(NASA-CR-170973) BREADBOARD STELLAR TRACKER SYSTEM TEST REPORT Final Report, Oct. 1982 - Jan. 1984 (Ball Bros. Research Corp.) 58 p HC A04/MF A01 CSCL 17G

N84-17166

Unclas
G3/04 18287

BREADBOARD STELLAR TRACKER SYSTEM

Test Report

TR83-25 January 1984

Prepared for

George C. Marshall Space Flight Center

NASA

Contract No. NAS8-34263


PREPARED BY:

J. C. Kollodge
Manager

K. A. Parrish
Test Data and Processing

APPROVED BY:

for D. W. Vanlandingham
Director
Electro-Optical Products

Ball Aerospace Systems Division

BOULDER, COLORADO 80306

# TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

# Section 1
# PROGRAM SUMMARY

BASD has, in the past, developed several unique position tracking algorithms for charge transfer device (CTD) sensors. These algorithms provide an inter-pixel transfer function with the following characteristics:

- High linearity
- Simplified track logic
- High gain
- High noise rejection
- Self-compensation for variations in:
  - Source intensity
  - Image diameter
  - Interpixel cross talk

A previous test program using the GE charge injection device (CID) showed that accuracy for BASD's breadboard was limited to approximately 2% of a pixel ($1\sigma$) whereas analysis and simulation indicated the limit should be less than 0.5% of a pixel, assuming the limit to be detector response and dark current noise. The test program was conducted under NASA contract No. NAS8-34263. (See BASD report No. TR81-04 "Breadboard Stellar Tracker System" August 1, 1981.) The test approach for that program did not provide sufficient data to identify the sources of error and left open the amount of contribution from parameters such as:

- Image distribution and geometric distortion
- Chromatic distortion of the image
- Asymmetric pixel point spread response and cross talk
- Anomalies in breadboard tracker optics
- Response and dark current variations in the CID
- Errors in the basic position algorithms
- System alignment errors

The test approach was therefore changed to one more capable of taking data from which error sources could be identified. The current cooperative program with MSFC was conducted in an effort to further evaluate the performance characteristics of BASD's tracking algorithms and their breadboard CID tracker.

Under the conditions of this program, BASD transferred their algorithms to MSFC and provided tracking test data for MSFC analysis and evaluation.

Data was taken both with BASD's CID (ST-256D) and an improved CID provided by MSFC (ST-256E). The data was recorded on disks and transmitted to MSFC on magnetic tape.

The period of performance for the program was October 1982 through January 1984. The program has been extremely helpful in identifying problem areas and requirements for further optimization of both the software and hardware design.

# Section 2
# CONCLUSIONS AND RECOMMENDATIONS

The data review conducted at BASD was limited to a qualitative survey of selected samples from each data set rather than detailed analyses. Some important observations were made identifying problems not previously recognized.

The original intent was to evaluate the tracker performance using a position algorithm that involves an eight pixel track block and a relatively unique optics/image configuration. Simulations with other algorithms involving 9, 16, and 25 pixels showed good performance, but the 8 pixel one was best and therefore selected for this evaluation.

Data was obtained that will be useful in evaluating the performance for the eight pixel algorithm. However, the hardware implementation for the breadboard proved too sensitive (to alignment of the focal distance) to obtain conclusive data. Preliminary review of the problem revealed a need for alternate optics to accommodate the requirements, but this solution could not be implemented within the program constraints. The breadboard was therefore modified to track with the 9 pixel algorithm which does not require unique optics, and the tests were repeated.

The data was taken with red (>0.56 μm), white (3200K tungsten), and blue/green (<0.6 μm) light at varying focal distances.

## 2.1 OBSERVATIONS AND CONCLUSIONS

The general observations and conclusions from the limited data review at BASD are as follows:

- The test approach used by BASD provides focal plane data in a format that is useful for evaluating system and focal plane performance with high resolution.

- Erratic performance was observed with the eight pixel algorithm because of the optical implementation for the breadboard. However, there is sufficient evidence that both algorithms work as predicted when properly implemented.

- Deviation from gaussian distribution of the convoluted image/pixel point spread response caused unpredicted anomalies in linearity of the interpixel transfer function; and in turn affect the accuracy.

- The image/pixel response shape varies with color and/or focus.

- The image/pixel response shape is different for the BASD and MSFC detectors because of differences in electrode structure.

- The smallest image/pixel spread response that was achieved, at best focus, was approximately 3.0 to 3.5 pixels wide ($\pm 3\sigma$ points). This is close to the desired nominal for the nine pixel algorithm but is almost twice the desired diameter for the eight pixel algorithm.

- Observations to date indicate that the minimum apparent image diameter may be influenced more by the pixel-to-pixel cross talk than by the lens performance. Furthermore, this cross talk, and in turn the apparent image diameter, varies with color.

- For BASD's algorithms, the dominant effect from varying image diameter is in signal-to-noise ratio (SNR) rather than in interpixel position interpolation errors.

- The single readings for fine maps indicates that there is a time dependant drift in fixed pattern noise. Data showed the MSFC detector readout noise was approximately 200 $e^-$/read whereas pattern noise variations of $10^4$ $e^-$ were observed over several days.

- This test program provided supportive evidence that the tracker and algorithms are performing as predicted. It also revealed design areas that must be refined to achieve the predicted system performance.

## 2.2 RECOMMENDATIONS

Test results with the nine pixel algorithm should be indicative of the performance that can be achieved except for any systematic errors that could be further reduced with refined hardware and position algorithms.

Results with the eight pixel algorithm were erratic because of the breadboard optics used. Since this algorithm shows promise for significant improvement over others, it is recommended that the breadboard be redesigned to a less sensitive configuration and the test repeated.

Further test and analysis on the upgraded detector from MSFC are also recommended, because of the limited amount of data obtained on it during this program. Since that device is representative of the CID design intended for future flight programs it is important that extensive evaluation take place both at the detector level and the tracker level.

# Section 3
# TEST DESCRIPTION

## 3.1 OBJECTIVES

The primary objective was to make improvements to the test approach and to take position tracking data with both the BASD and MSFC breadboard detectors for MSFC analysis. The end objective is to evaluate the accuracy performance and identify error sources.

A secondary objective was to take pixel data, using single readings under dark conditions, and evaluate the repeatability of the fixed pattern noise over a relatively long period of time.

## 3.2 GENERAL APPROACH

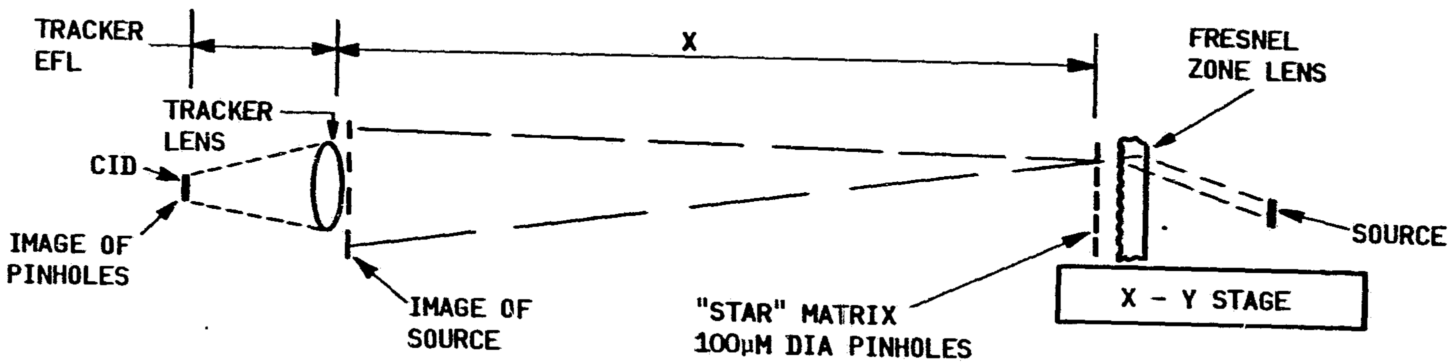
The approach was to have the tracker view a matrix of sources. The matrix was incremented in precise steps and at each step the pixel data containing the source (eight or nine pixels as appropriate) was recorded on disk. The data can then be used to interpolate position using a variety of algorithms.

The accuracy can be determined by comparing the interpolated position against the uniform stepping increments of the positioner or by observing the consistency of the relative separation between sources in the matrix.

The focal plane was rotated 45 degrees to the direction of travel for the matrix to allow a two-axis displacement in the tracker coordinates and somewhat random data points on the pixels.

## 3.3 EQUIPMENT DESCRIPTION

Figures 3-1 and 3-2 illustrate the optical setup used for the test. Figure 3-3 is a block diagram of the test equipment used in taking the data.




- FRESNEL LENS IMAGES SOURCE AT TRACKER LENS THROUGH EACH PINHOLE
- TRACKER LENS IMAGES STAR MATRIX ON CID
- DIMENSIONS AND DISPLACEMENTS ARE REDUCED BY $\frac{EFL}{X}$ ON CID

EXAMPLE: SET $\frac{X}{EFL} = 50$, THEN

| | |
|---|---|
| PINHOLE IMAGE DIA | ~2.0 μM (0.1 PIXEL) (≤2.5 μM TYPICAL) |
| X - Y STAGE RESOLUTION | 0.05 μM (0.0025 PIXEL) |



