are required to obtain a full exposure on the tube. The illumination level for the resolution test pattern should give one-half of a full exposure for an exposure time of one frame period. The resolution pattern with its one-half full exposure illumination will allow the camera resolution to be more rapidly adjusted in the Continuous Scan Mode. A simple grey scale pattern would also be useful, although exposures of various durations on the uniform field could be used instead.

Camera Operational Ground Commands

To operate the integrating TV camera, eleven operational ground commands are recommended. They are listed in Table 6. The first seven commands are for the camera's sequential operation during astronomical observation. The last four commands are used during telescope focusing and alignment, these commands may also be used during camera optimization adjustments. Commands 10 and 11 are optional commands which will require a tradeoff study. The faster scan rates would yield faster telescope focus and alignment at the expense of some added circuit complexity and added power dissipation in the camera electronics, mainly in the deflection amplifiers.

During the sequential operation the camera is cycled through five modes. They are: PREPARE, EXPOSE, HOLD, READY AND READOUT. The sequential operation employed is safe because the scanning beam is off when the photocathode is operating. There are no scanning electrons to generate secondaries at the scanned surface even if a portion of the target is being overexposed by photoelectrons. The field mesh behind the target is kept at zero potential during

TABLE 6

TV Camera Operational Commands:

1. PREPARE ....P
2. EXPOSE ....EX
3. HOLD ....H
4. READY ....RY
5. READOUT ....RD
6. HEATER ON ....HØN
7. HEATER OFF ....HØFF
8. CONTINUOUS SCAN, LOW MESH ....CSN
9. CONTINUOUS SCAN, HIGH MESH ....CSNHI
10. FAST CONTINUOUS SCAN, LOW MESH .....FCSN
11. FAST CONTINUOUS SCAN, HIGH MESH ....FCSNHI

exposure, so that secondaries generated by primary photoelectrons cannot cause charging of the exit surface.

The positive charging of a SEC target on the scanned surface by secondary electron emission during scanning is called "crossover". If allowed to continue with field mesh voltages much above 100 volts, the scanned surface of the target can rise to a potential sufficient to destroy the target layer.

The PREPARE mode is a sequence of operating states for the dual purpose of erasing any residual image, including buried charge patterns within the target layer, and establishing the proper target conditions for the following exposure. Table 7 shows the steps used during a prepare cycle.

During the EXPOSE mode the photocathode and image section voltages are ON, integrating the incoming image into the storage target. The field mesh voltage is ZERO, which limits the maximum target voltage excursion to the target bias level.

After an exposure the tube can be put into the HOLD mode where the photocathode and image section are OFF, the reading electron gun is OFF, and the field mesh voltage is low. The integrated image stored in the target will not degrade perceptibly after as many as 50 hours of storage. This mode is a safe standby mode.

The READY mode is the mode used prior to readout, to allow time for the wall, mesh, and target electrodes to be switched and to settle to their readout levels.

During the READOUT mode the stored image is scanned out by the reading section's electron gun. During READOUT the photocathode voltage is OFF. It is safe to have a high field mesh potential during READOUT. The resultant high reading beam decelerating field contributes greatly to the high MTF and low beam pulling characteristics of current SEC-vidicon tubes.

Another requirement of sequential tube operation is that of "target pulsing". This is a procedure in which the target bias voltage is raised approximately 0.2 volts above that used for the final PREPARE step and for the EXPOSE mode. If this were not done, the scanning electron beam would fail to land properly on those areas of the target that have received little or no exposure. The "target pulsing" bias voltage insures that the scanning beam will land even in those portions of the target where the exposure was zero. Although "target pulsing" insures that threshold level signals will not be compressed or lost in the readout process, it does give the video signal a non-zero black or "zero exposure" level.

The tube's electron gun heater may be commanded ON or OFF via the HEATER ON and HEATER OFF commands. This flexibility allows the heater to be turned off during long exposure thus eliminating the possibility of background signal caused by light from the heater reaching the photocathode.

The CONTINUOUS SCAN modes are used to align and focus the telescope and camera systems. The low mesh mode is a safe operating mode where the target cannot "crossover" and be damaged. In all the CONTINUOUS SCAN modes the photocathode image section and gun section are both simultaneously ON. When operating in the HIGH MESH mode, care must be observed that the exposure is not so great as to cause the target to "crossover". The camera should contain circuitry that automatically detects the absence of a crossover condition before allowing the mesh to switch to or remain at its high level while in the CONTINUOUS SCAN modes. The crossover detector output should be a telemetered signal. Also, the camera logic should be such that while the telescope is being slewed the camera will not be allowed to go into a high mesh condition.

The FAST CONTINUOUS SCAN modes are sixteen times faster than the normal scan rates, thus being helpful for rapid optimizing of some of the telescope and camera parameters.

Table 7 is the Camera Sequence Truth Table for the Camera Sequences that are used on Princeton's ground based observing camera, and on the Stratoscope and Sounding Rocket Integrating Television Camera Systems. The table lists the functional sequence of the camera's operation in its various modes.

Camera Telemetry Requirements

Table 8 lists the telemetry channels recommended for monitoring the TV camera. These channels will provide camera status, verification of commands and housekeeping data required to evaluate the camera performance. Table 8 indicates the minimum allowable channel signal to noise ratio and minimum bandwidth. All channels are dc coupled with the dc error included within the noise limits.

