NASA CR 160029

# CIRCULAR SCAN STREAK TUBE DEVELOPMENT

Scott Nevin

ITT Electro-Optical Products Division
3700 East Pontiac Street
Fort Wayne, Indiana 16803

July 1980

Final Technical Report for Period May 1976 - March 1979

(NASA-CR-160029) CIRCULAR SCAN STREAK TUBE DEVELOPMENT Final Technical Report, May 1976 - Mar. 1979 (ITT Electro-Optical Products Div., Fort) 48 p HC A03/MF A01 CSCL 20F G3/74

N80-33211

Unclas 34114

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

## Preface

A continuously operating streak tube with 10 picosecond temporal resolution is the design goal of this development. An annular array of silicon diodes continuously scanned by an electron beam was the basic design investigated. Initial tubes having directly bombarded arrays had both reliability and resolution difficulties. A modular design in which the scanning beam information was converted to an optical signal by a phosphor, and this signal fed to the array by fiber optic couplers was shown to be free of array degradation problems, and to have useful resolution. The electron gain of the original bombarded array design was obtained by use of a microchannel plate in the CRT section of the modular design.

Circular scan streak tubes having single microchannel plates and fiber optic coupled arrays had measured time resoutions of 35 ps FWHM. The 200 MHz deflection power was 5 watts.

Higher electron optical resolution of the scanning beam and additional microchannel plate gain to achieve single photoelectron detection capability are recommended.

TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF TABLES

## 1.0 Introduction

For several applications NASA has identified a need for a detector system that will allow measurements of baselines megameters in length with an accuracy of 10-20 mm. For baselines this long and present laser pulse energy capabilities in the visible wavelength range, the prime detector of the return pulse must be sensitive enough to detect single photons. Furthermore, since laser ranging with a length accuracy of less than $\Delta \ell$ requires the measurement of optical pulsewidths of duration

$$\Delta t = 2\, \Delta \ell / c,$$

where c is the velocity of light, the prime detector must resolve 67 ps pulses for a 10 mm accuracy. The time-resolution goal of this prime detector development effort is 10 ps accuracy, so that the overall system performance will not be compromised by the prime detector itself.

Solid state detectors and photomultiplier tubes cannot now achieve this time resolution. In fact, only so-called "streak tubes" can be considered for use as the prime detector for this type of laser ranging system. The straightforward approach of this project is to develop a photon-counting video-signal output streak-tube which is synchronously scanned at 200 MHz rate so that the total number of cycles is counted, with an electronic counter, to determine the gross range, while the laser pulsewidth centroids (probe and return) allow vernier measurement of the pulse separation with an accurance of ± 10 ps. A streak-tube of this type has not, to our knowledge, been built or described in the literature.

The key functional elements of the circular-scan streak tube are shown schematically in Figure 1.1. The principle-of-operation is as follows:

Light pulse strikes the cathode in a small spot,

Electrons are released from the cathode in all directions from the spot,

Electrons are rapidly accelerated to high velocity,

Electron lens focuses the electrons onto a microchannel plate (MCP),

Two sets of deflection plates deflect the electron beam in a circular path,

The MCP produces a gain of 1E3*,

Electrons from the MCP are accelerated to high velocity and impinge on the self-scanned array (SSA),

A gain of ∿500 is achieved in the SSA before storage and readout,

Sequential readout of the individual SSA elements, and

Time-of-flight of reflected light pulse determined for range calibration.

*(The computer notation xEy ≡ $x \cdot 10^y$ is used here)

000 042

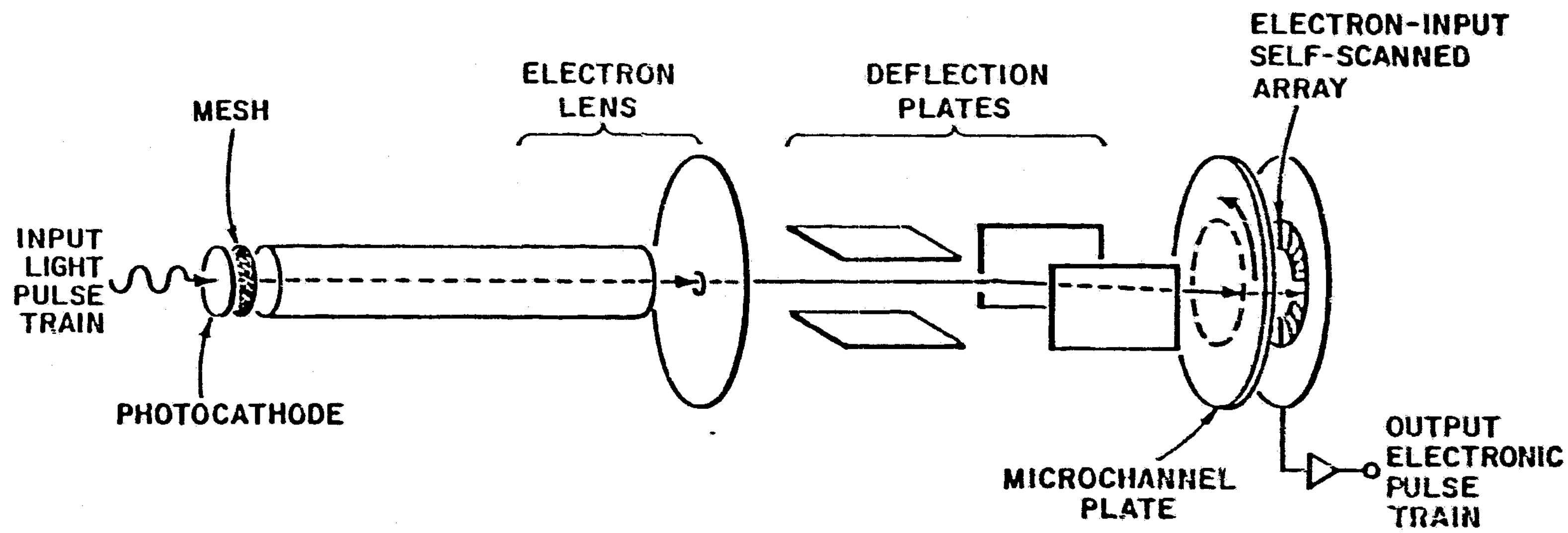



Figure 1.1 Schematic Diagram of Circular Scan Streak Tube With Self-Scanned Array Readout

In one possible mode of operation of the CSST in a laser ranging system, Figure 1.2, a 200 MHz deflection circuit will produce a continuous circular-scan of signal electrons across the output face of the CSST. A small portion of the emitted laser pulse is used to gate the counter circuit on and is also reflected into the CSST, causing registration of the output laser pulse waveform on the readout array. During the time between probe-pulse emission and return-pulse receipt the total integral number of 5 ns time periods is counted. Then the return-pulse optical signal is registered on the readout array. Finally, the total laser pulse transit time is determined by adding the time difference between the output pulse and the first full 5 ns period counted to the time given by 5 ns times the number of counted periods, and then adding to this the time between the last full 5 ns period counted and the return pulse. The range is then found from this transit time measurement. Thus, the CSST acts as a vernier detector for achieving a range measurement accuracy of about 3 mm. The CSST also provides an optical waveform digitization capability for more complex receiver tasks at frequencies in excess of 10 GHz.

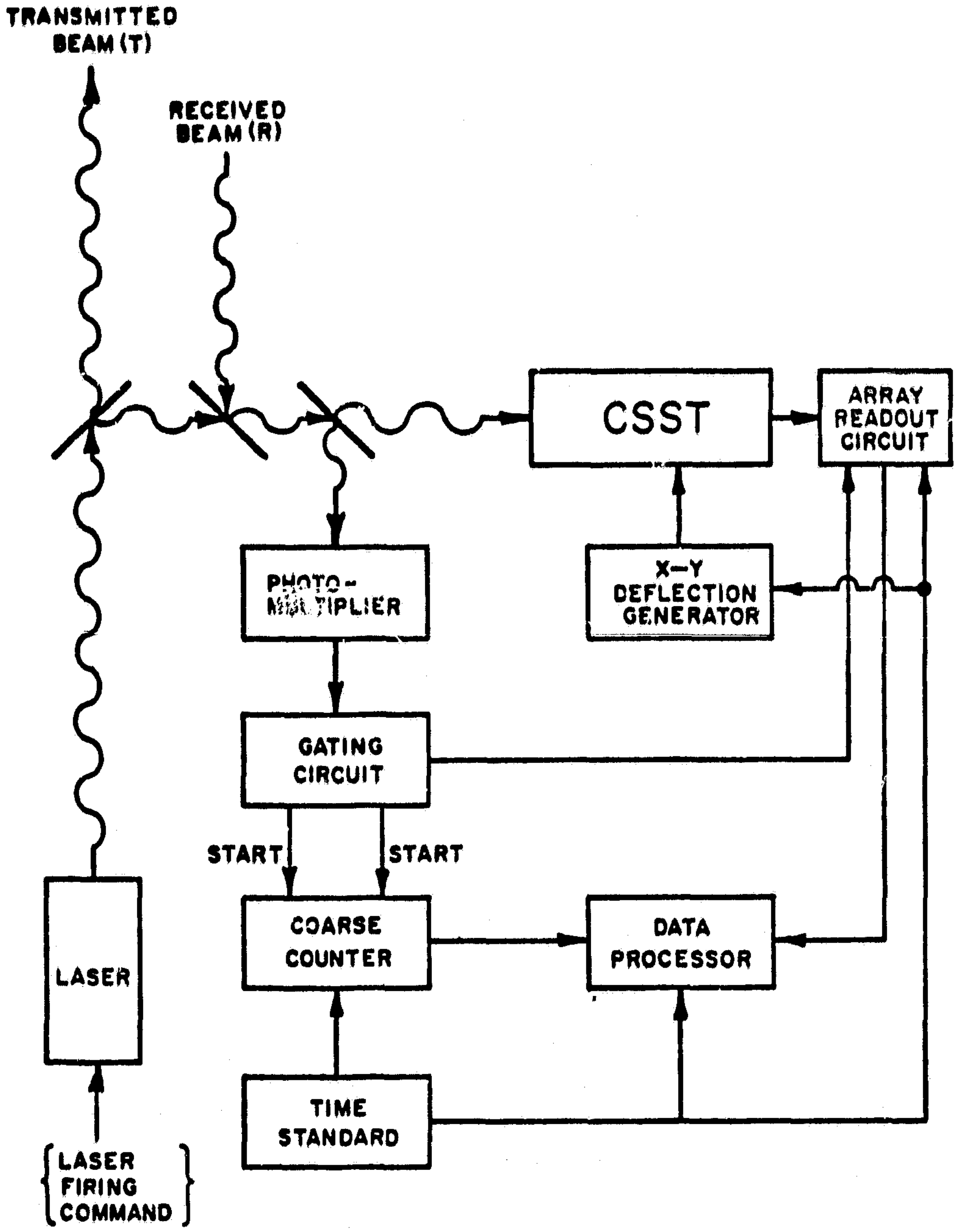



Figure 1.2 Block Diagram of a Laser Rangefinder With Self-Scanned Array Readout

The Circular-Scan Streak-Tube Development, Interim Report of November, 1978, discussed the CSST electron optics, the 720 element array (Figure 1.3) and the deflection circuits.

The Type RO-720 arrays gave variable results, sometimes surviving high temperature vacuum bakes and sometimes failing. No array was operational after the vacuum bake and photocathode processing cycle. Consequently, only phosphor output tubes were obtained as testable devices.

The array problems were probably inherent in the materials subjected to high temperature, long time bakes. The thin protective oxide and the handling required during tube assembly undoubtedly also contributed to the failure of some arrays.

A design that eliminates baking the array, or subjecting it to alkali vapors, is to fiber optically couple the array to the phosphor of a modular type of CSST as shown in Figure 1.4.