A/N 3973

Figure 3-1 High Accuracy Optical Test Approach

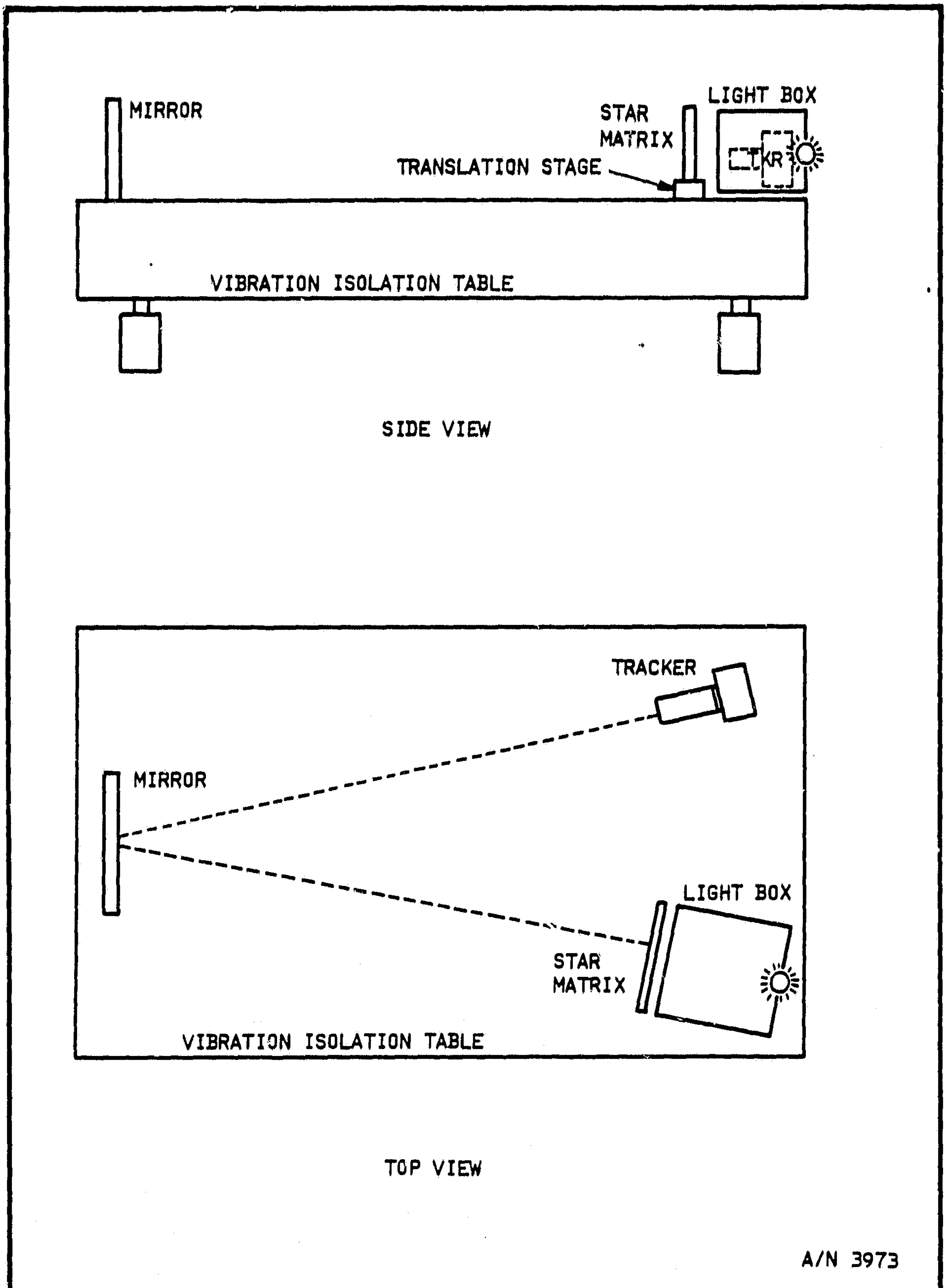



Figure 3-2 Optical Test Setup

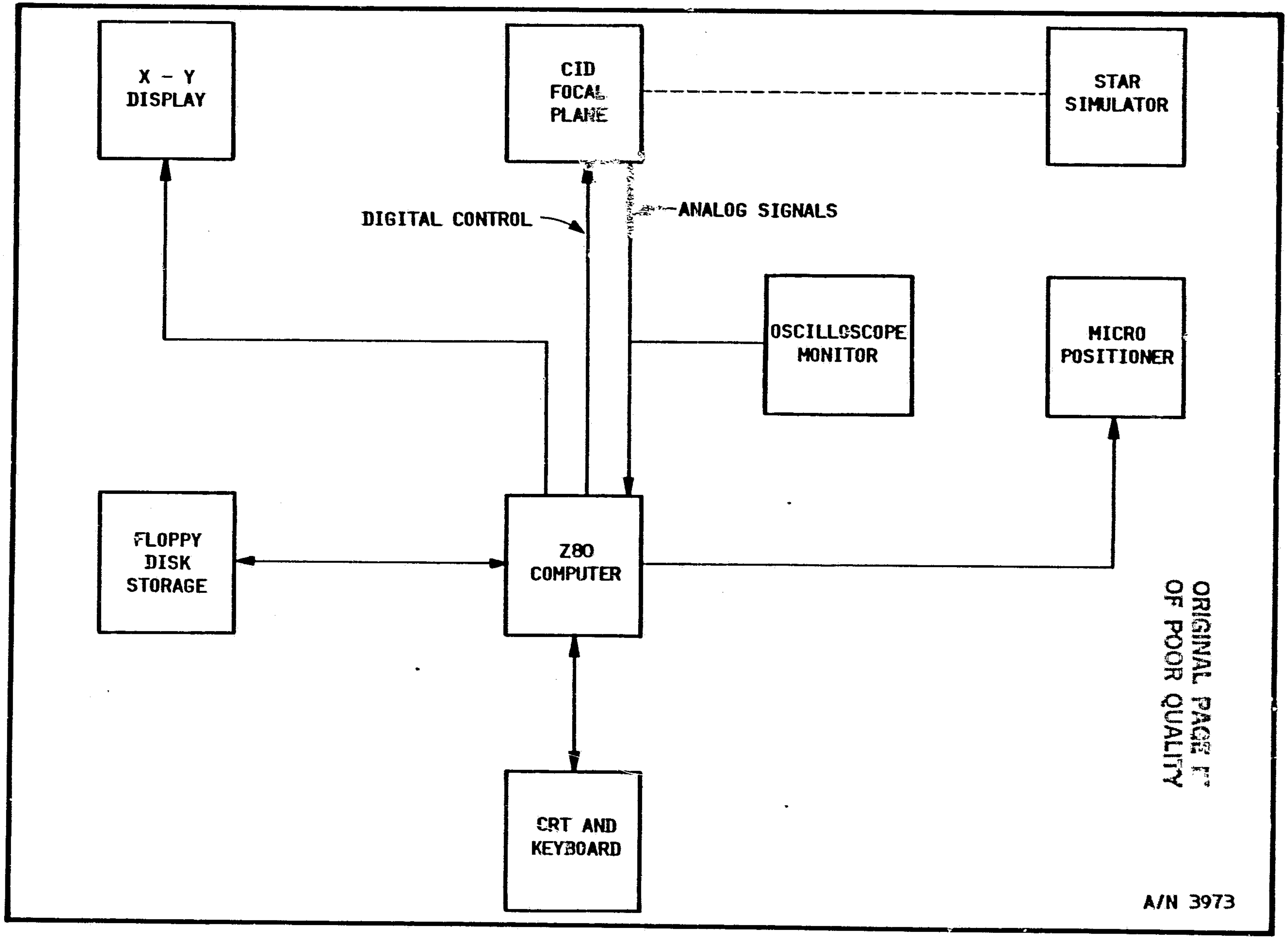



Figure 3-3 Block Diagram of Equipment in Test Setup

A halogen lamp, focused on the tracker lens via the Fresnel lens and projected through a matrix of pinholes, served as the star simulator. The matrix was mounted on a computer controlled translation stage and moved in discrete increments to provide positional input to the star tracker optical assembly for position accuracy tests. The star tracker system performed a coarse acquisition search with the star matrix in the initial position. The tracker then proceeded to acquire and track all of the stars in the field of view. After locking on a star, six data readings were taken and recorded on disk. A list of star positions was created in memory to serve as a starting point for subsequent passes. The list was used to speed up test time by eliminating the coarse acquisition pass for the remainder of the run. After data was taken on all stars in the field of view, the translation stage, under computer control, moved the star matrix a fixed increment. Upon determining that the next test position had been reached, the tracker accessed the star list and obtained the last position of each star, which it used as an initial track position. Again, after being allowed to lock onto a star, data was taken. When all stars in the list had been tracked, the stage was moved and the process repeated until data had been taken at the required number of positions.

A Cromemco Z-80 microprocessor development system was interfaced with the star tracker optics head and performed the acquisition and track logic functions.

The star simulator and star tracker optics were mounted on an isolation table and covered with a cloth shroud to provide thermal, optical, and convection isolation from the ambient environment.

## 3.4 BREADBOARD STAR TRACKER

The breadboard optics consisted of a Cine Nikor f/2.8, 100 mm effective focal length camera lens for the nine pixel algorithm. Image shaping optics were added for the eight pixel algorithm. Figures 3-4 and 3-5 show the configuration of the tracker optics and focal plane electronics.

Two versions of GE's ST-256 CID (Revisions D and E) were used as detectors. The first was a device procured by BASD in mid-1980 and the second was fur-

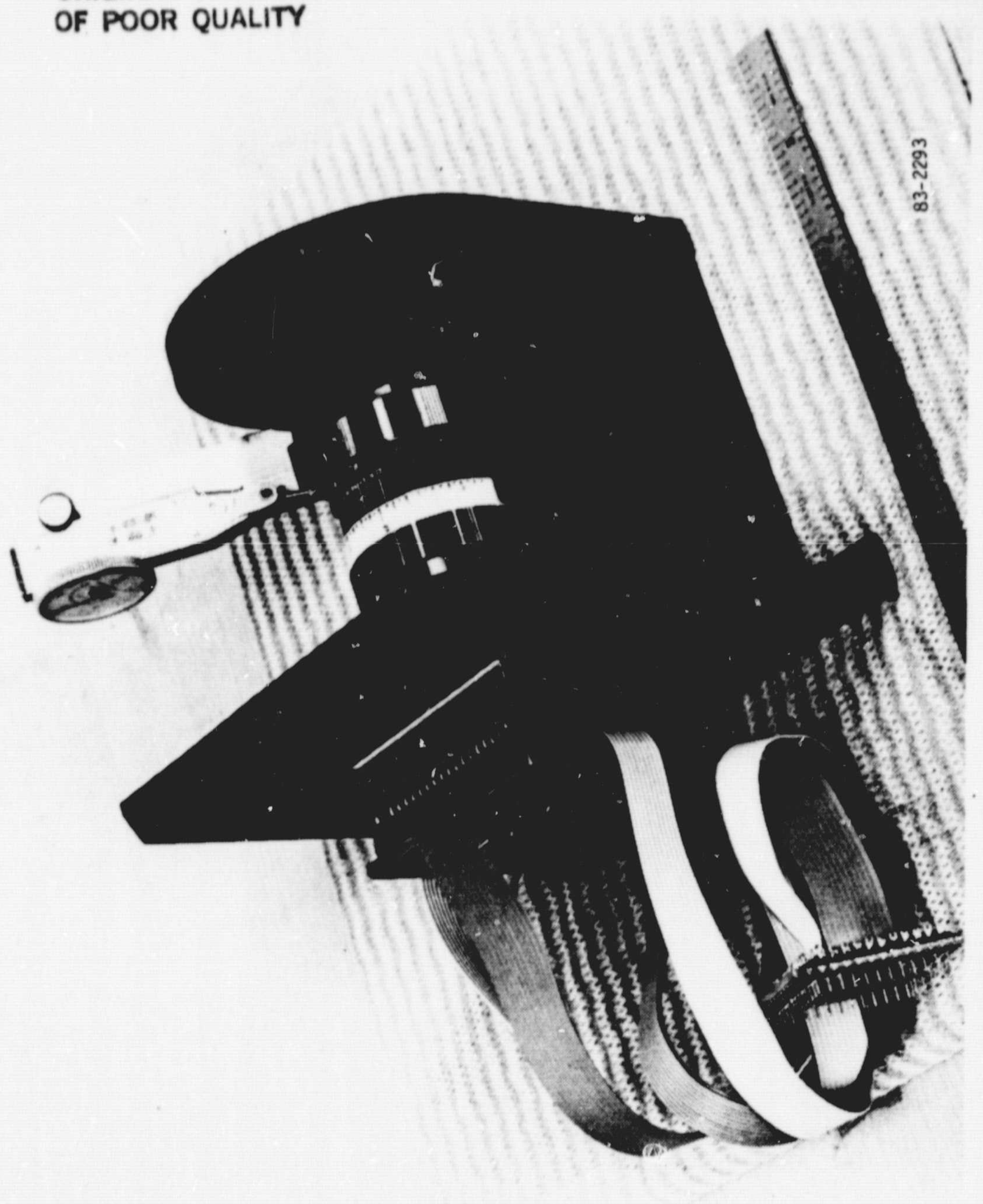



Figure 3-4 Tracker Optics

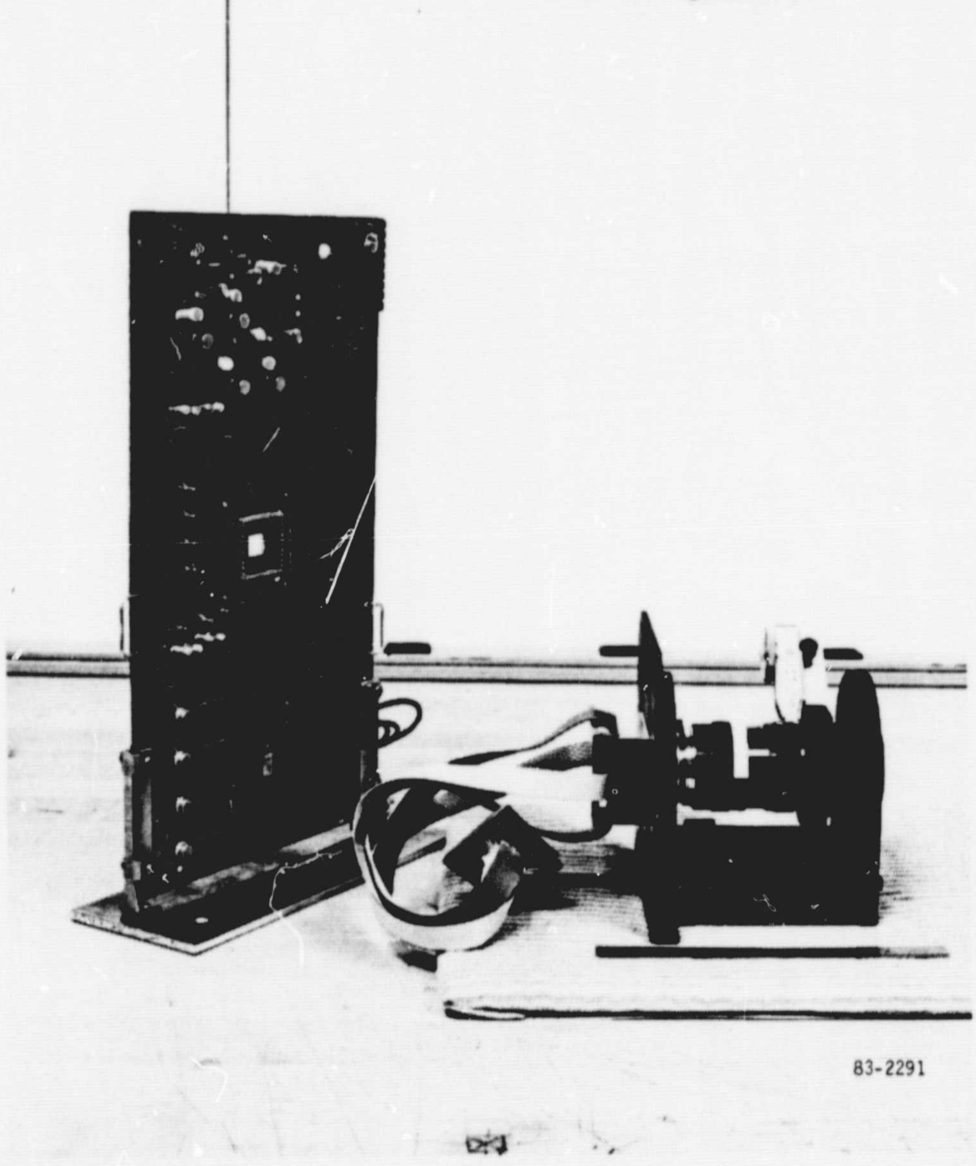



Figure 3-5 Tracker Optics and Focal Plane Electronics

nished by MSFC in October 1983. The array consists of 256 x 256 pixels that are 20 x 20 μm in size. For the tracker optics, this yields a pixel subtense of 41.25 arc seconds and a FOV of approximately three degrees.

The intent was to develop the test software and take preliminary data with BASD's detector while waiting for the new one for the final test.

Some of the features that were planned for incorporation in the new detector were as follows:

- Scanner Design. The internal node capacitance of the scanners has been trimmed to increase the parameter margins (clock voltage, transistor threshold voltage, etc.) over which reliable operation can be obtained.

- Clamp Scanner. A clamp scanner has been added so that voltage can be maintained on all unaddressed array row electrodes. This improves dynamic range when extended objects are being imaged by preventing the photocurrent at unaddressed pixels from discharging the row conductors.

- On-Chip Preamplifier Transistor. MOS transistors, connected as source-followers, have been added in series with each output line. This change should greatly reduce interference from associated electronic circuits by keeping the sensitive signal lines completely within the sensor chip. The topological layout of the sense lines has been balanced to maintain equal capacitance on all signal output lines.

- Compensation Line. The 257th row, at the top of the array, is used as a compensation line to reduce the dynamic range requirements of the off-chip amplifier/sample-hold circuitry. This line is connected to the negative input of the four signal differential-amplifiers. In previous designs, there have been problems in obtaining completely satisfactory operation using this compensation technique. If the compensation line is made identical to all other array rows, it is photosensitive and can cause interference when illuminated. If there is no charge storage region provided for the compensation line pixels, the line capacitance is different than other array lines. In this design, the compensation line is made identical to other array lines but a drain (collector) region has been added adjacent to each compensation line pixel so that any charge collected is drained off.

- Narrow Electrodes. The primary cause of fixed pattern noise in CID imagers has been traced to variations in the crossover capacitance between row and column electrodes. Since the charge storage capacity of the row and column electrodes is a direct function of electrode width squared, the signal-to-fixed pattern noise ratio improves as electrode width is reduced. This structure has ~55% of the storage capacitance of the ST-256D design with a field oxide isolation and 80% with channel stop isolation. The row-column cross-over capacitance has been reduced by a factor of four.

Major semiconductor process improvements for device fabrication are:

- Thin Oxide Implant. The exposed thin oxide regions in the array (the thin oxide not covered with electrodes) will be implanted to set the threshold voltage of these regions above the electrode operating voltages. This prevents any surface charge from affecting array operation.

- Fine Grain Polysilicon. Processes developed to achieve fine grain polysilicon electrodes will be used. This fine grain structure reduces the row-column crossover capacitance variations and hence fixed pattern noise.

- Channel Stops. Mask levels have been included in this imager design to retain the option of using implanted channel stops in place of the thick field oxide to provide isolation between adjacent sensing sites. The use of channel stops to achieve a higher, more uniform spectral responsivity is presently being explored at GE on other programs. If this approach proves successful, this option can be exercised at a later date.

- Antireflection Coating. An aluminum patterning process which does not result in a lift-off glass residue layer is planned for these sensors. An antireflection silicon nitride layer can then be applied directly on the upper polysilicon electrode to enhance responsivity.

## Section 4
## TEST DATA AND REDUCTION CONSIDERATIONS

All the test data supplied prior to December 1983 were taken with the BASD detector (ST-256D); with the detector cooled to lower than -20°C. Data with both the eight and the nine pixel algorithms were submitted primarily for MSFC use in checking their software performance.

