Ball Aerospace Systems Group

TDS and BMT for CASES ADF (ADF RAMS)

Project 3659

Acceptance Test and Final Report

Presented to

Marshall Space Flight Center

Contract Number NAS8-38581

13 February 1992

AGENDA

ADF RAMS ACCEPTANCE TEST
13 - 14 February 1992

Thursday, 13 February:

9:00	Introduction	EOC Conf. Rm.
9:15	Overview of Program To-Date Milestones Design Review Contract Modification	EOC Conf. Rm.
9:45	Action Items & Resolution	EOC Conf. Rm.
10:00	Overview of System Design RAMS Concept BMT System Design	EOC Conf. Rm.
10:30	BREAK	
10:45	Overview of System Design (Continued) TDS System Design Specifications/Compliance	EOC Conf. Rm.
11:15	Summary Design Changes Since Design Review	EOC Conf. Rm.
11:30	Verification Approach Facility/Equipment	EOC Conf. Rm.
12:00	LUNCH	Ball Cafeteria
1:00	Verification (Continued) TDS Results BMT Results	FM-2 Conf. Rm.
2:00	Acceptance Testing of TDS	FA-1 Clean Rm

Friday, 14 February:

9:00	Acceptance Testing of BMT	FA-1 Clean Rm
11:30	Discussions, Buy-Off Paperwork	FM-2 Conf. Rm.

Program Overview

Objectives

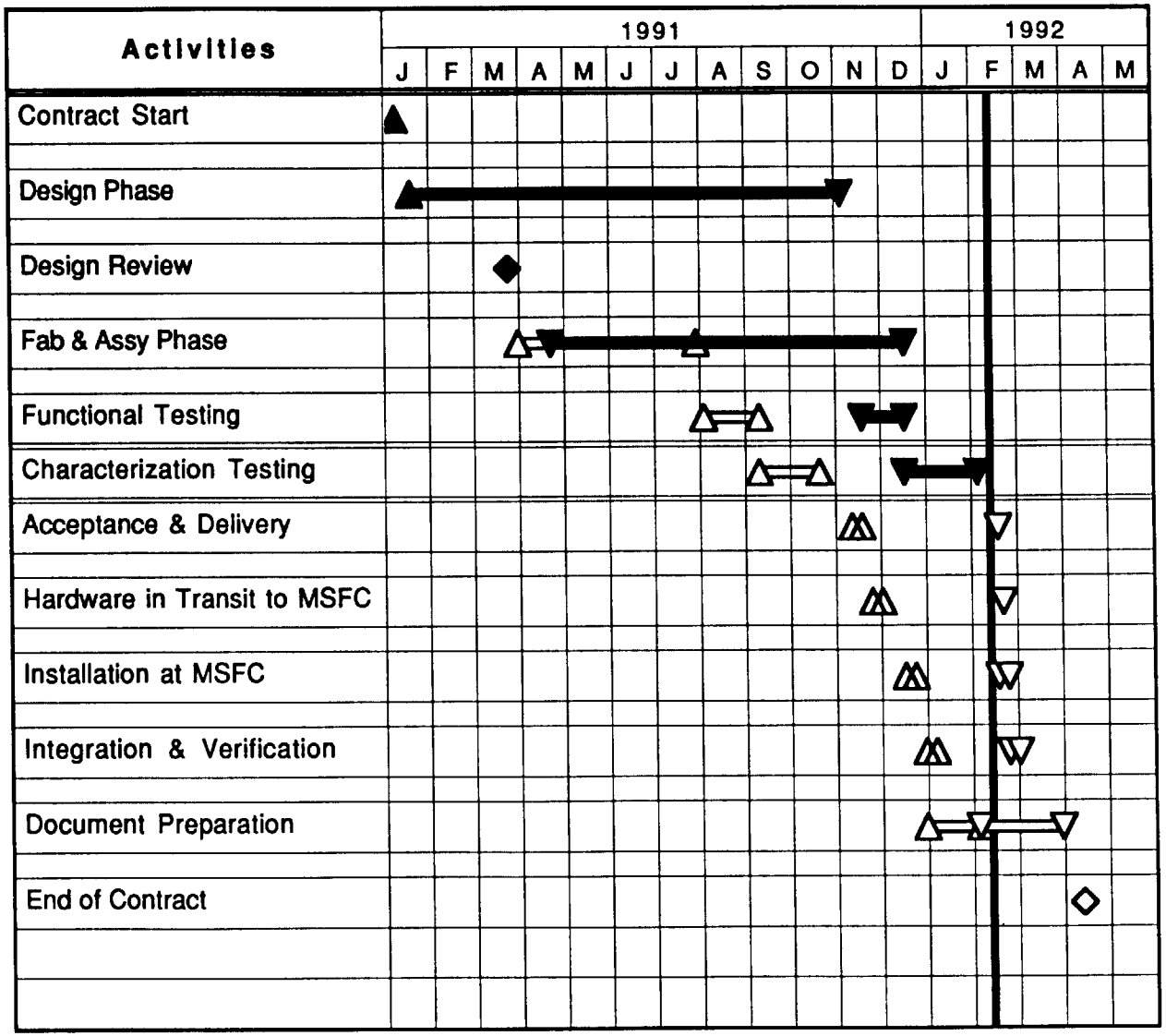
- Provide a fully functional prototype measurement system that unobtrusively measures motions of the CASES mast and tip assembly

- Provide specified interfaces that are appropriate for the CASES advanced development facility

Approach

- Modify BECD's existing RAMS (Remote Attitude Measurement Sensor) prototype design as necessary
- Provide a 3-axis RAMS to serve as the Boom Motion Tracker (BMT)
- Provide a 2-axis RAMS to serve as the Tip Displacement Sensor (TDS)

MILESTONE SCHEDULE FOR THE ADF RAMS PROGRAM



February 13, 1992

Summary of Contract Modification Elements (Effective 12/12/91)

- Additional system engineering
  - Alignment requirements
  - Obstructed views
  - Target configuration changes
- Additional design efforts
  - Redesign alignment system
  - Additional optical design tasks
  - Additional electronic design tasks
- Extend program schedule 17 weeks
- Provide pre-installation survey trip to MSFC
- Provide additional on-site support for installation and verification

Statement Of Work Changes Affecting Design

- Relaxation of accuracy specifications (defined as goals)
- Elimination of QC tasks
- Approval to deliver redlined drawings

Status of Action Items

Item No.	Action Item	Responsible Individuals	Activity	Status
1	Provide further definition for BMT and TDS data interfaces	J. Weathers (CD) D. Hope (BECD)	Pin-outs submitted to NASA 4/28/91	Closed
2	Complete design for interfacing support structures	A. Patterson (MSFC)	Sketches provided to BECD 2/10/92	Closed
3	Test for vibration environment of MPESS	A. Patterson (MSFC)	Completed 6/3/91; not a problem	Closed
4	Verify that target overlap will not occur	C. Poulson (BECD)	Revised test plan 5/24/91	Closed
5	Define preselected update rates for the TDS	A. Bukley (MSFC) H. Davis (BECD)	Defined 5/2/91	Closed

Status of Action Items (Concluded)

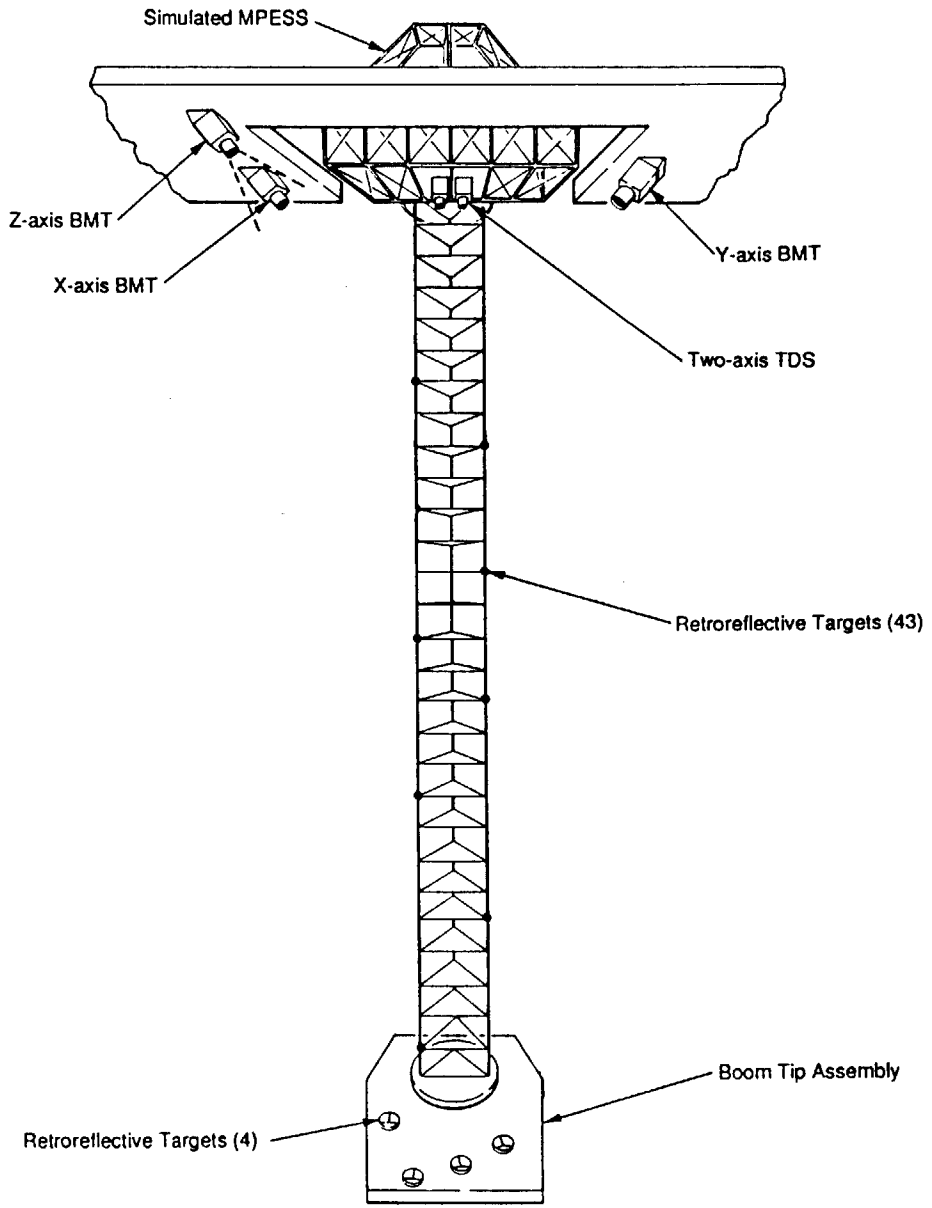
Item No.	Action Item	Responsible Individuals	Activity	Status
6	Determine worst-case tilt angle for tip assembly	A. Bukley (MSFC)	Estimated to be no more than 5 deg	Closed
7	Recommend appropriate spare parts	H. Davis (BECD)	Submitted spare parts list 5/17/91 Identified ROMs and PALs 7/2/91	Closed
8	Provide information on laser absorption by water vapor	H. Davis (BECD)	Submitted info on 4/2/91	Closed
9	Correct target orientation for BMT	A. Bukley (MSFC) H. Davis (BECD)	Submitted new configuration on 11/22/91	Closed

Overview of System Design

Technical Overview

- The MSFC Advanced Development Facility (ADF) will support ground testing of the proposed CASES flight experiment to:
  - Evaluate prototype hardware, mechanisms, and software
  - Resolve key technical issues affecting safety or mission success
- CASES consists of a 32-m extendible boom with a 150-lb tip assembly and gas thrusters at the tip for control
- The TDS provides knowledge of the boom tip position with respect to the base
- The BMT monitors the position of 37 targets along the length of the boom to assess mode shapes/frequencies

RAMS Satisfies The Sensor Needs Of The CASES ADF



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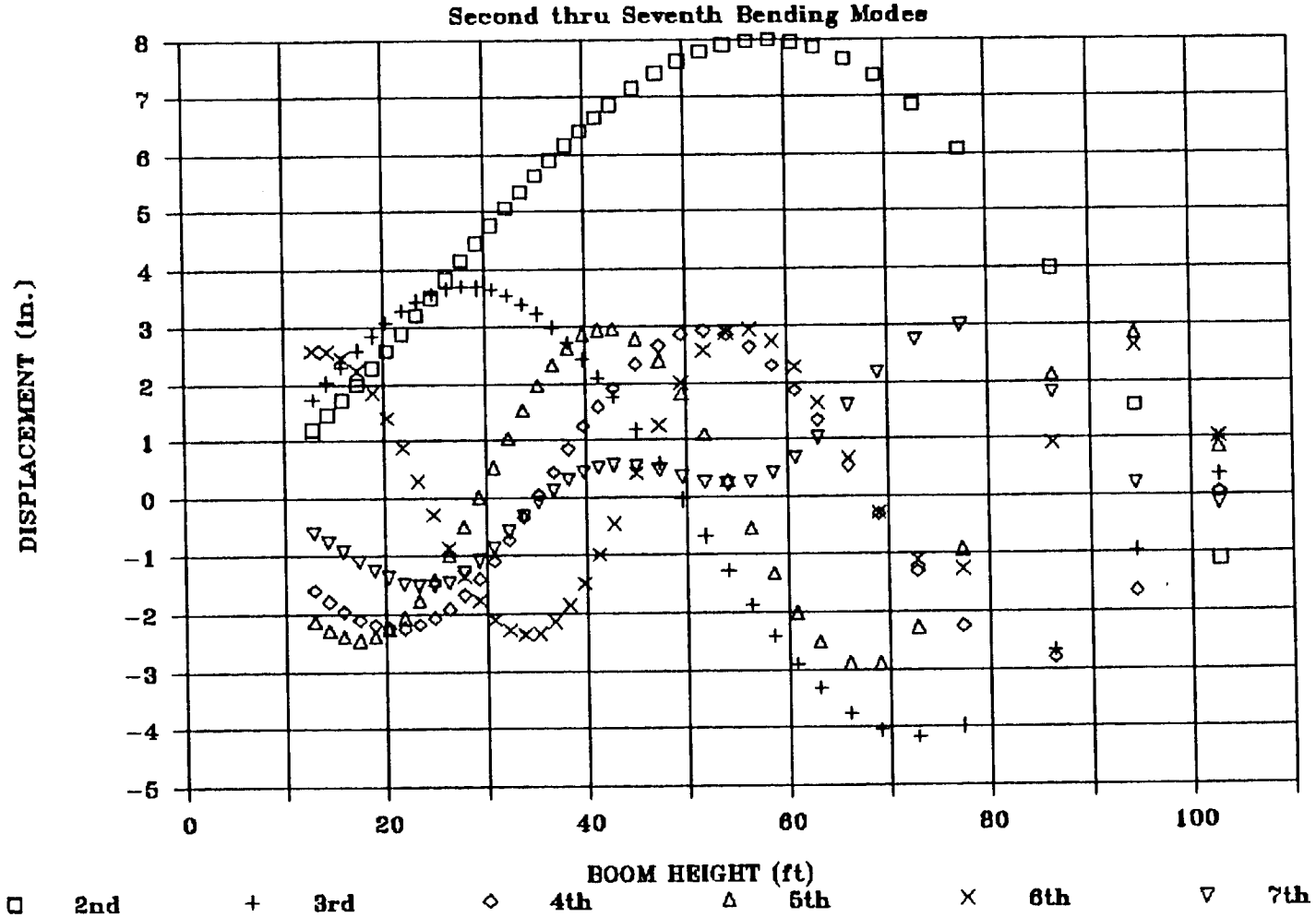
Dynamic Behavior Of The CASES Boom

- Spreadsheet analyses have aided in evaluating FOV requirements and potential target overlap
- The number of BMT targets was reduced from 42 to 37 to avoid potential overlap
- The maximum expected displacements for the mode shapes are:

Mode No.	Maximum Displacement
2 (First X-axis Bending)	10 in.
5 (Second Y-axis Bending)	8 in.
8 (Third X-axis Bending)	6 in.
11 (Fourth Y-axis Bending)	6 in.
14 (Fifth X-axis Bending)	3 in.
16 (Sixth Y-axis Bending)	3 in.
18 (Seventh Y-axis Bending)	3 in.

- Based on these maximum displacements, a FOV of ± 1 deg is sufficient

ADF RAMS Mode Shapes



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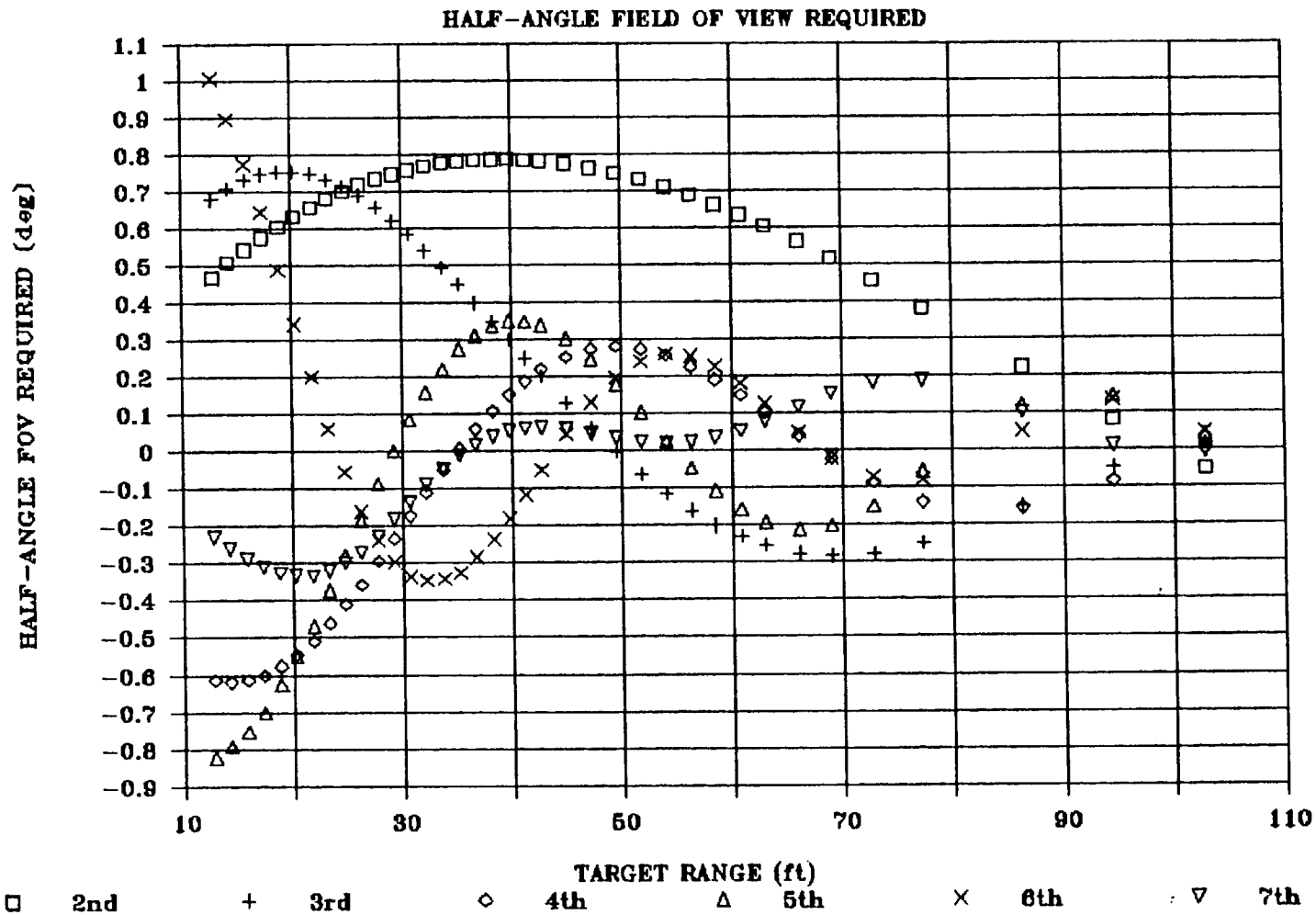
Cases Mode Shapes



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Review of RAMS Concept

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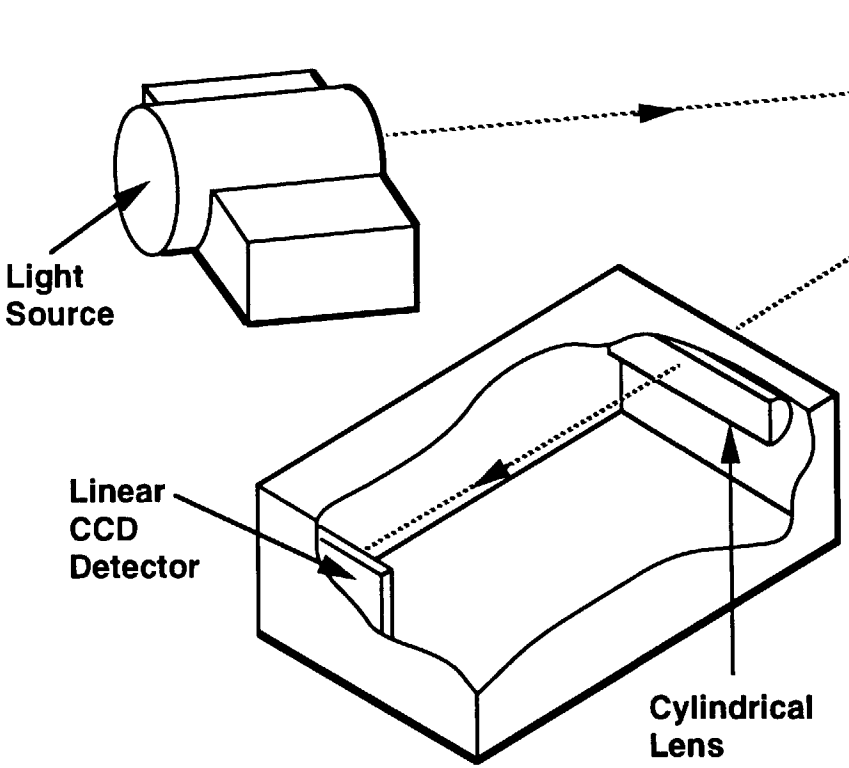
RAMS Concept



- Light source illuminates multiple reflective targets
- Reflected images are focused on the detector
- Target displacements cause image position on the detector to shift
- This shift in image position is proportional to the angular displacement of the target

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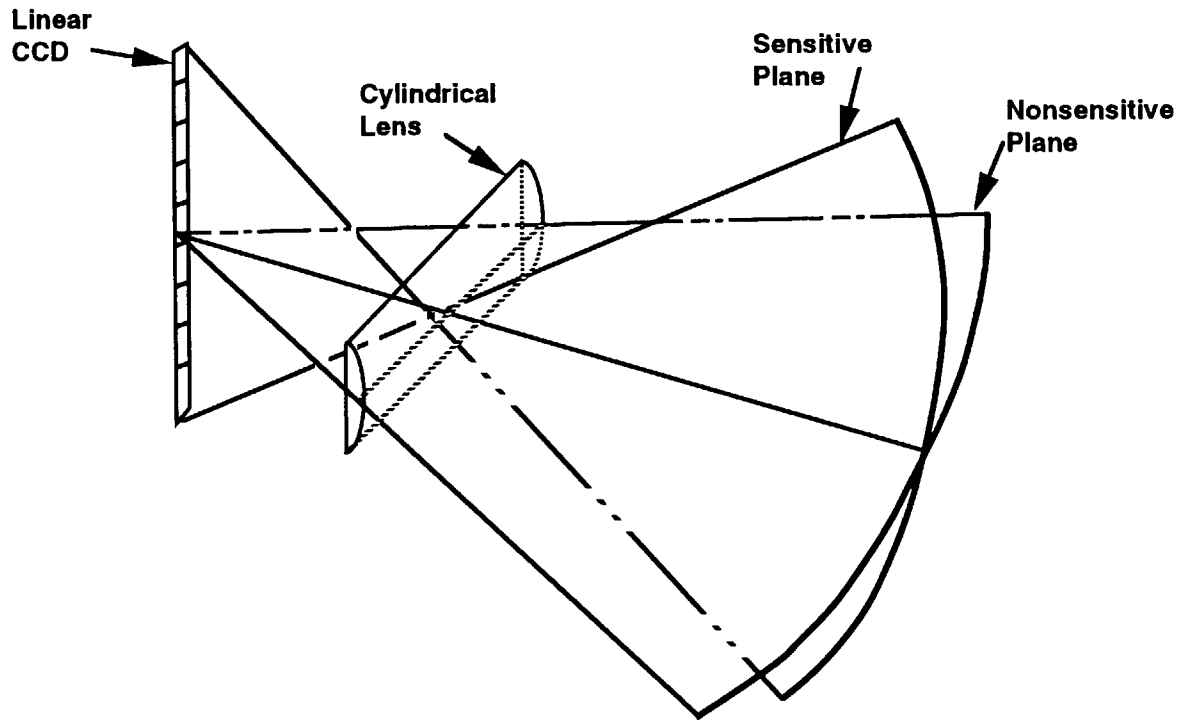
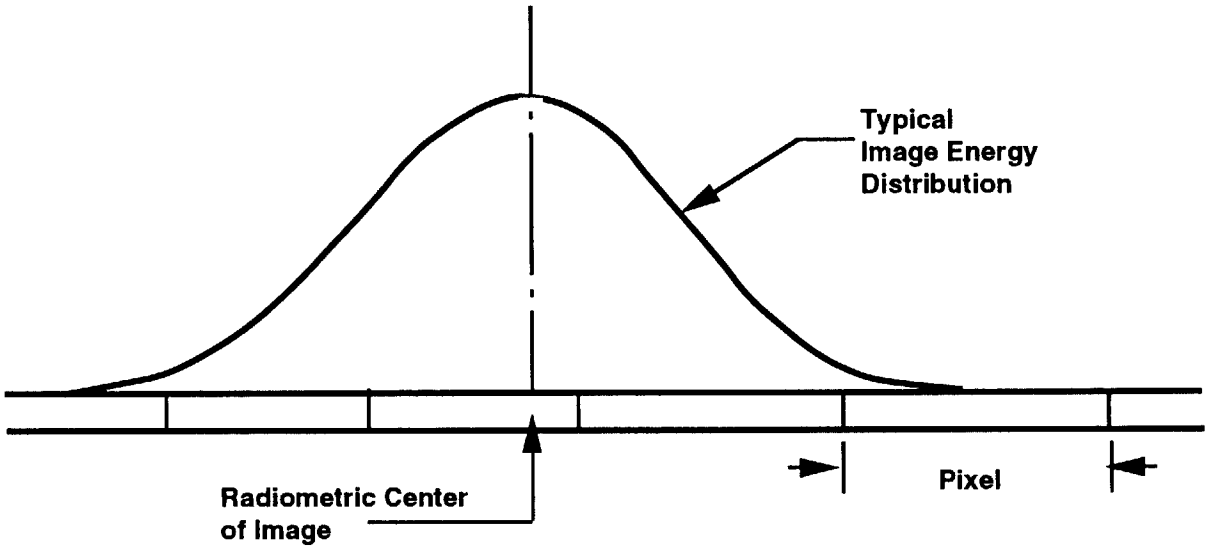
Sensor Concept