A question that arises is the resolution of this design. The modulation transfer function (MTF) of discrete array devices, such as microchannel plates, fiber optics, or solid state arrays, is not as cleanly handled by mathematical analysis as it is for "continuous" devices such as lenses and film. Discrete device MTFs are not single valued, and large variations in the measured MTF data of a fiber optic plate are reported in the literature[1]; Figure 1.5 might be considered typical. But Drougard[2] has shown that the measurements using a long (compared to the fiber optic channel diameter) slit gives an unambiguous MTF that is useful for many imaging applications. This situation probably applies to the CSST whose detector array elements are about 16 channel diameters in length.

| RETICON NO. RO-720 PARAMETERS | |
|---|---|
| DIODE BIAS POTENTIAL | 5V |
| DIODE CIRCLE MINIMUM RADIUS | 3.44mm |
| DIODE RADIAL LENGTH | 250$\mu$m |
| DIODE WIDTH | 20$\mu$m |
| DIODE CENTER/CENTER SPACING | 30$\mu$m |
| SENSITIVITY UNIFORMITY | ±15% |
| SATURATION CHARGE | 4.5pC |
| DYNAMIC RANGE (RATIO OF SATURATION SIGNAL TO PEAK FIXED PATTERN NOISE) | 300 |

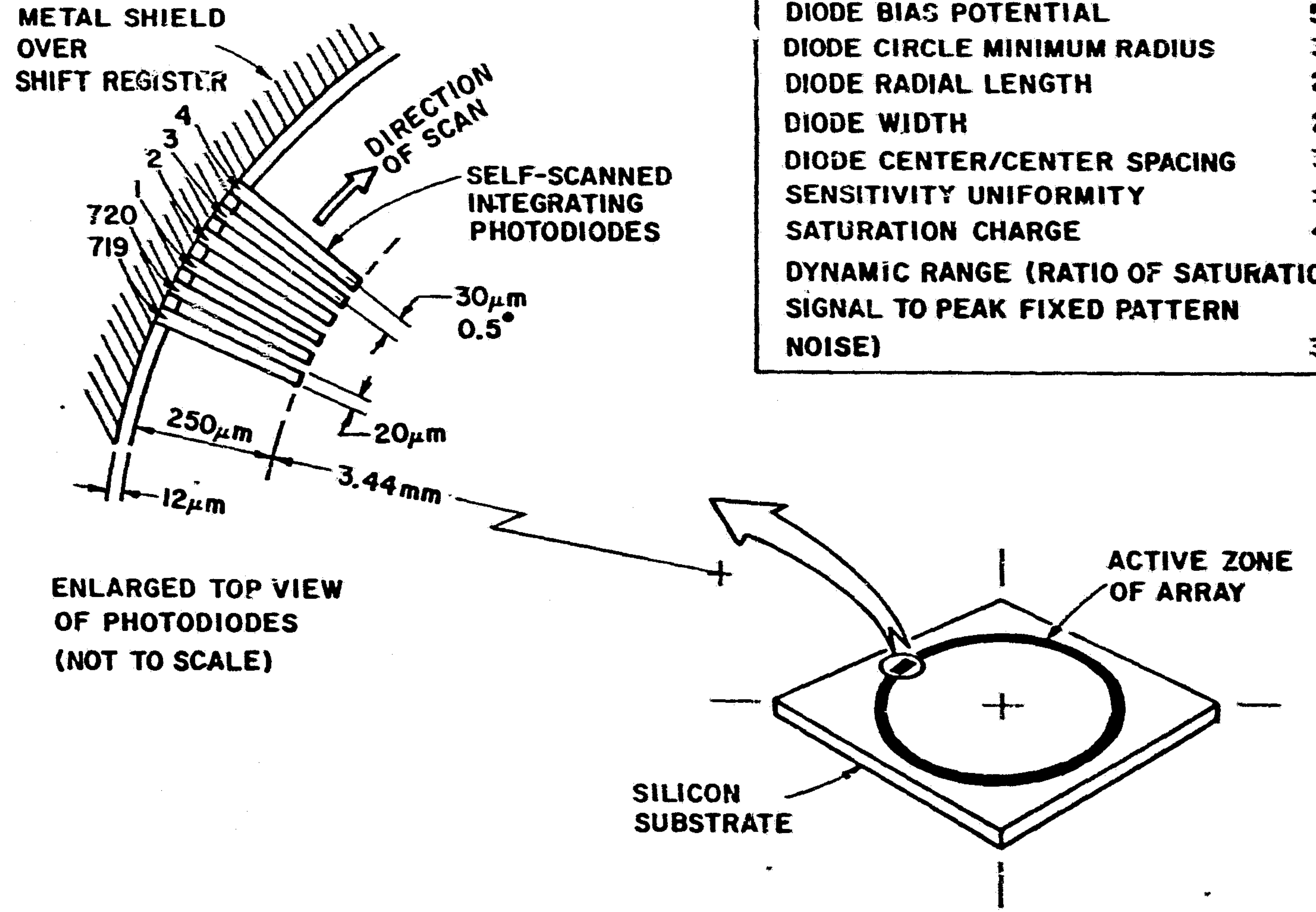



Figure 1.3 Layout of Pixels on the Reticon Model RO-720 Circular Photodiode Array

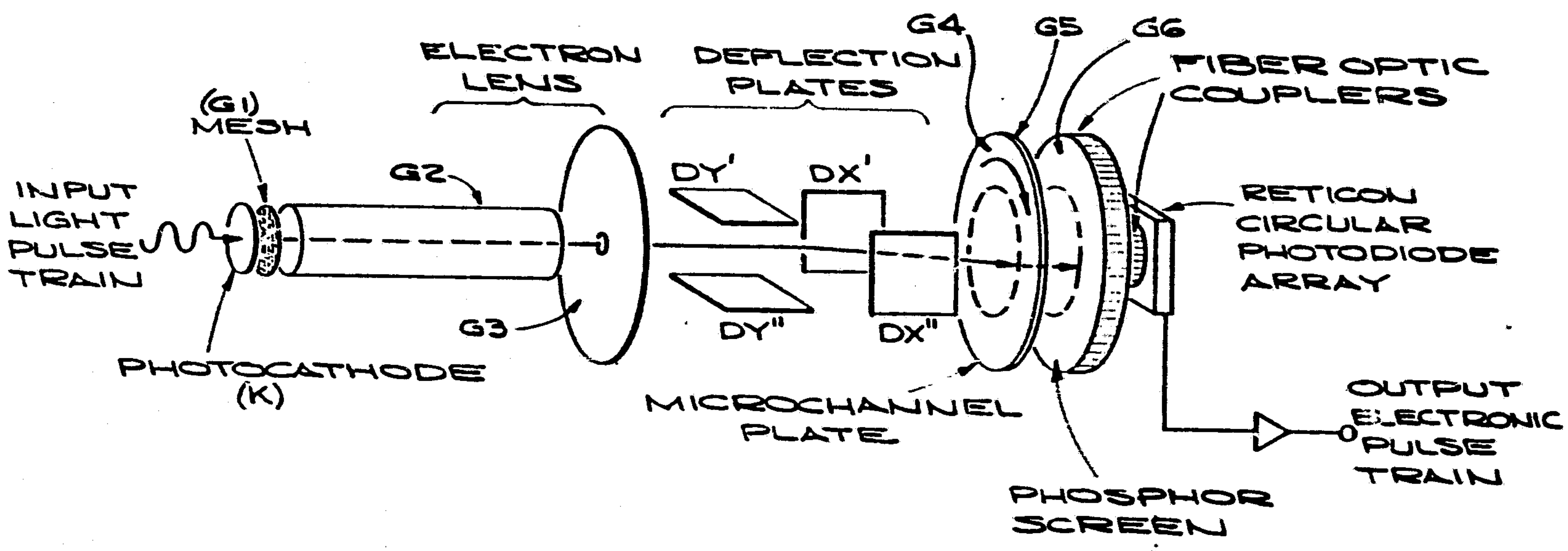



Figure 1.4 Phosphor-Fiberoptic Coupled Array
Modular Circular Scan Streak Tube

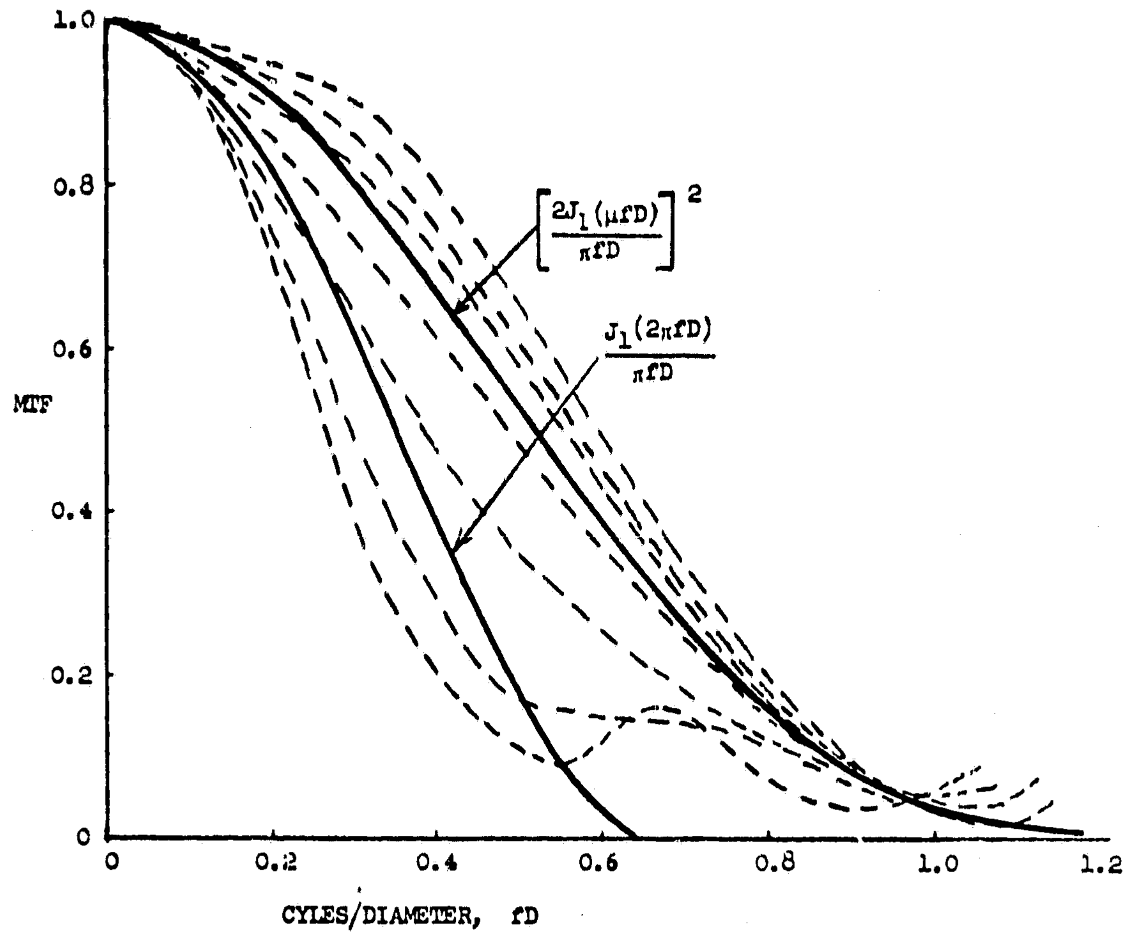



Figure 1.5 Measured Variation in MTF Taken at Different Positions on a Coherent Fiber Bundle (After Allan)

Drougard's equation for this long slit MTF is

$$M\ (f)_b = [2J_1\ (\pi fD)/\pi fD]^2 \tag{1}$$

where $J_1(\pi fD)$ is the Bessel function of the first kind of argument $\pi fD$.

Eberhardt has shown (ITT Technical Note 126) that Drougard's equation is closely approximated by the Gaussian

$$M\ (f)_G = \exp\ (-10f^2D^2/3) \tag{2}$$

The Gaussian approximation is somewhat more conservative (lower amplitude) than the Bessel function expression. The Gaussian MTF gives the associated line spread and point spread functions

$$L\ (x)_G = L\ (0)\ \exp\ (-3x^2/D^2) \tag{3}$$

$$P\ (r)_G = P(0)\ \exp\ (-3r^2/D^2) \tag{4}$$

where L (0) and P (0) are the peak image intensities at the center of the line and point images respectively, and r is the radial displacement from the center of the point image.