Subsequent test data was taken with the MSFC detector, (ST-256E); with the detector temperature controlled to +4°C. The data includes single read, dark, 12x12 pixel maps and nine pixel tracking data.

A list of data sent to MSFC is included in Appendix A.

Tracking data sets were taken with the CID at best focus, as indicated by peak signal from the track pattern, and up to plus and minus 50 μm axial displacement from best focus. Tests were made with red (>0.56 μm) white (3200K tungsten) and blue (<0.6 μm) light at each position.

The algorithms developed by BASD and supplied for data reduction and analysis were based on a uniform pixel response, with no cross talk, and a gaussian image distribution.

The individual pixel data supplied to MSFC can be combined using these algorithms to observe and analyze the various parameters of interest.

Representative performance is discussed in the following paragraphs.

### 4.1 PIXEL POINT SPREAD RESPONSE

Pixel point spread response data was furnished by GE for the two detectors under test. The data was taken by scanning a 2 to 4 μm spot across the pixel and recording the output as a function of position.

The horizontal and vertical point spread response for BASD's detector are shown in Figures 4-1 and 4-2 respectively for 4200A to 6000A. Two axis point spread response for the MSFC detector is shown in Figures 4-3 and 4-4 for 5000A and 9500A respectively. Typical average response and response variation curves are shown in Figure 4-5 for the CID. Some general observations are as follows.

- Cross talk between adjacent pixels exists for both detectors and varies in magnitude with color, being greatest for red light. The effect is to cause an apparent related variation in image diameter.

- Electrode structure is evident in both detectors with blue/visible light because of absorption, reflection and interference effects. It becomes less prominent with red light except along the rows of the MSFC detector. This latter effect is the result of blocking by the aluminum strip (approximately 2 μm) along the columns of the MSFC detector which is not included in the BASD detector.

Cross talk results when charge generated at one pixel is deposited on an adjacent one. The effect of this charge spreading is a resultant change in the apparent image diameter. BASD's algorithms have the affect of measuring changes in apparent diameter and compensates for them.

The electrode structure causes a wide deviation in response function from the uniform response used by BASD in developing position algorithm. However, with the color dependent variations, a uniform response is not a bad assumption to best fit all the data. Some refinements, to compensate for the structure may make improvements. Compensation for the cross talk is, to some extent, included in the algorithms because of the gaussian distribution assumed for the optical image.

A/N 3973

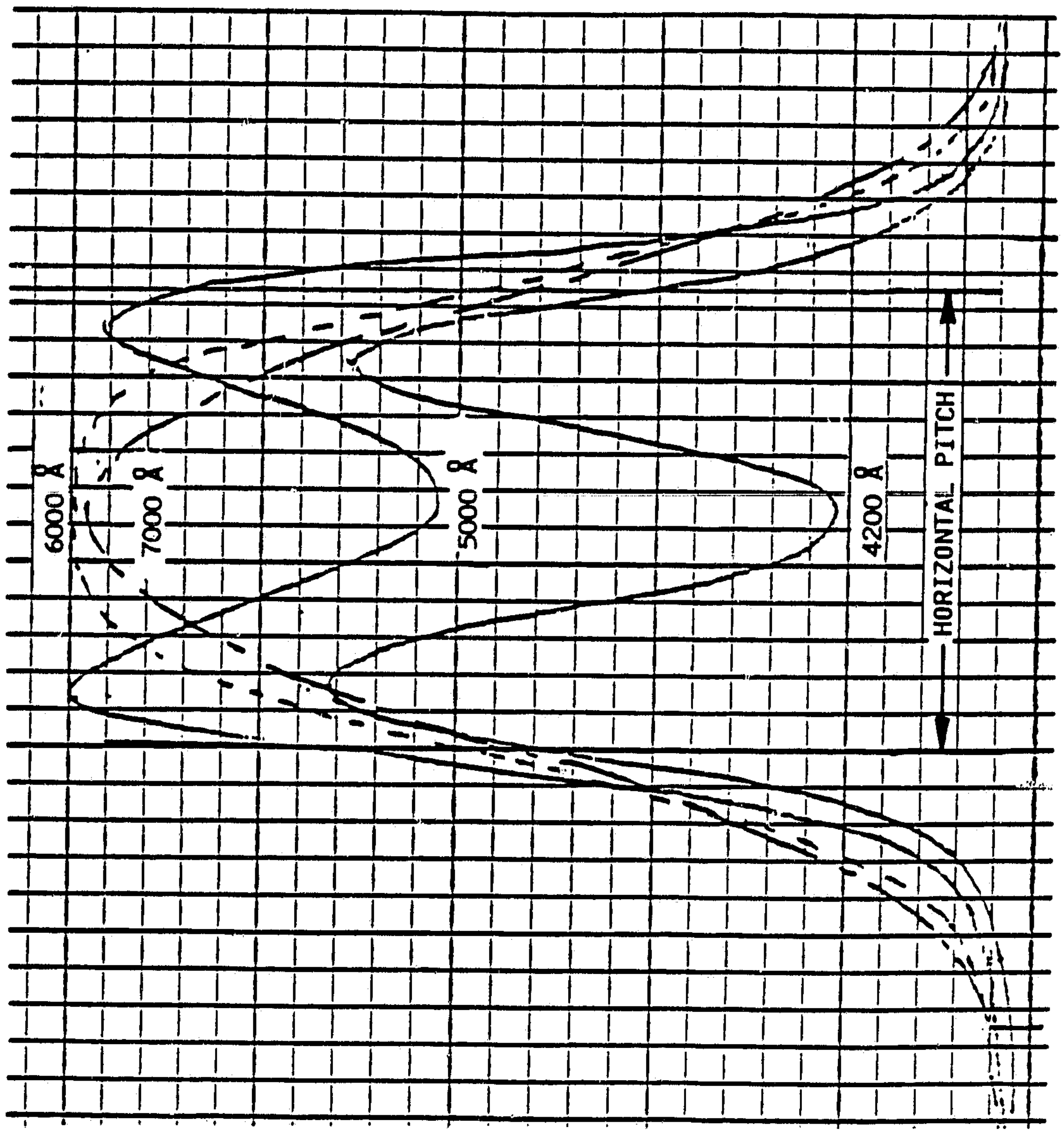



Figure 4-1 CID Pixel Point Response - Horizontal (BASD Detector)

A/N 3973

ORIGINAL PAGE IS
OF POOR QUALITY

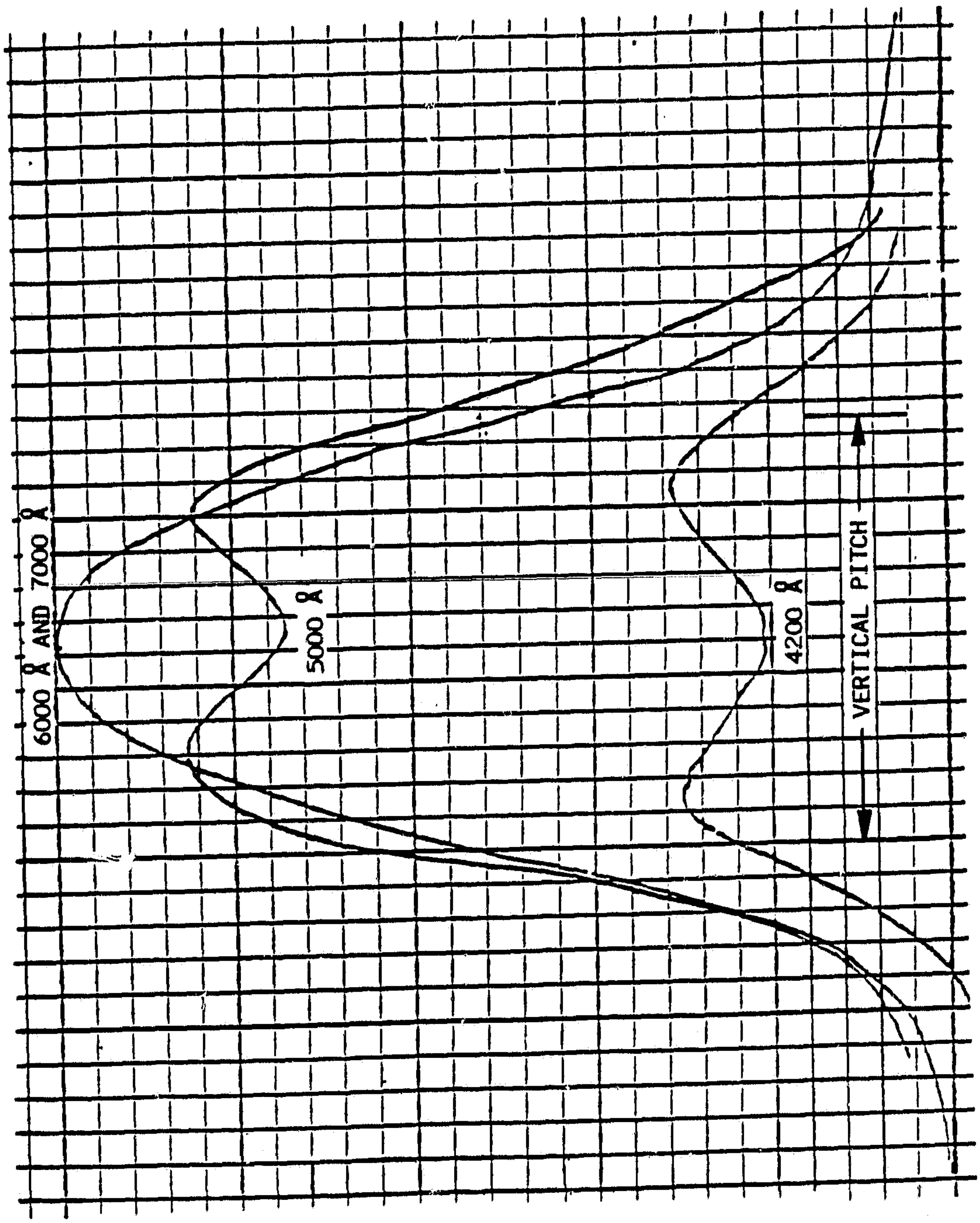



Figure 4-2 CID Pixel Point Response - Vertical (BASD Detector)

ORIGINAL PAGE IS
OF POOR QUALITY

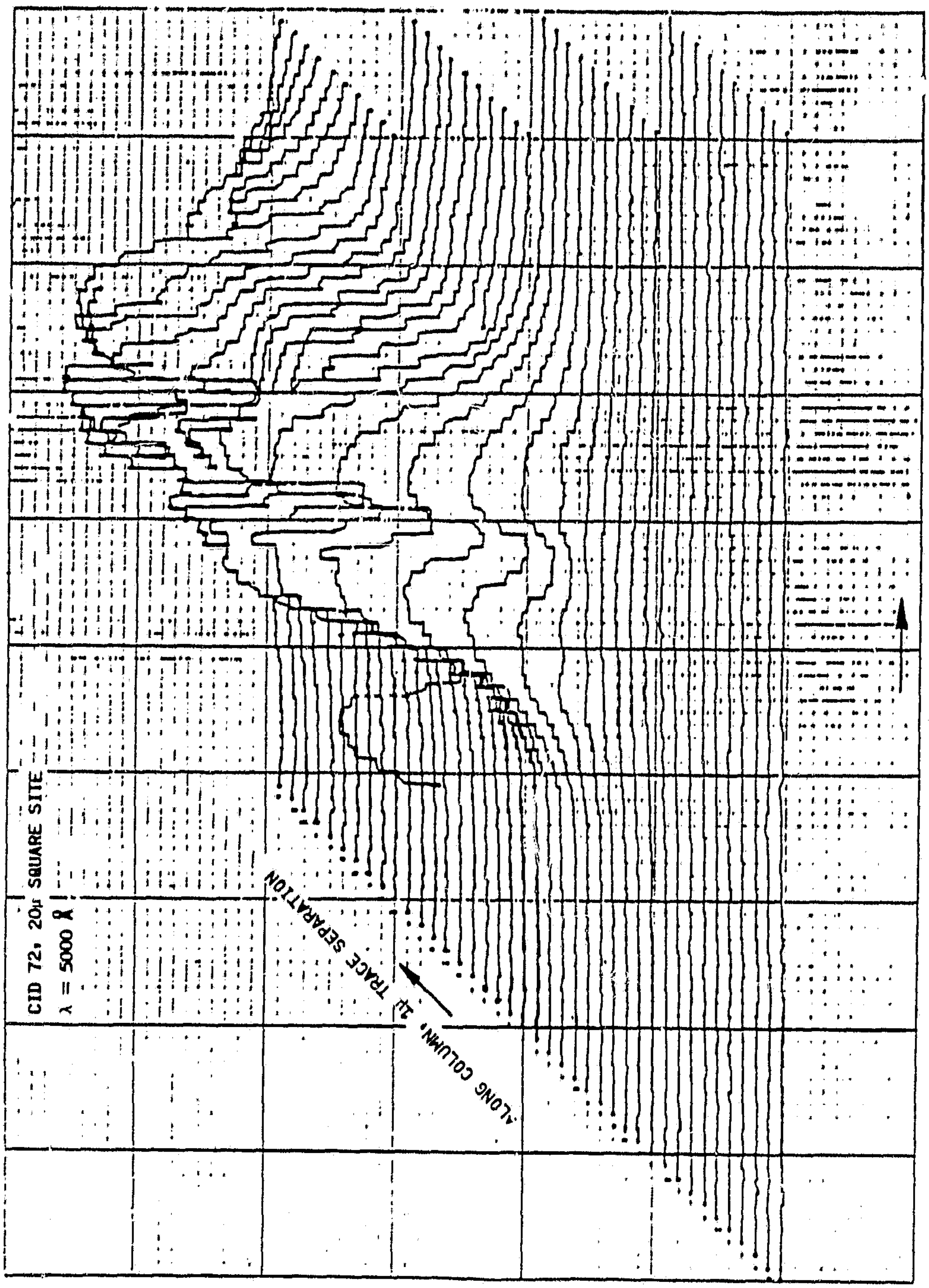



Figure 4-3 CID Pixel Point Response (MSFC Detector)