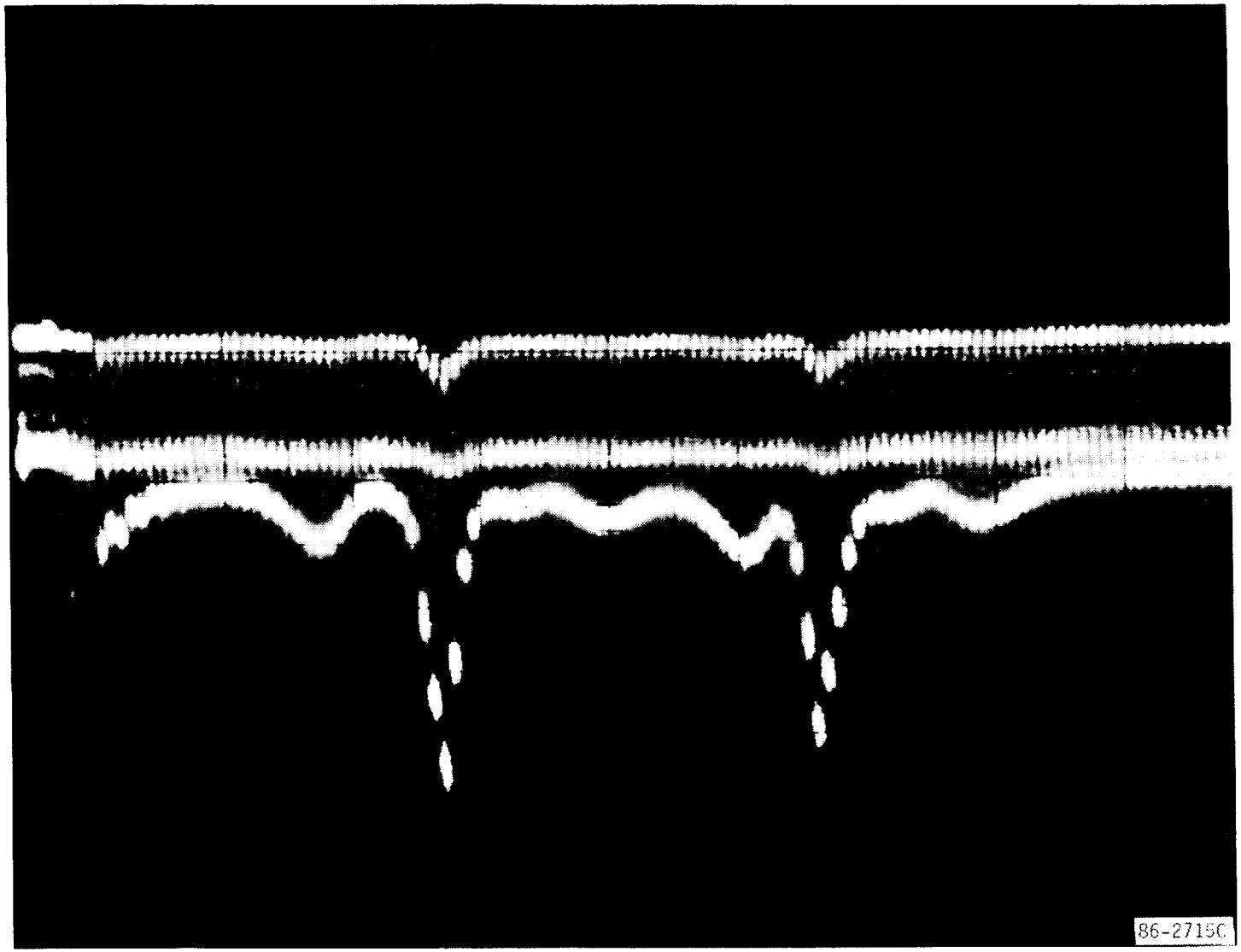
- Linear CCD detector is sensitive to image motion in one plane (parallel to CCD)
- Two linear detectors, mounted orthogonally, provide 3-axis measurements:
  - Pitch
  - Yaw
  - Roll about LOS

Subpixel Sensing



- Target image extends over several pixels
- Proprietary Ball algorithms accomplish:
  - Centroiding of image energy distribution
  - Interpolation of centroid location to 2 percent pixel
  - Accommodation of focus changes resulting from varying target ranges

Sensor Signal Display Showing Two Targets and Individual Pixels



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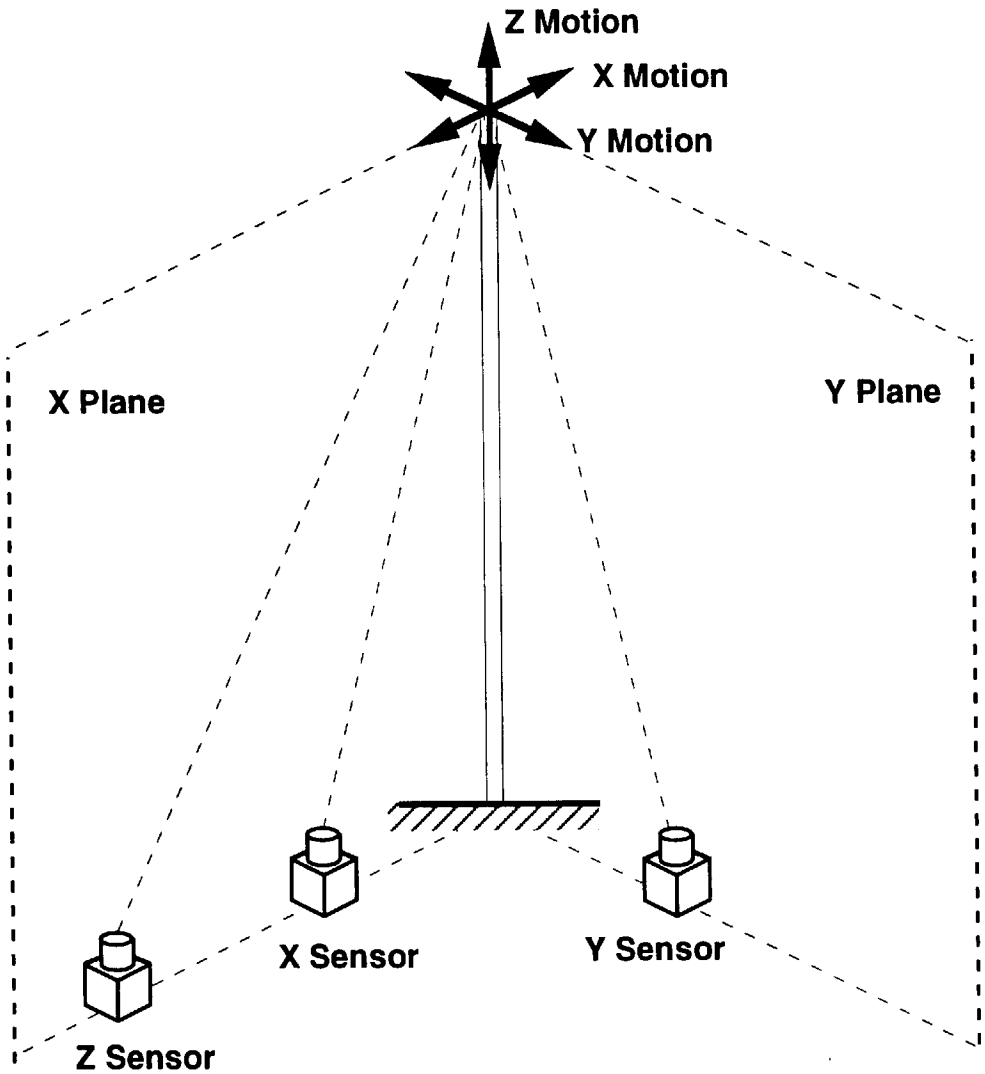
Boom Motion Tracker (BMT)

System Design

A2542/1054.048

Boom Motion Tracker Measurement Approach

- Single-axis X and Y sensors measure motions in their respective planes
- Z sensor is sensitive to motions in both X and Z directions
- Z motions are measured by subtracting the X motions from observed Z sensor changes



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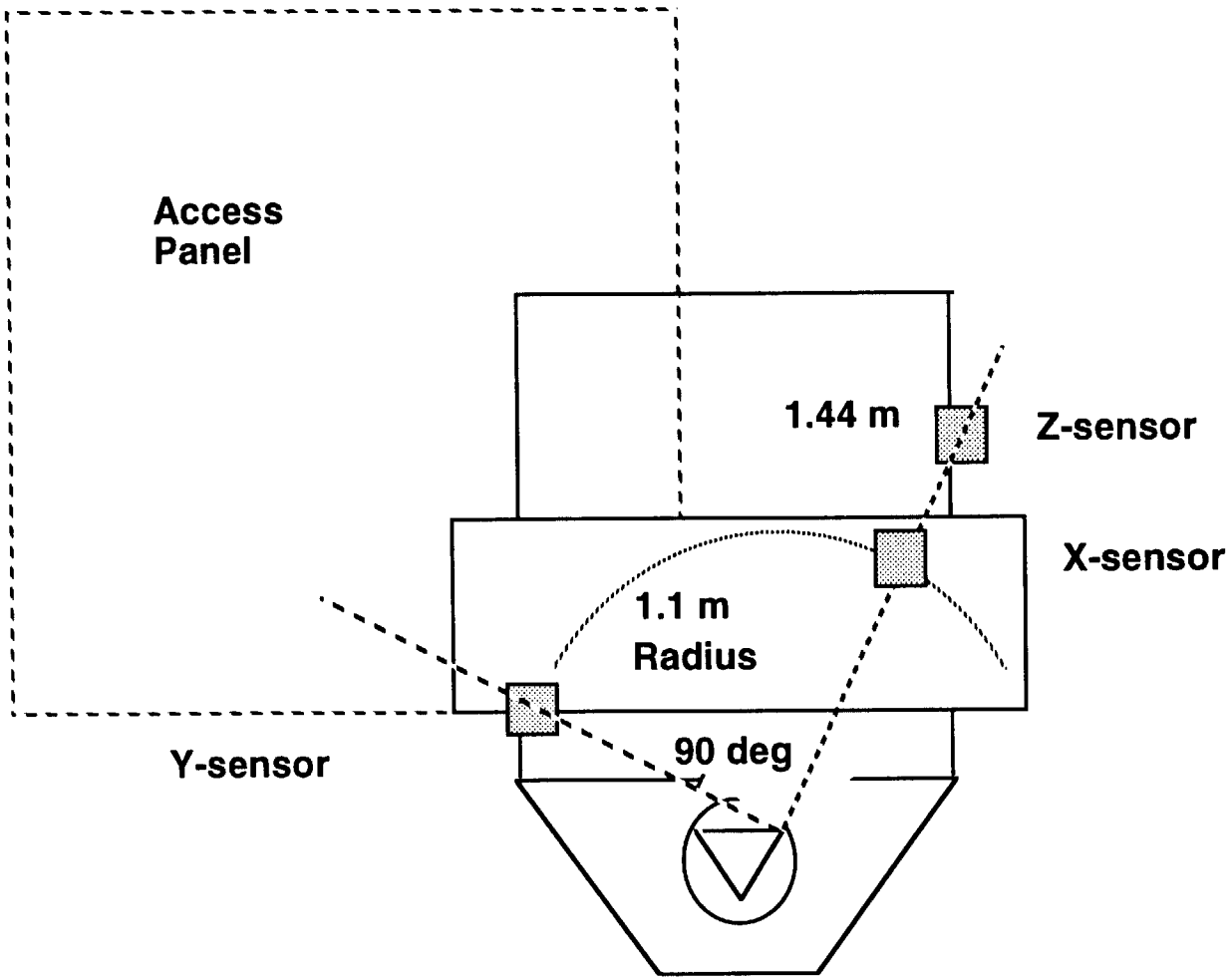
Boom Motion Tracker (BMT) Mounting Locations



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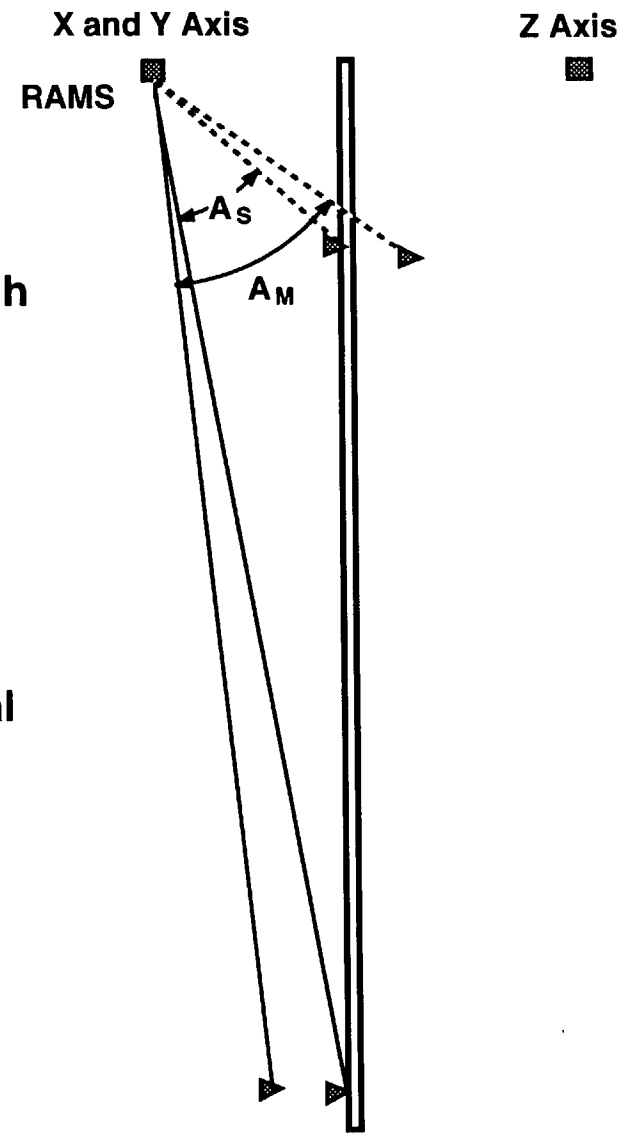
Boom Motion Tracker Field of View Requirements

- Sensor field of view must be large enough to accommodate all of the following:
  - Static FOV A_S (includes all targets)
  - Dynamic motion ($A_M - A_S$)
  - Additional margin to accommodate potential misalignments
- The lens is mounted such that the optical axis bisects the total FOV angle defined above



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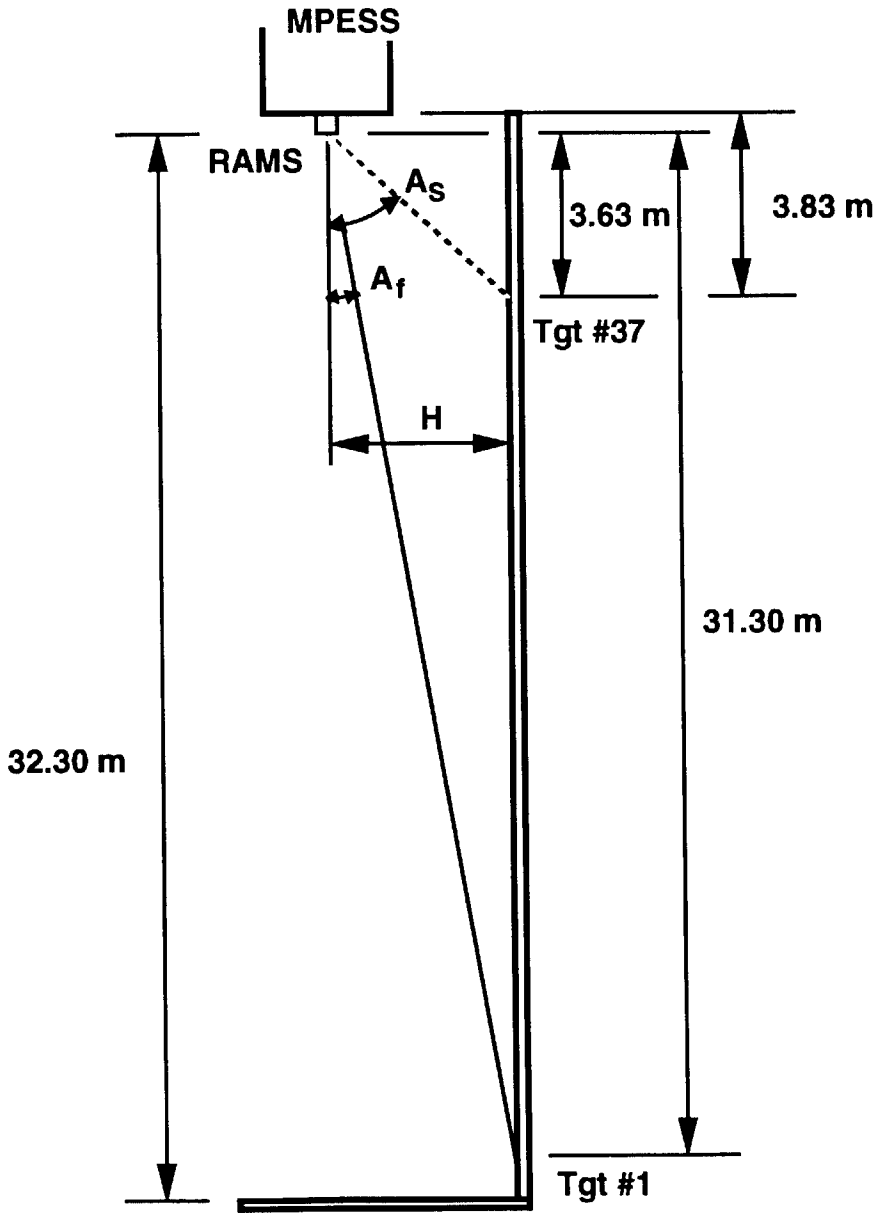
BMT Static Field of View



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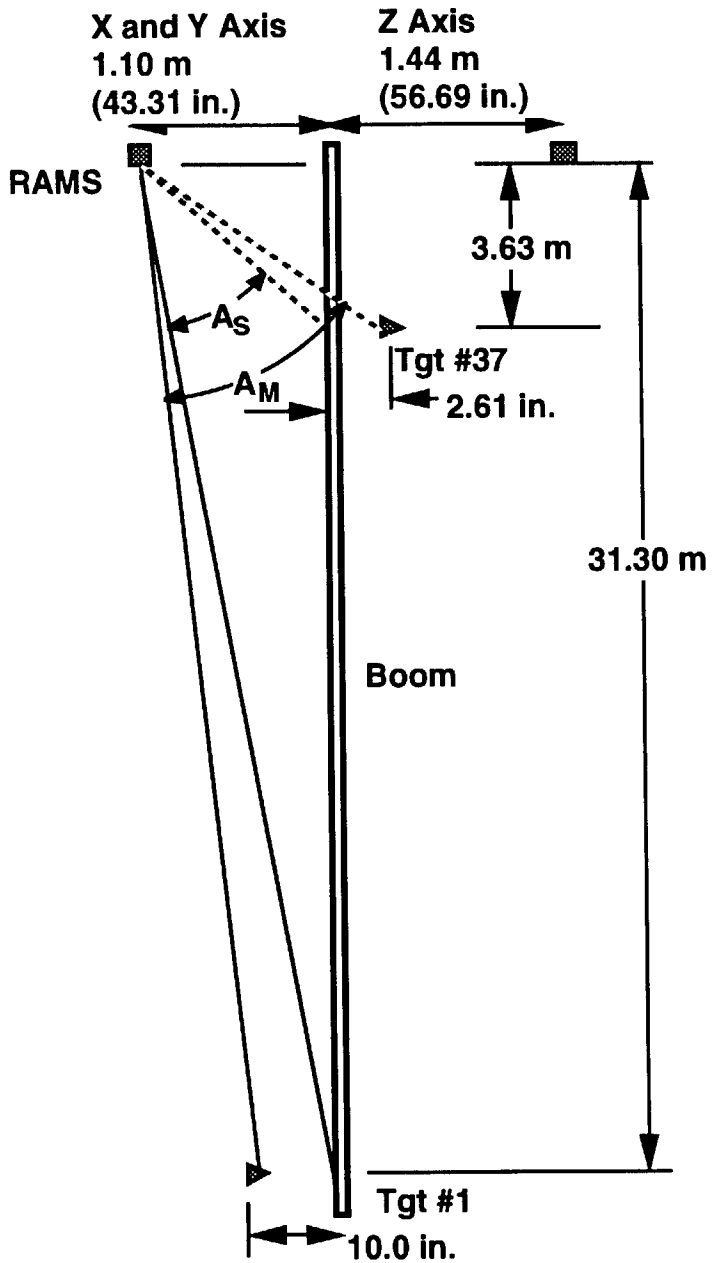
BMT Dynamic Field of View



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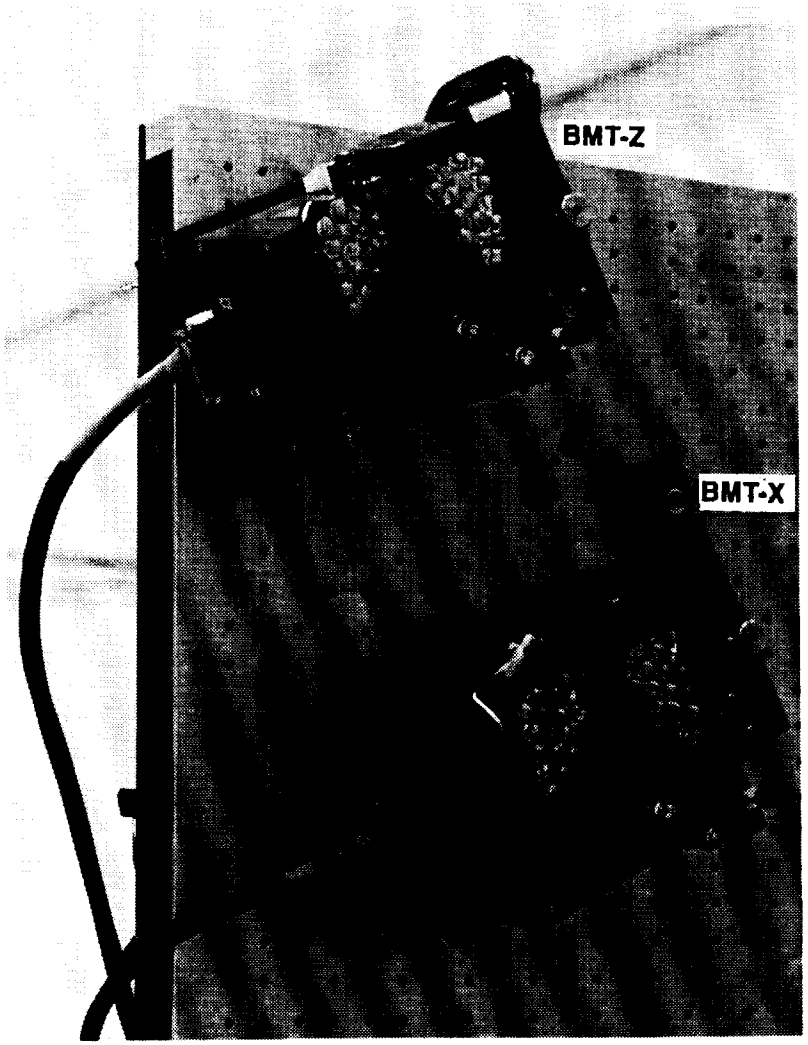
Boom Motion Tracker FOV Summary

PARAMETER	BMT X, Y (deg)	BMT Z (deg)
Static FOV requirement	14.9	18.9
Additional FOV (dynamic FOV requirement)	1.4	1.4
Total FOV required	16.3	20.3
Actual FOV	19.3	23.6
FOV Margin	3.0	3.3

BMT Sensor Heads (X and Z Sensors)