A further advantage of the Gaussian formulation is that it gives a cascaded resolution of devices that is described by the simple equation

$$f_c = [f_1^{-2} + f_2^{-2} + f_3^{-2} + \ldots.]^{-\frac{1}{2}} \tag{5}$$

where $f_n$ is the resolution of the $n^{th}$ device and $f_c$ is the resulting resolution of the cascaded assembly.

Note that all the resolution values must be at the same modulation ration (e.g. 4%).

One can predict the tube resolution as follows. The test tubes having the electron gun (cathode thru deflection plates) impinging on a phosphor had a measured resolution (Table 2.2, Interim Report)of 18 lp/mm. Measured resolution of a conventional proximity focused microchannel plate tube is 22 lp/mm. Combining the 18 lp/mm and 22 lp/mm using equation(5), gives 13.9 lp/mm as the projected resolution delivered to the Reticon array. The combined tube and array resolution (30 μm spacing, 33 lp/mm resolution) predicted is 12.8 lp/mm.

This resolution borders on the minimum acceptable, but the practical aspects of this modular approach led to some tests at ITT after the inital contract was completed, made by coupling a 720 array to an existing phosphor-on-fiber-optic output test CSST.

Using a fiber optic attached to a Reticon 720 array, the line spread of a 25 μm diameter spot imaged ontc this assembly was measured, Figure 1.6. Then a similar measurement was made when the fiberoptic/array was coupled to an early CSST test tube (that had only 5 lp/mm resolution). The resulting line spread function, Figure 1.7 was encouraging.

A calculation of the assembly's transfer characteristic showed that 10 electrons from the photocathode might develop a charge packet of 1E5e per pixel, about 1/300 the array's dynamic range.

Based on the data above, NASA authorized a contract extension and modification to build and evaluate a modular CSST. The following sections discuss the phosphor output Circular Scan Streak Tubes fiber optically coupled to a circular array, their assembly and evaluation.

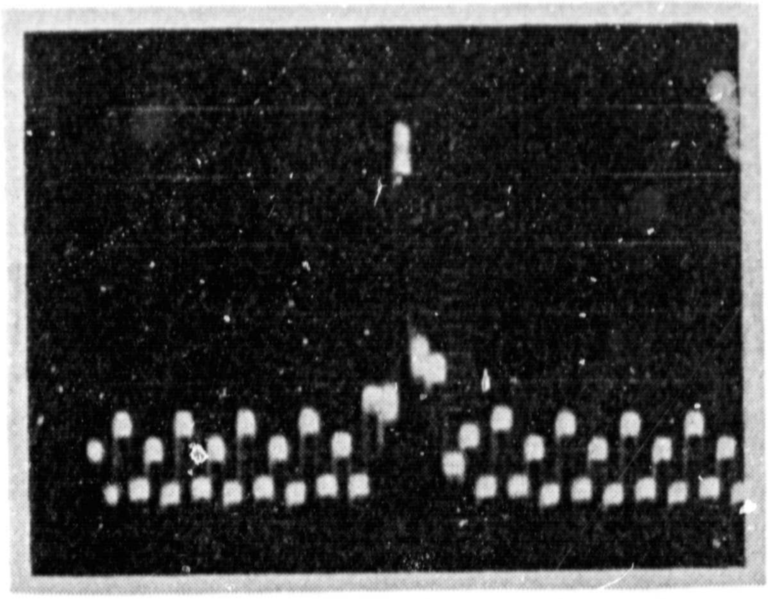


Figure 1.6 Measured Line Spread Function of 25μm Diameter Optical Spot Imaged Onto Fiber Optic (6μm c/c) Coupled to RO-720 Array

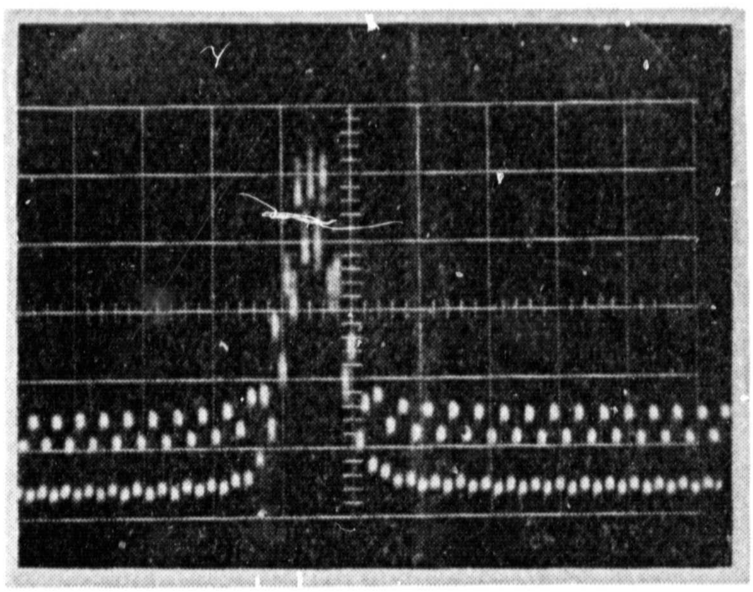


Figure 1.7 Measured Line Spread Function of 25μm Diameter Optical Spot Imaged Ontc CSST #077701 Having Fiber Optic RO-720 Array Readout

## 2.0 Design Considerations

The Appendix reviews the design criteria that established the 720 array elements on a 7.125 mm diameter circle. Therein the overall electron-optical resolution was assumed to be 40 lp/mm, an optimistic value. Measured microchannel plate image tubes (proximity focused from photocathode to MCP and from MCP to phosphor) are typically 22 lp/mm. The CSST's electron gun (CRT type) resolution (without MCP) was measured as 18 lp/mm (Interim Report, Table 2.3). The combined sections can be calculated to have 13.9 lp/mm resolution.

Using the equations of the Appendix one calculates the limiting temporal resolution (Reticon 720 array, 200 MHz sweep frequency, 50 μm input spot) as tabulated below.

Table 2.1

Temporal Resolution vs E.O. Resolution for 30μm Array Pixels

| | | | | |
|---|---|---|---|---|
| Electron Optical Resolution ($f_\ell$), lp/mm | 10 | 15 | 20 | 30 |
| Limiting Temporal Resolution (T), ps | 29 | 22 | 19 | 17 |

One can see that it is desirable to hold the electron optical resolution at or above 20 lp/mm, and that at 10 lp/mm there is a 50% decrease in temporal resolution.

The modular assembly, of course, loses the 500x gain obtained in the electron bombarded array. A fiber optic coupled assembly has about 55x gain from the phosphor bombardment, but subsequent coupling losses reduce this to 15x, perhaps only 10x depending on the matching factor between the phosphors spectral output and the Reticon array's spectral sensitivity. (Fiber optic transmission and coupling losses are included in these figures.) The 500 gain of the electron bombarded array can be made up by the 10x gain of the optically coupled array, and 50x additional gain from MCP. Thus a total MCP gain of 50,000 is needed.

Three MCP options were considered:

(1) a cascade of standard plates--such as a V-MCP plate assembly,

(2) a "saturable microchannel plate", SMCP, built by Galileo Electro-Optics Corp.,

(3) a single MCP

Because the existing V-plate assemblies and the Galileo SMCP seemed to be of low resolution, the single MCP was chosen to demonstrate the design concept validity.

## 2.1 Modular CSST

### 2.1.1 Tube Design

The proposed tube design was to build the fiber optic/phosphor output version CSST (4725189-1), replacing the 40 mm diameter conventional microchannel plate with a 25 mm diamter micro-channel plate. The spacing between MCP output surface and phosphor would be that of a standard MCP image tube, .050", rather than the approximately 5 mm used in the earlier array output tubes.

The actual resolution obtained for the 5 mm MCP-to-phosphor tube (#077701 of the earlier program) was 5 lp/mm, versus a projected value of 10.5 lp/mm. The close spaced, low voltage (6 kV) image section of the modular CSST was projected to have a resolution (into the array) of 15.6 lp/mm, a considerable improvement.

### 2.1.2 Mechanical Improvements Incorporated

The earlier glass envelope CSST (4725180-1), Figure 2.1, had poor internal alignment and was difficult to assemble. A

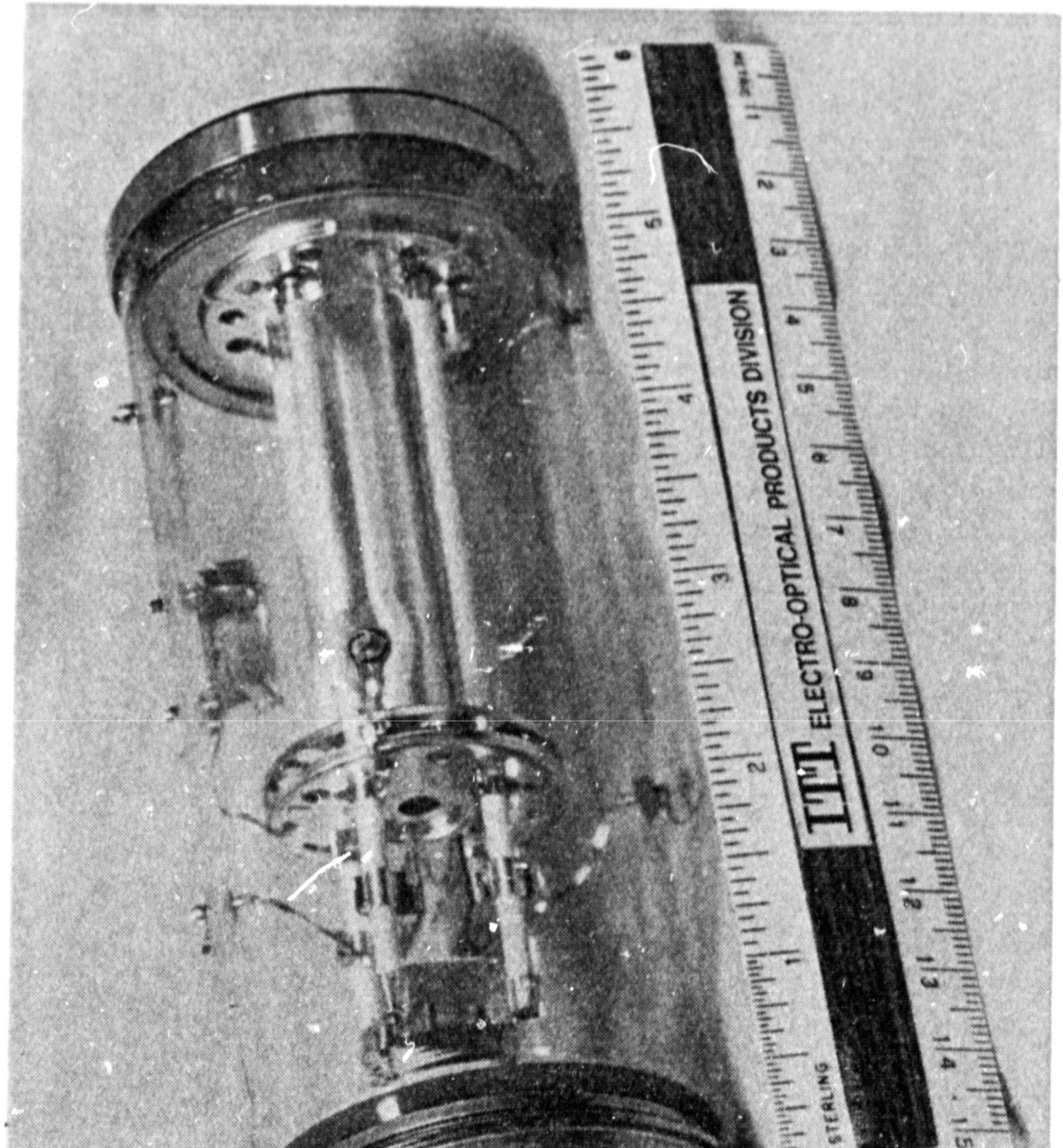



Figure 2.1 Photograph of the First Test CSST (#250177)

review of the tube assembly costs and yields lead to the conclusion that it would be wise to redesign the tube assembly, particularly since 25 mm diameter parts could be used throughout rather than 40 mm diameter parts.