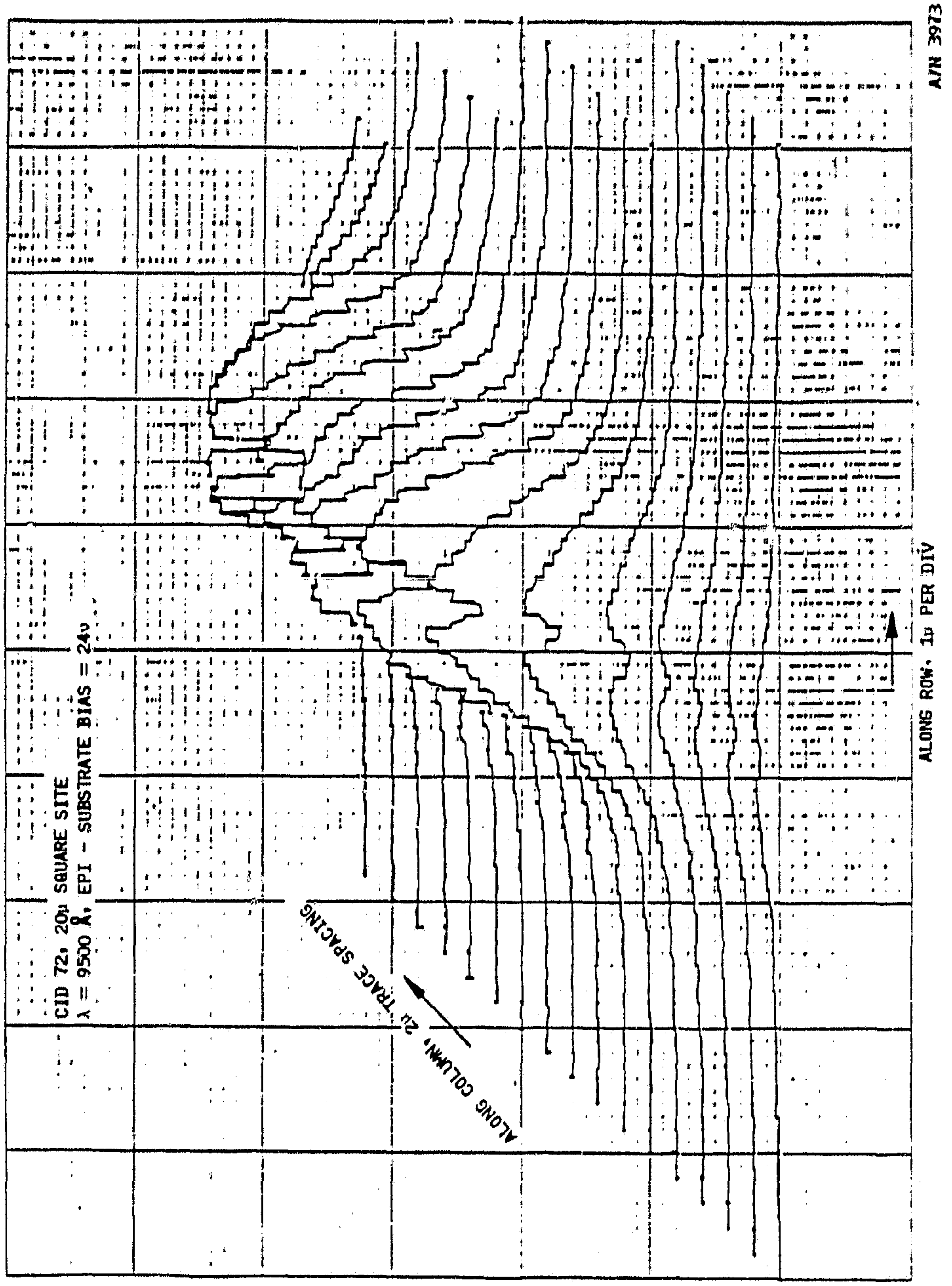



Figure 4-4 CID Pixel Point Response (MSFC Detector)

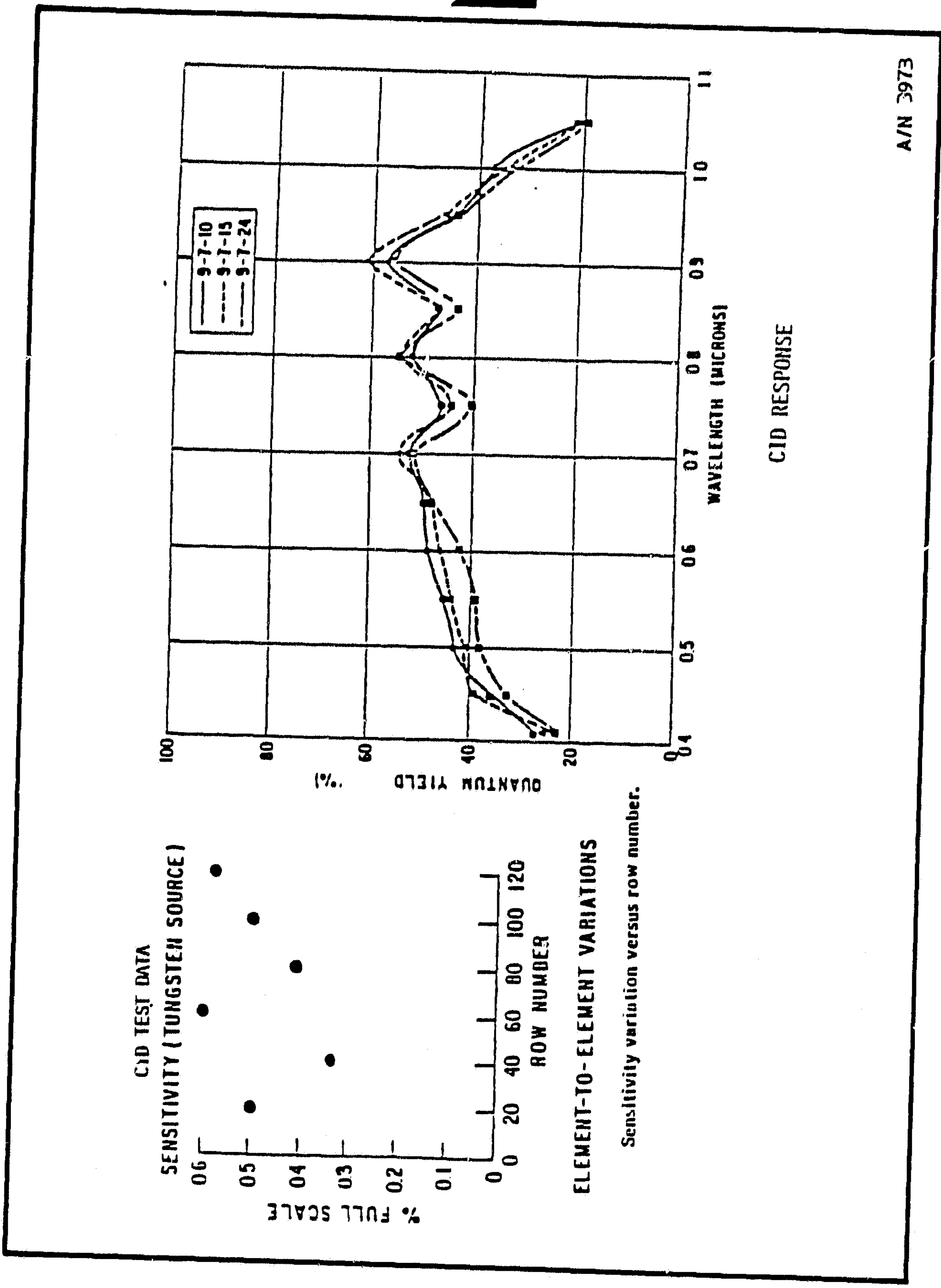



Figure 4-5 CID Response and Variations

## 4.2 PIXEL AND IMAGE SPREAD RESPONSE

Column and row pixel data from the test program can be used to display the convolution of pixel point response with the image point spread function. Figures 4-6 and 4-7 are samples of the typical spread functions for the rows and columns derived from pixel data as the image moved across the track pattern. The data shown is for the best focus with white light using the BASD detector and is similar to that for other colors.

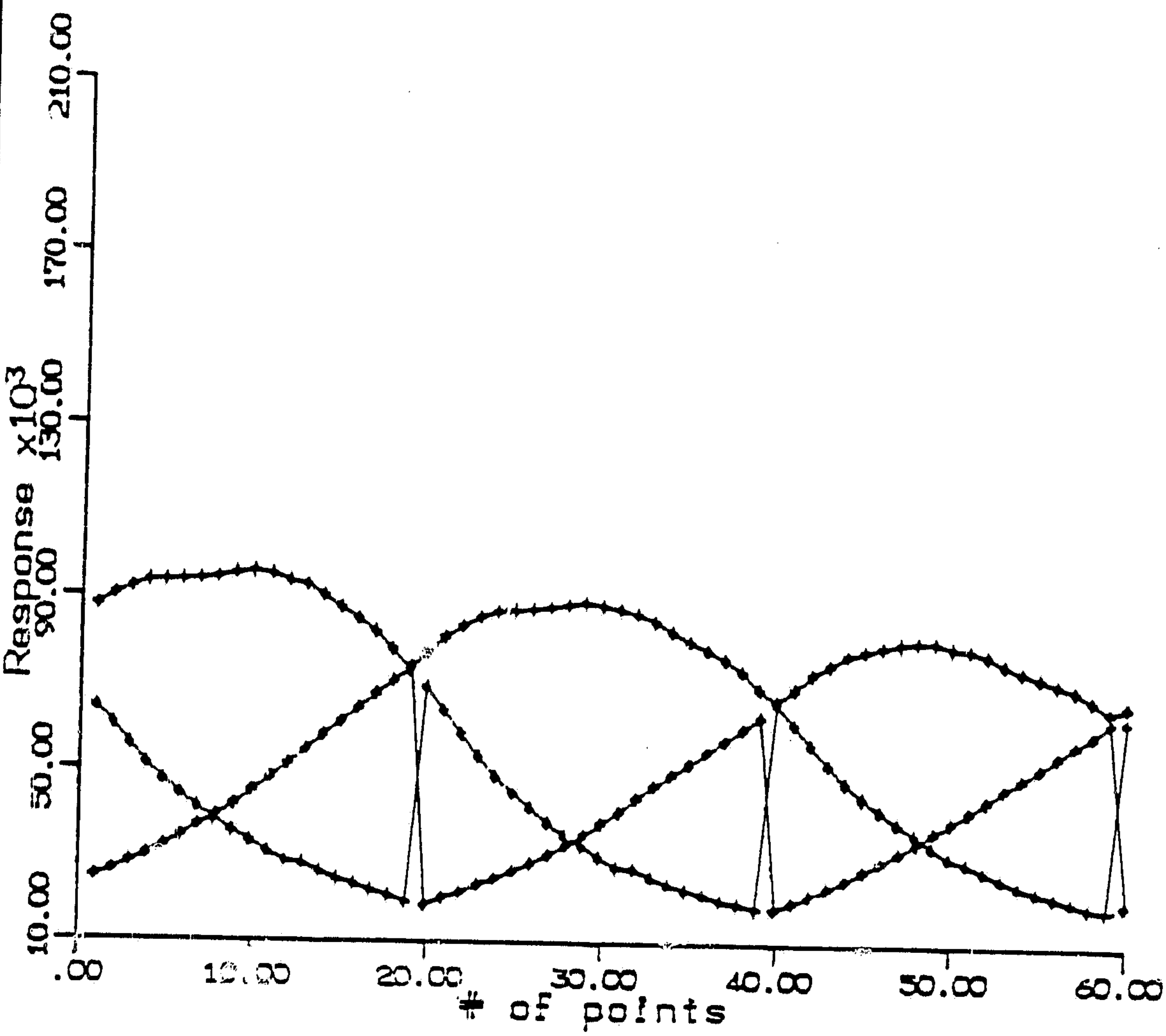
Note that the finite image size (unknown) has smoothed the effects of the pixel electrode structure and results in a response spread that approximates the gaussian distribution that BASD used to develop their algorithms.

Response for the MSFC detector under the same conditions is shown in Figures 4-8 and 4-9 and shows more evidence of the electrode structure than the BASD detector did.

Although it is possible to refine the algorithms to take into account the best response shape, the test setup was not controlled to the precision required to reliably characterize the response. Furthermore, it is questionable whether it can be controlled to the level required for improvements over the current performance. A better approach may be to observe the systematic characteristics of the interpixel transfer functions (position vs. output) and make corrections to achieve the desired results; without specific knowledge of the parameter that is being corrected.

## 4.3 INTERPIXEL TRANSFER FUNCTION (POSITION VS. OUTPUT)

The ultimate performance of the tracker is determined by how well the output describes the position of the source image within the FOV. Since the pixels give a spatial (or angular) digital resolution equivalent to their dimensions, the objective is to accurately interpolate the position between pixels. This is done with a centroiding algorithm using the pixel/image response discussed above. The limit would be a system implementation that is essentially limited by the detector random anomalies; a feat not yet achieved by CTD users.




A/N 3973

Figure 4-6 Row Crossings Image/Pixel Spread Response (BASD Detector) for White Light at Best Focus

ORIGINAL PAGE IS
OF POOR QUALITY

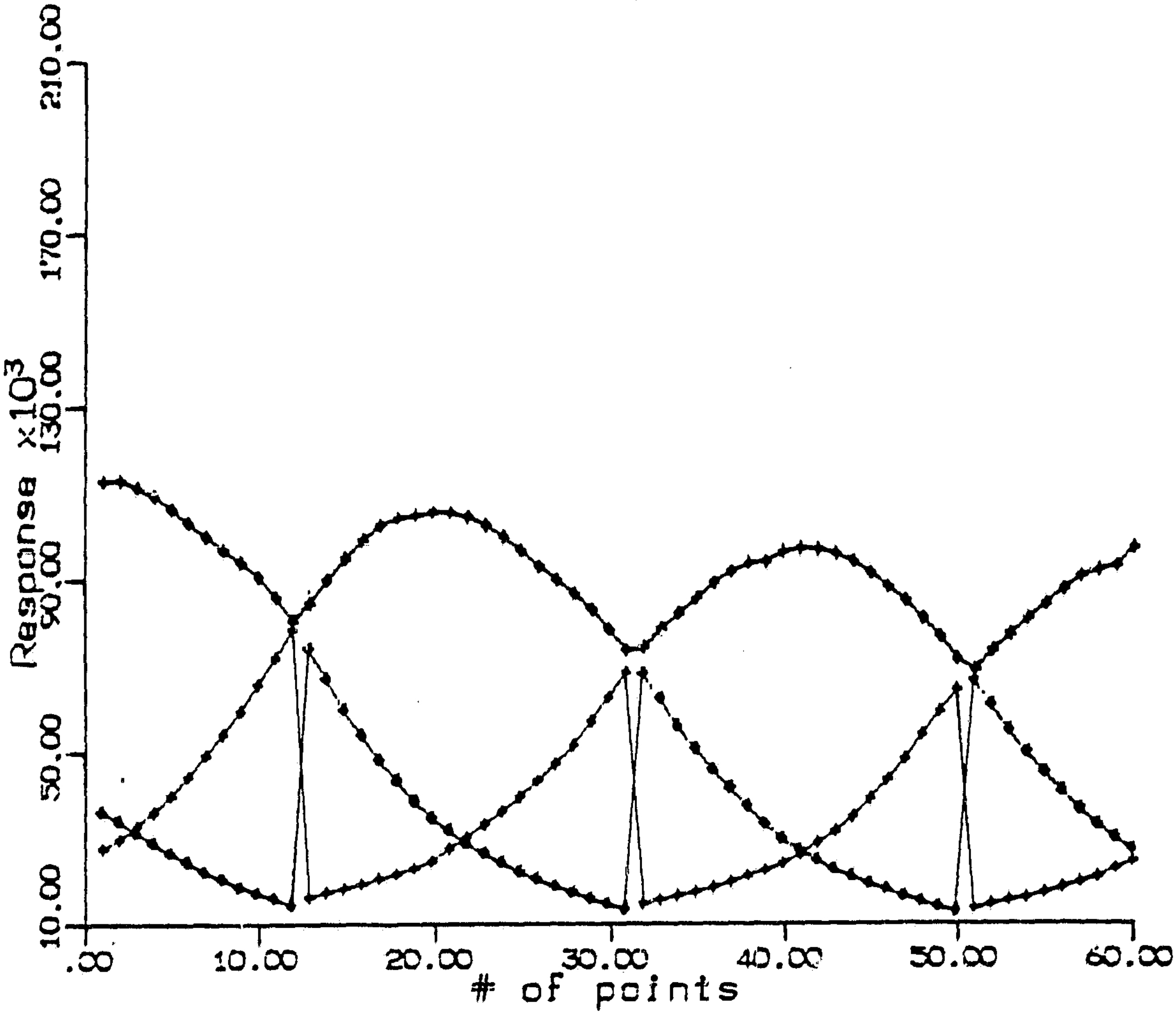



Figure 4-7 Column Crossings Image/Pixel Spread Response (BASD Detector) for White Light at Best Focus