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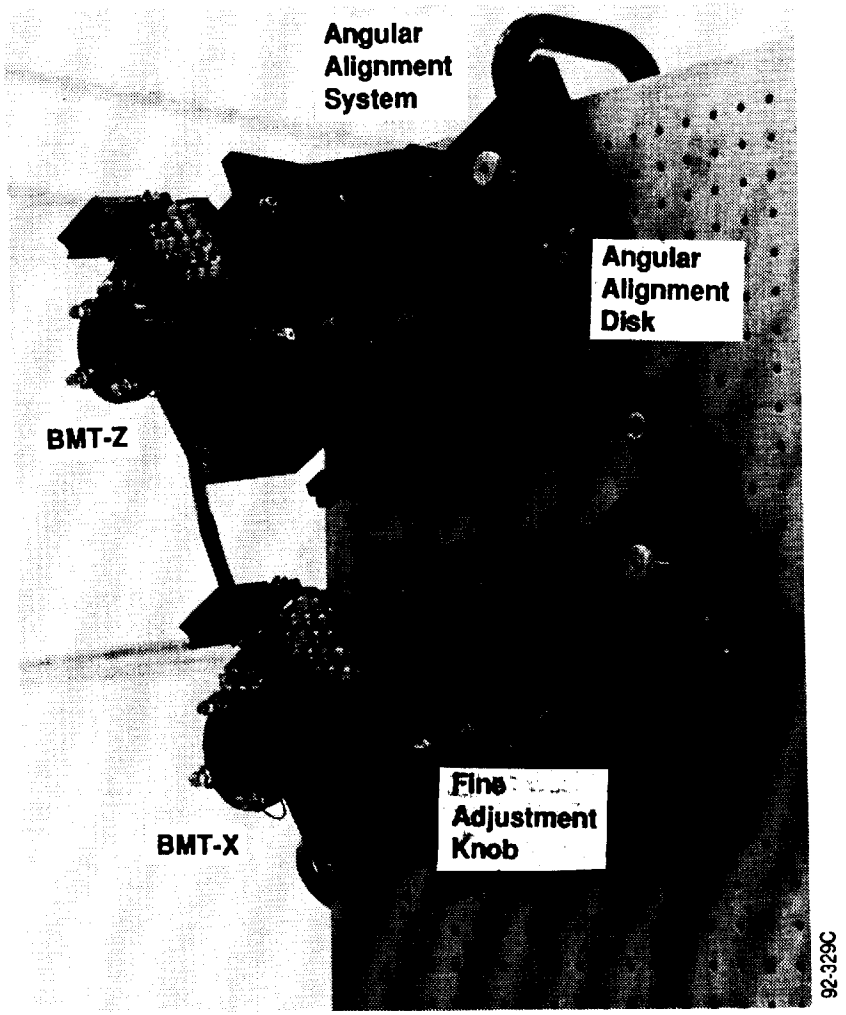
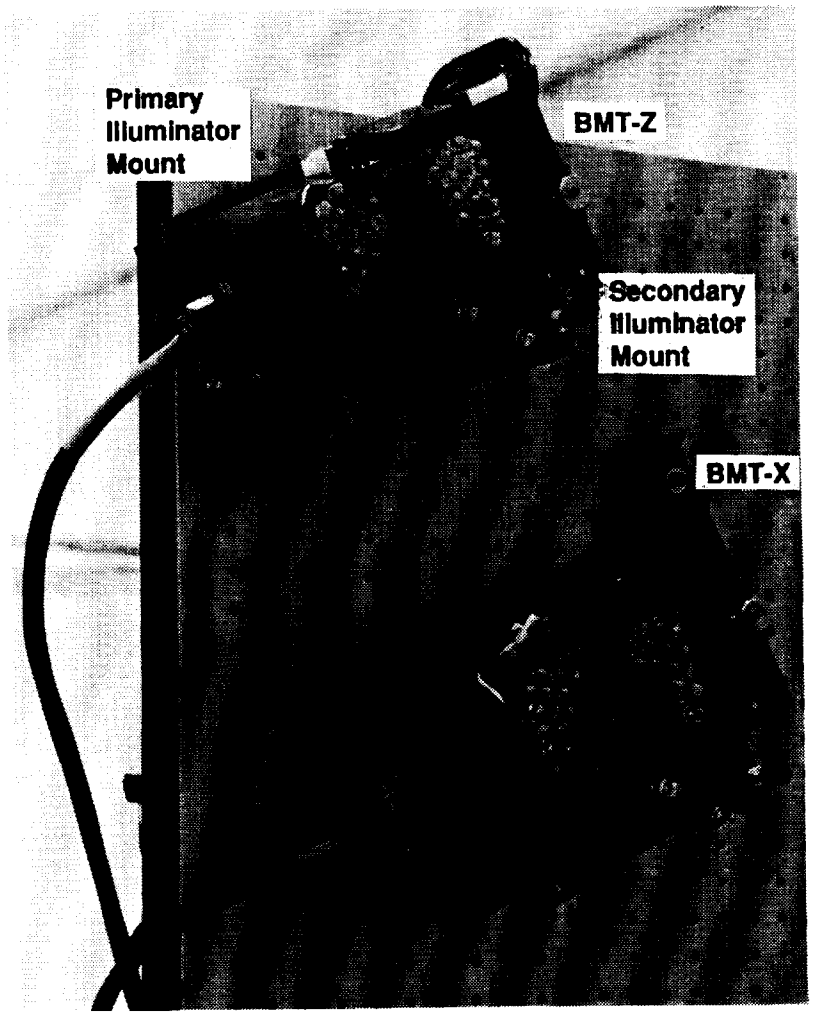
BMT Sensor Head Mount and Alignment Features



BMT Sensor Heads With Illuminators Operating



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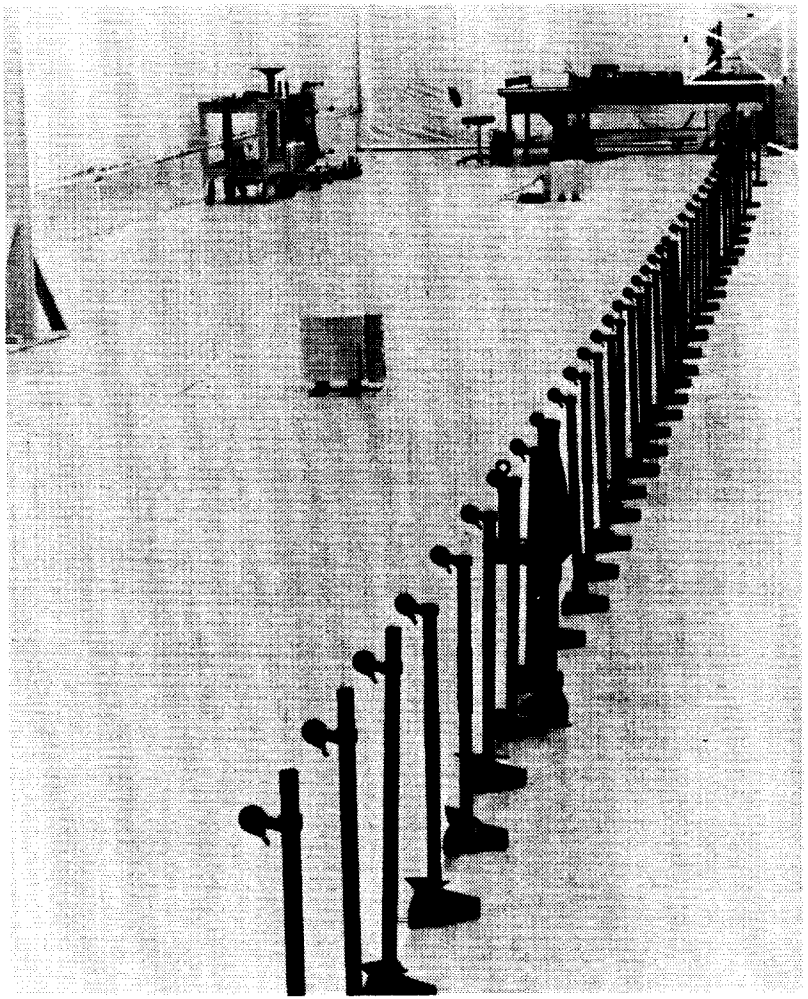
Boom Motion Tracker (BMT) Target Array (37 Retroreflective Tape Targets)



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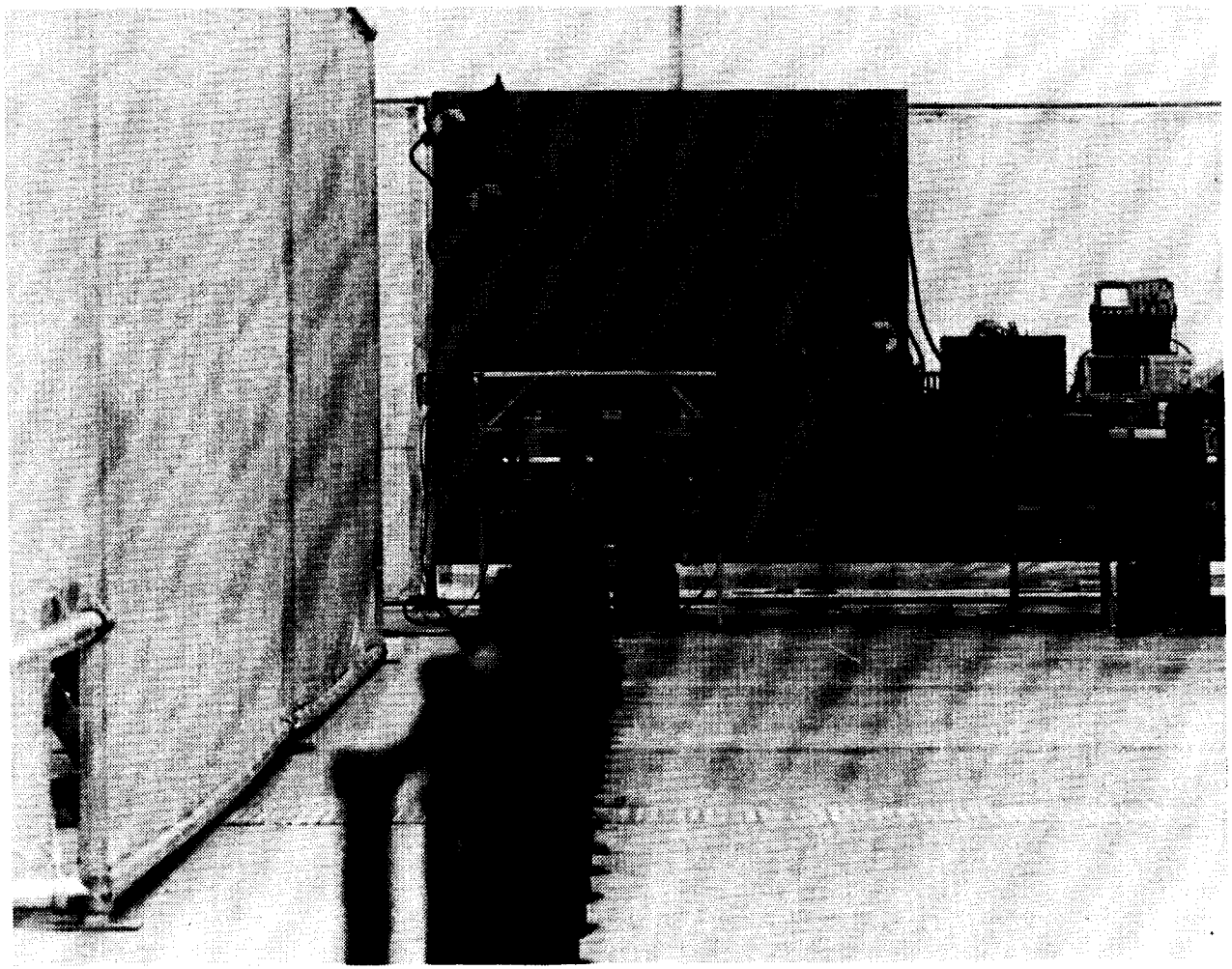
BMT Illumination As Viewed From the Far Target



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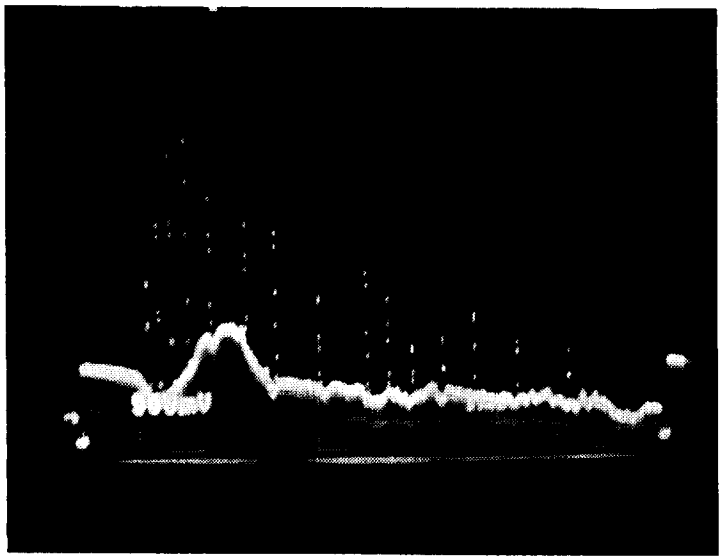
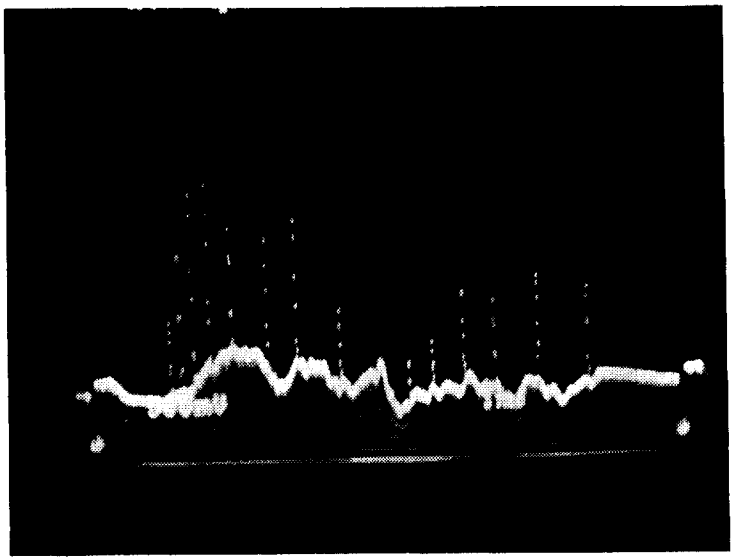
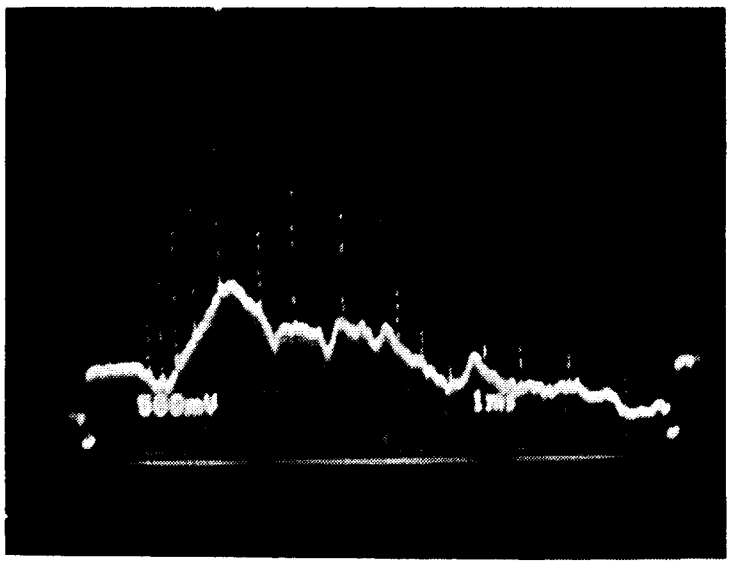
Oscilloscope Pictures of Target Images for the Three BMT Sensors



BMT-X



BMT-Y



BMT-Z

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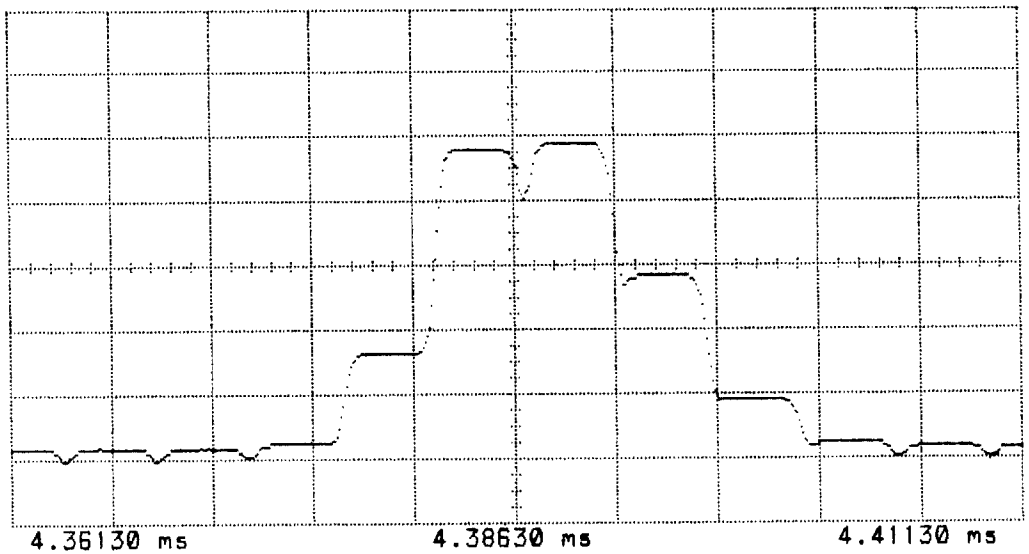
Target Image Shape at the Beginning of a Pixel

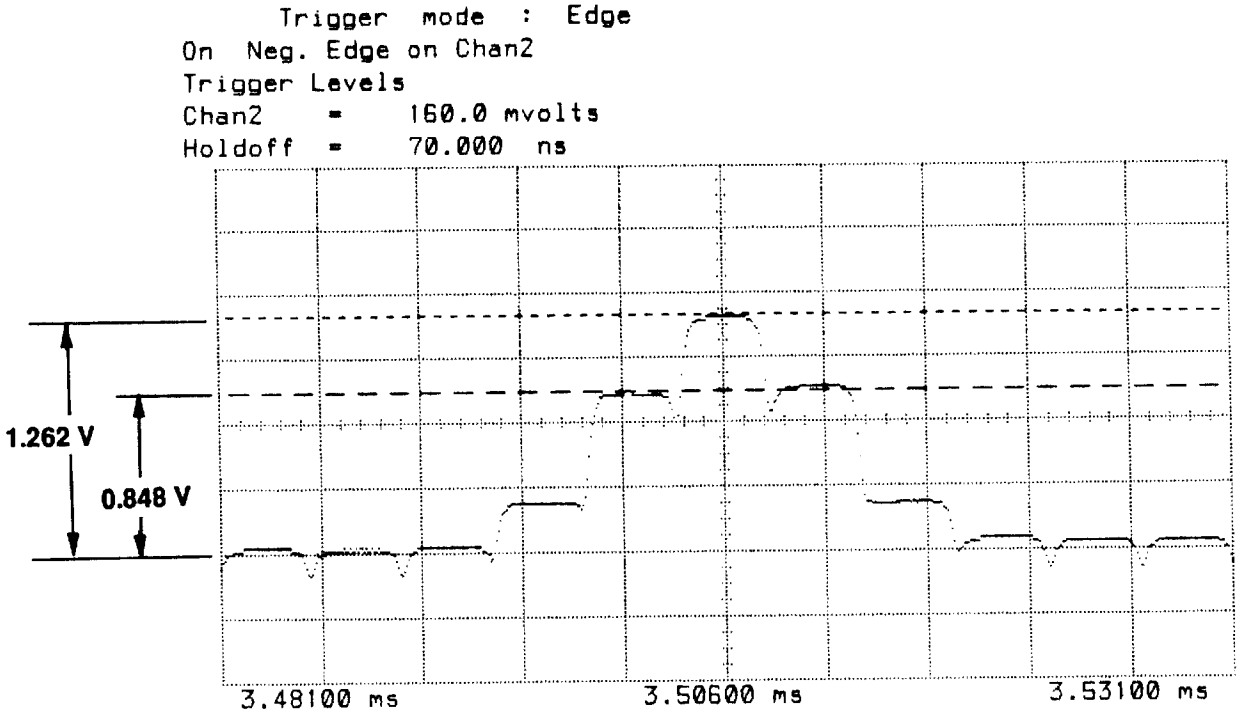


Ch. 1 = 350.0 mvolts/div
Timebase = 5.00 us/div

Offset = 1.435 volts
Delay = 4.38630 ms

Trigger mode : Edge
On Neg. Edge on Chan2
Trigger Levels
Chan2 = 160.0 mvolts
Holdoff = 70.000 ns

Target Image Shape at the Mid-point of a Pixel



Shape Factor

$$\frac{1.262\ V}{0.848\ V} = 1.49$$

Ch. 1 = 350.0 mvolts/div
Timebase = 5.00 us/div
Delta V = 413.0 mvolts
Vmarker1 = 1.603 volts

Offset = 1.435 volts
Delay = 3.50600 ms
Vmarker2 = 2.016 volts

A2542/1054.046

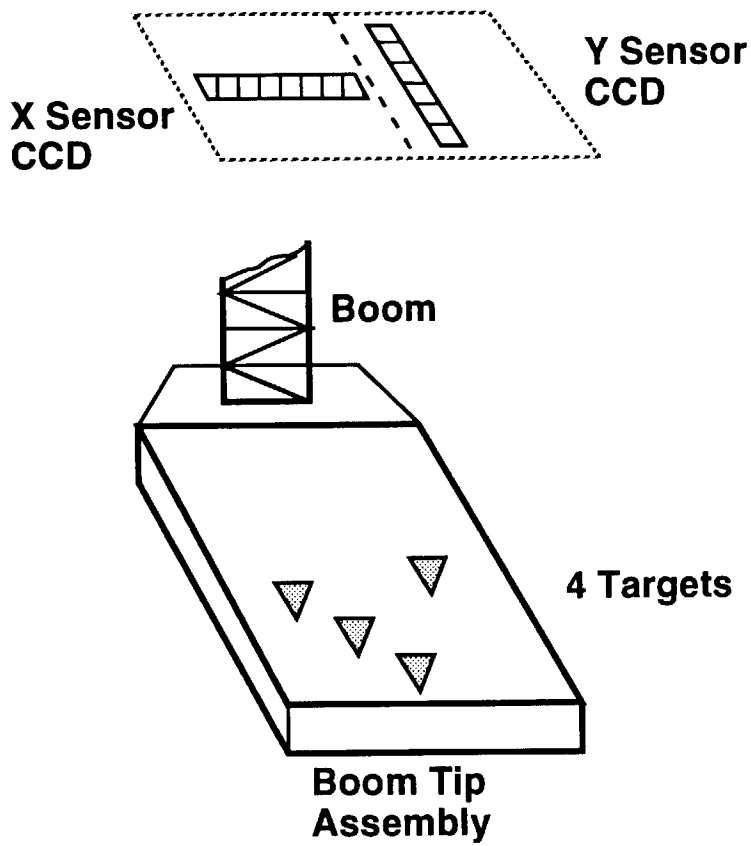
Tip Displacement Sensor (TDS)

System Design

A2542/1054.047

Tip Displacement Sensor Measurement Approach

- Four (4) active (LED) targets are mounted on the boom tip assembly in a unique pattern
- Single-axis X and Y sensors measure motions in their respective planes
- X and Y sensors are mounted nearly above the center of the target array



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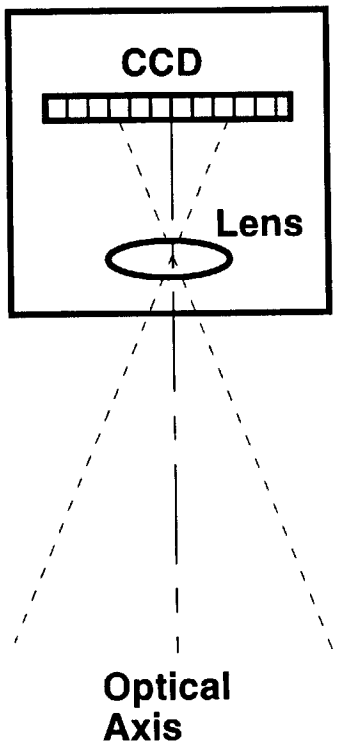
Tip Displacement Sensor Sensor Concept

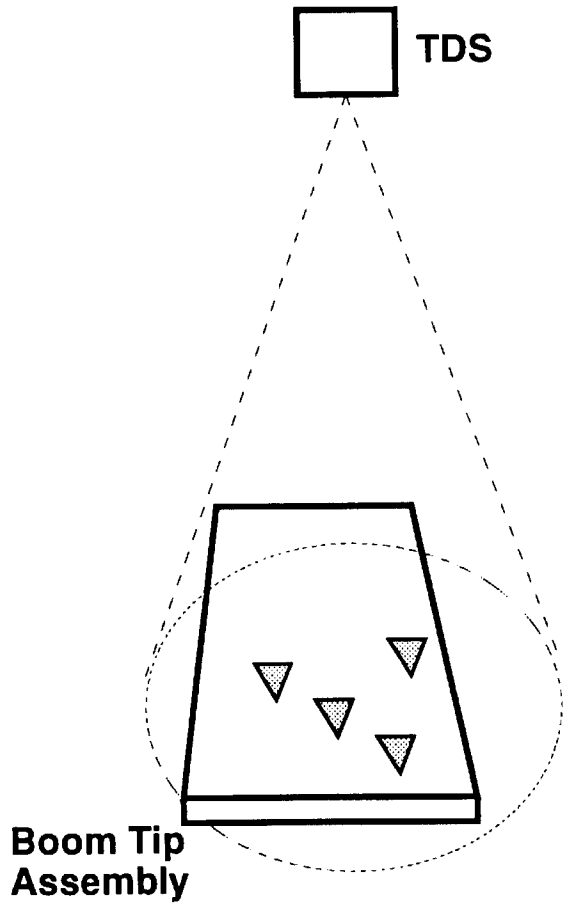
- CCD detector is mounted orthogonal to the optical axis and centered
- Narrow FOV and long focal length provide the specified resolution



Tip Displacement Sensor Field Of View Requirements

- Observe four targets located within a rectangular area of 0.76 m by 1.14 m (static condition)

- Observe all targets while the boom tip assembly translates ±10 in. in either X or Y directions



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Tip Displacement Sensor FOV Summary

PARAMETER	TDS X, Y (deg)
Static FOV requirement	2.03 (X) 1.35 (Y)
Additional FOV (dynamic FOV requirement)	0.90 (X) 0.90 (Y)
Total FOV required	2.93 (X) 2.25 (Y)
Actual FOV	4.27 (X, Y)
FOV Margin	1.34 (X) 2.02 (Y)