Accordingly, a mostly ceramic and metal body with a gun that could be fixtured from the envelope was designed. Tooling and parts, Figures 2.2., 2.3, and 2.4, were made. The image section was a 25 mm MCP image tube with its input ring modified so attachment could be made to the gun envelope. The design dimensions are shown in Figures 2.5 and 2.6.

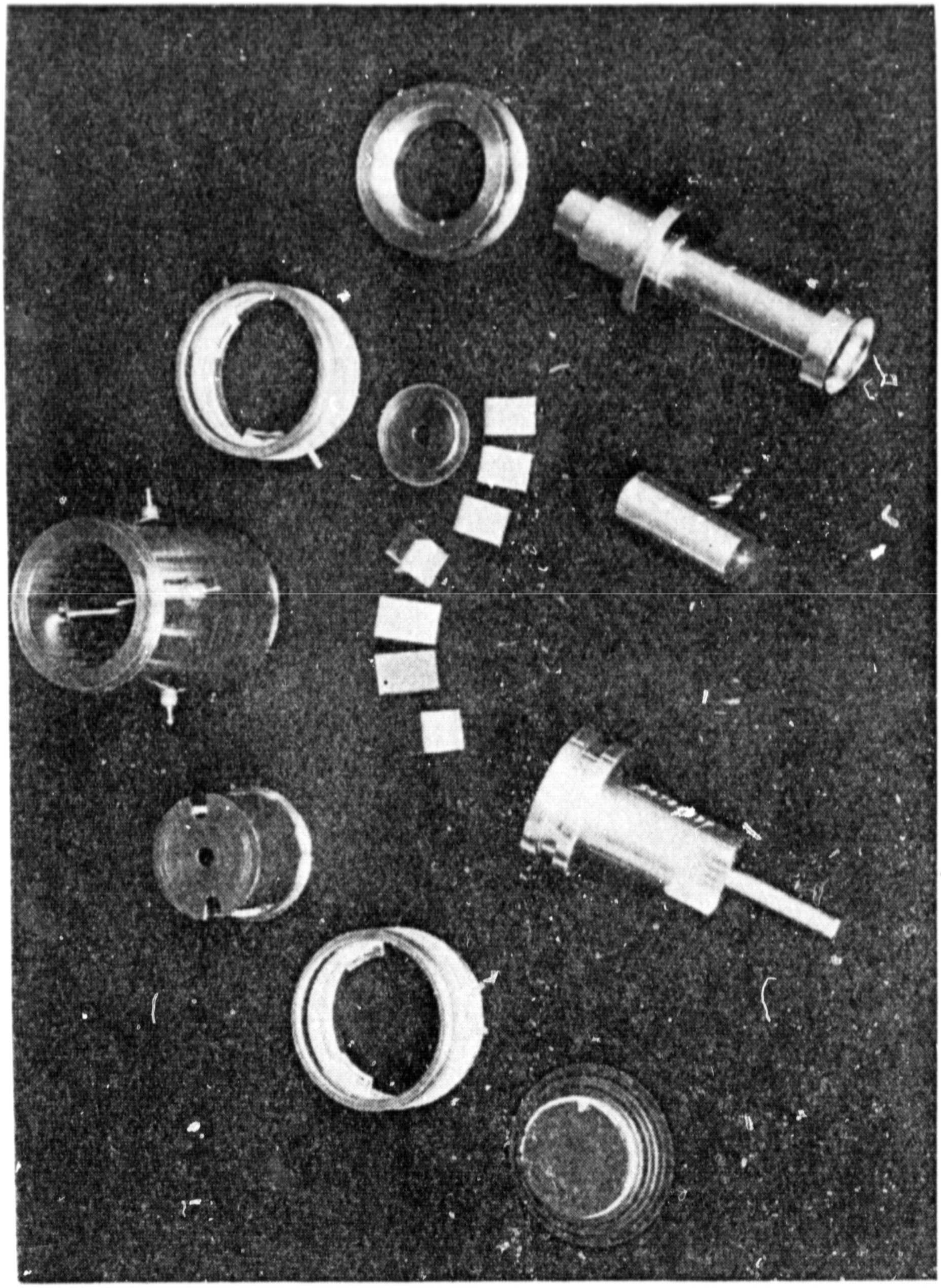


Figure 2.2 CSST Parts and Fixtures

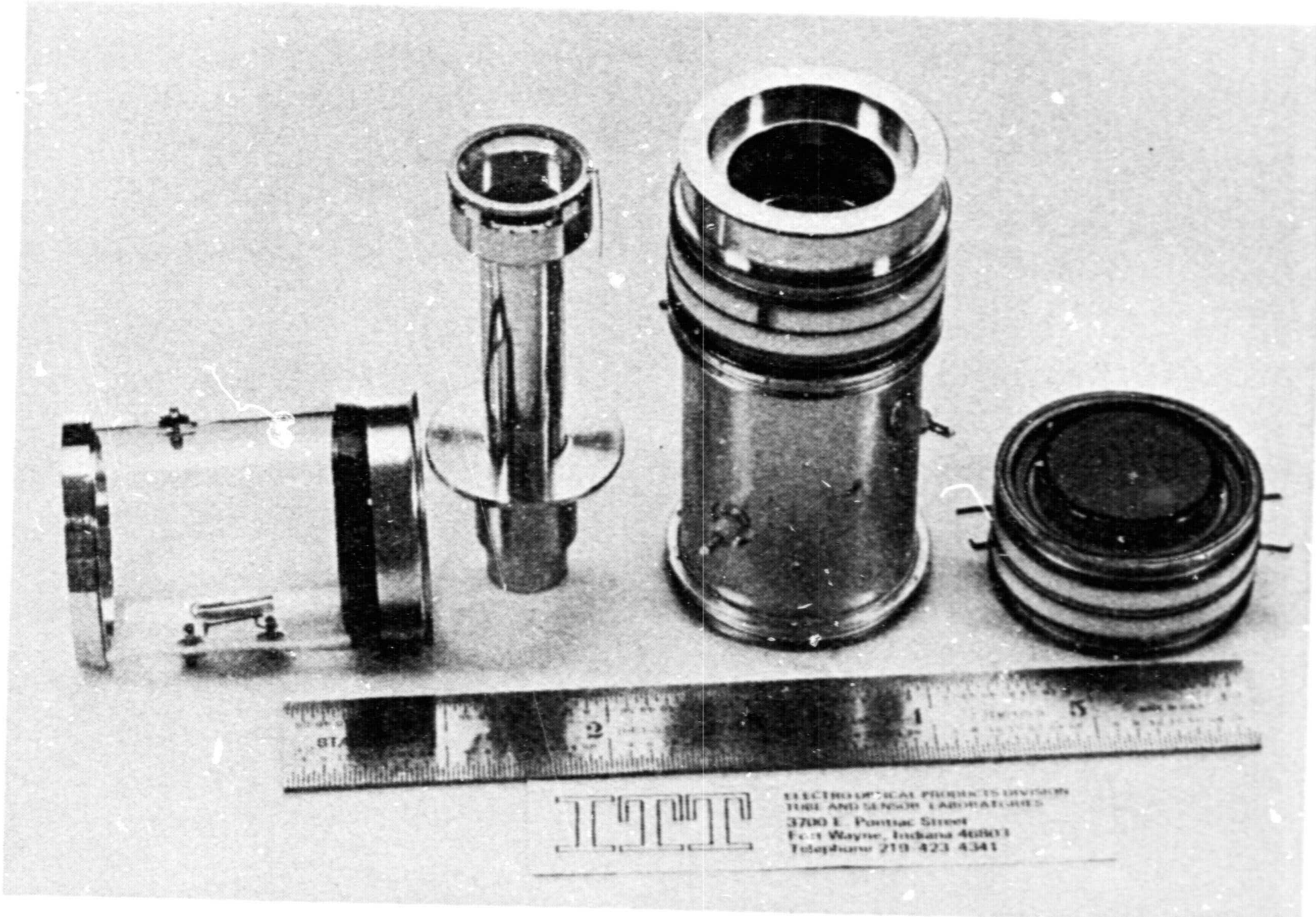



Figure 2.3 CSST Sub-assemblies

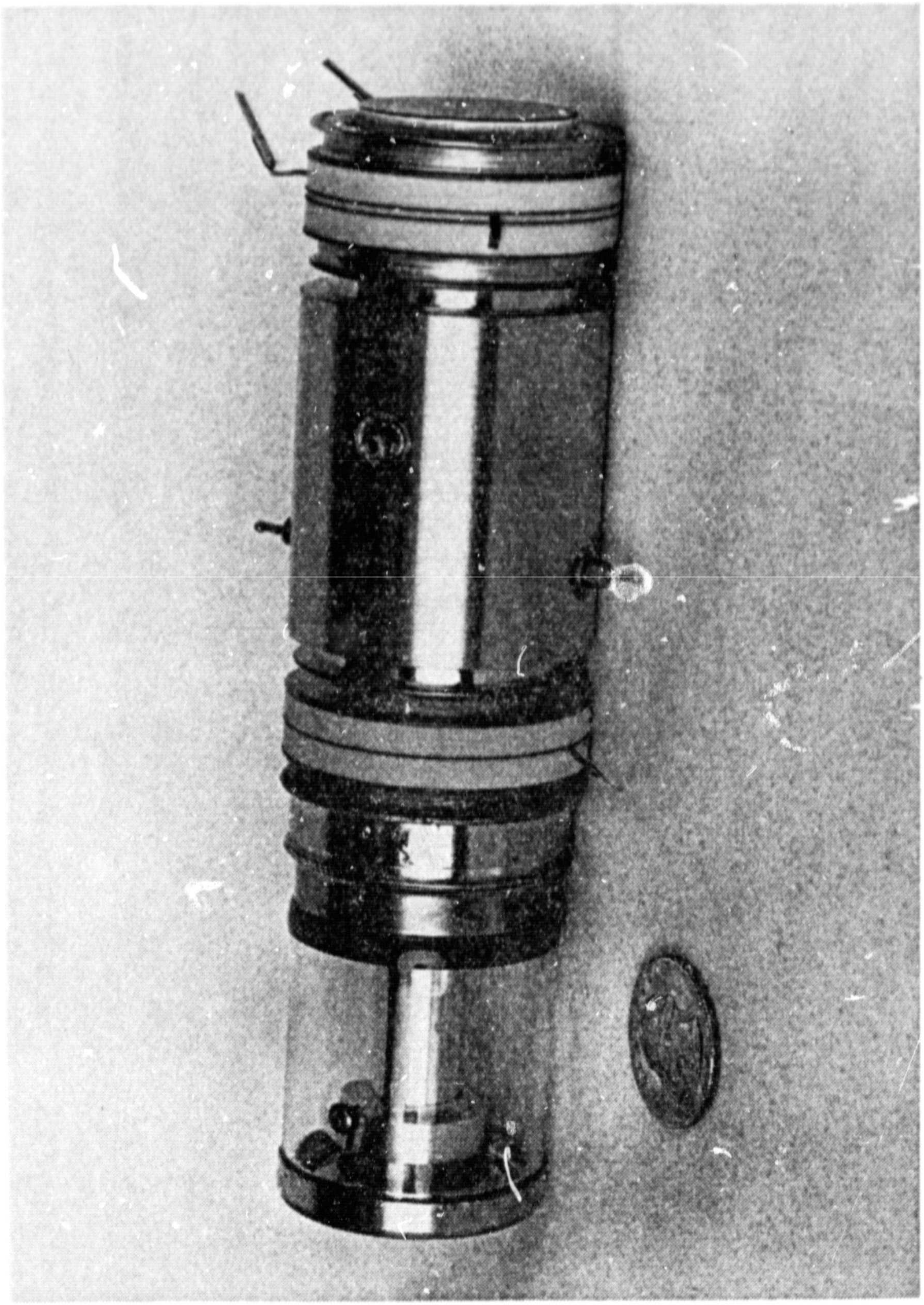


Figure 2.4 Circular Scan Streak Tube, Phosphor Output

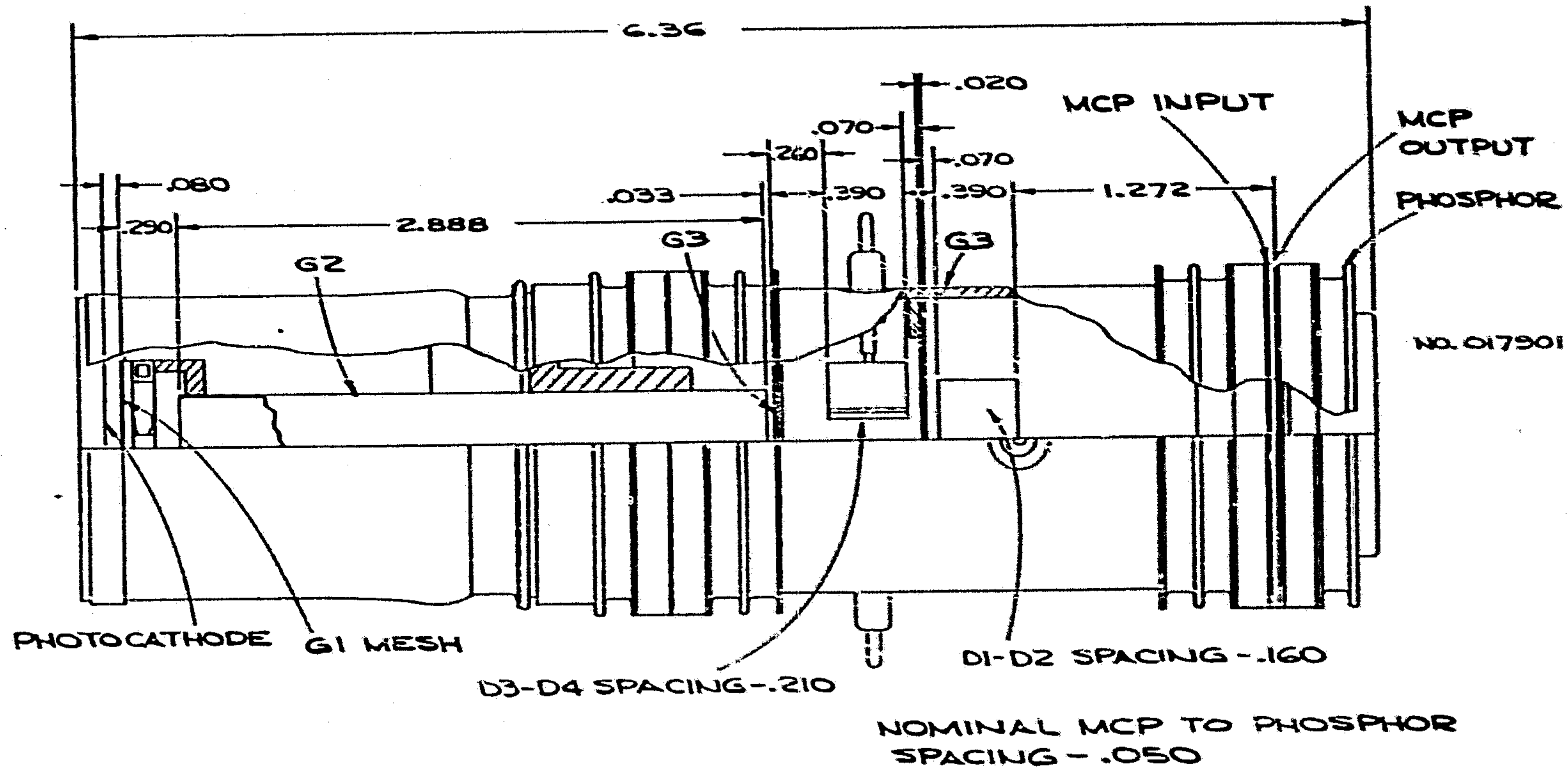



Figure 2.5 ELECTRODE MECHANICAL SPACINGS CIRCULAR SCAN STREAK TUBE

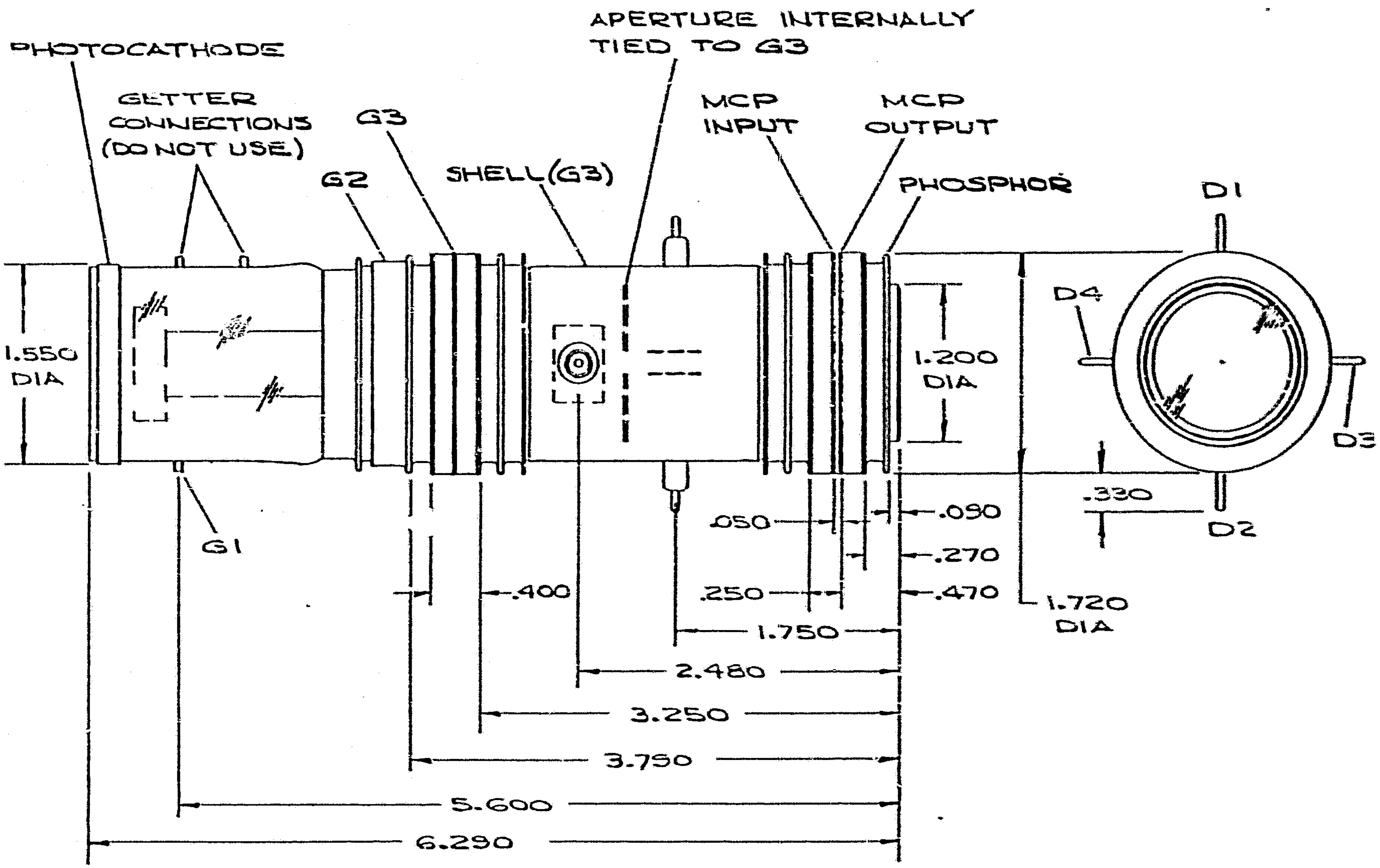



Figure 2.6 CSST OUTLINE DRAWING

## 3.0 Tubes Assembled and Tested

A summary of the tubes (Figure 2.5) assembled is shown below.

TABLE 3.1

| Tube No. | Status | Notes |
|---|---|---|
| 127801 | Leak at braze | Mechanical sample to NASA 2/14/79 |
| 017901 | Good tube | Potted - to NASA 3/15/79 |
| 027901 | Heliarc weld leak | Rewelded, reprocessed |
| 027901A | Good tube | Potted - to NASA 4/17/79 |
| 027902 | Broken | Broken when sealing |
| 037901 | Leaker | Leak at frit seal |
| 037902 | Broken fiber optic | Optic cracked at heliarc |

Despite the use of conventional 25 mm Gen II image tube parts, there were numerous difficulties with welds, leaks, and seals, not atypical of new tube designs at birthing. Overall, the design was a considerable improvement over the original CSSTs built, the assembly was well aligned, easily assembled, and rugged. In quantity it could be built in production at reasonable cost.

Static test data from tubes #017901 and #027901A are summarized in Table 3.2.

The Reticon RO-270 array was attached to a fiber optic coupler, Figure 3.1 using type M62 Lens bond (Summers Laboratories), to make the assembly of Figure 3.2.

TABLE 3.2

CIRCULAR SCAN STREAK TUBE MEASURED CHARACTERISTICS

| | | |
|---|---|---|
| 1. TUBE SERIAL NUMBER | 017901 | 027901A |
| 2. INPUT WINDOW | Corning 7056 | Corning 7056 |
| Cathode Type | S20 | S20 |