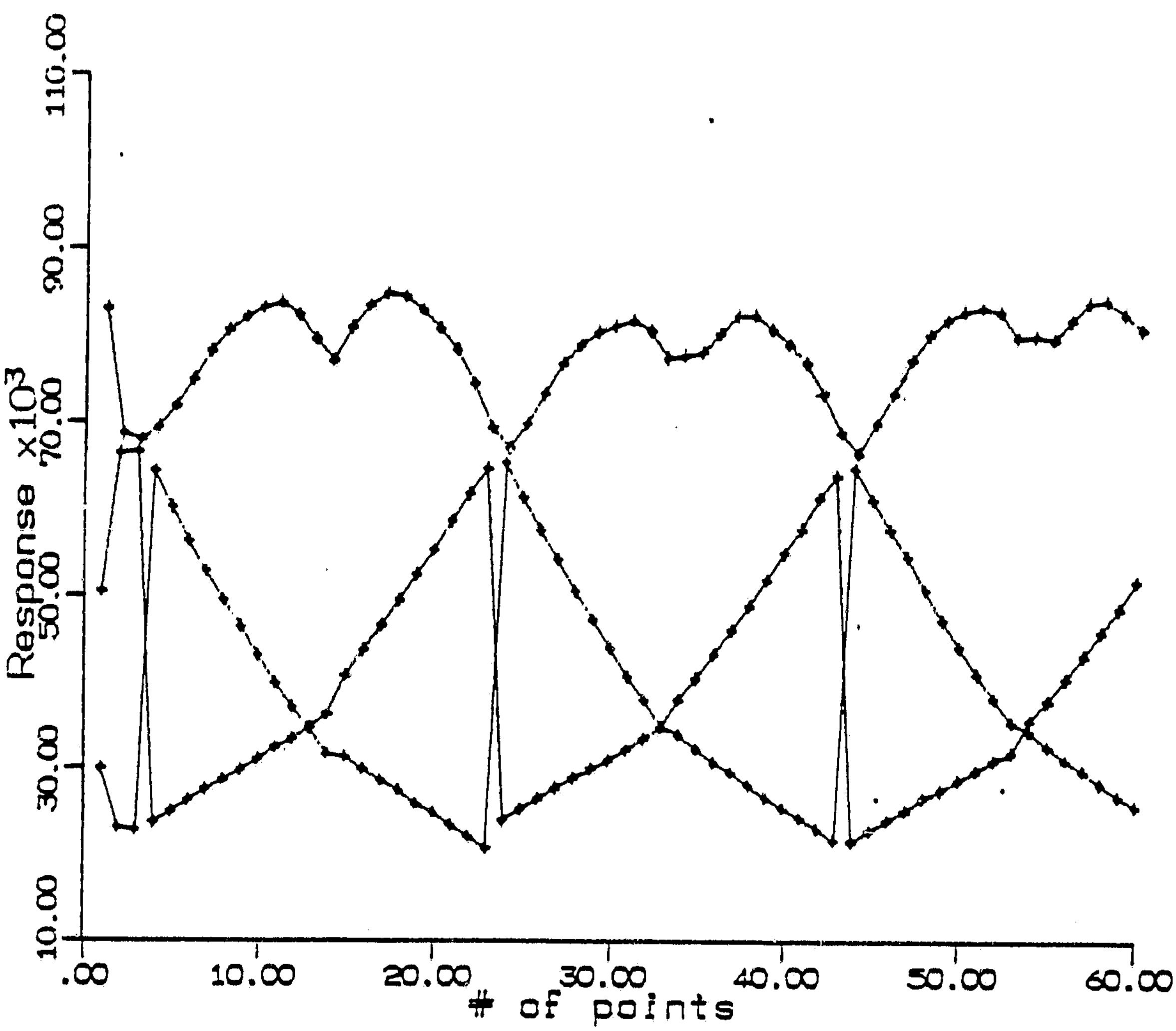



Figure 4-8 Row Crossings Image/Pixel Spread Response (MSFC Detector) for White Light at Best Focus

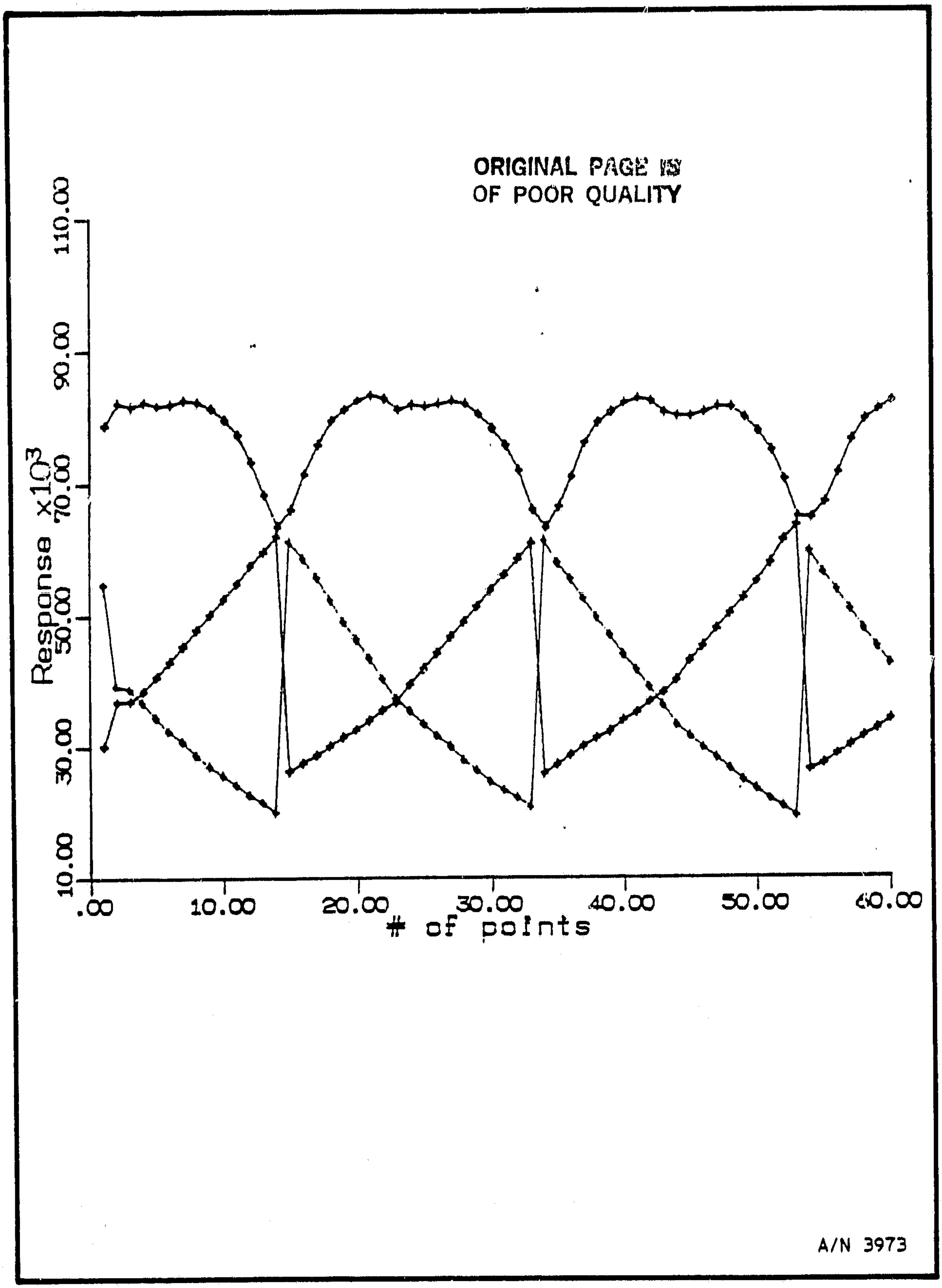



Figure 4-9 Column Crossings Image/Pixel Spread Response (MSFC Detector) for White Light at Best Focus

Based on the performance parameters of the CID that were supplied by GE this detector should limit tracker accuracy to approximately 0.005 pixels with a perfect system implementation. BASD's system implementation and position algorithms show promise to approach this limit with a relatively broad range of variation in system parameters.

The objective of this program was to introduce variations in focus and color, the two most damaging and uncontrollable parameters, and observe their affects on performance.

### 4.3.1 Transfer Function With 8 Pixel Algorithm

The data plots of Figure 4-10 and 4-11 are representative of some of the better data observed for the eight pixel algorithm prior to discovering a serious problem with the breadboard optics concept. It was taken with BASD's detector and shows performance close to that predicted by analysis. However, it also reveals a cross axis coupling effect each time the track pattern is moved and a slight, systematic, nonlinearity of the transfer function, especially crossing the columns. These anomalies could not be detected with the previous test approach used by BASD and it is expected that this data will show accuracy performance in the same 0.01 to 0.02 pixel range as previously observed. The anomalies can be corrected with hardware and software which will improve performance. Some significant points about this data are summarized below.

- The position output, f(x) or f(y), goes through four transitions as the image is moved across one pixel. The output, therefore, cycles between 0 and 0.25 and the algorithm forces it to these limits in a linear manner independent of image size, shape, or intensity. Thus, in effect, the digital resolution has been quadrupled and the transfer function provides extremely high accuracy between transitions.

- Anomalous appearance of data near the 0 and 0.25 points is a result of insufficient resolution, in the position increments, to achieve a data point at those positions.

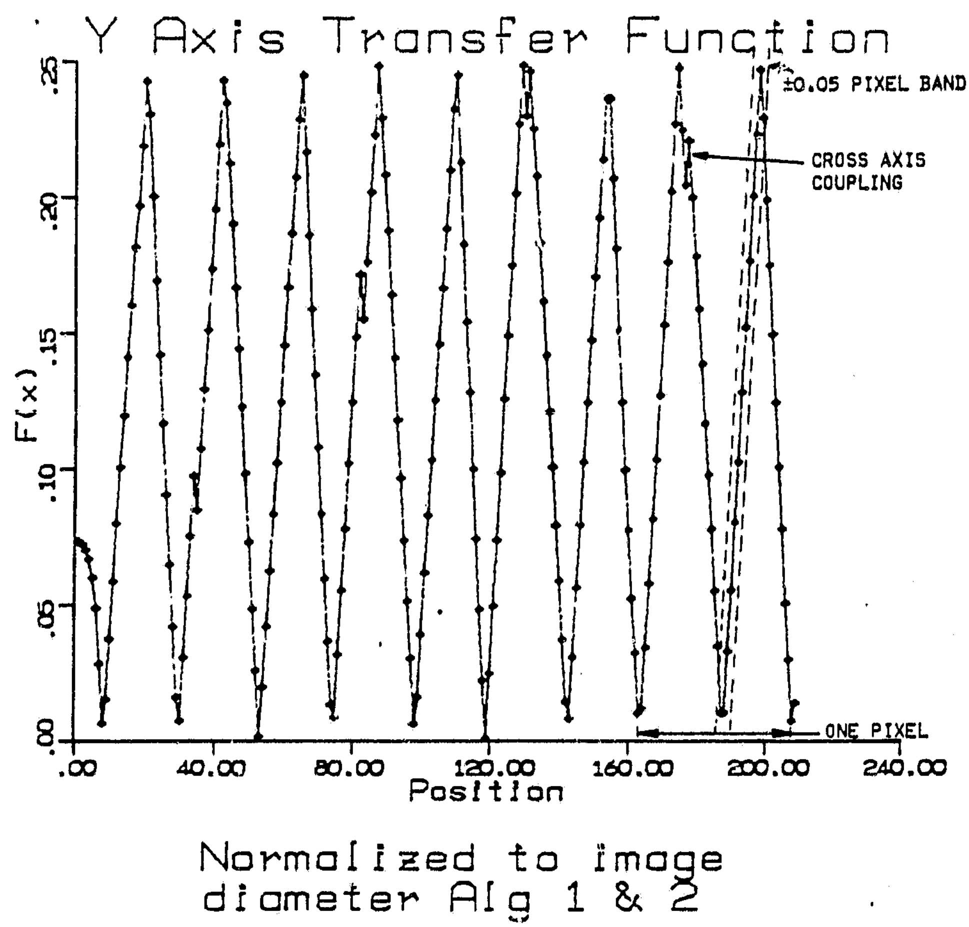
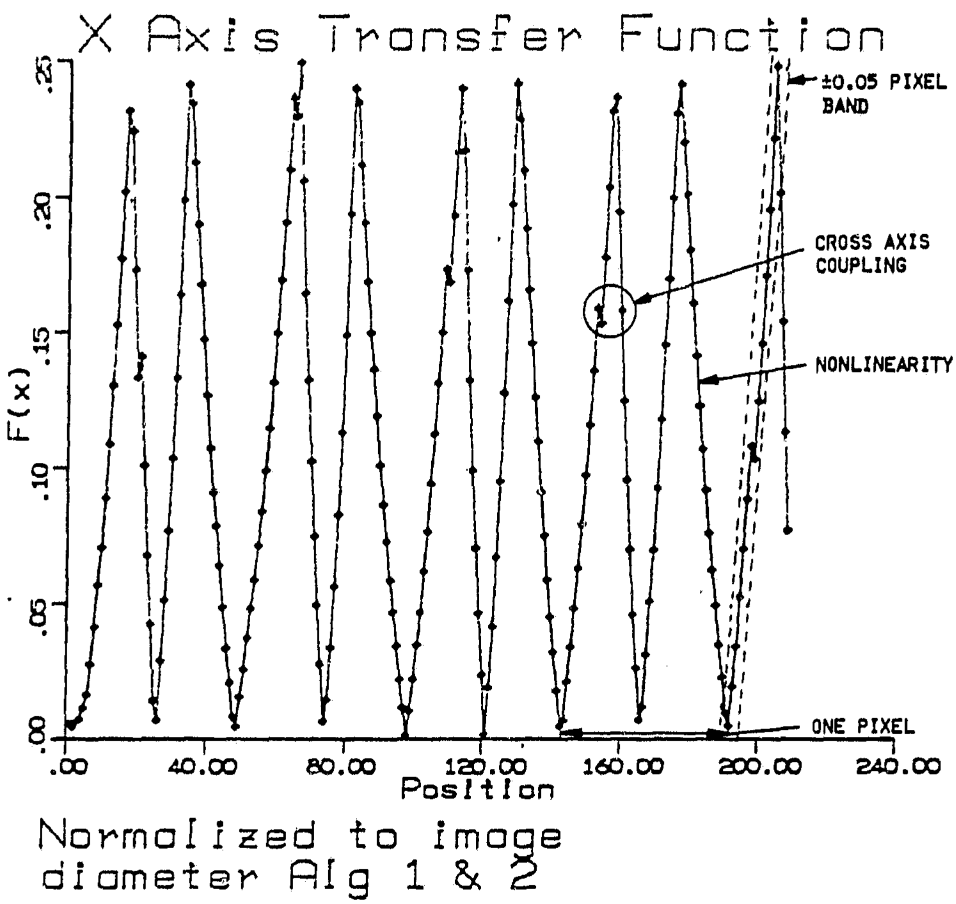