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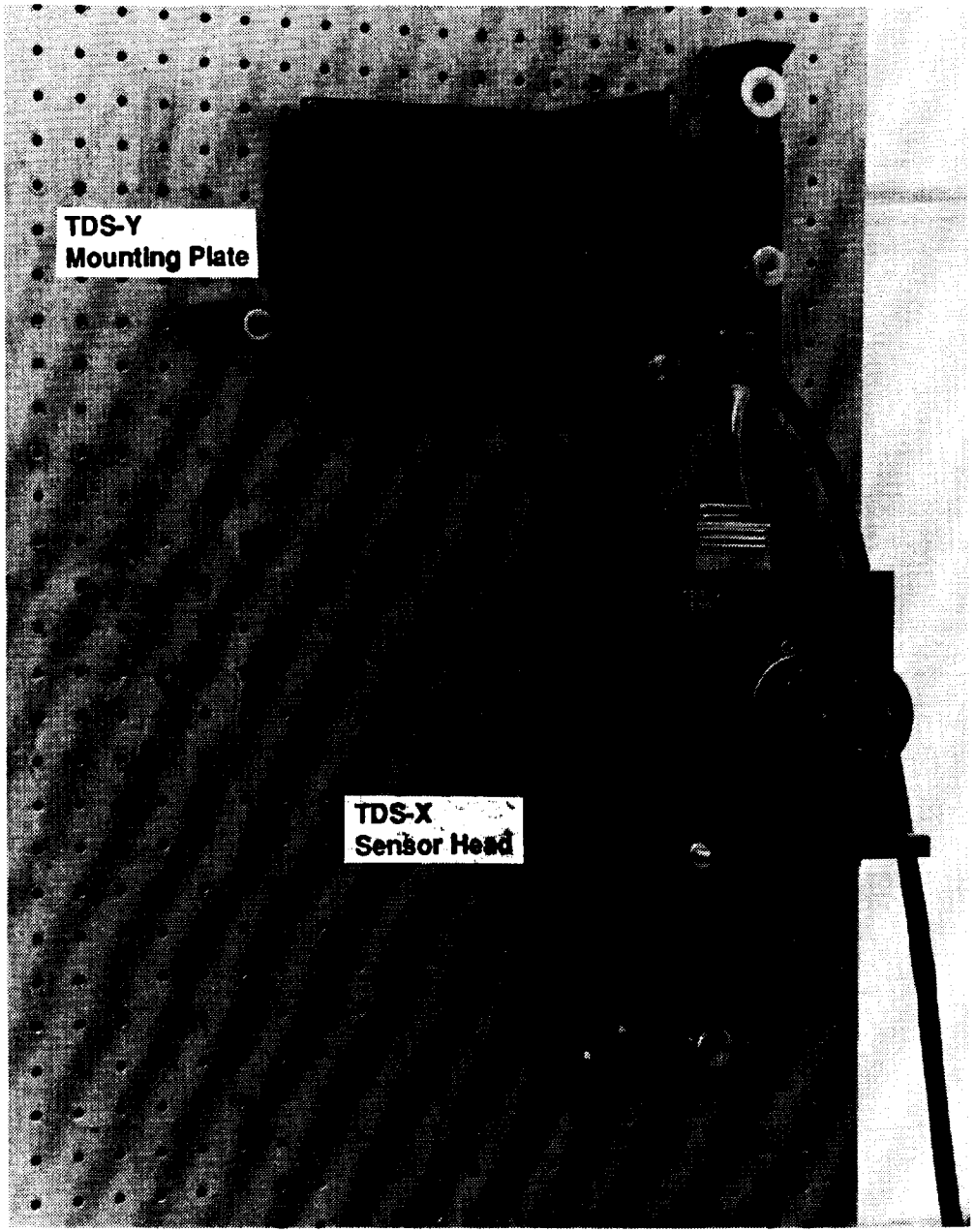
Tip Displacement Sensor (TDS)



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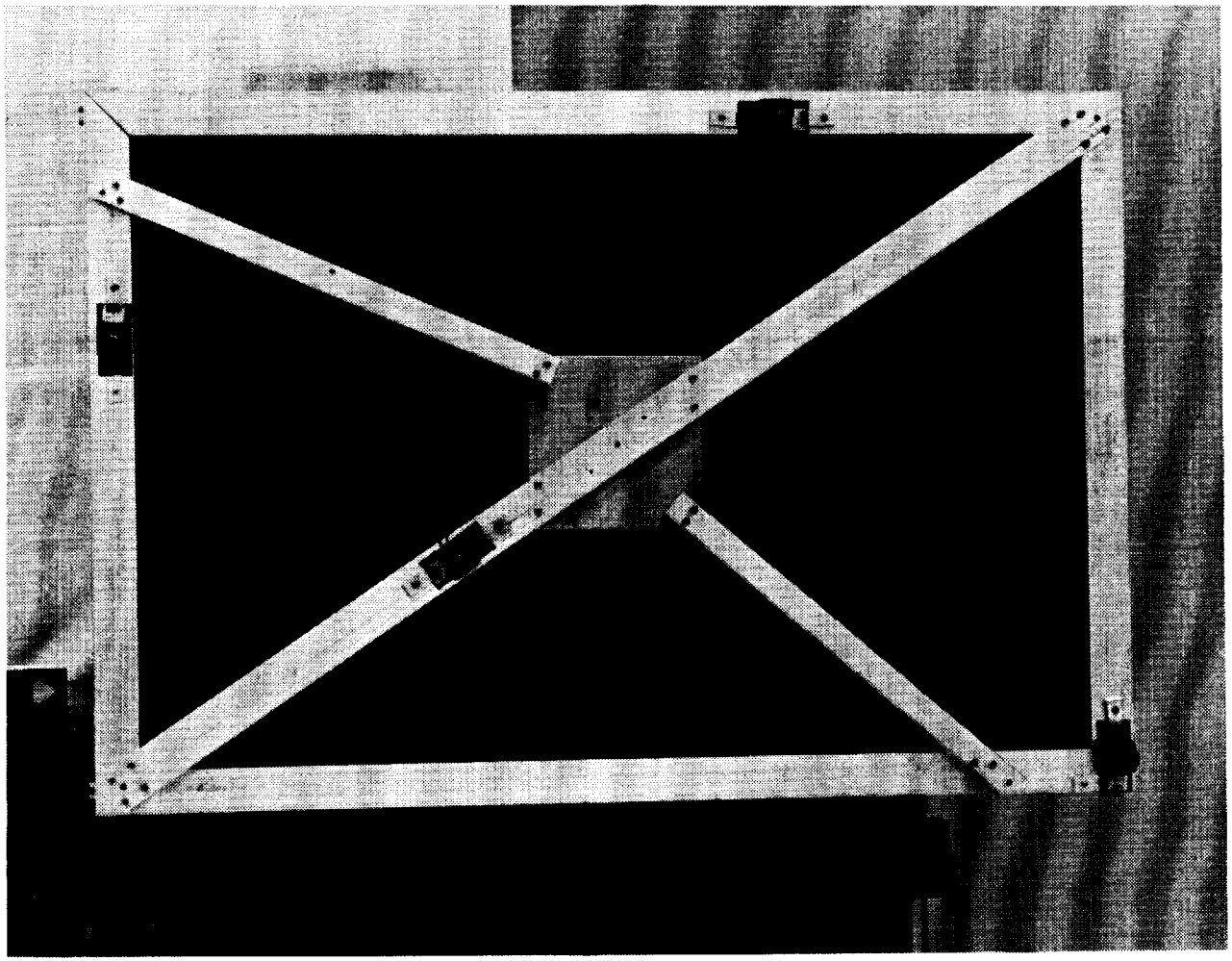
TDS Target Test Fixture (With Targets Illuminated)



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Specifications and Compliance

A2542/1054.029

Specification Compliance Matrix Tip Displacement Sensor (TDS) for CASES ADF

SOW PARA.	CHARACTERISTIC	REQUIREMENT	COMPLIANCE
3.1.3	Type of measurements	Two-axis translation	Complies
3.1.3	Measurement accuracy	Within 0.008 in. (Goal)	Complies
3.1.3	Range of target displacement	±10 in.	±10 in.
3.1.3	Location of TDS sensor heads	On the MPESS simulator and within 2 m of the boom	Complies
3.1.3	Installed orientation	Operate in inverted position	Complies
3.1.3	Number of targets tracked	At least 4	4
3.1.3	Update rate	20 to 500 Hz (selectable)	Complies; provides 10 selectable rates
3.1.3	Weight	(not specified)	90 lb
3.1.3	Average power	Less than 75 W	131 W
3.1.3	Operating environment	Day or night, ambient temperature and pressure	Complies
3.1.3	Form of output data	Transverse and longitudinal displacements	Provides 2-axis, in-plane displacement values
3.1.3	Type of interface	Analog (range of ±10 V)	Complies

Specification Compliance Matrix Boom Motion Tracker (BMT) for CASES ADF

SOW PARA.	CHARACTERISTIC	REQUIREMENT	COMPLIANCE
3.1.2	Type of measurements	Three-axis translation	Complies
3.1.2	Measurement accuracy	Within 0.01 in. (Goal)	Complies (except for Z-axis sensor)
3.1.2	Range of target displacement	±10 in.	±10 in.
3.1.2	Location of BMT sensor heads	Within a 6-ft radius of the boom	Complies
3.1.2	Installed orientation	Operate in inverted position	Complies
3.1.2	Number of targets tracked	37	37
3.1.2	Update rate	100+ Hz	100 Hz
3.1.2	Temporal delay between first and last target position measurements	1.5 ms	Zero delay
3.1.2	Weight	Less than 150 lb	115 lb
3.1.2	Average power	Less than 100 W	175 W
3.1.2	Operating environment	Day or night, ambient temperature and pressure	Complies
3.1.2	Form of output data	Transverse and longitudinal displacements	Complies
3.1.2	Type of interface	GPIO or HPIB or TTL with handshaking (at least 30 channels)	Parallel interface with 32-bit wide data bus

Design Changes Since Design Review

- Modifications to alignment system (TDS and BMT)
- Reduction in number of BMT targets (from 42 to 37)
- Reduction in field of view required for near targets (BMT only)
- Changed from laser illuminators to LEDs (TDS and BMT)
- Changes in target configuration (TDS and BMT)
- Changes in optical filters (TDS and BMT)
- Change in sensor location (TDS only)
- Change in sensor mounting surface (TDS and BMT)
- Addition of electronic "windowing" to exclude invalid image sources

Verification

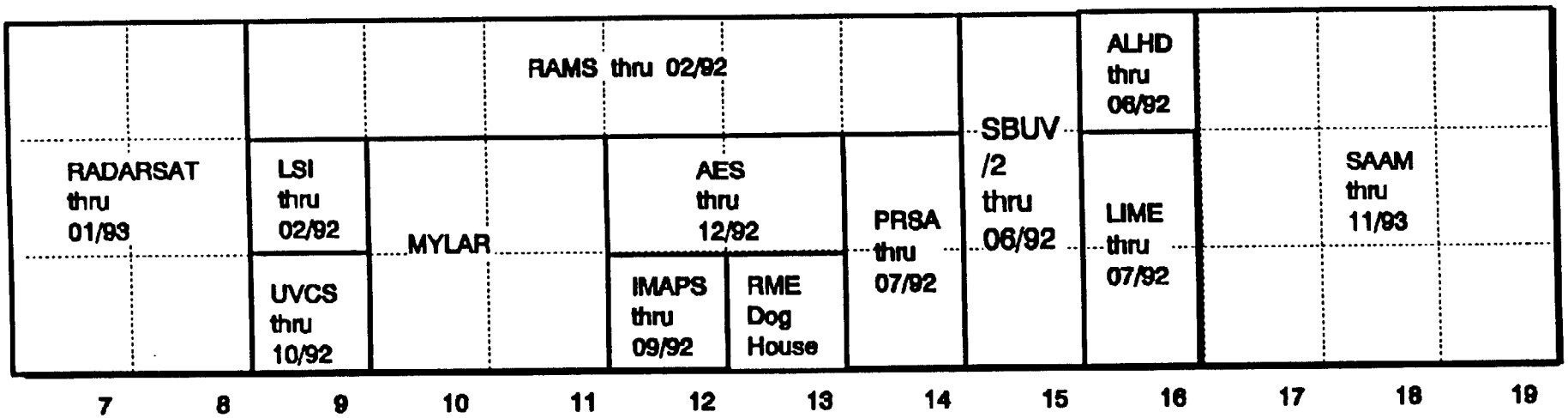
Verification Approach

- Use FA cleanroom (Class 100,000)
- Characterize illuminators (BMT and TDS)
- Install targets per test plan
- Install and align sensors relative to target locations
- Verify system operation (Rates, signal-to-noise, data, etc.)
- Characterize sensors
  - Field-of-view
  - Linearity
  - Accuracy
  - Sub-pixel accuracy
- Evaluate system performance
  - Full data complement
  - Target motion
  - Weight
  - Power consumption
  - Update rate

Boulder Production and Test Operations

Cleanroom Scheduling

FA CLEANROOM
FED STD 209-D
Class 100,000



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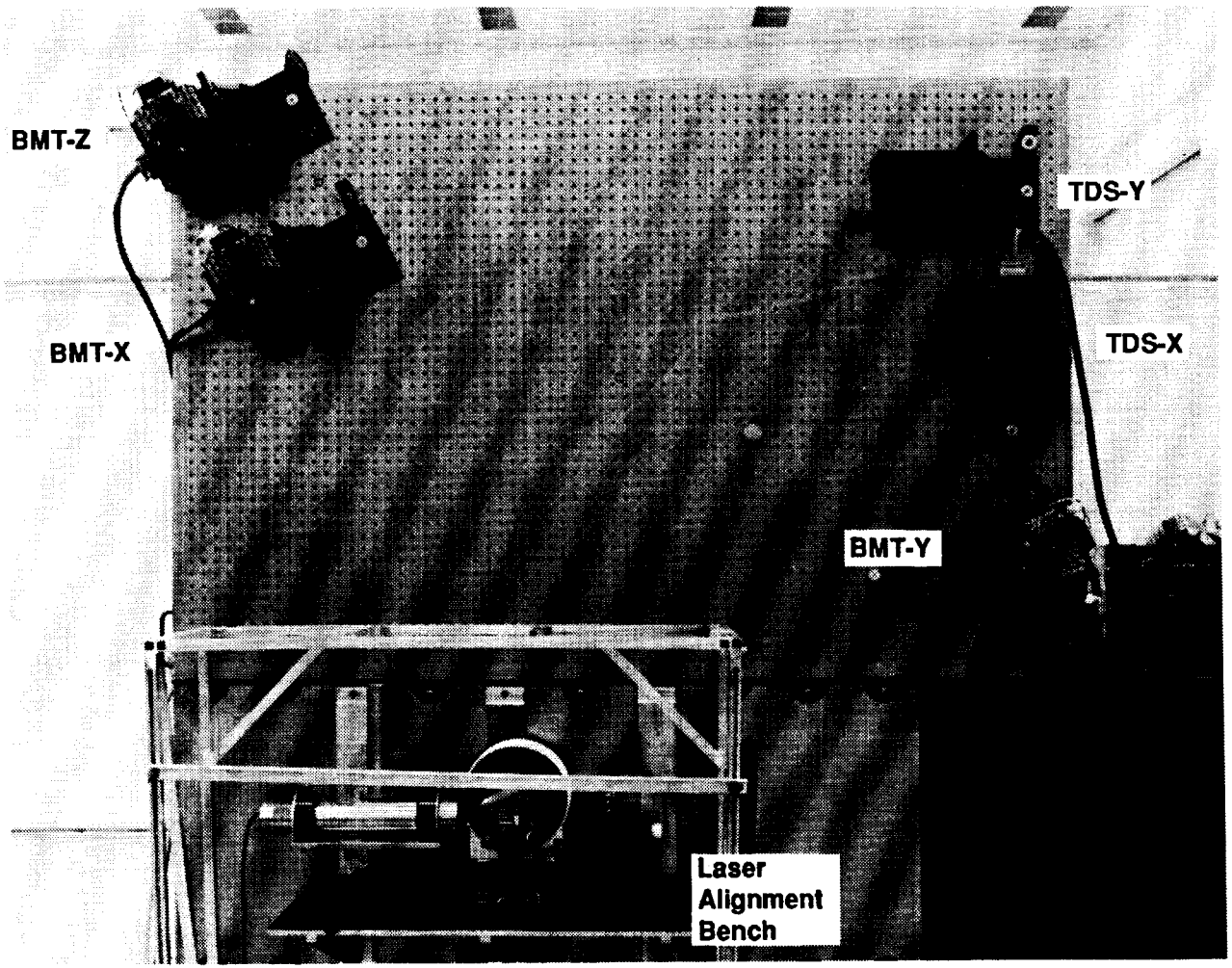
ADF RAMS Test Facility



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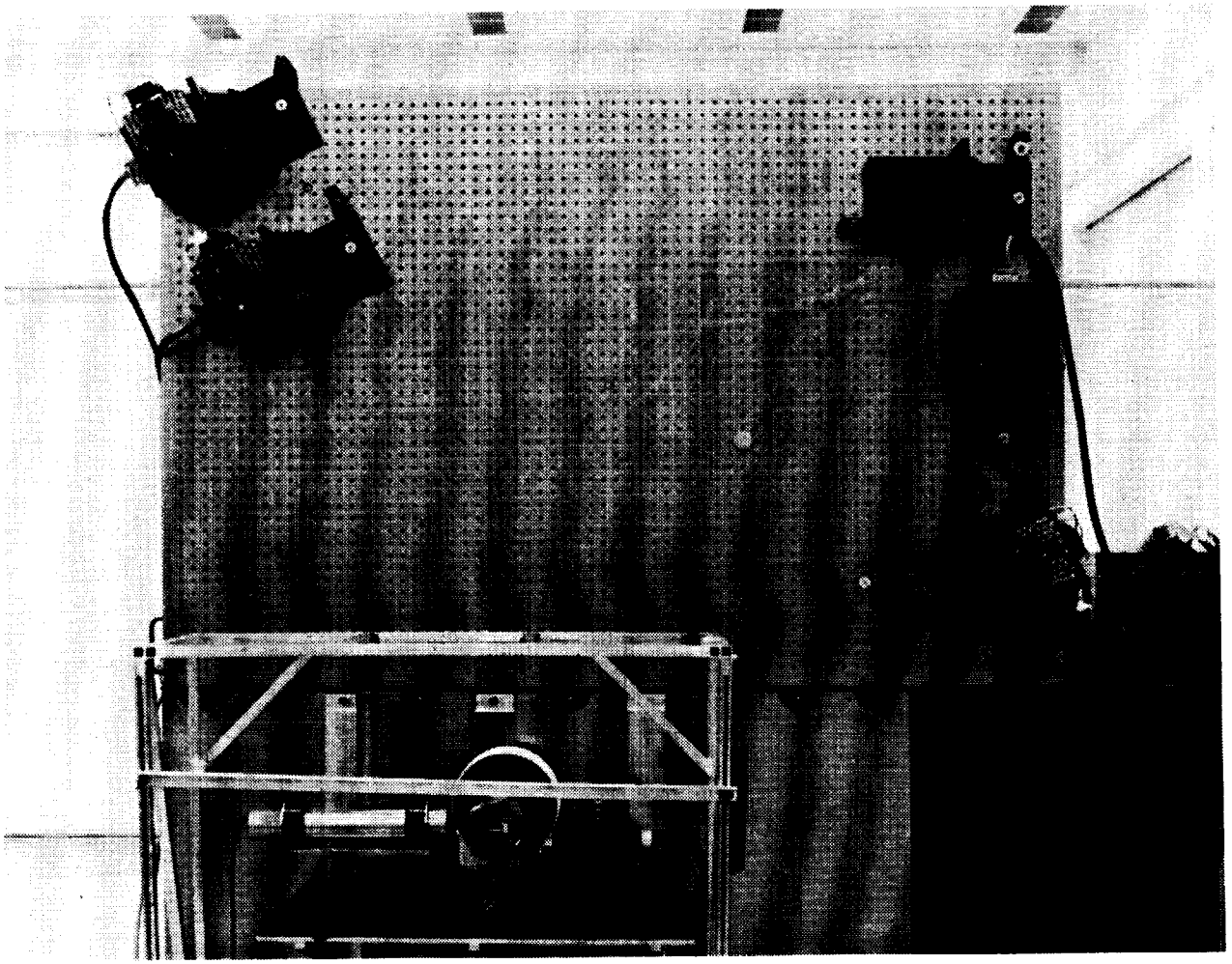
ADF RAMS Test Facility (With BMT Illuminators Operating)



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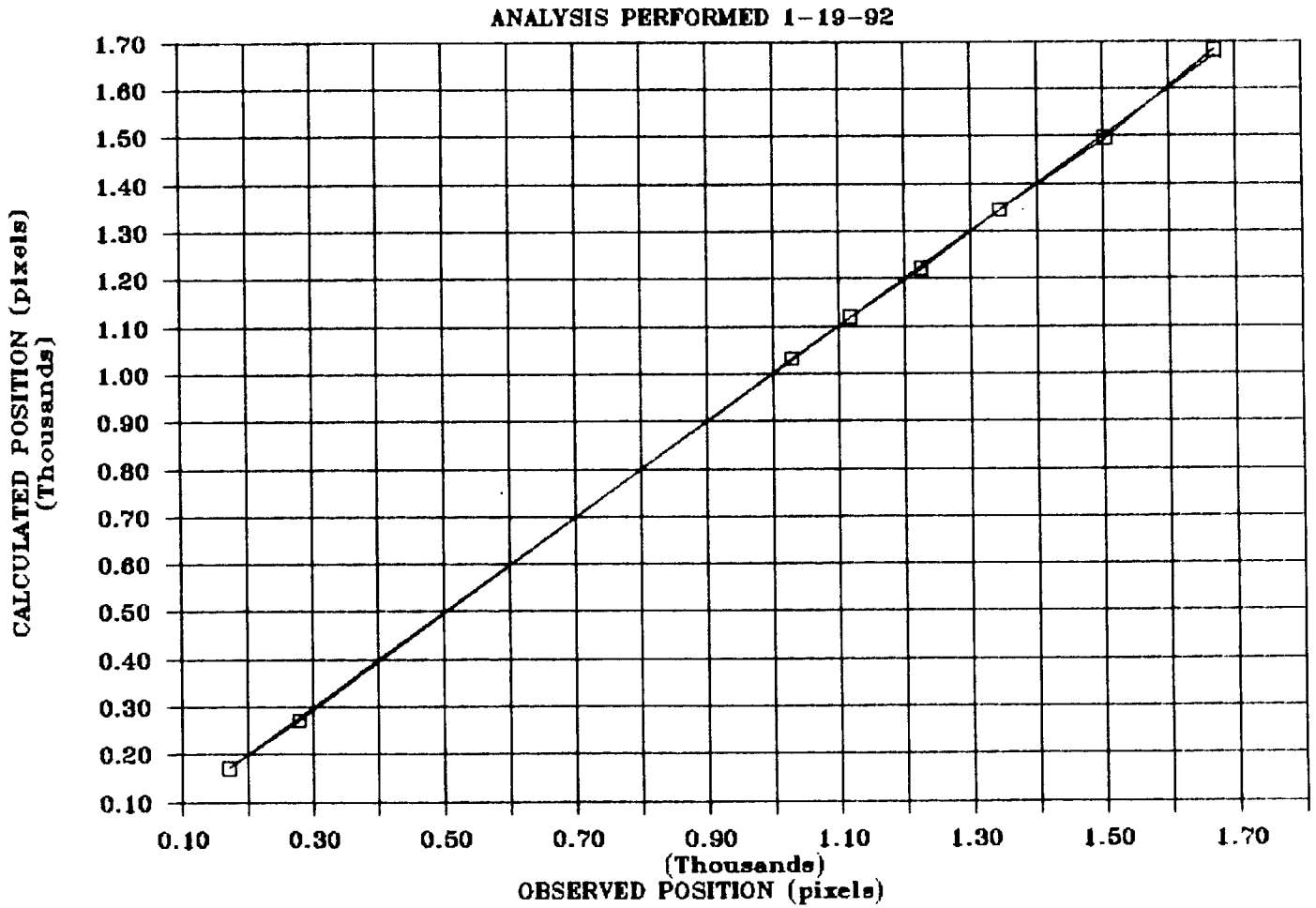
BMT Verification Results

Alignment Procedure For BMT Sensors

- Install and align (coarsely) the primary illuminator
- Install and align (coarsely) the sensor head (without cylinder lens installed)
- Adjust sensor head and illuminator alignments as necessary to image the entire target line
- Install and align cylinder lens assembly
- Install and align secondary illuminator assembly
- Check calibration of target positions
- Verify adequate margins for
  - Sensitive plane FOV
  - Non-sensitive plane FOV
  - Balanced illumination of targets

BMT-Y Calibration

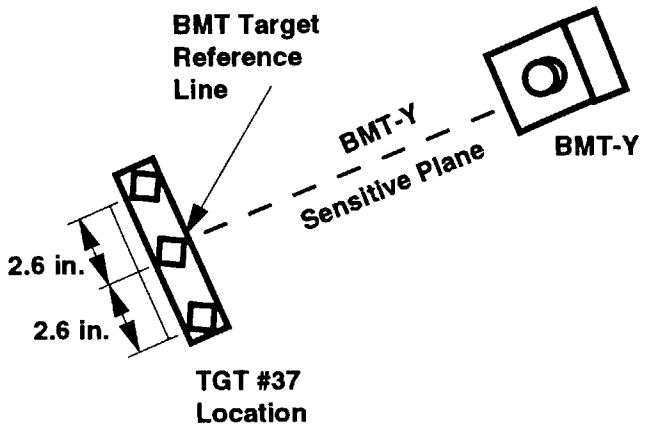


BMT Test Data (Sample)

target	x average	x std	x low	x high
1	164.84	0.023093	164.79	164.86
2	199.92	0.013256	199.91	199.95
3	264.46	0.009817	264.44	264.47
4	306.39	0.008032	306.37	306.40
5	361.91	0.081143	361.78	361.99
target	y average	y std	y low	y high
1	169.86	0.014985	169.84	169.89
2	224.25	0.008020	224.23	224.26
3	282.45	0.009687	282.43	282.46
4	332.09	0.007148	332.07	332.10
5	399.16	0.006355	399.15	399.17
target	z average	z std	z low	z high
1	97.14	0.013914	97.12	97.16
2	137.85	0.014690	137.82	137.87
3	212.31	0.012009	212.30	212.33
4	259.95	0.009479	259.94	259.97
5	324.12	0.014981	324.09	324.14

frames= 10 start= 1, end= 5, options= 14

Field of View Test for the BMT



- Three targets spaced 2.6 in. apart define the ±1 deg FOV required in the non-sensitive plane for target #37
- This test was repeated with appropriate spacings and target sizes at target #30 location