Automation of On-board Testing and Optimization

The extent of automatic on-board testing and optimization of the television sensors on the LST that is desirable requires some consideration.

Based on the experience at Princeton in using SEC-vidicons for ground based observations one is inclined to separate the topics of testing and optimization. This is because once an SEC-vidicon has been optimized with a given set of parameters they have not required reoptimization. Of course, the operating life and reliability requirements are more severe on the LST than in a ground based observing program. For example, it is only prudent that in the LST mission, that means be provided to adjust the gun heater voltage to offset long term aging or wearout effects in the gun cathode.

TABLE 7, CAMERA SEQUENCE TRUTH TABLE

MODES	BEAM	HEATER	PHOTO-CATHODE	SCAN SIZE	SCAN RATE	TARGET	MESH	ERASE LIGHTS
PREPARE I FRAMES		ON 2 MIN. PRIOR						
0-4	ON	ON	ON	OVER	NORMAL	PREPARE	LOW	ON
5	ON	ON	OFF	OVER	NORMAL	PREPARE	LOW	OFF
6	ON	ON	OFF	NORMAL	NORMAL	PREPARE	LOW	OFF
7	OFF	ON	OFF	NORMAL	NORMAL	NORMAL	HIGH	OFF
8-11	ON	ON	OFF	NORMAL	NORMAL	NORMAL	HIGH	OFF
RETURN TO HOLD	OFF	OPTIONAL	OFF	ZERO	NORMAL	NORMAL	LOW	OFF
EXPOSURE	OFF	OPTIONAL	ON	ZERO	NORMAL	NORMAL	ZERO	OFF
HOLD	OFF	OPTIONAL	OFF	ZERO	NORMAL	NORMAL	LOW	OFF
READY	OFF	ON 2 MIN. PRIOR	OFF	NORMAL	NORMAL	PULSED	HIGH	OFF
READOUT (REQUIRES 10 SEC. OF READY PRIOR TO READOUT)	ON	ON	OFF	NORMAL	NORMAL	PULSED	HIGH	OFF
CONTINUOUS SCAN LOW	ON	ON 2 MIN. PRIOR	ON	NORMAL	NORMAL	NORMAL	LOW	OFF
CONTINUOUS SCAN HIGH	ON	ON 2 MIN. PRIOR	ON	NORMAL	NORMAL	NORMAL	HIGH	OFF
FAST CONT. SCAN LOW	ON HIGH	ON 2 MIN. PRIOR	ON	OVER	FAST (16 TIMES FASTER)	NORMAL	LOW	OFF
FAST CONT. SCAN HIGH	ON HIGH	ON 2 MIN. PRIOR	ON	OVER	FAST	NORMAL	HIGH	OFF

TABLE 8

Recommended Telemetry Channels

Channel	Minimum Signal/Noise	Minimum Bandwidth (Hz)
1. Mesh Voltage	1000:1	1
2. Wall Voltage	1000:1	1
3. Photocathode Voltage	1000:1	1
4. Target Voltage	1000:1	1
5. Focus Current	1000:1	1
6. Beam Current	50:1	100
7. Heater Current	50:1	1
8. Photocathode Power Supply Current	50:1	100
9. Deflection Line Current	50:1	100
10. Deflection Frame Current	50:1	100
11. Erase Lamp Current	25:1	1
12. Sequence Status	100:1	100
13. Input Voltage	100:1	1
14. Input Current	100:1	1
15. Wall Voltage Adjustment	100:1	1
16. Photocathode Voltage Admustment	100:1	1
17. Beam Current Adjustment	100:1	1
18. Focus Current Adjustment	100:1	1
19. Heater Voltage Adjustment	50:1	1
20. Photocathode Temperature	50:1	1
21. Preamplifier Temperature	50:1	1
22. Electronic Temperature	50:1	1
23. Crossover Detector	25:1	10

Changes in the environment of the ground based cameras have required the readjustment of the focus parameters. One example was the image section magnetic focus shift induced when the camera was installed on a spectrograph with substantial steel structural parts. A comparable situation may well exist in the LST mission if it proves impractical to fully shield the tube from external axial field variations. In this case, an automatic means of compensating for the external field changes would be highly desirable.

Another form of automatic optimization that should be part of the electronic design of the camera is to have a beam current regulator that adjusts the gun bias (G1 voltage) to maintain the proper beam current in the face of aging induced drifts in the gun emission characteristics.

Aside from the two areas mentioned above, and the intrinsic automatic adjustments internal to the camera electronics, such as closed loop regulation of wall voltage, focus current, etc; it appears that automatic optimization of tube performance would not be justified considering the very infrequent need for optimization and the complexity that such automation would entail.

On the other hand, automatic and fairly frequent (perhaps daily) On-board Automatic Testing of tube performance is clearly a necessary feature. Frequent, because LST observing time will be too valuable to risk operating with a sensor which has gone out of adjustment without the user's knowledge. Automatic, because the testing must be done quickly to minimize non-productive time (although such tests can probably be scheduled in periods not suitable for observing); and because the testing is a tedious routine series of tests and measurements that can be readily automated. One can envision a software controlled sequence where the test image projector is energized, a television exposure made, and the spatial frequency response measured in the output video signal.

Whether the video signal is analyzed on-board or on the ground is an LST system engineering question. To permit the testing to go on when ground contact is not available seems to be a strong argument for on-board evaluation of the video (via tracking filters, etc.), with only the results telemetered down when convenient.

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