| Sensitivity | 290 μA/1 | 250 μA/1 |
| Absolute Sens. (@ 530 nm) | 45 mA/W | 45 mA/W |
| Quantum Effic. (@ 530 nm) | 10.5% | 10.5% |
| 3. MESH (G1) | 750 LPI (55% transmission) | 750 LPI (55% transmission) |
| 4. ELECTRON LENS- | | |
| Design (Dwg No.) | S-4725028 | S-4725028 |
| V(G1)/V(G3) | 0.37 (Cathode to G1 = 1070V) | 0.38 (Cathode to G1 = 1020V) |
| V(G2)/V(G3) | 0.27 (Cathode to G1 = 1070V) | 0.27 (Cathode to G1 = 1020V) |
| Magnification | 0.82 | 0.69 |
| 5. BEAM DEFLECTION ASSEMBLY- | | |
| Design (Dwg No.) | S-4725028 | S-4725028 |
| Deflection Sensitivity Entrance Plates (Cath) | 20.2V/mm/kV | 14.8V/mm/kV |
| Exit Plates (Phos) | 17.8V/mm/kV | 16.2V/mm/kV |
| 6. MICROCHANNEL PLATE- | | |
| Serial Number | 1652-21 | 1720.36 |
| Channel Length-to-Diameter Ratio | 40 | 40 |
| Channel Diameter | 12.2 μm | 12.2 μm |
| Channel Spacing | 14.6 μm | 14.6 μm |
| Bias | $8^{o}$ 30' | $8^{o}$ 30' |

TABLE 3.2 Continued

7. GAIN

| Applied Voltage | Gain,017901 | Gain,027901A |
|---|---|---|
| 500 | 16 | - |
| 570 | - | 100 |
| 600 | 54 | - |
| 640 | - | 200 |
| 700 | - | 300 |
| 760 | - | 400 |
| 800 | - | 500 |

8. SCREEN

| | | |
|---|---|---|
| Serial Number | 79-06 | 79-05 |
| Type | P-20 | P-20 |
| Active Diameter | 25 mm | 25 mm |

9. TUBE

| | | |
|---|---|---|
| Resolution* | 12 line pairs/mm | 9 line pairs/mm |
| Resolution Measurement | Cath -2.78 kV | Cath -3.17 kV |
| Operating Conditions | G1 -1.71 kV | G1 -1.97 kV |
| | G2 -2.04 kV | G2 -2.35 kV |
| | G3,4,5 - 0kV | G3,4,5 - 0kV |
| | G6 +0.2kV | G6 +0.5 kV |
| | Phos +4.07 kV | Phos +4.5 kV |
| | MAG. 0.82 | MAG. 0.69 |

10. DEFLECTION PLATE CAPACITY

| | | |
|---|---|---|
| Plate #1 to plate #2 | 2.7pF | 2.1pF |
| Plate #3 to plate #4 | 3.0 | 2.0 |
| Any plate to all others | 4.2 | 3.0 |

11. PHOTOCATHODE TO MESH CAPACITY

| | | |
|---|---|---|
| G2 guarded | 13.0pF | - |

*Resolution for 017901 was measured with the 3 bar test chart at 10:1 optical demagnification and the optical input bandwidth restricted with a wratten #74 filter. For 027901A the optical input bandwith was unrestricted and the test chart projected at 1:1 magnification.