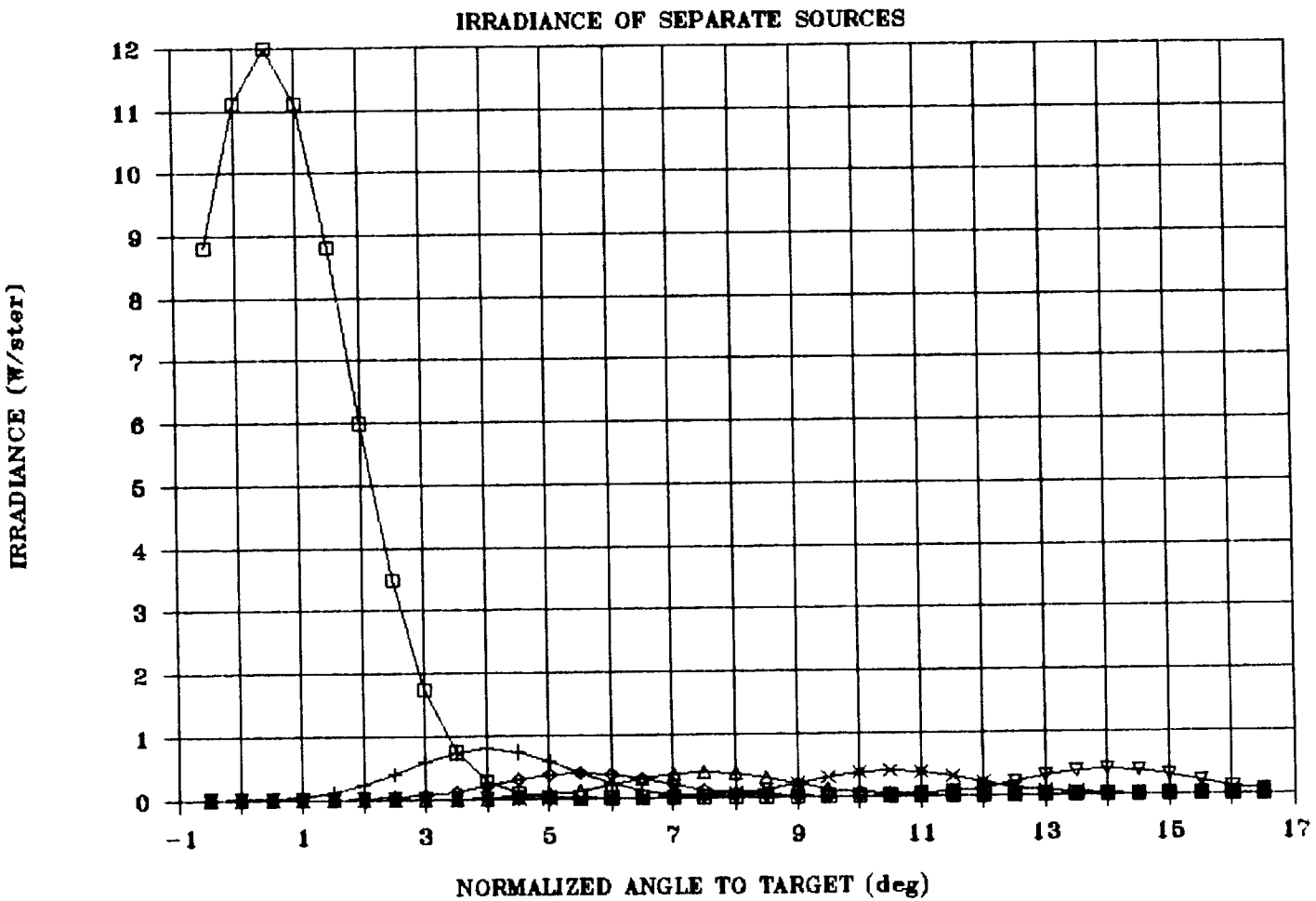
BMT Illuminator Radiometry

- Each primary illuminator contains 36 AND-brand light-emitting diodes (LEDs)
  - 30 are pointed towards the far target
  - The remaining 6 are pointed at closer targets
  - Each LED contributes ~0.4 W/Steradian

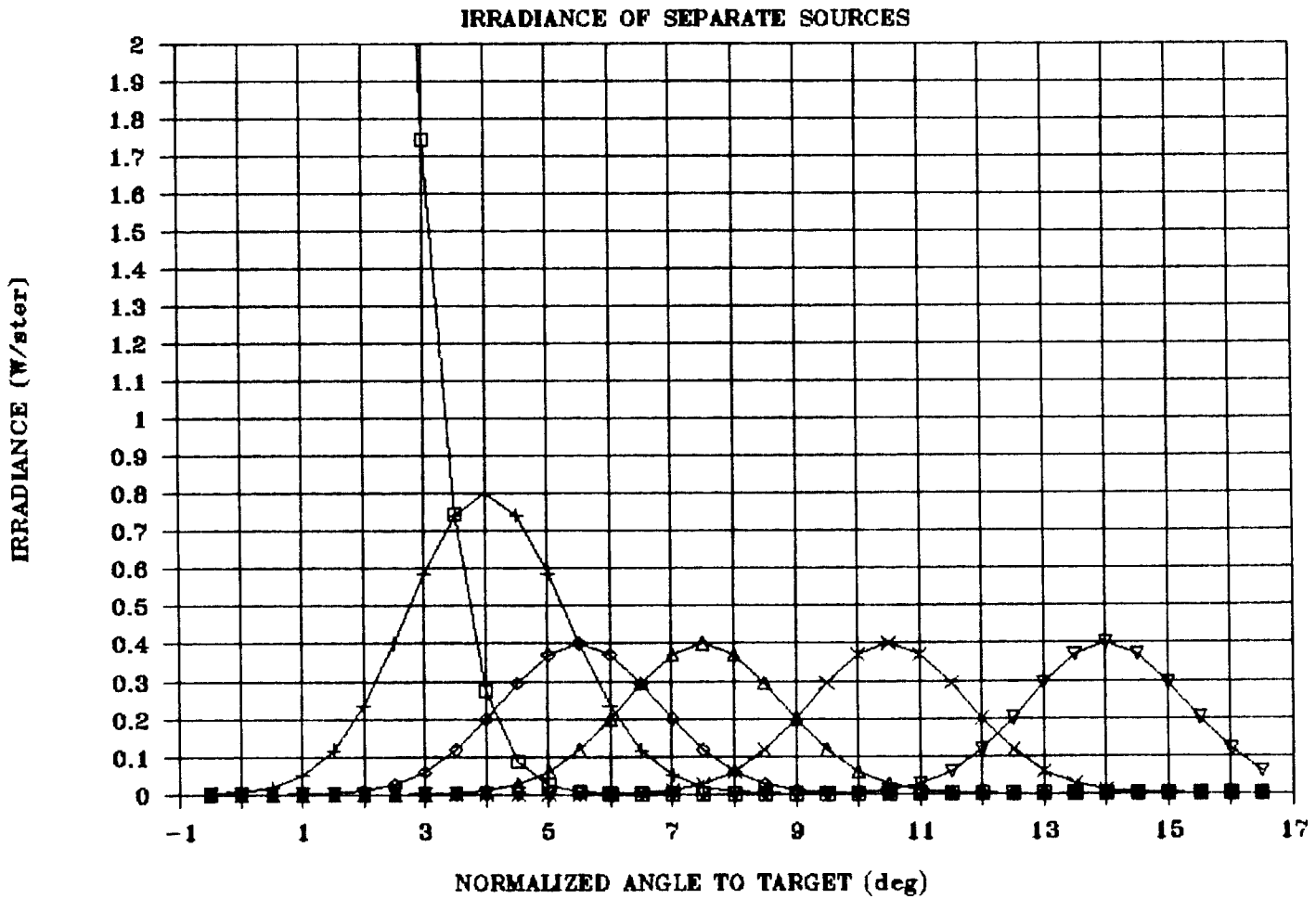
- Alignment of individual LEDs was chosen to optimize image signal (receiver power) for all targets

- The secondary illuminator contains 3 smaller (3 candela) LEDs mounted in a ring in front of the lens. These ensure illumination of the nearest targets.

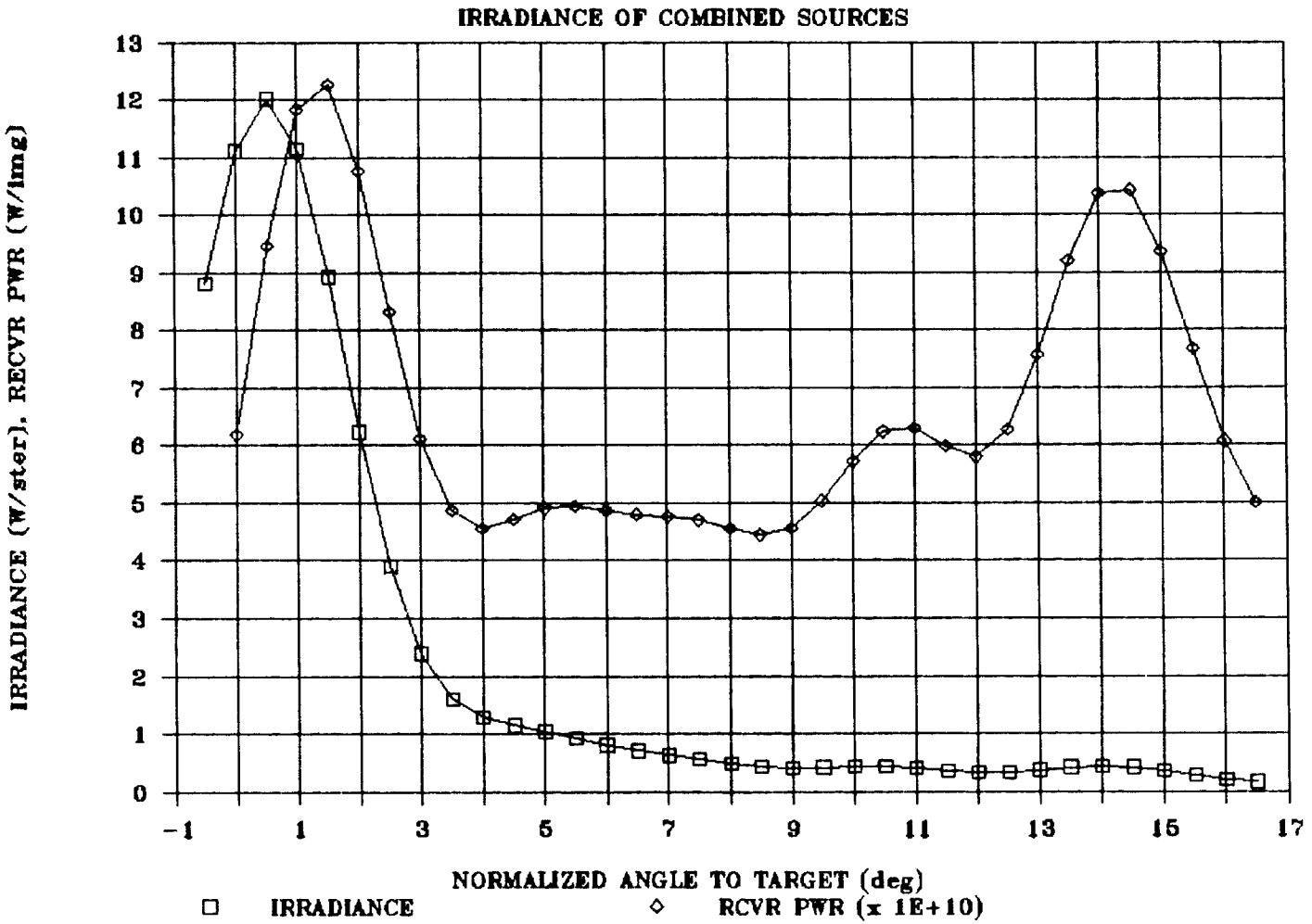
BMT-Z Illuminator



BMT-Z Illuminator (Continued)



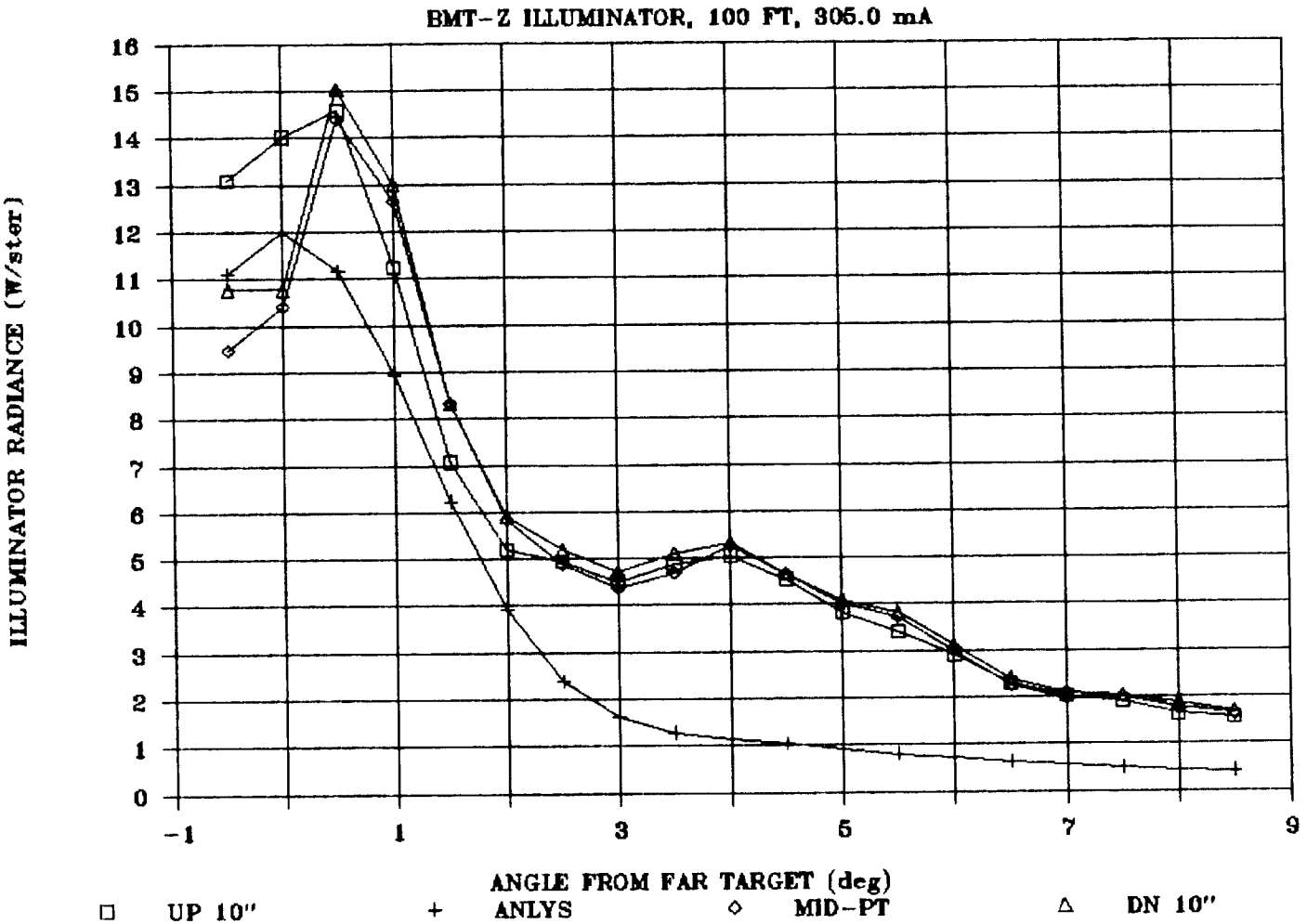
BMT-Z Illuminator (Concluded)



Actual BMT Illuminator Performance

- Each primary illuminator assembly was evaluated radiometrically
- The assembly was rotated past a photometer cell. Radiance was measured at 0.5 deg steps for points on the centerline and at ±10 in. (above and below)
- Each illuminator met or exceeded the expected output radiance

Illuminator Characterization



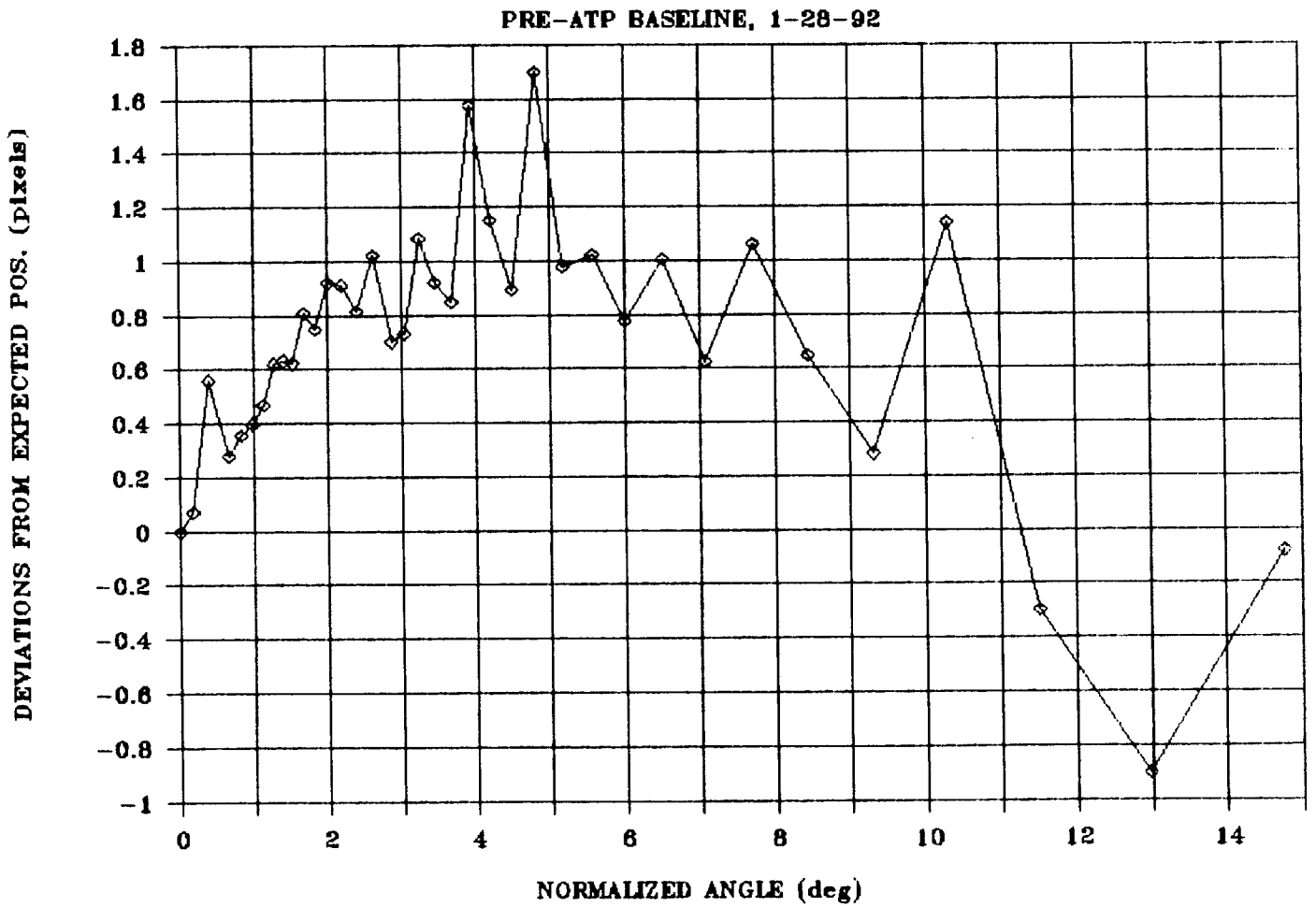
BMT Linearity Test

- Actual offset distances were measured:
  - BMT-X: 43 3/16 in.
  - BMT-Y: 43 1/16 in.
  - BMT-Z: 55 11/16 in.

- Analysis spreadsheet was revised to reflect
  - Actual offset distance
  - Target #1 pixel number (actual)

- Spreadsheet values for focal length and detector slope were adjusted to maximize agreement between predicted and observed pixel numbers for target locations

Linearity Test For BMT-Y

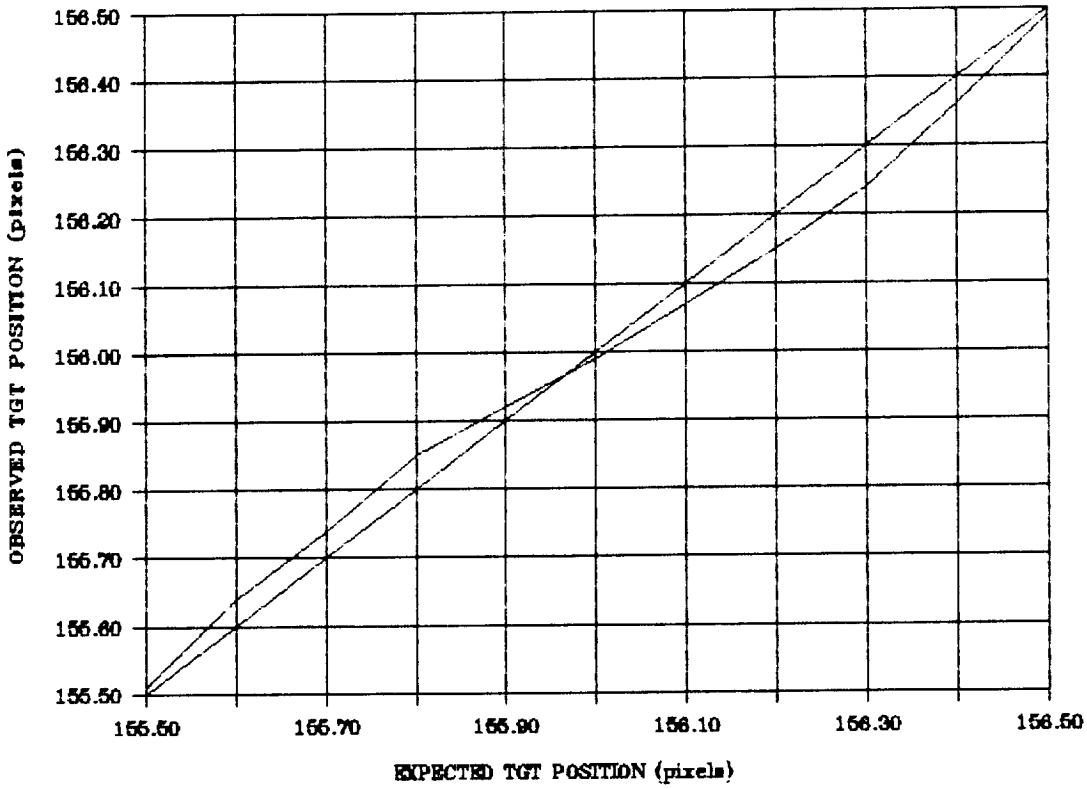


Sub-pixel Characterization

- The interpolation algorithm generates a non-linear transfer function
- This output must be linearized by means of a correction look-up table
- The appropriate correction curve is programmed into a PAL (programmable array logic)
- Sub-pixel characterization was accomplished for targets #1, #15, and #37