Figure 4-10 Eight-Pixel Transfer Function (BASD Detector) for Row Crossings




A/N 3973

Figure 4-11 Eight-Pixel Transfer Function (BASD Detector) for Column Crossings

- The ±5% error band is shown only to illustrate the scale. This is equivalent to a ±2 arc second error band for the three degree FOV. It is expected the RMS error for this data is less than ±2% (less than 1 arc second). Approximately 50 data points were taken per pixel crossing giving them a relative spacing of less than one arc second.

- The transients in either axis were caused by asymmetrical image coupling when the track pattern was moved one pixel in the opposite axis to keep the star centered. This problem can be eliminated with a hardware change.

- The noticeable nonlinearity, especially in the column crossings, is a result of a nongaussian pixel/image response and approximations that were made in the development of the algorithm. Corrections can be introduced in software when the parameters are characterized through more detailed analysis of the data.

- The asymmetry of half pixel transitions, more noticeable in column crossings, is a result of misalignment in the optics. This characteristic will be removed by selection of constants from the test data, since perfect alignment is difficult to achieve. Analysis has shown that up to 20% asymmetry can be corrected without adversely affecting other system performance parameters. It is this parameter that was extremely sensitive to axial position with the breadboard optics.

- Once the proper constants are chosen for symmetry and the optics have been corrected, any variations in the half pixel transition lengths will be a result of pixel-to-pixel reponse and dark current variations. The combined effect of these variations is expected to result in an error of approximately 0.005 pixel (RMS).

### 4.3.2 Transfer Function for 9 Pixel Algorithm

The nine pixel algorithm has the same features as the eight pixel one except that the former cycles over half pixel increments, resulting in half the digital resolution, and has a lower internal scale factor (signal per unit displacement). Analysis has shown that, with proper implementation, the eight pixel concept would give a scale factor twice that of the nine pixel resulting in an equivalent improvement in noise equivalent angle (NEA).

An advantage of the nine pixel algorithm is that it does not require unique optics.

The transfer functions in each axis and related image/pixel response for the nine pixel algorithm are shown in Figures 4-12 through 4-17 for the MSFC detector with red, white, and blue light at best focus. The results are similar to the eight pixel concept where now the output cycles are forced to 0 and 0.5 to represent half pixel transitions. Some observations are summarized below.

- The position output, f(x) or f(y), goes through two cycles per pixel transition thus effectively doubling the digital resolution for the CID.

- The gross cross axis coupling observed in the eight pixel concept is not evident here because of the difference in optics. Minor cross coupling effects are evident resulting from pixel to pixel response or dark current variations.

- Data near the 0 and 0.5 levels appear anomalous because the granularity of samples was not sufficient to sample at the exact 0 and 0.5 positions.

- There is asymmetry in slopes and the resultant effect of indicated pixel centers. This phenomenon reflects the asymmetry in the related image/pixel spread response which may be caused by either the lens, detector, or both.

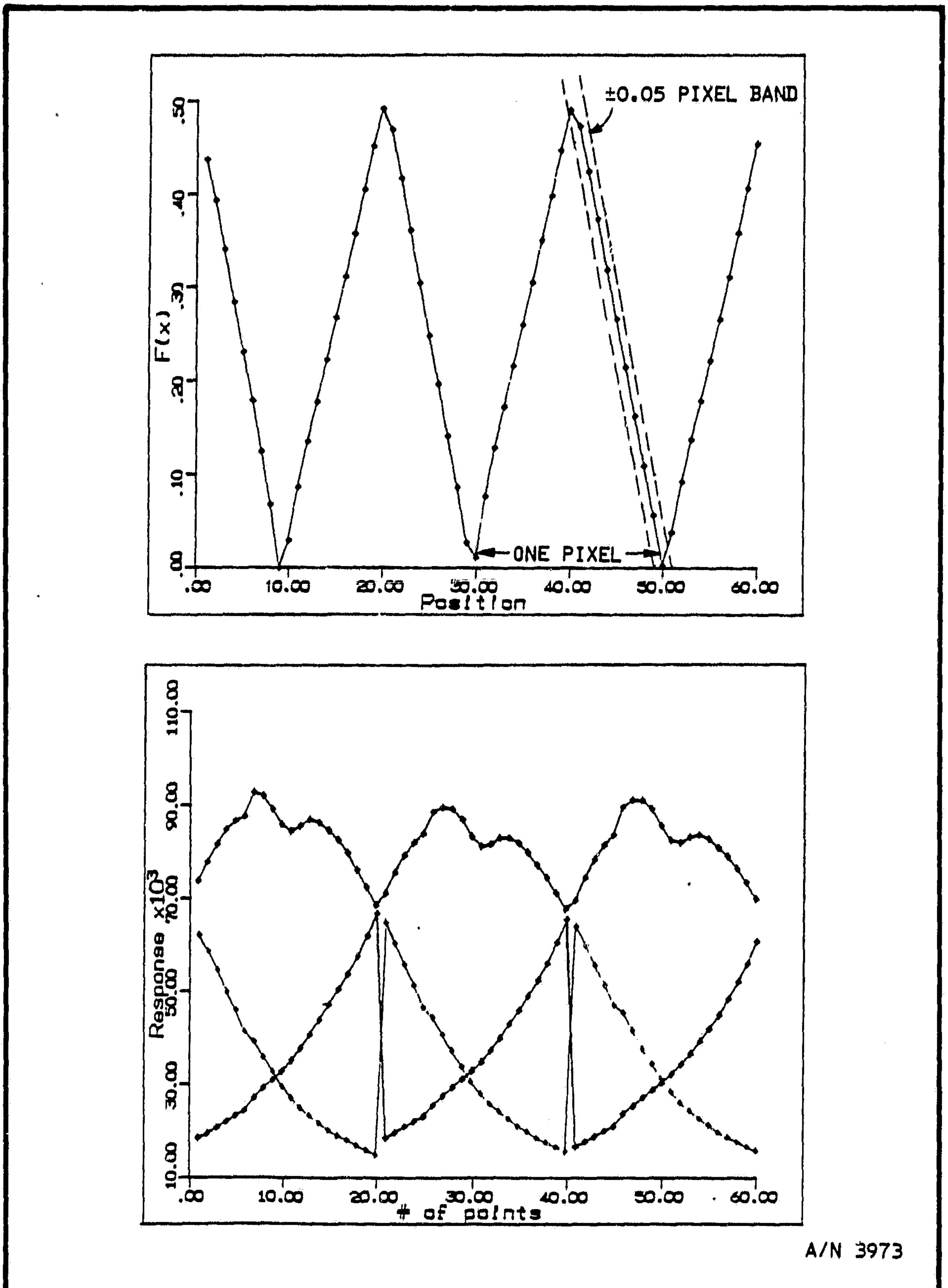



Figure 4-12 Transfer Function and Image/Pixel Spread Response (MSFC Detector) for Red Light, Best Focus, Crossing the Rows

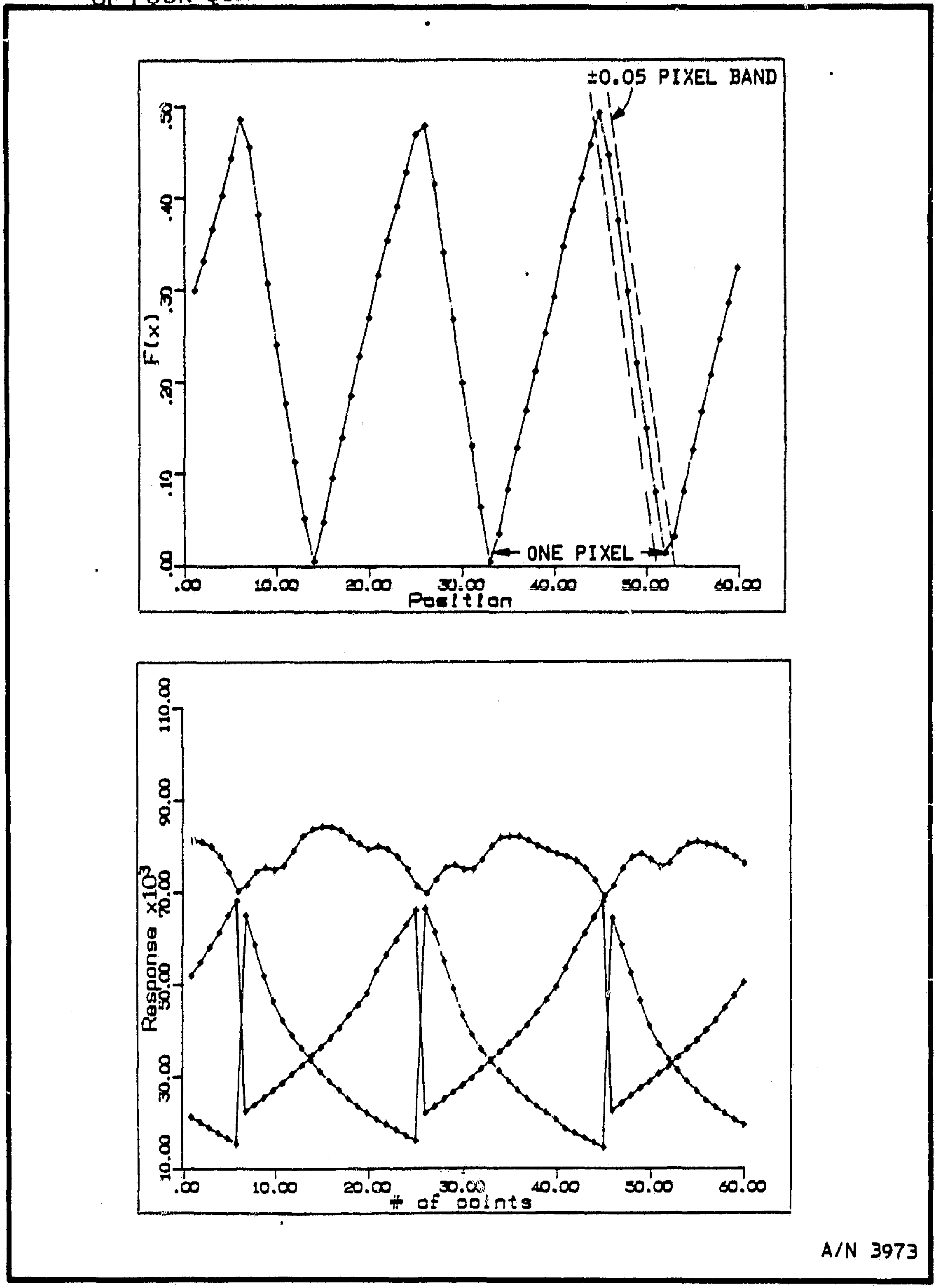



Figure 4-13 Transfer Function and Image/Pixel Spread Response (MSFC Detector) for Red Light, Best Focus, Crossing the Columns