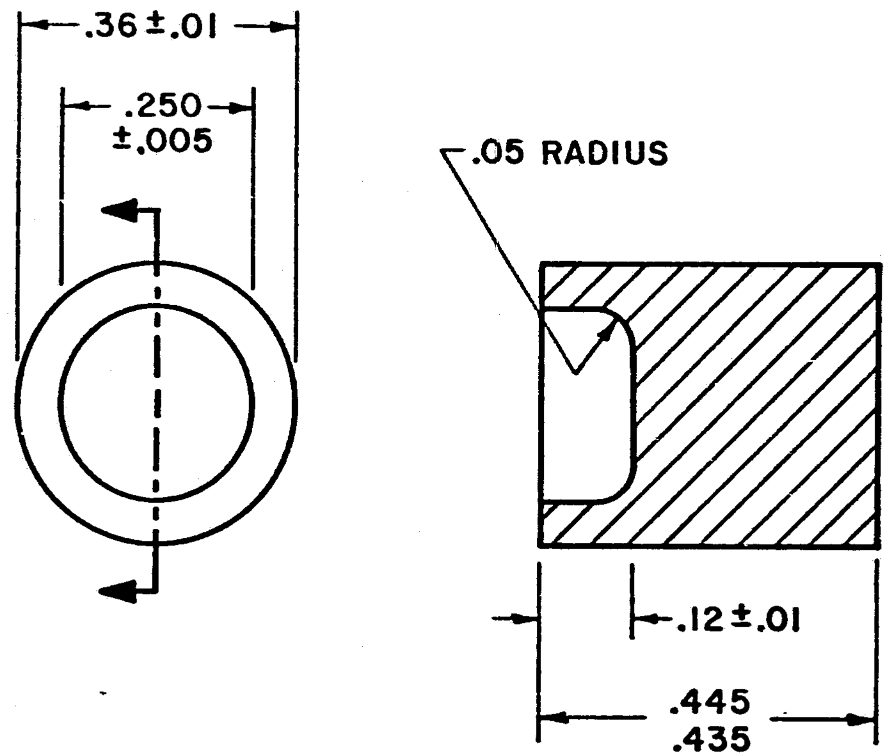



Figure 3.1 Fiber-optic Coupler

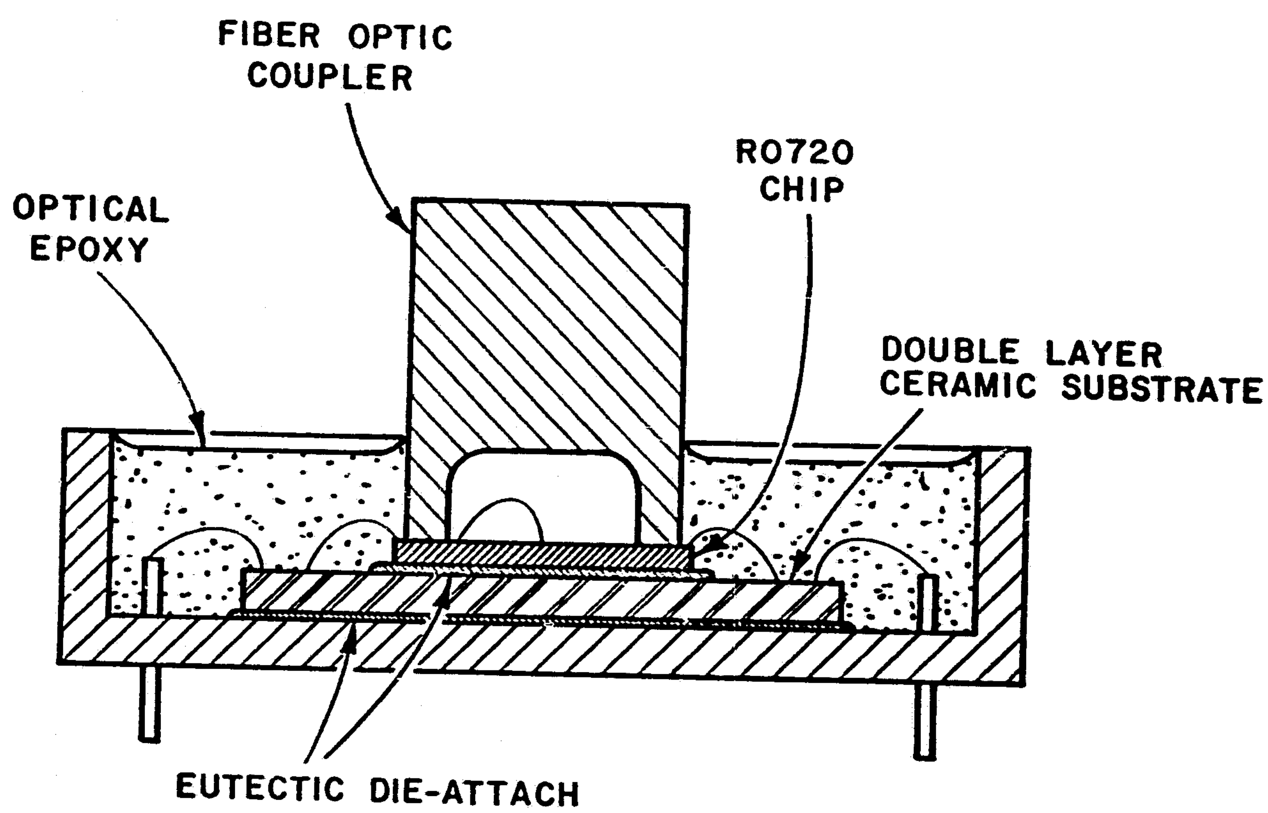



Figure 3.2 Fiber Optic Coupler with Array

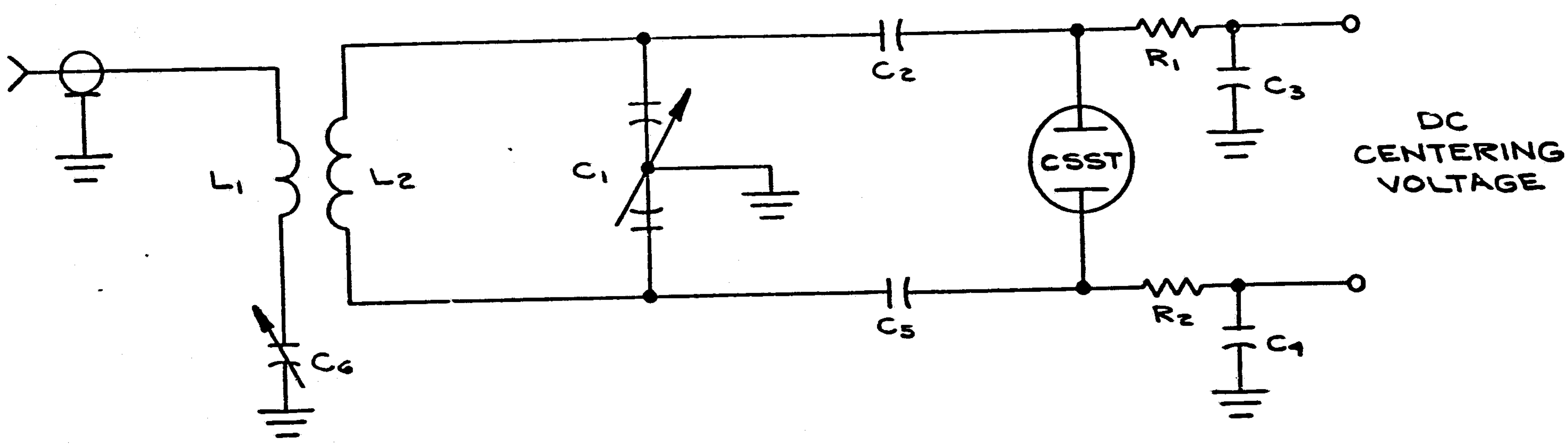
The deflection circuits originally supplied to NASA/GSFC (Interim Report, Figure 2.5) were replaced by more efficient and easily used units of the design shown in Figure 3.3. The beam centering circuit is shown in Figure 3.4 and the coupling circuit in Figure 3.5.

The CSST with fiber optic coupled array, Figure 3.6, was tested dynamically at ITT using a Power Technology, Inc. pulser driving a ILCL diode. The array used for testing was a Reticon RA-32x32 array and associated camera unit. This array's pixels are on .004" centers.

Light from the pulser was focused onto the photocathode in a spot small enough so all the resulting charge was delivered to only one pixel of the array (static setup). With the CSST operating at 200 MHz and the resulting 5 ns circular scan distributed around 69 pixels, the camera displayed modulation of the light pulse. The pulse was estimated to be 5 pixels, or 362 ps in duration.

The CSSTs were encapsulated as shown in Figure 3.7. The RF coax type connections to the deflection plates were needed, as was the isolation plate between the deflection plates.

Subsequently NASA tested[3] the assemblies using a Nd:YAG laser system. Four pulses from this laser are shown in Figure 3.8. Most interesting is the "pre-pulse". From the rate of rise one can estimate a minimum response time of 30 to 40 ps.




$C_1$ - 15pF SPLIT STATOR

$C_2, C_3, C_4, C_5$ - .002 μF

$C_6$ - 20pF

$R_1, R_2$ - 22 MΩ

$L_1$ - 1 TURN NO. 18 WIRE, .50 INCH I.D.