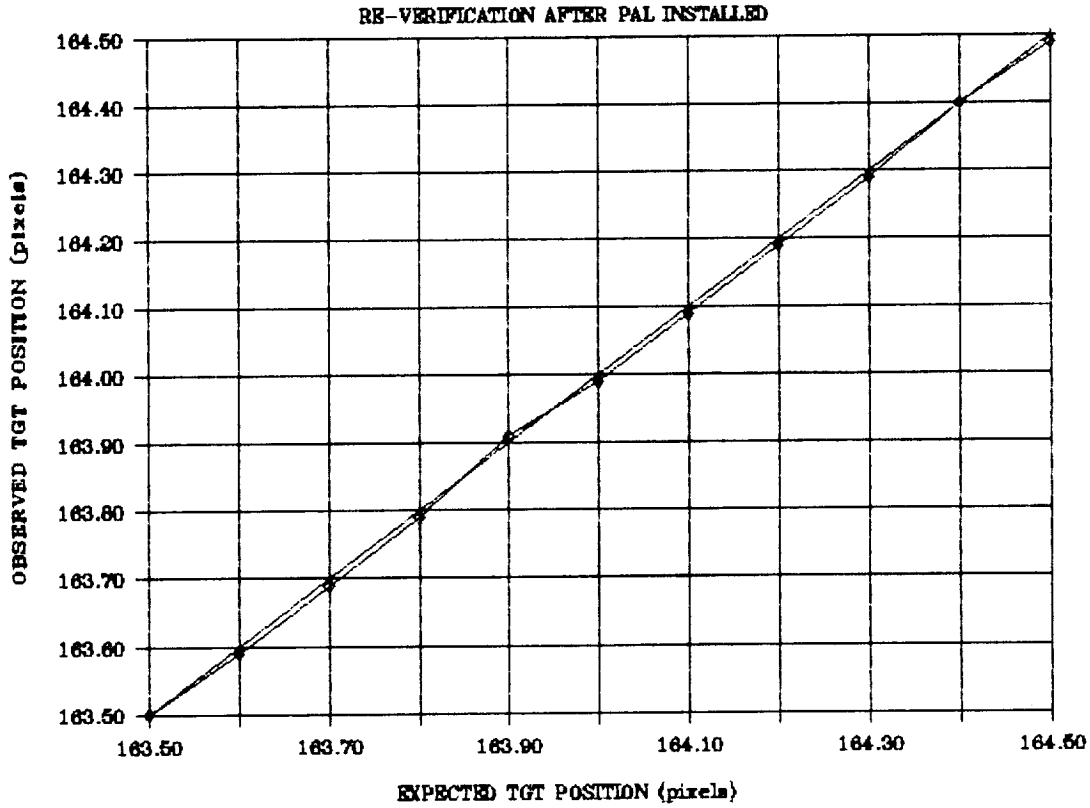
SUB-PIXEL CHARACTERIZATION, BMT-X

THIRD OF FOUR PIXELS, TGT #1



SUB-PIXEL CHARACTERIZATION, BMT-X

RE-VERIFICATION AFTER PAL INSTALLED



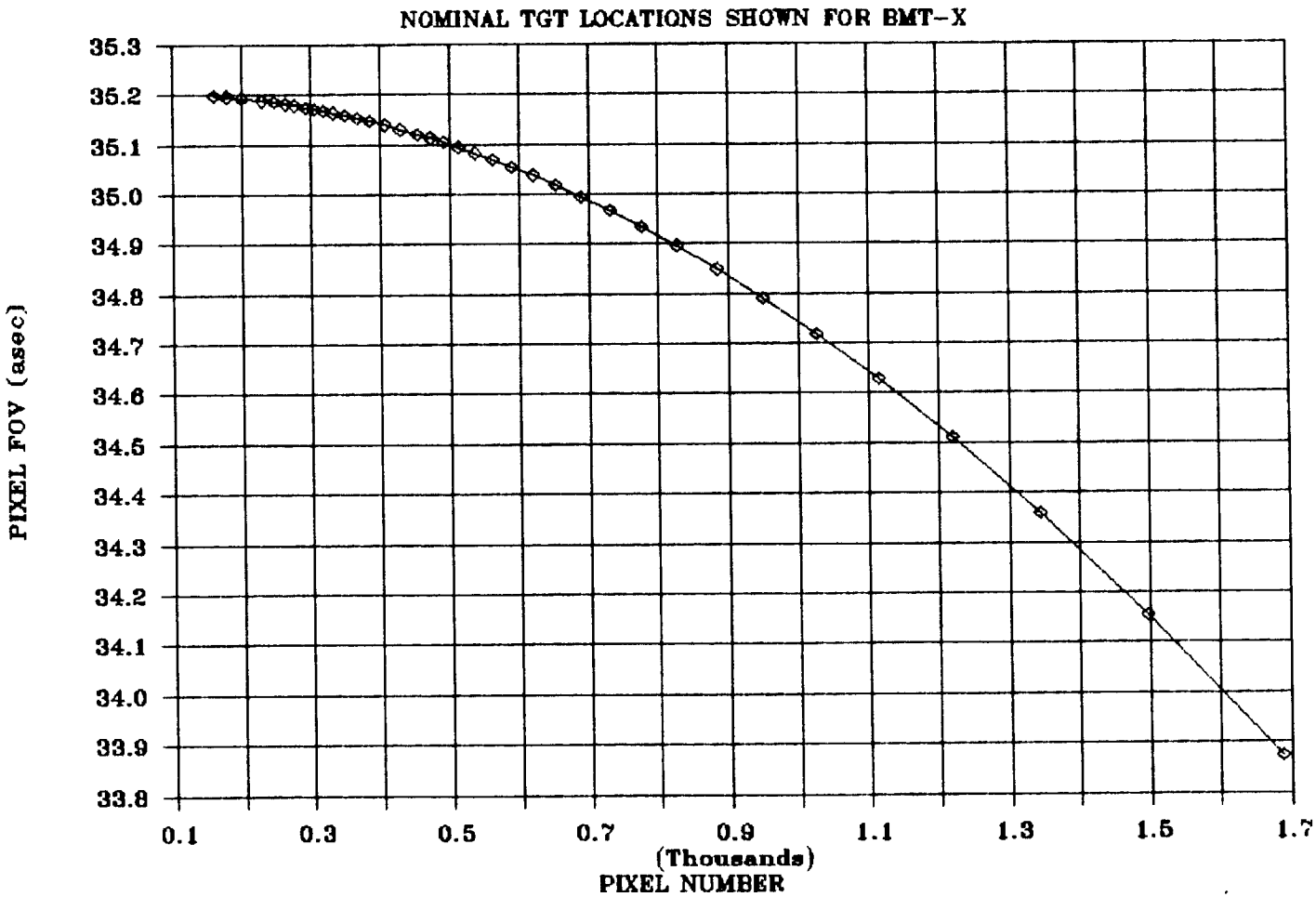
Pixel Field Of View For BMT

- FOV calculated for each sensor, based on measured offset distance and derived focal length and detector slope

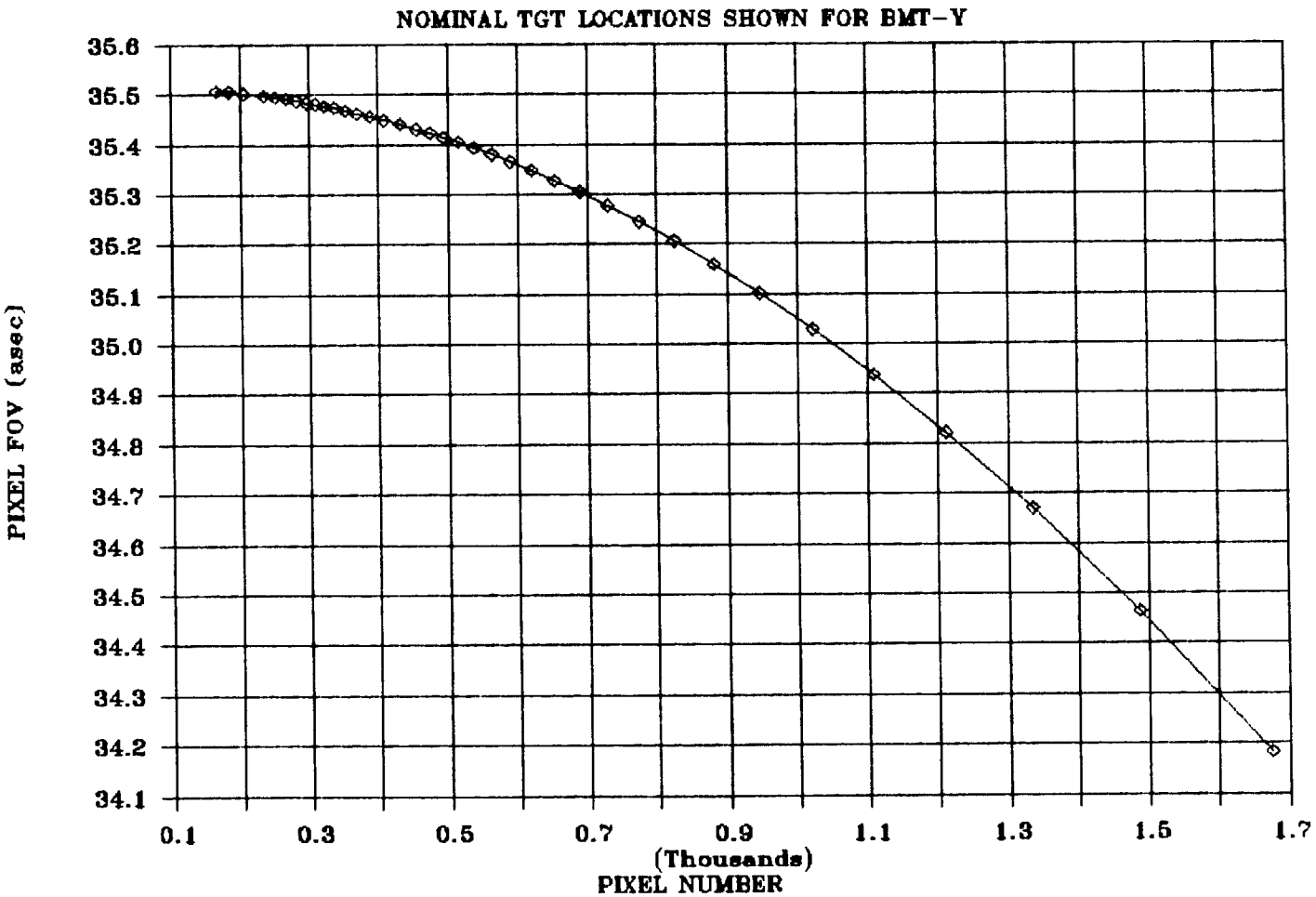
- Angle subtended by one pixel can be expressed in terms of pixel position (pixel number)

- In similar fashion, the equivalent lateral translation (per pixel) for each target can be expressed in terms of pixel position

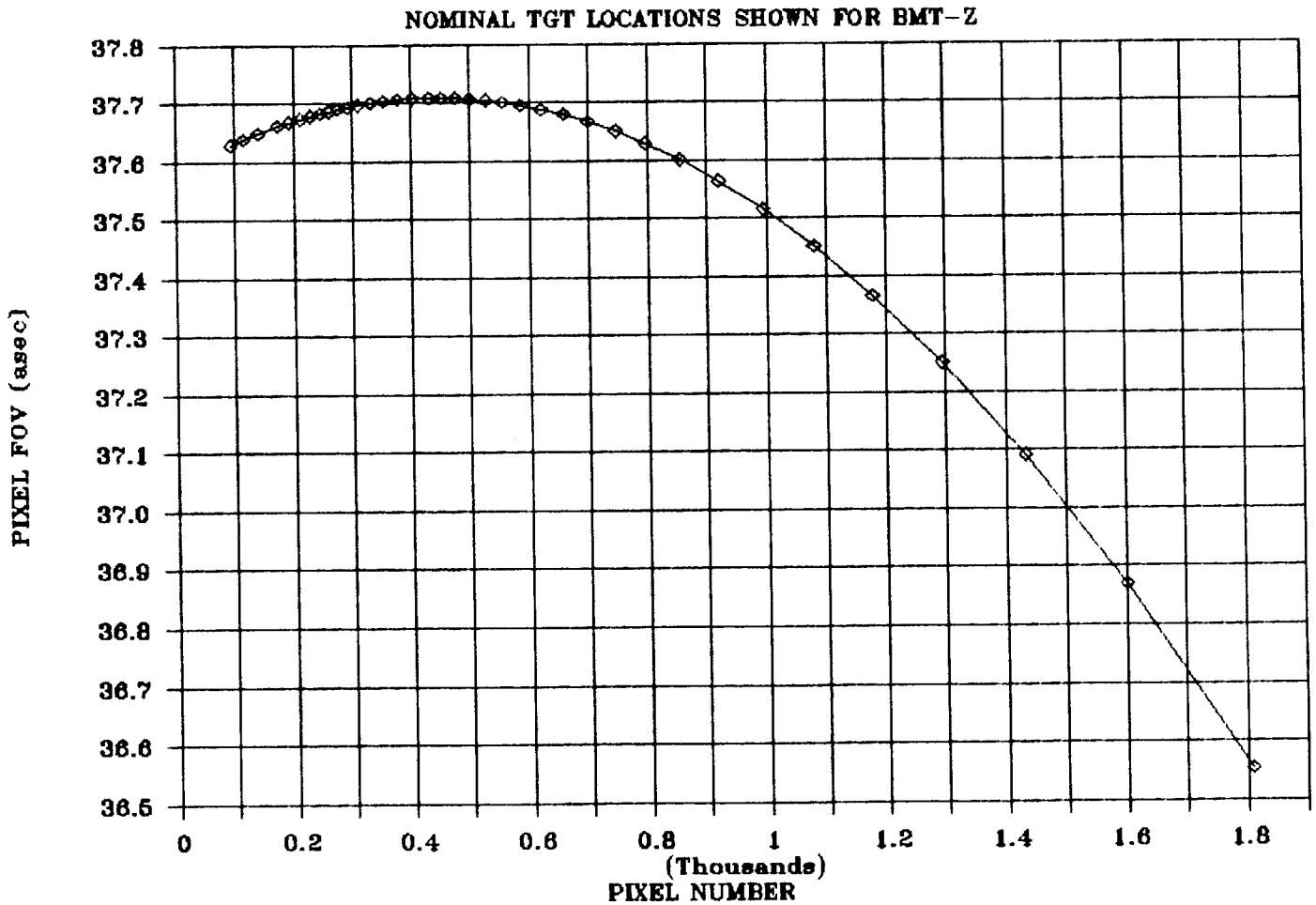
Angle Subtended By One Pixel



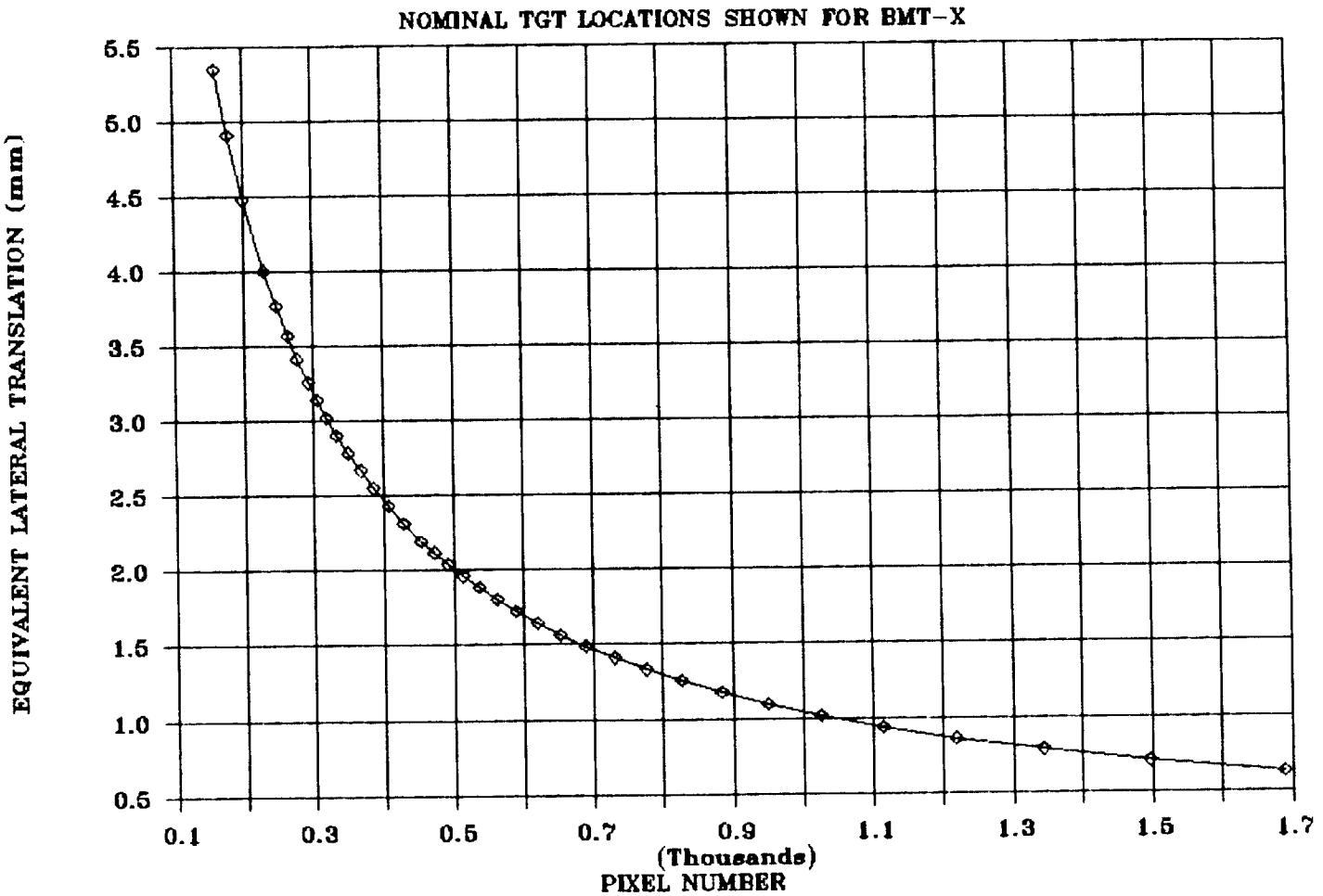
Angle Subtended By One Pixel



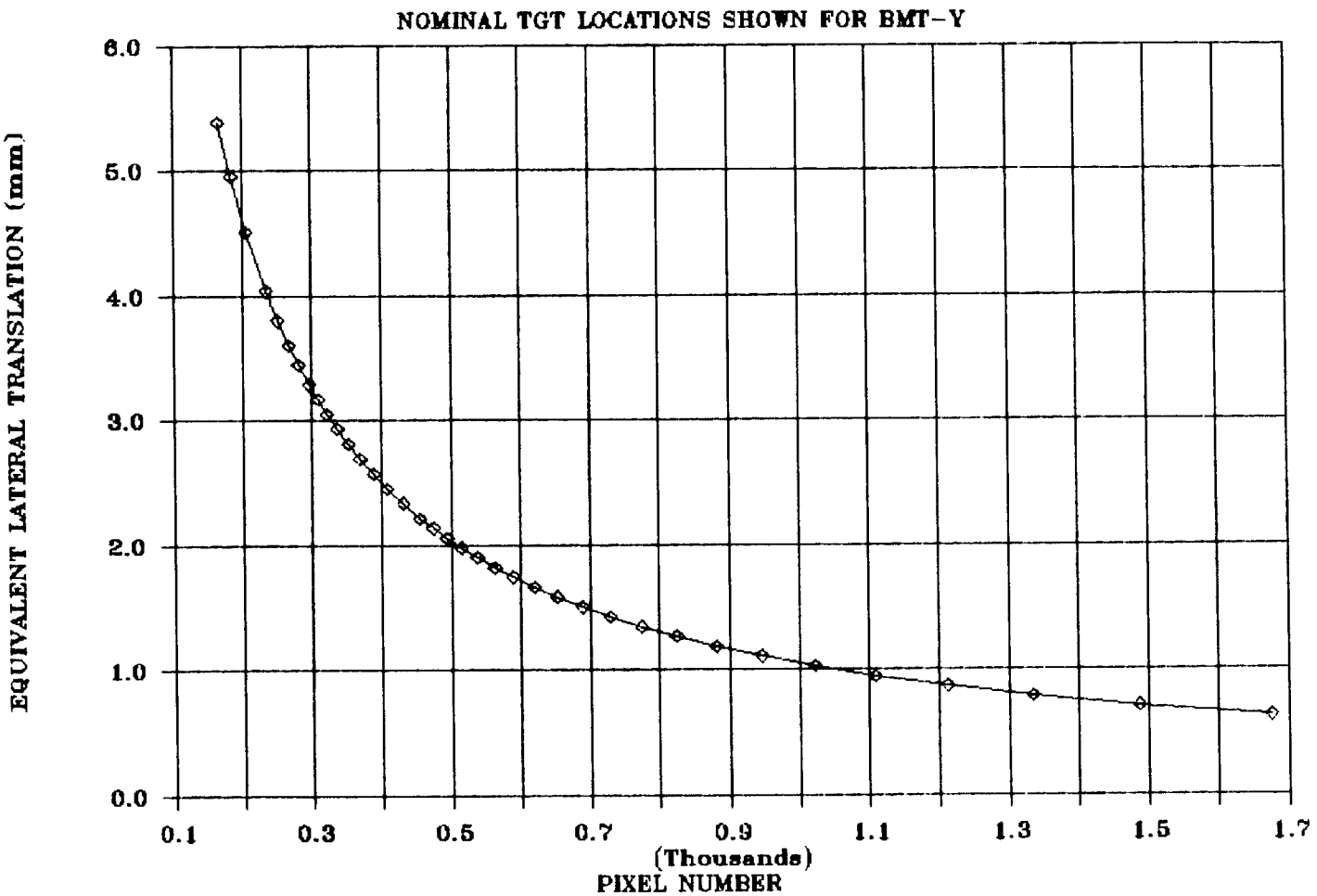
Angle Subtended By One Pixel



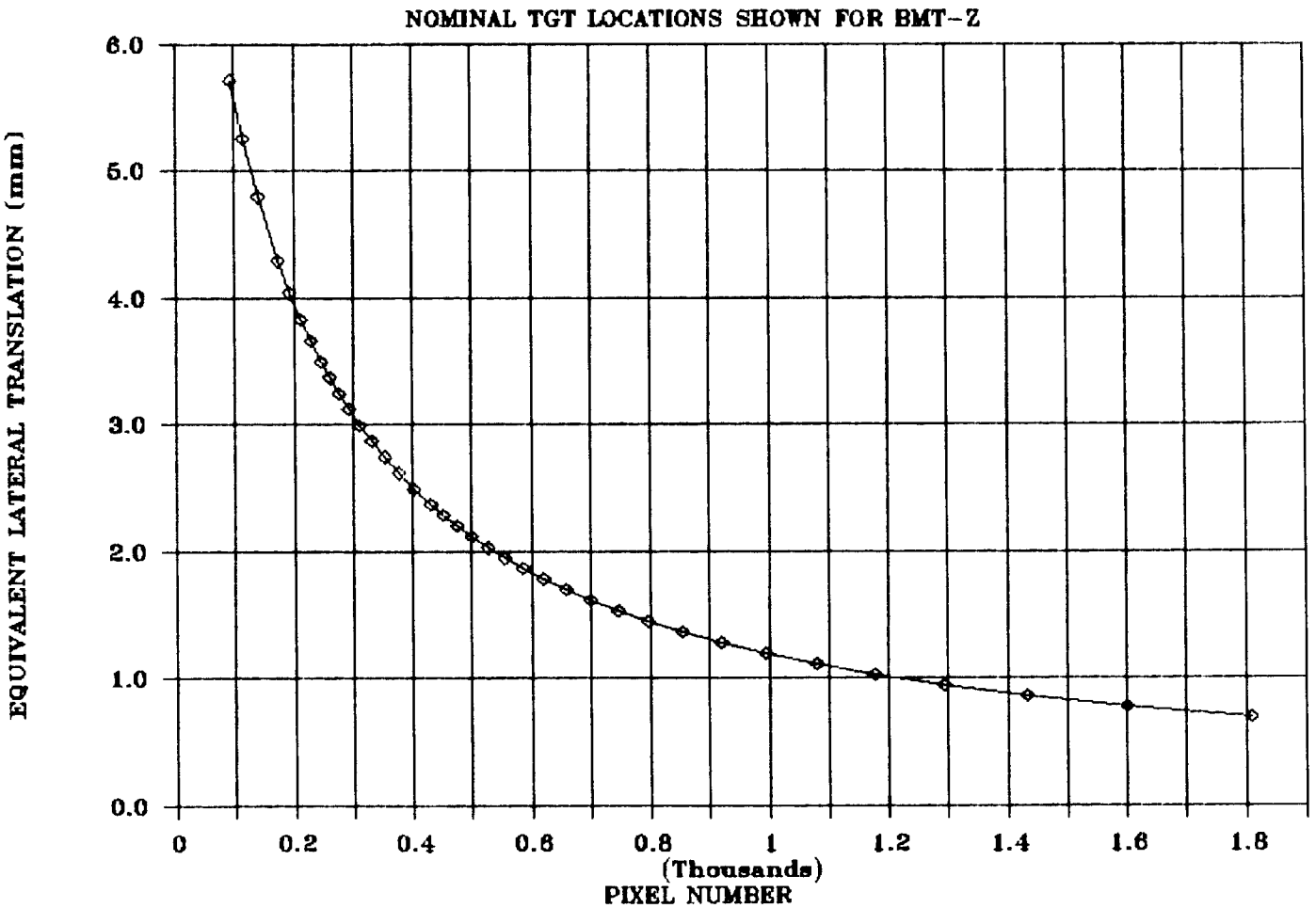
Angle Subtended By One Pixel (Concluded)



Angle Subtended By One Pixel (Concluded)



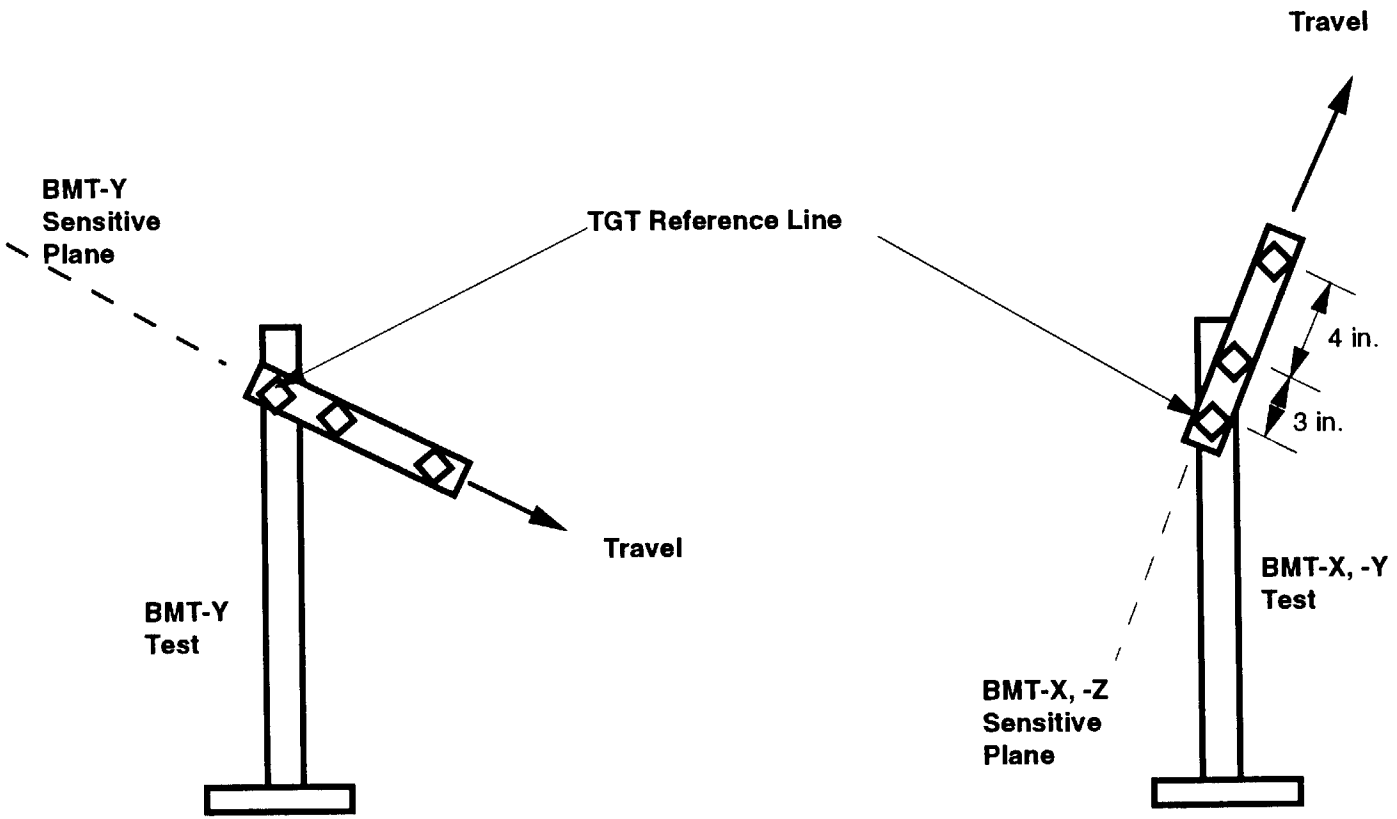
Angle Subtended By One Pixel (Concluded)