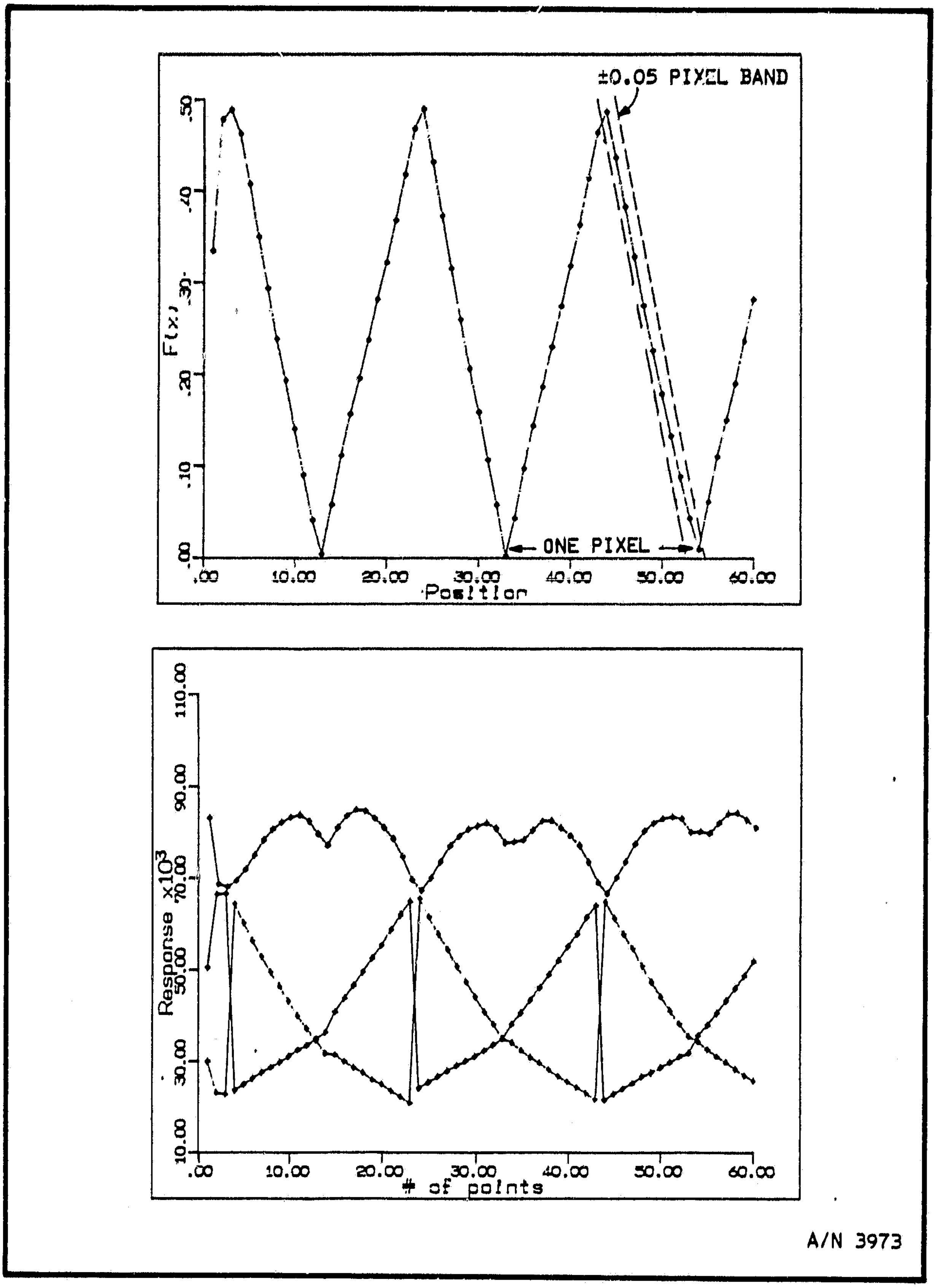
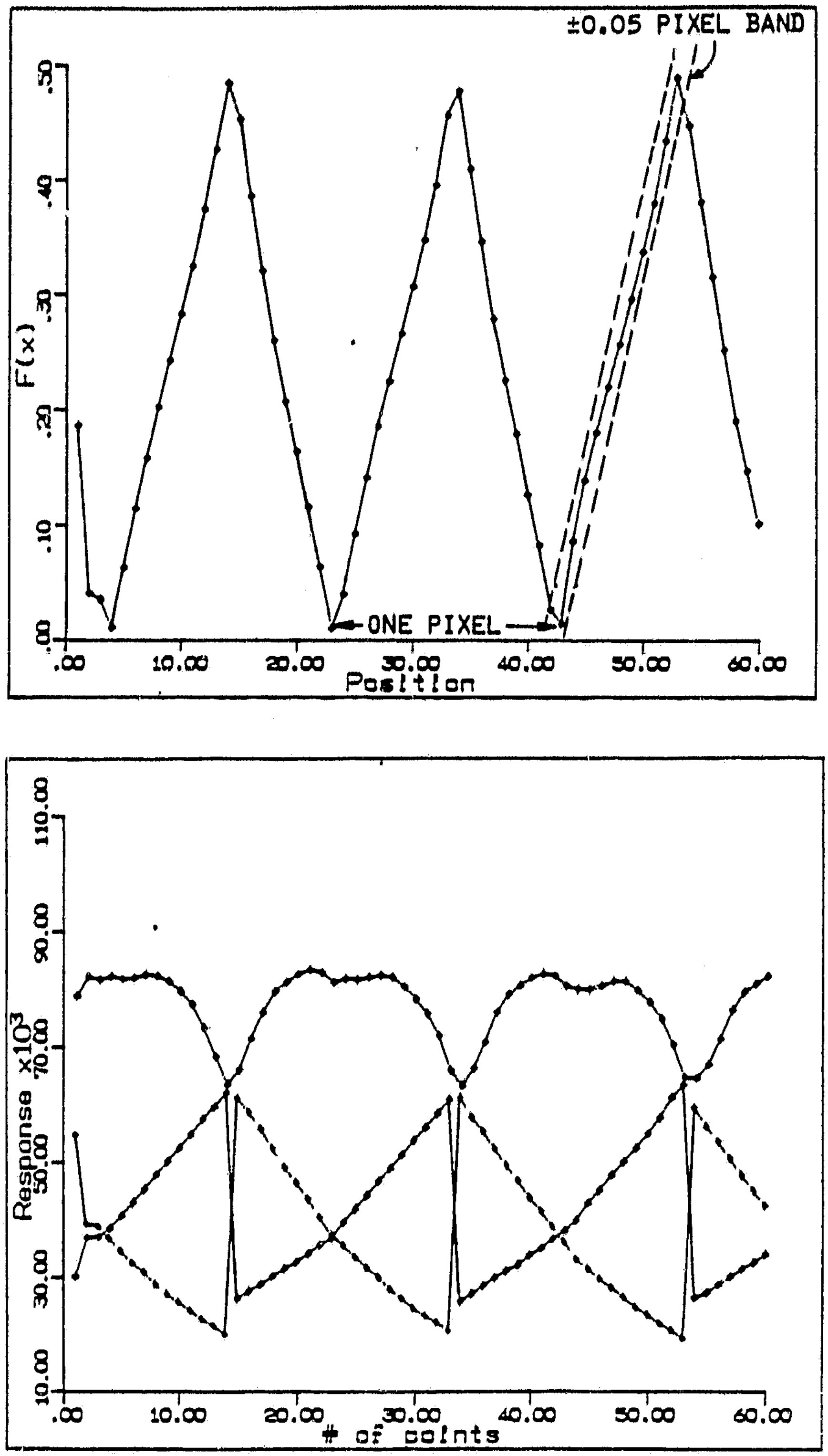



Figure 4-14 Transfer Function and Image/Pixel Spread Response (MSFC Detector) for White Light, Best Focus, Crossing the Rows

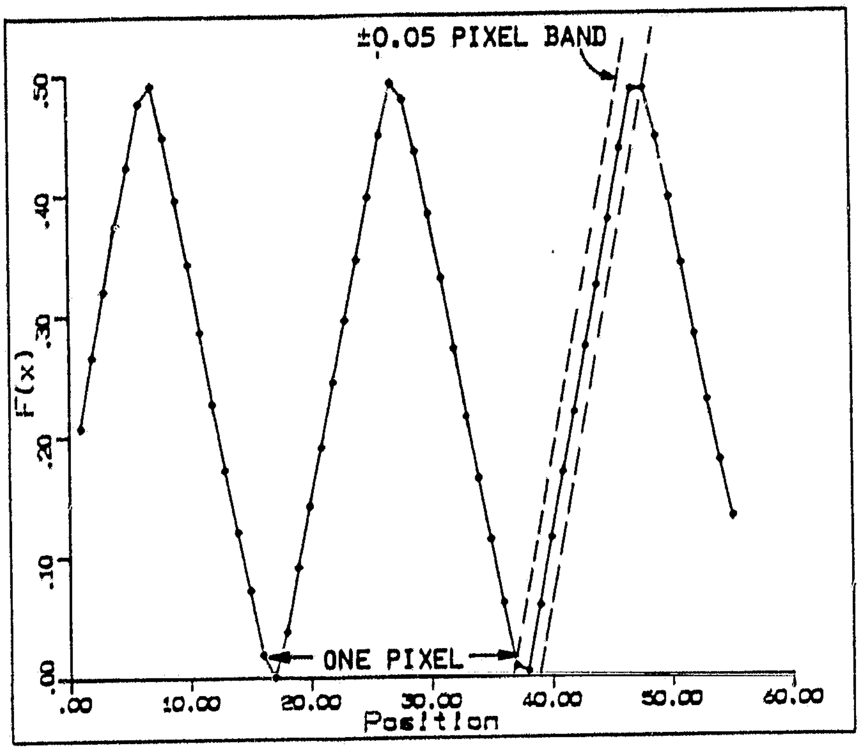


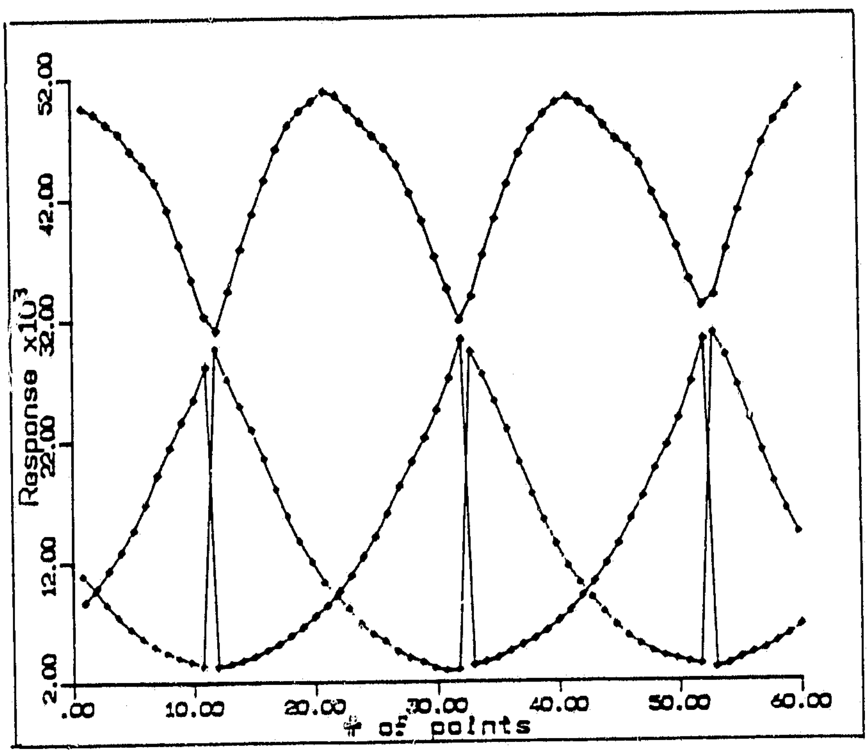

A/N 3973

Figure 4-15 Transfer Function and Image/Pixel Spread Response (MSFC Detector) for White Light, Best Focus, Crossing the Columns

ORIGINAL PAGE IS
OF POOR QUALITY

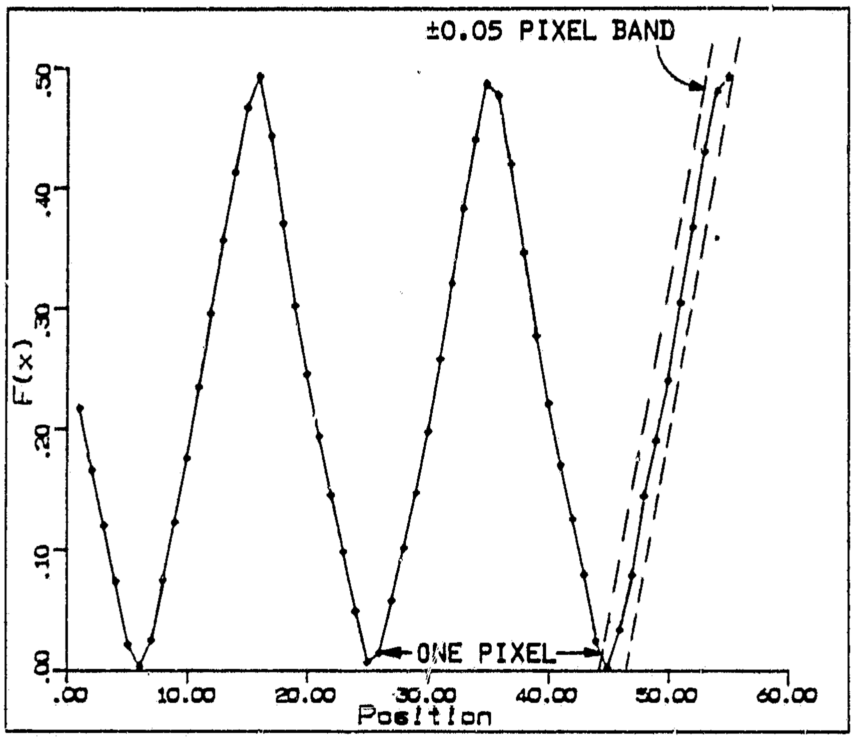


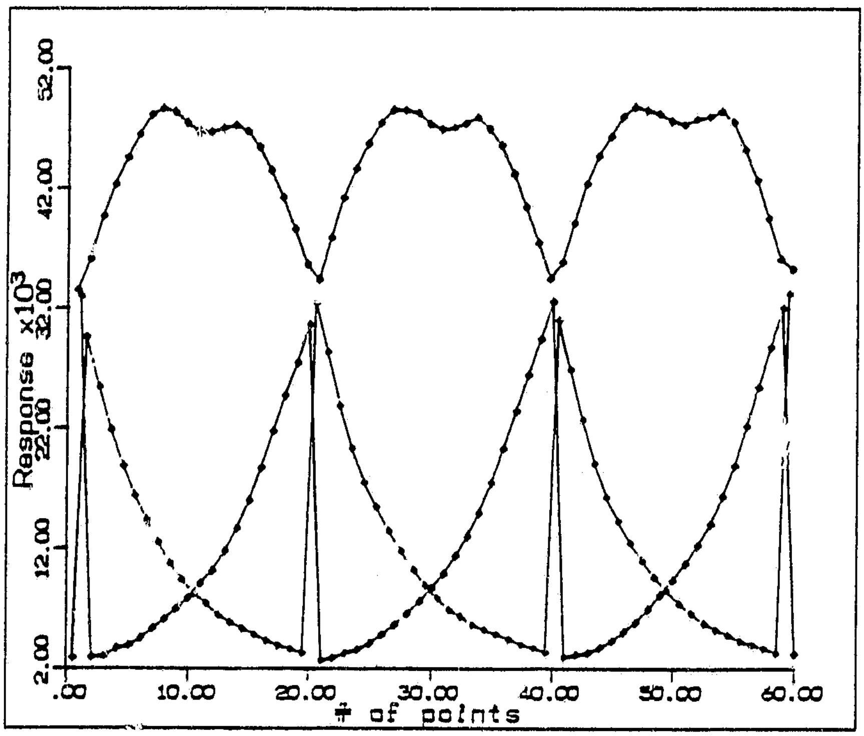



A/N 3973

Figure 4-16 Transfer Function and Image/Pixel Spread Response (MSFC Detector) for Blue Light, Best Focus, Crossing the Rows




A/N 3973

Figure 4-17 Transfer Function and Image/Pixel Spread Response (MSFC Detector) for Blue Light, Best Focus, Crossing the Columns

- As predicted from math models, the position algorithm is extremely tolerant of image/pixel response variations. Some of the systematic variations observed in the data may be reduced by minor modifications to the algorithm and lens properties.

## 4.4 FIXED PATTERN NOISE TEST

For precision tracking the CID is typically read, nondestructively, twice per update and the two readings subtracted to eliminate fixed pattern noise (FPN). This process results in signal loss which could be retrieved if the pattern noise was characterized and subtracted from single readings of the signal plus pattern noise. Implementation of this concept would require that the pattern noise be stable with time.

A test was therefore conducted over a period of several months to evaluate the FPN stability.