$L_2$ - 3 TURNS NO. 18 WIRE, .50 INCH I.D. .50 INCH LONG

Figure 3.3. CSST Deflection Circuit

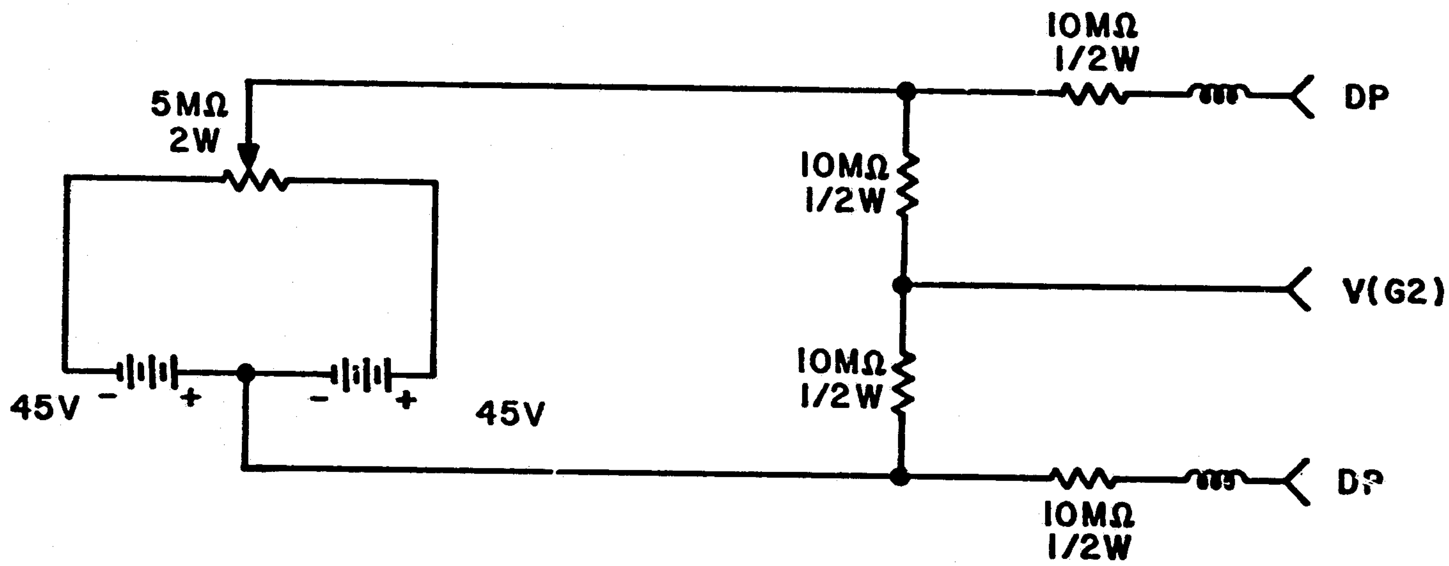



Figure 3.4 CSST Beam Centering Circuit

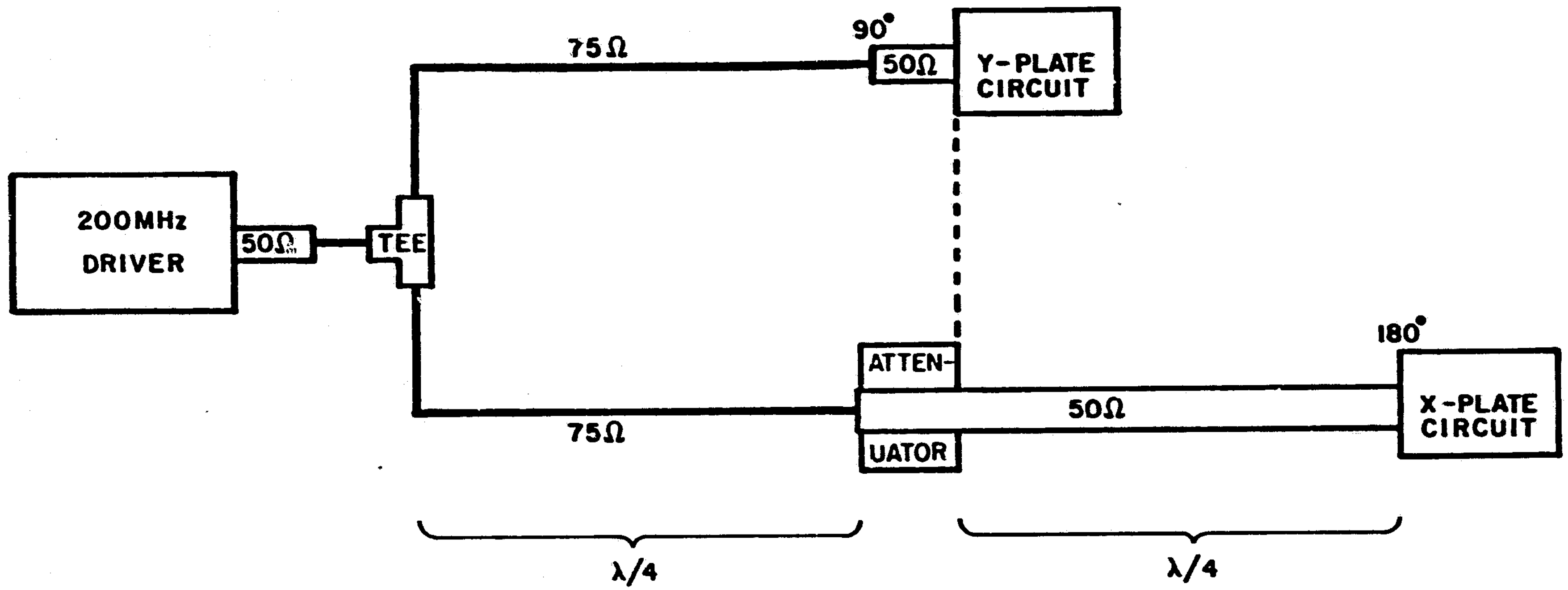



Figure 3.5 CSST Deflection Coupling Circuit

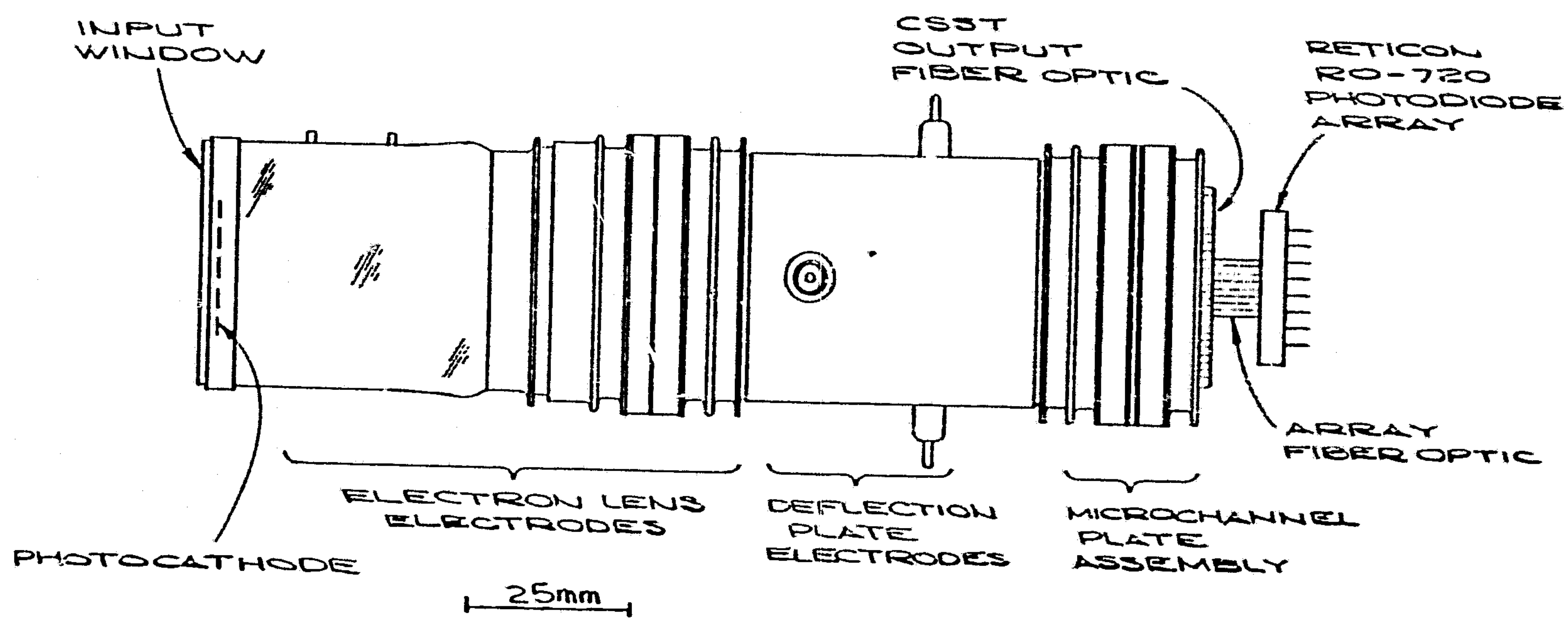



Figure 3.6 CSST with Fiber Optic Coupled Array

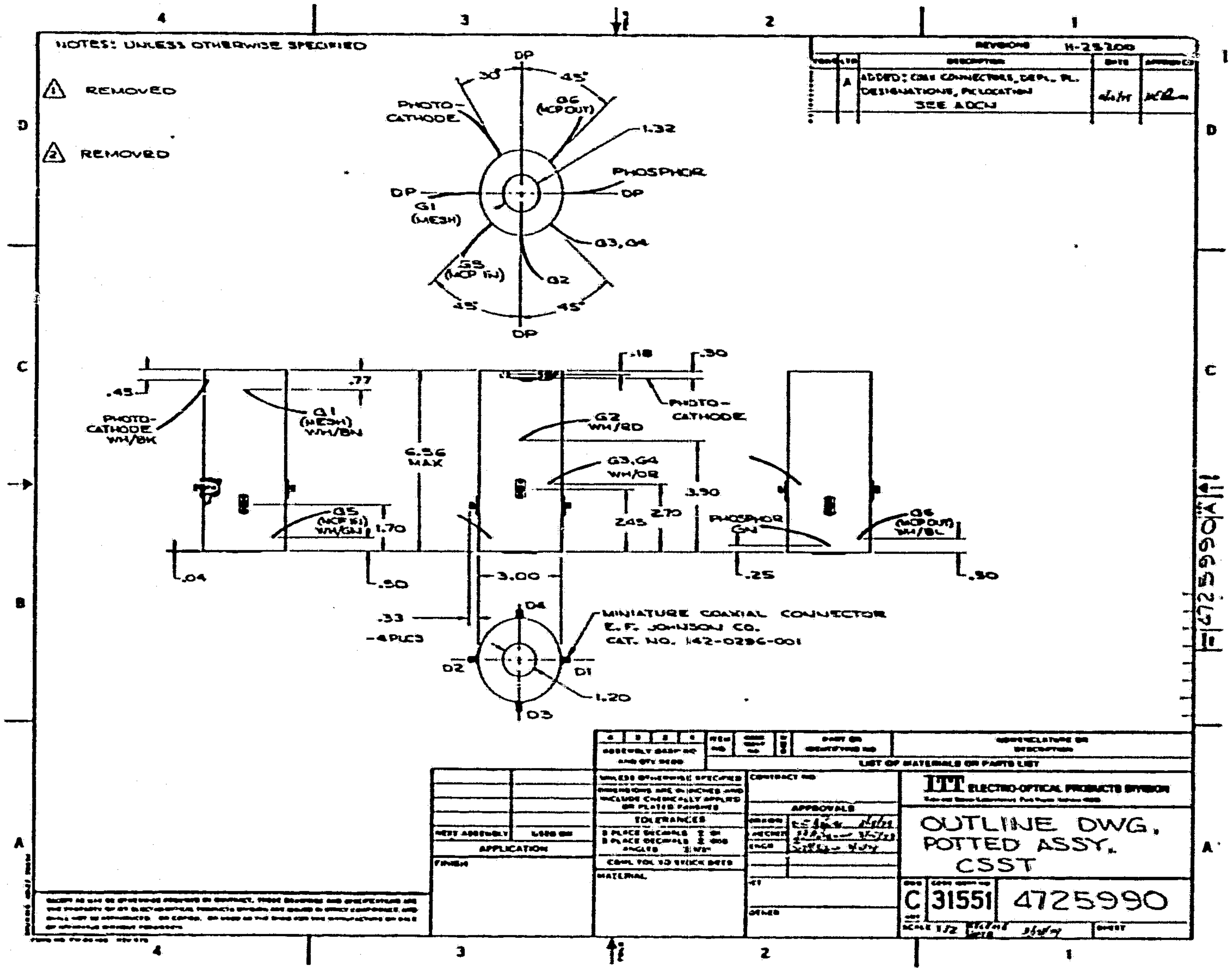



Figure 3.7 Encapsulated CSST

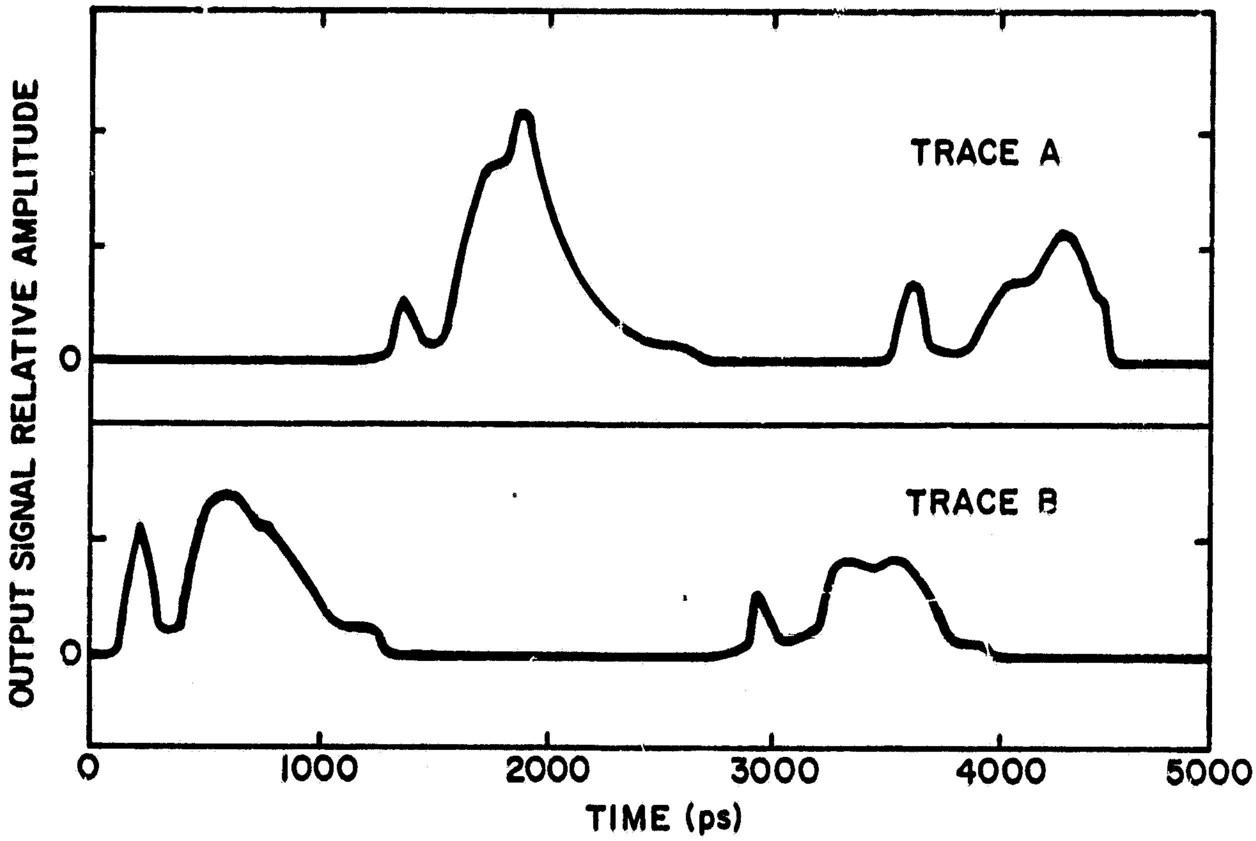



Figure 3.8 Sample CSST Output Traces Using a Nd:YAG Laser System Operating at 532 nm.

Another test at NASA/GSFC is shown in Figure 3.9, wherein the line spread function of the scanning CSST was measured using a HeNe CW laser. The 33 ps FWHM is in agreement with the estimate from Figure 3.8 and the prediction of Table 2.1 for the measured 12 lp/mm electron optical resolutions.

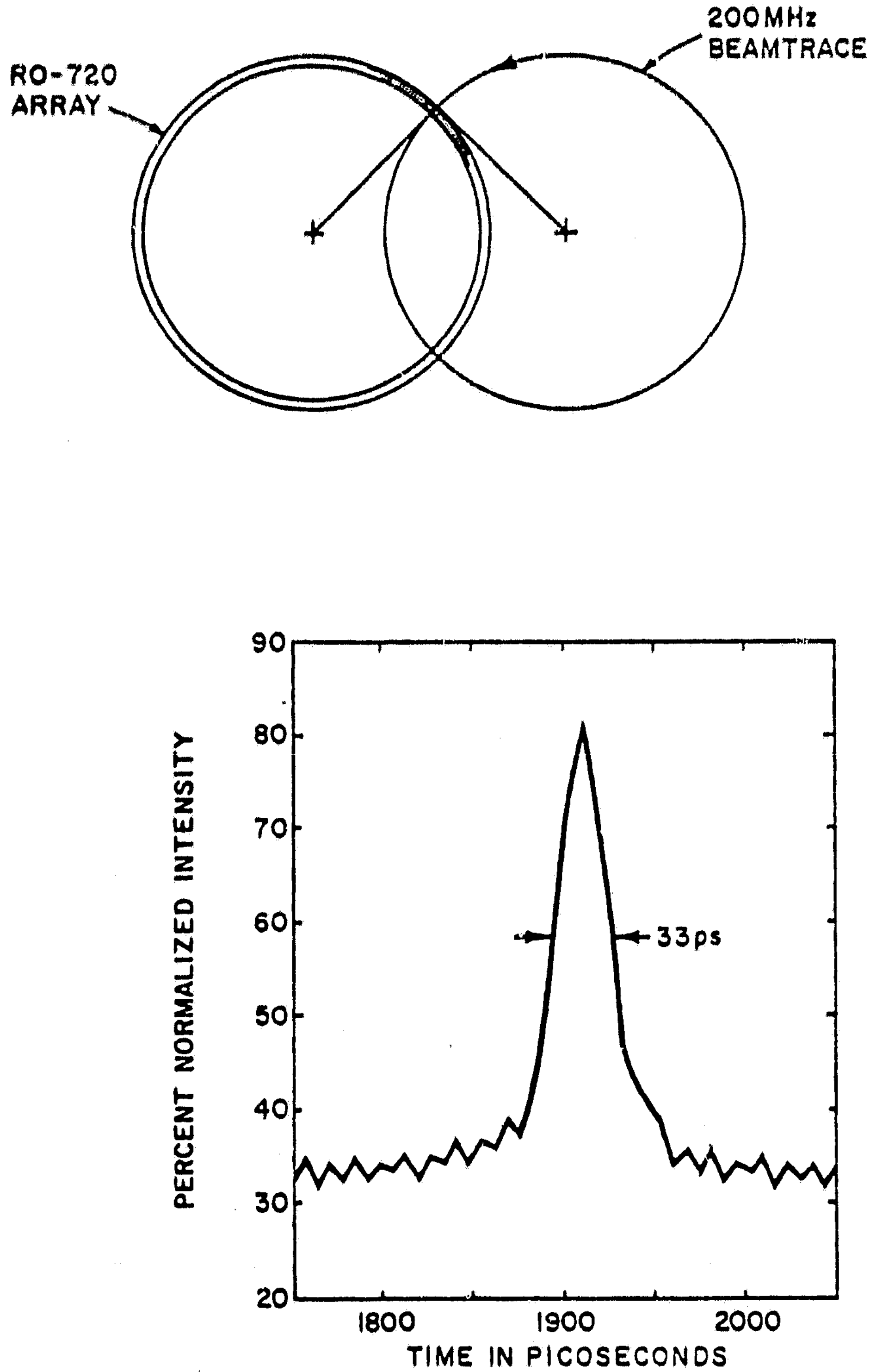



Figure 3.9 RELATIVE PLACEMENT OF THE CSST OUTPUT BEAMTRACE WITH THE CIRCULAR RETICON ARRAY AND THE MEASURED LINE-SPREAD FUNCTION.

## 4.0 Conclusions and Recommendations

The CSST fiber optically coupled to a circular readout array has been demonstrated to have a time resolution of about 33 ps, twice as good as the system goal value of 67 ps but not as good as the detector goal. The threshold detection level of devices built so far has been 100 photoelectrons, not the desired single photoelectron detection. To achieve this capability CSSTs with cascaded microchannel plates to provide the needed gain are proposed. The resolution loss due to cascaded microchannel plates is a subject of considerable debate, but the best experimental data indicates that it can be less than 10%. A Circular Scan Streak Tube with single photoelectron detection capability should be built.

## APPENDIX

## TIME DISPERSION AND ARRAY DESIGN

The overall time resolution (T) of the CSST is governed by the time dispersions which unavoidably arise due to the finite diameter of the optical input beam, the photoelectron velocity spread, the image transfer properties of the electron-lens/deflection-assembly/MCP/proximity focused section, and the dimensions of the pixels in the self-scanned array. The time dispersions resulting from each of these factors are given by

$$T_b = W/v_s \quad , \qquad (A\text{-}1)$$

$$T_c = \Delta v/(uE) \quad , \qquad (A\text{-}2)$$

$$T_t = 1/(v_s f_\ell) \quad , \text{ and} \qquad (A\text{-}3)$$

$$T_a = D/v_s \quad . \qquad (A\text{-}4)$$

The dispersion ($T_b$) caused by the beam diameter (W) is inversely proportional to the electron beam scan velocity ($v_s$) across the output ISSA. Chromatic time dispersion ($T_c$) caused by a photoelectron velocity spread ($\Delta v$), which is seen to be inversely proportional to the product of the electron charge/mass ratio (u) and the electric field strength (E) at the cathode. The limiting spatial resolution ($f_\ell$) of the electron-lens/deflection-assembly/MCP/proximity focused section gives rise to the technical time dispersion ($T_t$) given by Eq (A-3). Finally, Eq A-4 shows that the pixel width (D) induced time dispersion ($T_a$) is similar to the optical beamwidth dispersion equation. Adding all these dispersions in quadrature gives the overall time dispersion (T) of an ISSA readout CSST, including the component arising from the finite diameter of the optical input image:

$$T = (T_b^2 + T_c^2 + T_t^2 + T_a^2)^{1/2} \qquad (A\text{-}5)$$

Let us consider some of the design-performance tradeoffs of the ISSA by assuming that the scan frequency (F) is 200 MHz, and that the input optical beam diameter is W = 50 μm (2 mils). Also, let

N be the number of pixels in the circular array. The streak velocity across the circular ISSA is given by

$$v_s = NDF, \quad \text{(A-6)}$$

if the simplifying assumtpion is made that the pixel width is equal to the pixel/pixel center/center spacing. Thus, $T_b$ = 50x5E3/(ND) = 2.5E5/(ND), and $T_a$ = 5E3/N, where the units of $T_b$ and $T_a$ are picoseconds for D expressed in microns. The optical beam/pixel resultant time dispersion (T') can be expressed in terms the maximum ISSA circumference (C=ND) which can be accomodated by the size of the chip and the ISSA pixel center/center spacing:

$$T' = (T_b^2 + T_a^2)^{1/2}. \quad \text{(A-7)}$$

Substituting Eqs (A-1 and A-4) into Eq (A-7), it is found that

$$T' = 2.41E\text{-}1\ (2.5E3 + D^2)^{1/2}, \quad \text{(A-8)}$$

and the calculated time resolutions within the design range corresponding number of pixels are given in Table A-1.

Table A-1 - Time Dispersion of the Beamwidth and Array Components versus Number of Pixels for W = 50 μm

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| D (μm) | 55 | 50 | 45 | 40 | 35 | 30 | 25 | 0 |
| T' (ps) | 17.9 | 17.1 | 16.2 | 15.4 | 14.7 | 14.1 | 13.5 | 12.1 |
| N | 377 | 415 | 461 | 518 | 592 | 691 | 829 | ∞ |

Substitution of Eqs (A-1 - A-4) into Eq (A-5) yields

$$T = ((mW)^2 + D^2 + (m/f_\ell)^2 + v_s^2\ (\Delta v\ /(uE))^2\ )^{1/2}/v_s, \text{ or} \quad \text{(A-9)}$$

$$T = ((mW)^2 + D^2 + (m/f_\ell)^2 + (CF)^2(\Delta v/(uE))^2\ )^{1/2}/(CF). \quad \text{(A-10)}$$

Using the nominal values for the optical input beam diameter and tube parameters; magnification, m + 1, W = 50 μm, $f_\ell$ = 40 lp/mm, C = 20.7 mm, F = 200 MHz, Δv = 6E5 m/s, E= 1 kV/mm, we see that

ELECTRO-OPTICAL PRODUCTS DIVISION ITT

Eq (A-10) can be rewritten as

$$T = ((2.5E{-}3) + D^2 + (5.3E{-}4) + (1.7E19)(1.2E{-}23))^{\frac{1}{2}}/4.1E9,$$

$$T = (3.3E{-}3 + D^2)^{\frac{1}{2}}/4.1E9.$$

Under these conditions we find that the total time resolution depends upon the pixel/pixel separation of the SSA as follows:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| D(μm): | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | (0) |
| T(ps): | 24 | 22 | 20 | 19 | 17 | 16 | 15 | 14 | (14). |

Our chosen pixel/pixel spacing of 30 μm (and 720 pixels) is therefore a reasonable compromise between the difficulty of making a die with close-spaced pixels and wider spacing (with fewer elements).

## REFERENCES

1. Allan, W.B., Fiber Optics, Plenum Press, 1973

2. Drougard, R., JOSA 54, 907 (1964)

3. Johnson, C.B., et al, Appl Opt 19, Sep'80 (to be published)