BMT Accuracy Tests

- Klinger translation stages provided sufficient accuracy (0.1 μm) but limited travel (<4 in.)
- Three targets spaced along a strip provided independent measurements throughout the 10-in. range of travel for target #1
- Data from 100 frames was averaged
- Accuracy test results generally met the specified goal of 0.01 in. for BMT-X and BMT-Y
- BMT-Z accuracy is somewhat marginal, due partly to reduced offset distance

BMT Accuracy Test Method



A2542/1054.057

BMT-X Sensor Accuracy Test For Target #1

11-Feb-92
BMTXACCY

Number of targets:	3	
Tgt orientation:	In-line in the sensitive plane, X-oriented	
Tgt separation:	Tgts at 0", 3" and 7" from tgt reference line	
Tgt location: BMT-X	31.32 m	slant range (Tgt #1 location)
Image distance: BMT-X	0.0819 m	
Tgt travel:	3.00 in.	(all tgts traveled away from tgt reference line)
Travel step size:	1.50 in.	
No. of frames averaged:	100	
BMT-X offset dist.:	43.1875 in.	
Range to tgt #1:	31.299 m	

Step Ident.	Actual Displac. (in.)	Target Number	BMT-X Average Position (pixels)	BMT-X Std. Dev. (pixels)	BMT-X Measured Displac. (in.)	BMT-X Position Error (in.)
0	0.000	1	160.63	0.012581	0.000	- -
0	0.000	2	174.84	0.013964	0.000	- -
0	0.000	3	193.62	0.010297	0.000	- -
1	1.500	1	167.74	0.013677	1.498	-0.002
1	1.500	2	181.95	0.014624	1.498	-0.002
1	1.500	3	200.73	0.010339	1.497	-0.003
2	3.000	1	174.84	0.016644	2.993	-0.007
2	3.000	2	189.08	0.019070	2.999	-0.001
2	3.000	3	207.80	0.010196	2.987	-0.013

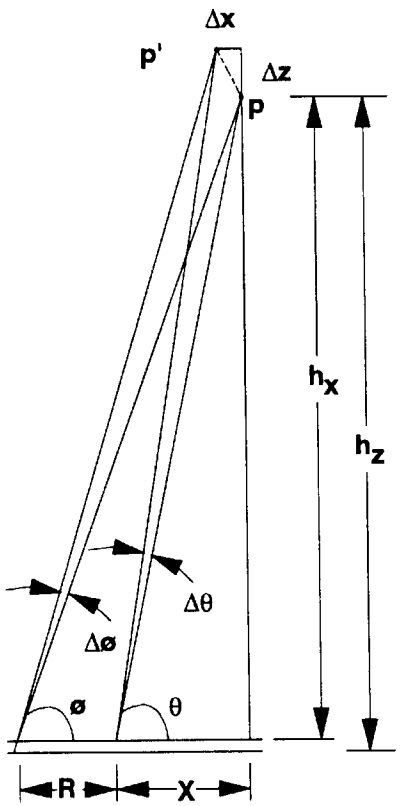
BMT-Y Sensor Accuracy Test For Target #1

11-Feb-92
BMTYACCY

Number of targets:	3	
Tgt orientation:	In-line in the sensitive plane, Y-oriented	
Tgt separation:	Tgts at 0", 3" and 7" from tgt reference line	
Tgt location: BMT-Y	31.32 m	slant range (Tgt #1 location)
Image distance: BMT-Y	0.0812 m	
Tgt travel:	3.00 in.	(all tgts traveled away from
Travel step size:	1.50 in.	tgt reference line)
No. of frames averaged:	100	
BMT-Y offset dist.:	43.1875 in.	
Range to tgt #1:	31.299 m	

Step Ident.	Actual Displac. (in.)	Target Number	BMT-Y Average Position (pixels)	BMT-Y Std. Dev. (pixels)	BMT-Y Measured Displac. (in.)	BMT-Y Position Error (in.)	BMT-Y Position High (pixels)	BMT-Y Position Low (pixels)	Worst-case BMT-Y Measured Displac. (in.)	Worst-case BMT-Y Position Error (in.)
0	0.000	1	168.61	0.013069	0.000	- -	168.64	168.58		
0	0.000	2	182.74	0.011045	0.000	- -	182.78	182.71		
0	0.000	3	201.44	0.010088	0.000	- -	201.47	201.42		
1	1.500	1	175.65	0.008412	1.496	-0.004	175.67	175.63	1.506	0.006
1	1.500	2	189.81	0.011023	1.502	0.002	189.83	189.78	1.513	0.013
1	1.500	3	208.54	0.010882	1.508	0.008	208.56	208.51	1.517	0.017
2	3.000	1	182.73	0.009992	3.000	-0.000	182.76	182.7	3.013	0.013
2	3.000	2	196.88	0.014513	3.004	0.004	196.92	196.86	3.019	0.019
2	3.000	3	215.59	0.010251	3.006	0.006	215.61	215.56	3.014	0.014

BMT-Z Displacement Calculation Method



$$\tan\theta = \frac{h_x}{x},\ \tan(\theta + \Delta\theta) = \frac{h_x + \Delta z}{x + \Delta x} \quad (1)$$

$$\text{Tan } ø = \frac{h_z}{(R + X)},\ \tan(ø + \Delta ø) = \frac{h_z + \Delta z}{(R + X + \Delta x)} \quad (2)$$

Using equation (1):

$$\Delta z = (x + \Delta x)\tan(\theta + \Delta\theta) - h_x \quad (3)$$

Substituting equation (3) into equation (2):

$$\Delta x = \left[\frac{(R + X)\tan(ø + \Delta ø) - (h_z - h_x) - x\tan(\theta + \Delta\theta)}{\tan(ø + \Delta ø) + \tan(\theta + \Delta\theta)}\right] \quad (4)$$

Solve for Δx, then substitute that value into equation (3) to solve for Δz

A2542/1054.050

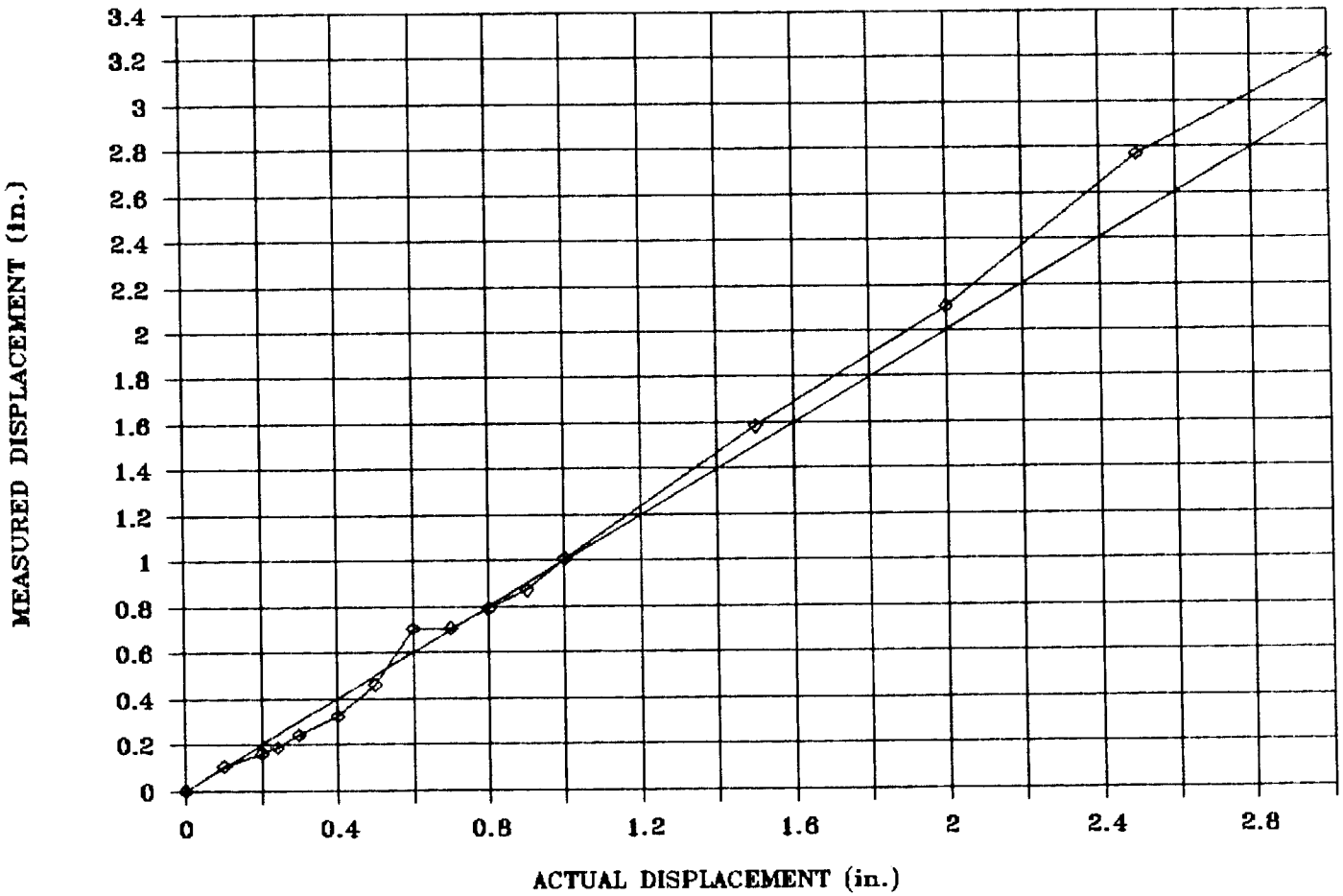
BMT-Z Sensor Accuracy Test For Target #1

BMT-Z SENSOR ACCURACY TEST FOR TARGET #1
4 Feb 92

Number of targets:	1		
Tgt orientation:	On the target line, X-Y oriented		
Tgt separation:	N/A		
Tgt location: BMT-X	31.32	m	slant range (Tgt #1 location)
Tgt location: BMT-Z	31.34	m	slant range (Tgt #1 location)
Image distance: BMT-X	0.0819	m	
Image distance: BMT-Z	0.0762	m	
Tgt travel:	3.00	in.	(target traveled away from
Travel step size:	0.1, 0.5	in.	BMT-Z, along tgt line)
No. of frames averaged:	100		
BMT-X offset dist.:	43.1875	in.	1.096964 m
BMT-Z offset dist.:	55.6875	in.	1.414465 m
BMT-X Range to tgt #1:	31.299	m	
BMT-Z Range to tgt #1:	31.314	m	
BMT-X Initial view angle:	87.993	deg	
BMT-Z Initial view angle:	87.414	deg	

Step Ident.	Actual Displac. (in.)	Target Number	BMT-X Average Position (pixels)	BMT-X Std. Dev. (pixels)	BMT-X Angle Change (deg)	BMT-Z Average Position (pixels)	BMT-Z Std. Dev. (pixels)	BMT-Z Angle Change (deg)	Delta X (in.)	Delta Z (in.)	Z Position Error (in.)
0	0.00	1	160.66	0.015407	0.00E+00	71.97	0.022122	0.00E+00	5.4E-14	-1.2E-12	-1.21E-12
1	0.10	1	160.63	0.019474	2.94E-04	71.96	0.023074	1.05E-04	-0.00257	0.10717	0.00717
2	0.20	1	160.62	0.016723	3.92E-04	71.95	0.024715	2.11E-04	-0.00277	0.16177	-0.03823
3	0.24	1	160.61	0.017442	4.90E-04	71.95	0.026713	2.11E-04	-0.00396	0.18807	-0.05193
4	0.30	1	160.60	0.017720	5.88E-04	71.94	0.024209	3.16E-04	-0.00415	0.24267	-0.05733
5	0.40	1	160.59	0.015246	6.86E-04	71.92	0.031526	5.26E-04	-0.00336	0.32559	-0.07441
6	0.50	1	160.56	0.038122	9.79E-04	71.90	0.038497	7.37E-04	-0.00494	0.46113	-0.03887
7	0.60	1	160.50	0.061076	1.57E-03	71.87	0.032159	1.05E-03	-0.00909	0.70399	0.10399
8	0.70	1	160.51	0.039753	1.47E-03	71.86	0.037201	1.16E-03	-0.00691	0.70599	0.00599
9	0.80	1	160.50	0.016963	1.57E-03	71.84	0.042465	1.37E-03	-0.00611	0.78897	-0.01103
10	0.90	1	160.49	0.014183	1.67E-03	71.82	0.035708	1.58E-03	-0.00532	0.87196	-0.02804
11	1.00	1	160.47	0.013574	1.86E-03	71.79	0.022789	1.89E-03	-0.00472	1.00963	0.00963
12	1.50	1	160.36	0.011414	2.94E-03	71.69	0.023186	2.95E-03	-0.00787	1.58297	0.08297
13	2.00	1	160.27	0.012128	3.82E-03	71.59	0.056433	4.00E-03	-0.00865	2.10407	0.10407
14	2.50	1	160.18	0.017987	4.70E-03	71.44	0.016179	5.58E-03	-0.00446	2.76770	0.26770
15	3.00	1	160.11	0.016677	5.39E-03	71.35	0.017761	6.53E-03	-0.00384	3.20850	0.20850

BMT-Z ACCURACY TEST



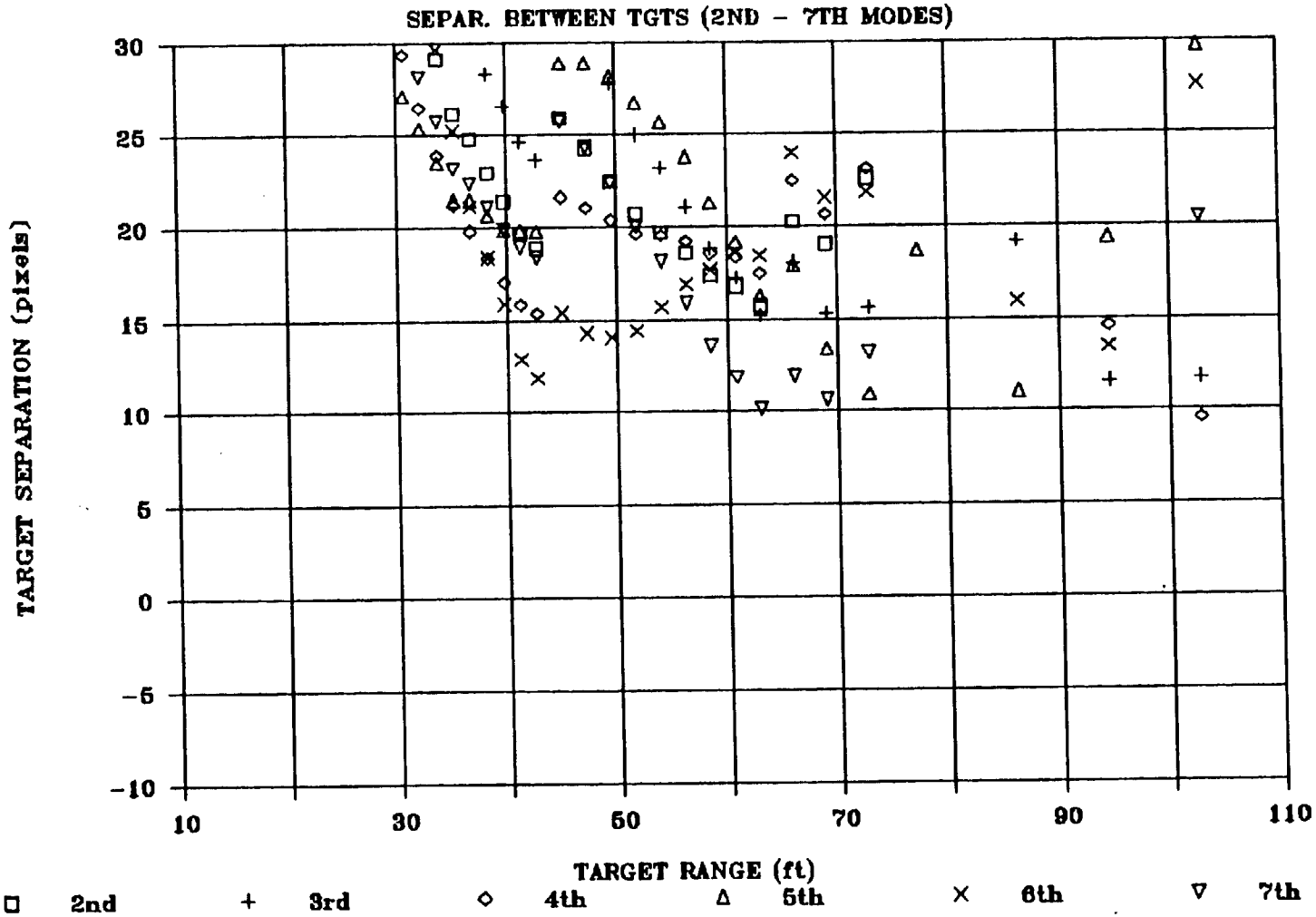
BMT Target Overlap Test

- From the mode shape analysis, the greatest potential for overlap occurs with targets #1 and #2 in the fourth bending mode

- Both targets were displaced the prescribed amounts and viewed by the BMT-Y sensor

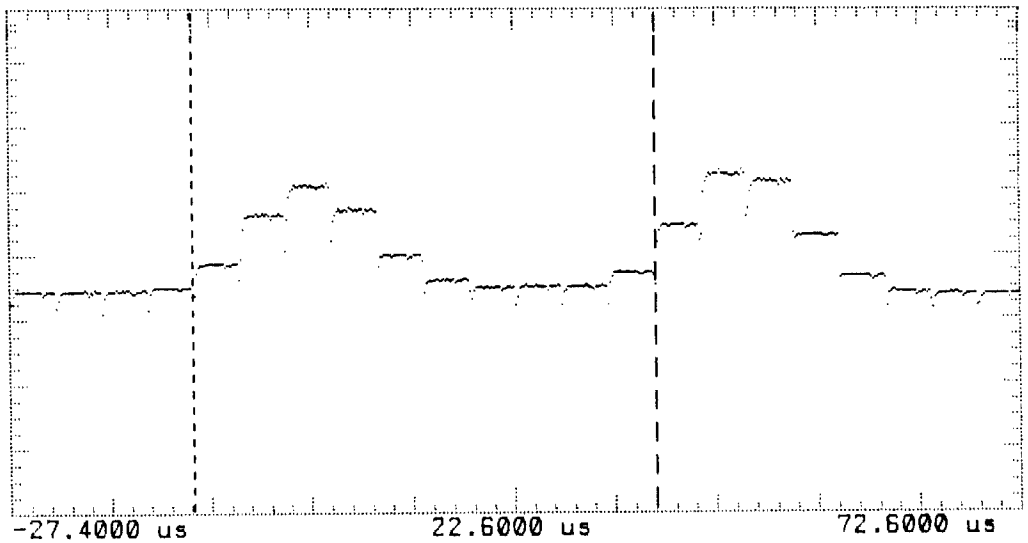
- With these displacements, the BMT successfully tracked both targets. The oscilloscope showed the targets to be separated by approximately 9.5 pixels

Cases Mode Shapes



A2542/1054.062

Target Overlap Test
TGT #1 and TGT #2



Ch. 1	= 500.0 mvolts/div	Offset	= 910.0 mvolts
Timebase	= 10.0 us/div	Delay	= 22.6000 us
Delta T	= -45.8000 us		
Start	= 36.6000 us	Stop	= -9.20000 us

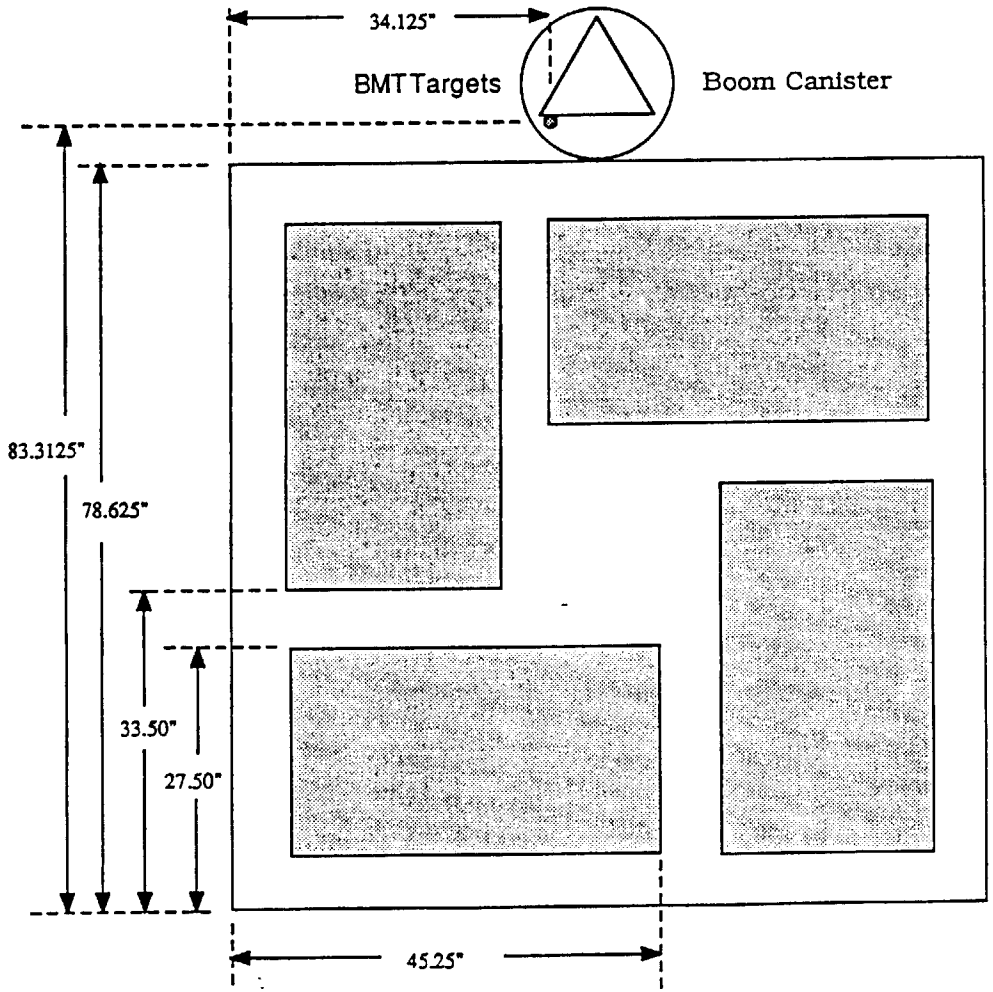
Trigger mode : Edge
On Neg. Edge on Chan1
Trigger Levels
Chan1 = 910.0 mvolts
Holdoff = 70.000 ns

Following target motion, these two targets are still separated by approximately 9.5 pixels