Maps of 12 x 12 pixels were taken periodically under dark conditions at the same location on the chip and at the same chip temperature. Single readings with one hundred NDROs each were used for the data sets.

A sample of data from 30 pixels was reviewed by BASD and showed that the FPN varied by approximately 5,000 $e^-$ (RMS) over several days with a maximum variation 12,000 $e^-$. The readout noise was then measured to determine the random noise contribution. The results, using 113 $e^-$ per count, were as follows.

channel 0..........................208 $e^-$/read
1..........................168 $e^-$/read
2..........................216 $e^-$/read
3..........................216 $e^-$/read

The readout noise was determined from a set of 30 readings from each channel using 200 NDROs. This data indicates that there is drift in the FPN with time, for if there were not, the variations should not exceed the readout noise. More detailed analysis by MSFC should reveal the extent of this drift.

## 4.5 GENERAL COMMENTS

The test results presented in this report were derived with commercial optics and algorithms developed by BASD using idealized image spread, and pixel response functions. From a qualitative review of the data it is evident that the algorithms are working, as predicted, to compensate for the many variables that exist in a tracker system of this type. It is also suggested that adjustments to the algorithms and optics will yield performance that more closely approaches the performance capability of the detector. Achieving that objective would provide a tracker with a focal plane accuracy of better than 1 part in 50,000 (RMS) using the GE ST-256 CID.

This test program has been extremely valuable in identifying problems that are correctable and providing evidence that performance of a detector limited system can be closely approached. Improvements are expected as a result of the detailed data analysis by MSFC and further development and study efforts by BASD.

# Appendix A
# DATA SUBMITTED TO MSFC

THE TRACK DATA CONTAINS COMMENTS IN THE FIRST PART OF EVERY RECORD.

THESE COMMENTS ARE DEFINED AS:

| SYMBOL | PARAMETER | UNITS |
|---|---|---|
| VL | LAMP VOLTAGE | V |
| FN | NEUTRAL DENSITY FILTER | No |
| FS | SPECTRAL FILTER | nm |
| DS | SOURCE DISTANCE | M |
| DP | PENHOLE SIZE | um |
| DI | INCREMENTAL STEP SIZE @ STAGE | um |
| W | WATER PUMP ON/OFF | -- |
| IT | TEC CURRENT | mA |
| F | FOCUS, PK=PEAK,+- n um | -- |
| T | ISOLATION TABLE ON/OFF | -- |
| RN | RUN NUMBER | -- |

DATA SENT ON MARCH 23, 1983

8 PIXEL ALGORITHM
BASD FOCAL PLANE

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=12 IL=5 FN= 3.0 FS=WHITE DS= 1.9 DP= 25
DI= 16.6 W= OFF IT=400 T=ON F=PEAK

| RUN # | FILE # |
|---|---|
| 1 | MDATA00-MDATA39 |
| 2 | MDATA40-MDATA79 |
| 3 | MDATA80-MDATA99<br>MDAT100-MDAT119 |
| 4 | MDAT120-MDAT159 |

DATA SENT ON APRIL 15, 1983

8 PIXEL ALGORITHM
BASD FOCAL PLANE

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=10.2 FN=4.0 FS=- DS=1.9 DP=25 DI=16.6 T=ON

| RUN # | COMMENTS | FILE # |
|---|---|---|
| 1 | TEC ONLY | 000-049 |
| 2 | 5 STARS, TEC ONLY | 050-099 |
| 3 | 5 STARS, TEC ONLY | 100-149 |
| 4 | TEC AND ICE, FOCUSED AT TEMP, OTHERWISE SAME AS #1 | 150-199 |
| 5 | 20 STARS, TEC AND ICE, DEFOCUS +2 MILS | 200-249 |
| 6 | 20 STARS, TEC AND ICE, DEFOCUS -2 MILS | 250-299 |

DATA SENT ON JUNE 24, 1983

.8 PIXEL ALGORITHM
BASD FOCAL PLANE

| RUN # | COMMENTS | FILE # |
|---|---|---|
| 1 | 10 STARS, +2 MILS DEFOCUS, WHITE LIGHT, 100 POSITIONS | 000-099 |
| 2 | 10 STARS, PEAK FOCUS, WHITE LIGHT, 100 POSITIONS | 100-199 |
| 3 | 10 STARS, -2 MIL DEFOCUS, WHITE LIGHT, 100 POSITIONS | 200-299 |
| 4 | 10 STARS, PEAK FOCUS, RED LIGHT, 100 POSITIONS | 300-399 |
| 5 | 10 STARS, +2 MIL DEFOCUS, RED LIGHT, 100 POSITIONS | 400-499 |
| 6 | 10 STARS, -2 MIL DEFOCUS, RED LIGHT, 100 POSITIONS | 500-599 |
| 7 | 47 STARS, +2 MIL DEFOCUS, RED LIGHT, 100 POSITIONS | 600-699 |
| 8 | 47 STARS, PEAK FOCUS, WHITE LIGHT, 100 POSITIONS | 700-799 |
| 9 | 3 STARS, PEAK FOCUS, WHITE LIGHT, 254 POSITIONS | 1000-1253 |
| 10 | 1 STAR, PEAK FOCUS, WHITE LIGHT, 254 POSITIONS | 0000-0253 |

DATA SENT ON SEPTEMBER 21, 1983

8 PIXEL ALGORITHM
BASD FOCAL PLANE

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=12 IL=5 FN=0.4 FS=GREEN DS=3.45M DP=180
DI=475uM W=ON/ICE IT=400 T=ON 100 POSITIONS

| RUN # | FOCUS | FILE # | |
|---|---|---|---|
| 1 | +13.0 MILS | 1300-1399 | T=OFF |
| 1 | +13.0 MILS | 1400-1499 | |
| 1 | +12.0 MILS | 1500-1599 | |
| 1 | +14.0 MILS | 1600-1699 | |

DATA SENT OCTOBER 20,1983

8 PIXEL ALGORITHM MSFC0200-1899.DAT
9 PIXEL ALGORITHM MSFC0000-0199.DAT
BASD FOCAL PLANE

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=12 IL=5 FN=- FS=BLUE/GREEN FILTER #3368
DS=6.09 DI=475uM W=ON/ICE IT=400 T=ON 100
POSITIONS

| RUN # | FOCUS | FILE # |
|---|---|---|
| 1 | -12.0 MILS | 0000-0099 |
| 2 | +13.3 MILS | 0100-0199 |
| 3 | +14.3 MILS | 0200-0299 |
| 4 | +12.3 MILS | 0300-0399 |
| 5 | +11.0 MILS | 0400-0499 |
| 6 | +10.0 MILS | 0500-0599 |
| 7 | +12.0 MILS | 0600-0699 |
| 8 | +9.0 MILS | 0700-0799 |
| 9 | +8.0 MILS | 0800-0899 |
| 10 | +10.0 MILS | 0900-0999 |
| 11 | +7.5 MILS | 1000-1099 |
| 12 | +6.5 MILS | 1100-1199 |
| 13 | +8.5 MILS | 1200-1299 |
| 14 | +6.0 MILS | 1300-1399 |
| 15 | +5.0 MILS | 1400-1499 |
| 16 | +7.0 MILS | 1500-1599 |
| 17 | +1.5 MILS | 1600-1699 |
| 18 | +0.5 MILS | 1700-1799 |
| 19 | +2.5 MILS | 1800-1899 |

ORIGINAL PAGE IS
OF POOR QUALITY

THERE WERE SOME CHANGES MADE IN THE COMMENT SECTION FOR THE TRACK DATA FILES:

| SYMBOL | PARAMETER | UNITS |
|---|---|---|
| VL | LAMP VOLTAGE | V |
| *ND | NEUTRAL DENSITY FILTER | No |
| *SF | SPECTRAL FILTER | nm |
| *FS | F-STOP | -- |
| DS | SOURCE DISTANCE | M |
| DP | PENHOLE SIZE | um |
| DI | INCREMENTAL STEP SIZE @ STAGE | um |
| W | WATER PUMP ON/OFF | -- |
| IT | TEC CURRENT | mA |
| F | FOCUS, PK=PEAK,+- n um | -- |
| T | ISOLATION TABLE ON/OFF | -- |
| RN | RUN NUMBER | -- |

NOTE: * ARE CHANGED VARIABLES

DATA SENT NOVEMBER 8,1983

ORIGINAL PAGE IS OF POOR QUALITY

9 PIXEL ALGORITHM
BASD FOCAL PLANE

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=12 IL=5 ND=0.5 SF=- FS=2.8 DS=6.09 DP=180 DI=475uM
W=ON/ICE IT=400 T=ON 100 POSITIONS

| RUN # | FOCUS | FILE # |
|---|---|---|
| 1 | -15.0 MILS | 0000-0099 |
| 2 | +14.5 MILS | 0100-0199 |
| 3 | -14.5 MILS | 0200-0299 |
| 4 | +14.0 MILS | 0300-0399 |
| 5 | -14.0 MILS | 0400-0499 |

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=12 IL=5 ND=0.9 SF=LWP #543 FS=2.8 DS=6.09 DP=180
DI=475uM W=ON/ICE IT=400 T=ON 100 POSITIONS

| RUN # | FOCUS | FILE # |
|---|---|---|
| 6 | -13.0 MILS | 0500-0599 |
| 7 | -13.5 MILS | 0600-0699 |
| 8 | -12.5 MILS | 0700-0799 |
| 9 | -14.0 MILS | 0800-0899 |
| 10 | -12.0 MILS | 0900-0999 |

DATA SENT DECEMBER 5, 1983

ORIGINAL PAGE IS
OF POOR QUALITY

9 PIXEL ALGORITHM
MSFC FOCAL PLANE

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=12 IL=5 ND=0.9 SF=- FS=2.8 DS=6.09 DP=180 DI=475uM W=OFF IT=400 T=ON 100 POSITIONS

| RUN # | FOCUS | FILE # |
|---|---|---|
| 1 | 0 MILS(PK) | 0000-0099 |
| 2 | -0.5 MILS | 0100-0199 |
| 3 | +0.5 MILS | 0200-0299 |
| 4 | -1.0 MILS | 0300-0399 |

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=12 IL=5 ND=0.6 SF=LWP #543 FS=2.8 DS=6.09 DP=180 DI=475uM W=OFF IT=400 T=ON 100 POSITIONS

| RUN # | FOCUS | FILE # |
|---|---|---|
| 5 | -1.67 MILS | 0400-0499 |
| 6 | -1.17 MILS | 0500-0599 |
| 7 | -0.17 MILS | 0600-0699 |
| 8 | -2.67 MILS | 0700-0799 |
| 9 | -0.67 MILS | 0800-0899 |

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=12 IL=5 ND=0.1 SF=BLUE/GREEN #3368 FS=2.8
DS=6.09 DP=180 DI=475uM W=OFF IT=400 T=ON
100 POSITIONS

| RUN # | FOCUS | FILE # |
|---|---|---|
| 10 | -2.50 MILS | 0900-0999 |
| 11 | -3.00 MILS | 1000-1099 |
| 12 | -3.50 MILS | 1100-1199 |
| 13 | -4.00 MILS | 1200-1299 |
| 14 | -4.50 MILS | 1300-1399 |
| 15 | -5.00 MILS | 1400-1499 |
| 16 | -5.50 MILS | 1500-1599 |
| 17 | -6.00 MILS | 1600-1699 |
| 18 | -6.50 MILS | 1700-1799 |

THE FINE MAP DATA WAS TAKEN IN THIS ENVIRONMENT; WITH THE LENS CAP ON, 100 NDRO'S AND AT THESE FIVE LOCATIONS ON THE CHIP:

| | |
|---|---|
| POSITION 1 | 16,16 |
| POSITION 2 | 16,48 |
| POSITION 3 | 48,48 |
| POSITION 4 | 48,16 |
| POSITION 5 | 32,32 |

| FILE NAME | DATE TAKEN |
|---|---|
| FMAP000.DAT | NOVEMBER 29, 1983 |
| FMAP001.DAT | NOVEMBER 30, 1983 |
| FMAP002.DAT | DECEMBER 1, 1983 |
| FMAP003.DAT | DECEMBER 2, 1983 |
| FMAP004.DAT | DECEMBER 5, 1983 |

DATA SENT JANUARY 16, 1984

9 PIXEL ALGORITHM
MSFC FOCAL PLANE

THESE VARIABLES REMAINED THE SAME THROUGHOUT THE TEST:

VL=12 IL=5 ND=0 SF=BLUE/GREEN #3368 FS=2.8 DS=6.09
DP=180 DI=475uM W=OFF IT=400 T=ON 100 POSITIONS

| RUN # | FOCUS | FILE # |
|---|---|---|
| 1 | -10.0 MILS(PK) | 0005-0099 |
| 2 | -10.5 MILS | 0100-0199 |
| 3 | -9.5 MILS | 0200-0299 |
| 4 | -11.0 MILS | 0300-0399 |
| 5 | -9.0 MILS | 0400-0499 |

THE FOLLOWING FINE MAP DATA WAS TAKEN IN THIS ENVIRONMENT: WITH THE LENS CAP ON, 100 NDRO'S AND AT THESE FIVE LOCATIONS ON THE CHIP:

| | |
|---|---|
| POSITION 1 | 16,16 |
| POSITION 2 | 16,48 |
| POSITION 3 | 48,48 |
| POSITION 4 | 48,16 |
| POSITION 5 | 32,32 |

| FILE NAME | DATE TAKEN | COMMENTS |
|---|---|---|
| FMAP005.DAT | DECEMBER 13, 1983 | |
| FMAP006.DAT | DECEMBER 22, 1983 | |
| FMAP007.DAT | JANUARY 4, 1984 | |
| FMAP008.DAT | JANUARY 6,1984 | |
| FMAP009.DAT | JANUARY 9, 1984 | 256 NDRO'S |
| FMAP010.DAT | JANUARY 10, 1984 | 256 NDRO'S |
| FMAP011.DAT | JANUARY 10, 1984 | |

FOR THE FOLLOWING FINE MAP DATA FILES A CHANGE WAS MADE IN THE LOCATIONS AT WHICH THE DATA WAS TAKEN:

| | |
|---|---|
| POSITION 1 | 16,16 |
| POSITION 2 | 5,64 |
| POSITION 3 | 64,64 |
| POSITION 4 | 64,5 |
| POSITION 5 | 32,32 |

| FILE NAME | DATE TAKEN | COMMENTS |
|---|---|---|
| FMAP012.DAT | JANUARY 11, 1984 | |
| FMAP013.DAT | JANUARY 12, 1984 | TAKEN IN THE AM |
| FMAP014.DAT | JANUARY 12, 1984 | TAKEN IN THE PM |
| FMAP015.DAT | JANUARY 13, 1984 | TAKEN IN THE AM |
| FMAP016.DAT | JANUARY 13, 1984 | TAKEN IN THE PM |