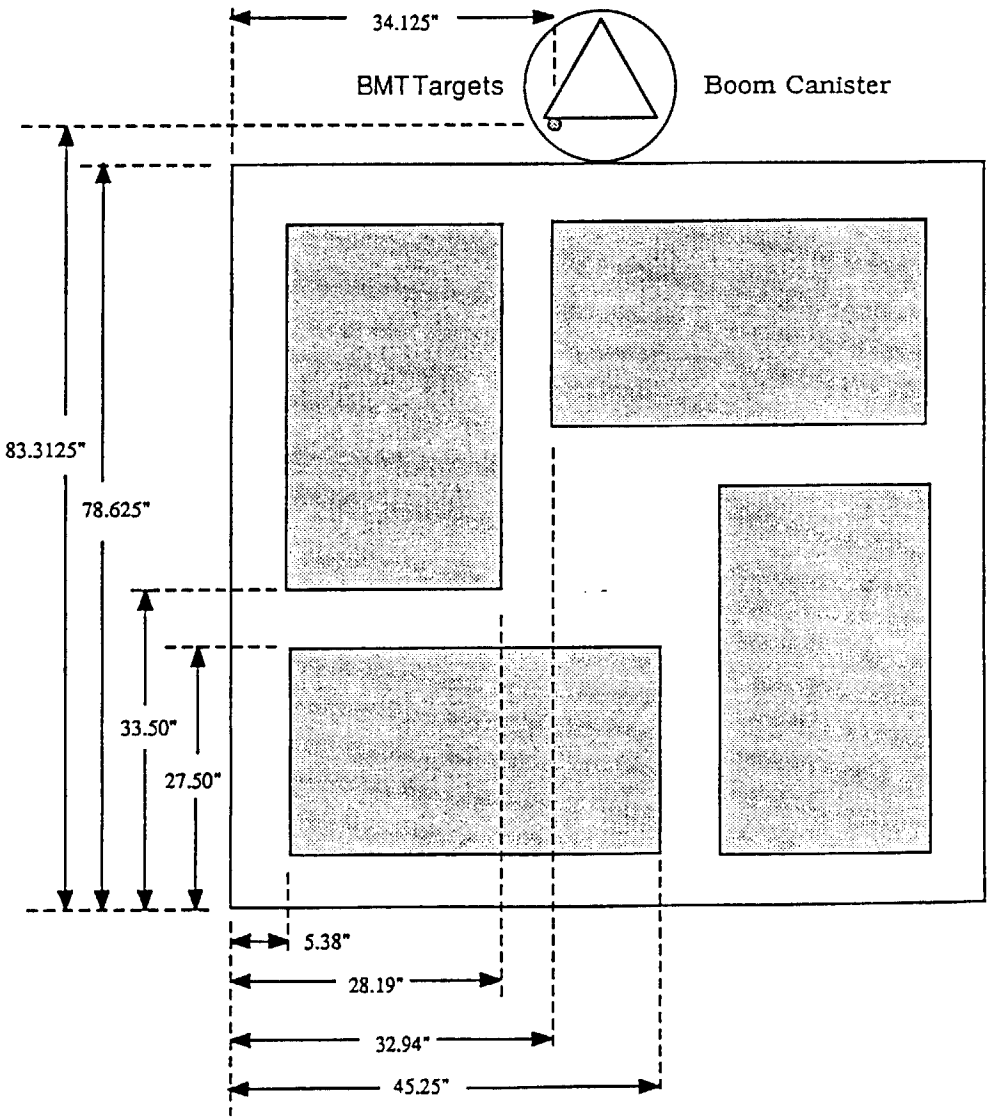
A2542/1054.040

TDS Verification Results

Tip Plate Configuration Definition

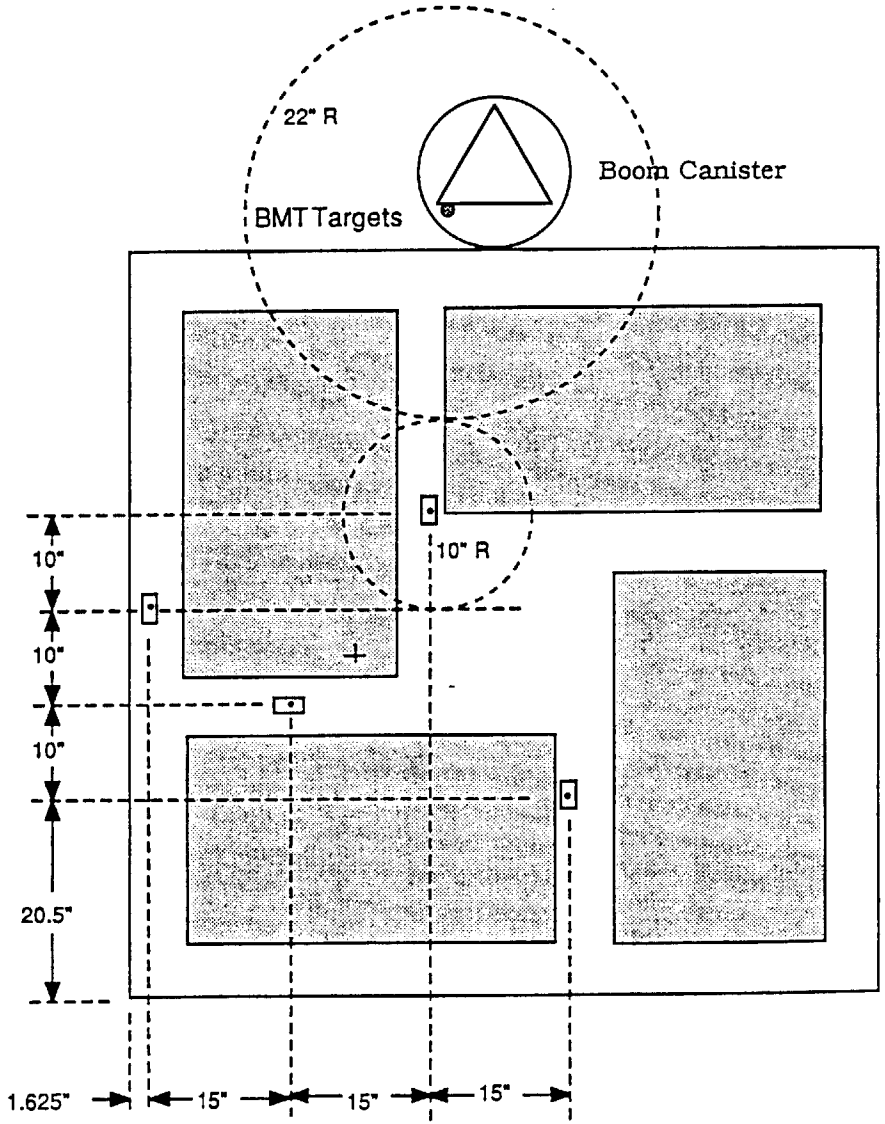


Tip Plate Configuration Definition



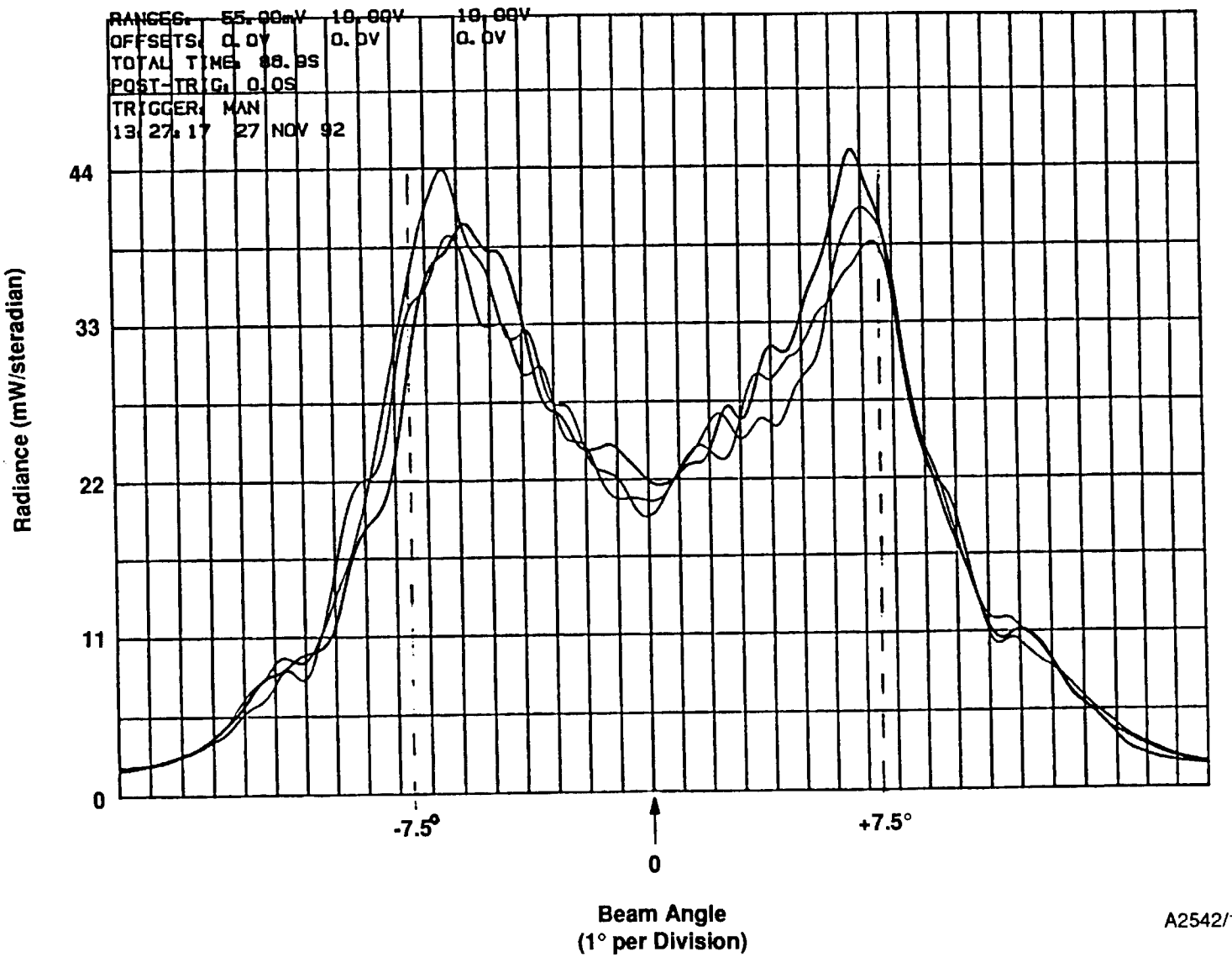
A2542/1054.054

Revised TDS Target Configuration



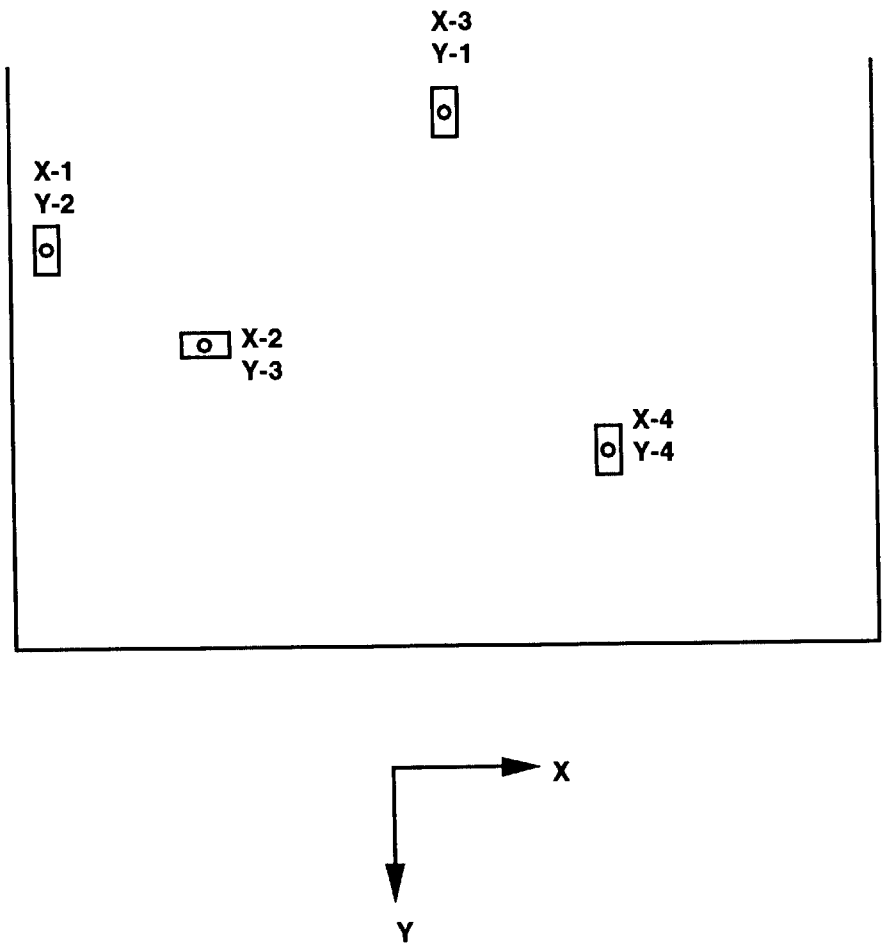
A2542/1054.055

TDS Target/Illuminator Characterization (Target # 1)

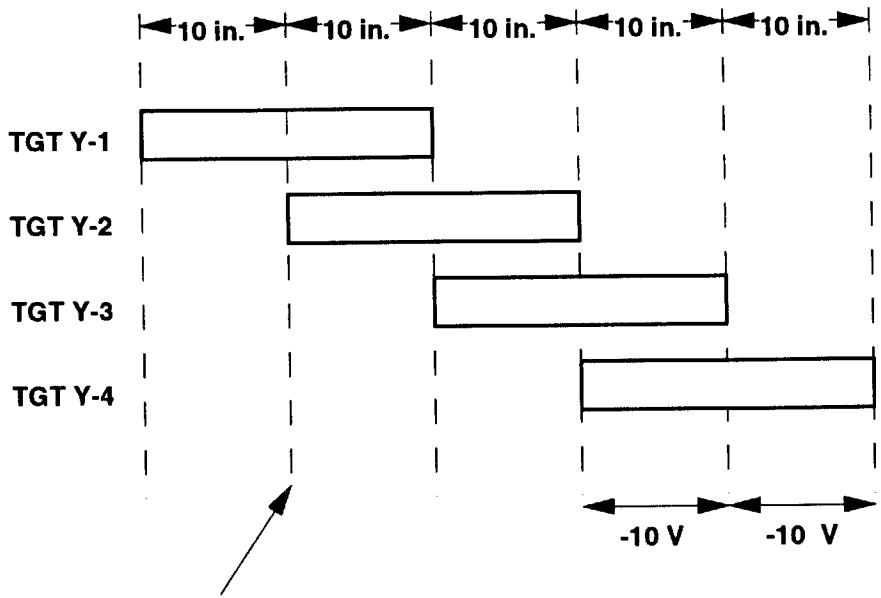


A2542/1054.053

TDS Target Identification



TDS Displacement Measurement Concept



±10 in. displacements equate to ±10 V changes in TDS output signal

The expected center of image motion for each target is programmed into the EPROM to establish the offset distance for zero analog output

X1 Linearity ATP

X Channel 1 FOV Center
TDS Data File B:T10B2058
Update Rate: 250 Hz
X1 LINEARITY

Data	X1		X1
Mean:	-0.96425	Stdev:	0.00183
Mean:	-1.47338	Stdev:	0.00197
Mean:	-1.98340	Stdev:	0.00138
Mean:	-2.48986	Stdev:	0.00149
Mean:	-2.99799	Stdev:	0.00157
Mean:	-3.50403	Stdev:	0.00173
Mean:	-4.01217	Stdev:	0.00170

Normalized Motion	Step Change
0.000	-
0.509	0.50913
1.019	0.51002
1.526	0.50646
2.034	0.50813
2.540	0.50604
3.048	0.50814
Average	0.50799
Stdev	0.00152

+ FOV Edge
TDS Data File B:T11B0122
Update Rate: 250 Hz
X1-X4 LINEARITY +FOV

Data	X1		X1
Mean:	9.21512	Stdev:	0.00081
Mean:	8.70726	Stdev:	0.00065
Mean:	8.19913	Stdev:	0.00081
Mean:	7.69214	Stdev:	0.00141
Mean:	7.18297	Stdev:	0.00157
Mean:	6.67756	Stdev:	0.00113
Mean:	6.16964	Stdev:	0.00165
Mean:	5.66243	Stdev:	0.00121

Normalized Motion	Step Change
0.000	-
0.508	0.50786
1.016	0.50813
1.523	0.50699
2.032	0.50917
2.538	0.50541
3.045	0.50792
3.553	0.50721
Average	0.50753
Stdev	0.00117

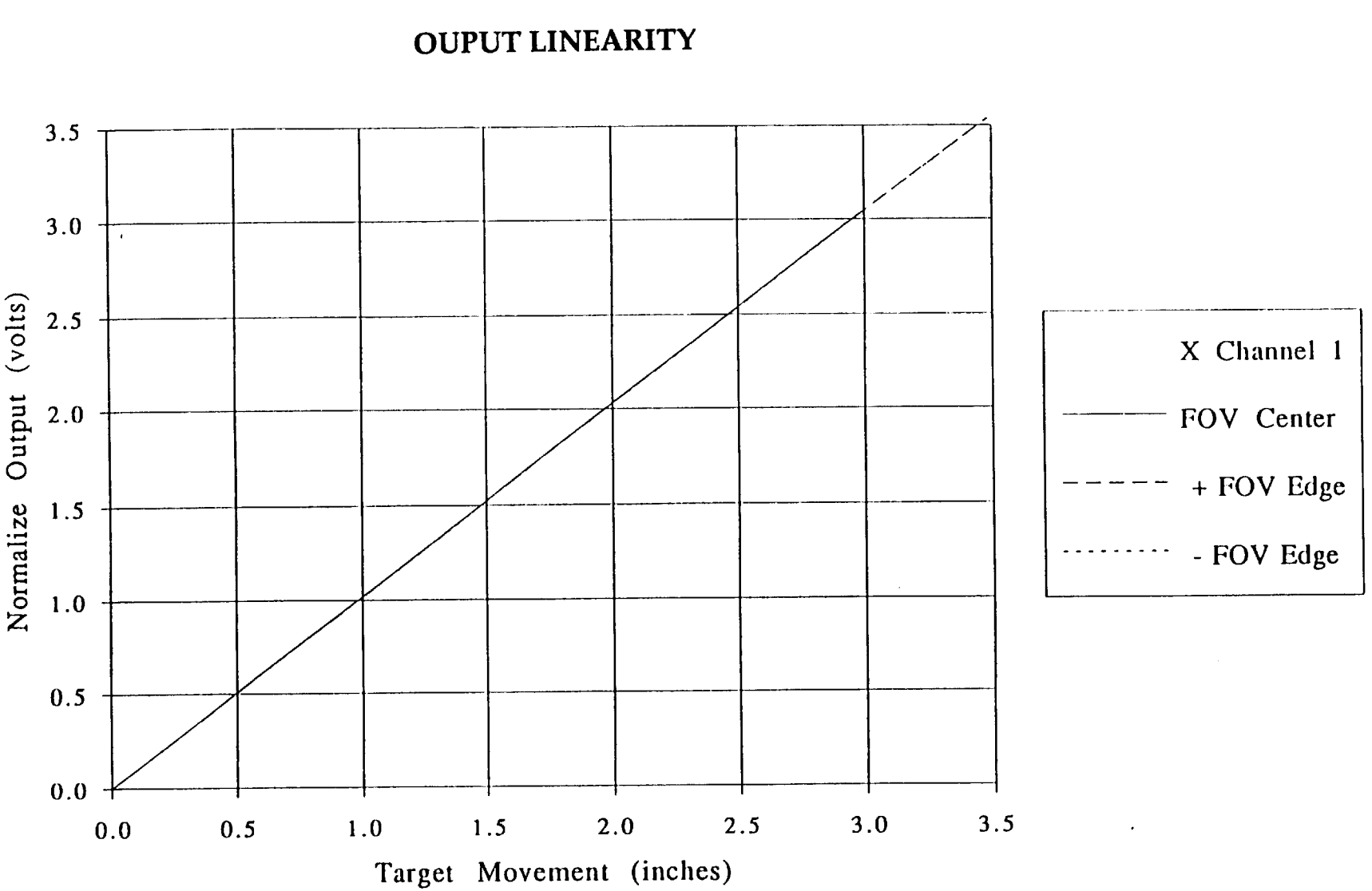
- FOV Edge
TDS Data File B:T11B0202
Update Rate: 250 Hz
X LINEARITY -FOV REPEAT

Data	X1		X1
Mean:	-5.92828	Stdev:	0.00105
Mean:	-6.43630	Stdev:	0.00114
Mean:	-6.93924	Stdev:	0.00153
Mean:	-7.44828	Stdev:	0.00103
Mean:	-7.95602	Stdev:	0.00163
Mean:	-8.46527	Stdev:	0.00131
Mean:	-8.97011	Stdev:	0.00153
Mean:	-9.47581	Stdev:	0.00087

Normalized Motion	Step Change
0.000	-
0.508	0.50802
1.011	0.50294
1.520	0.50904
2.028	0.50774
2.537	0.50925
3.042	0.50484
3.548	0.50570
Average	0.50679
Stdev	0.00236

Channel Scale Factor: 1.01487 Volts/Inch

X1 Linearity ATP (Concluded)

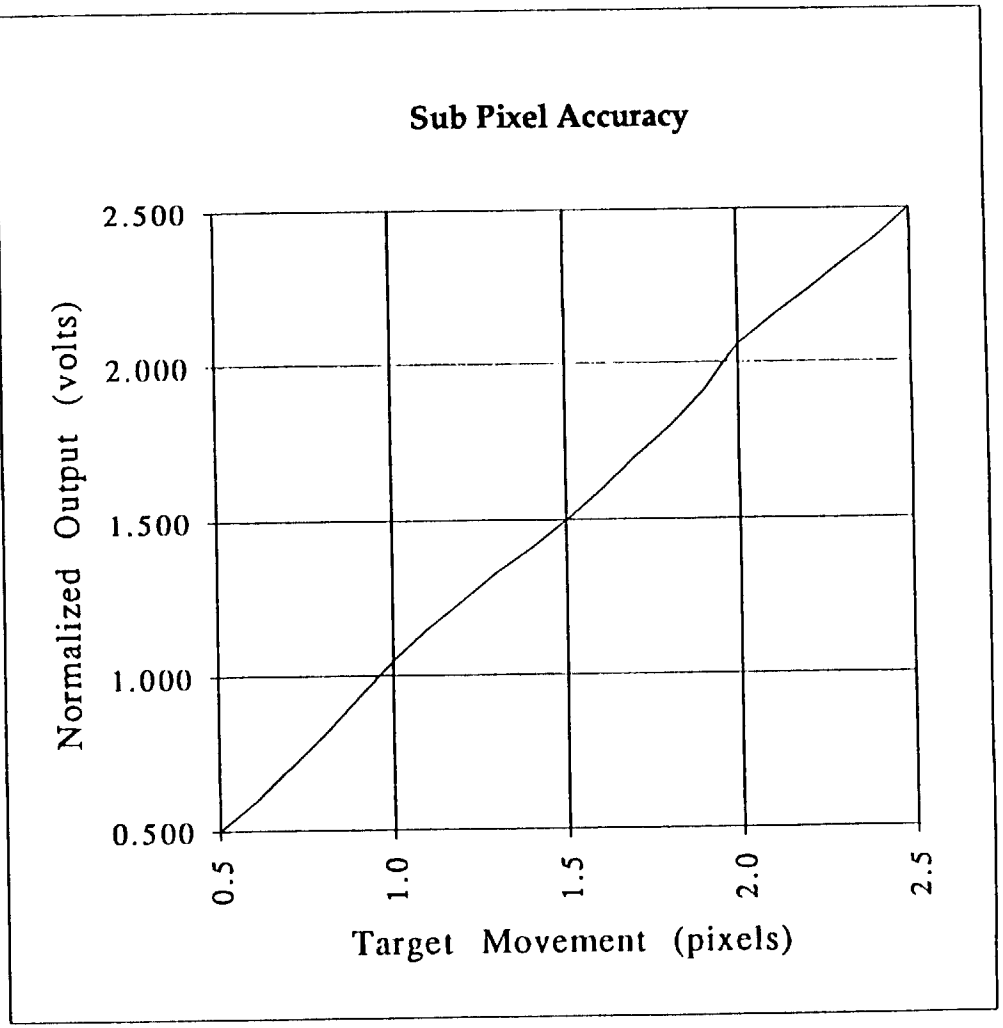


X Channel 1 Sub Pixel Accuracy Verification

TDS Data File B:T10B2203
Update Rate: 250 Hz

X1 SUB-PIXEL CORRECTION VERIFICATIC				Normalized	Normalized
Data	X1		X1	Pixel	Output
Mean:	-3.93426	Stdev:	0.00242	0.5	0.500
Mean:	-3.91865	Stdev:	0.00138	0.6	0.593
Mean:	-3.90036	Stdev:	0.00131	0.7	0.701
Mean:	-3.88191	Stdev:	0.00142	0.8	0.810
Mean:	-3.86184	Stdev:	0.00206	0.9	0.929
Mean:	-3.84189	Stdev:	0.00148	1.0	1.048
Mean:	-3.82473	Stdev:	0.00132	1.1	1.149
Mean:	-3.80958	Stdev:	0.00153	1.2	1.239
Mean:	-3.79438	Stdev:	0.00147	1.3	1.329
Mean:	-3.78100	Stdev:	0.00101	1.4	1.409
Mean:	-3.76610	Stdev:	0.00141	1.5	1.497
Mean:	-3.74935	Stdev:	0.00113	1.6	1.596
Mean:	-3.73119	Stdev:	0.00149	1.7	1.704
Mean:	-3.71450	Stdev:	0.00173	1.8	1.803
Mean:	-3.69631	Stdev:	0.00203	1.9	1.911
Mean:	-3.67166	Stdev:	0.00252	2.0	2.057
Mean:	-3.65668	Stdev:	0.00092	2.1	2.146
Mean:	-3.64271	Stdev:	0.00166	2.2	2.228
Mean:	-3.62773	Stdev:	0.00094	2.3	2.317
Mean:	-3.61330	Stdev:	0.00156	2.4	2.403
Mean:	-3.59690	Stdev:	0.00279	2.5	2.500

Output Volts per One/Tenth Pixel -0.01687



X2 Linearity ATP

X Channel 2 FOV Center
TDS Data File B:T10B2215
Update Rate: 250 Hz
X2 LINEARITY

Data	X2		X2
Mean:	2.55508	Stdev:	0.00145
Mean:	2.04819	Stdev:	0.00096
Mean:	1.53925	Stdev:	0.00088
Mean:	1.03073	Stdev:	0.00106
Mean:	0.52271	Stdev:	0.00126
Mean:	0.01202	Stdev:	0.00121
Mean:	-0.49511	Stdev:	0.00130

Normalized Motion	Step Change
0.000	-
0.507	0.50689
1.016	0.50894
1.524	0.50852
2.032	0.50802
2.543	0.51069
3.050	0.50713
Average	0.50837
Stdev	0.00139

+ FOV Edge
TDS Data File B:T11B0122
Update Rate: 250 Hz
X1-X4 LINEARITY +FOV

Data	X2		X2
Mean:	9.01288	Stdev:	0.00107
Mean:	8.50372	Stdev:	0.00101
Mean:	7.99757	Stdev:	0.00166
Mean:	7.48833	Stdev:	0.00086
Mean:	6.98087	Stdev:	0.00124
Mean:	6.47471	Stdev:	0.00086
Mean:	5.96828	Stdev:	0.00104

Normalized Motion	Step Change
0.000	-
0.509	0.50916
1.015	0.50615
1.525	0.50924
2.032	0.50746
2.538	0.50616
3.045	0.50643
Average	0.50743
Stdev	0.00145

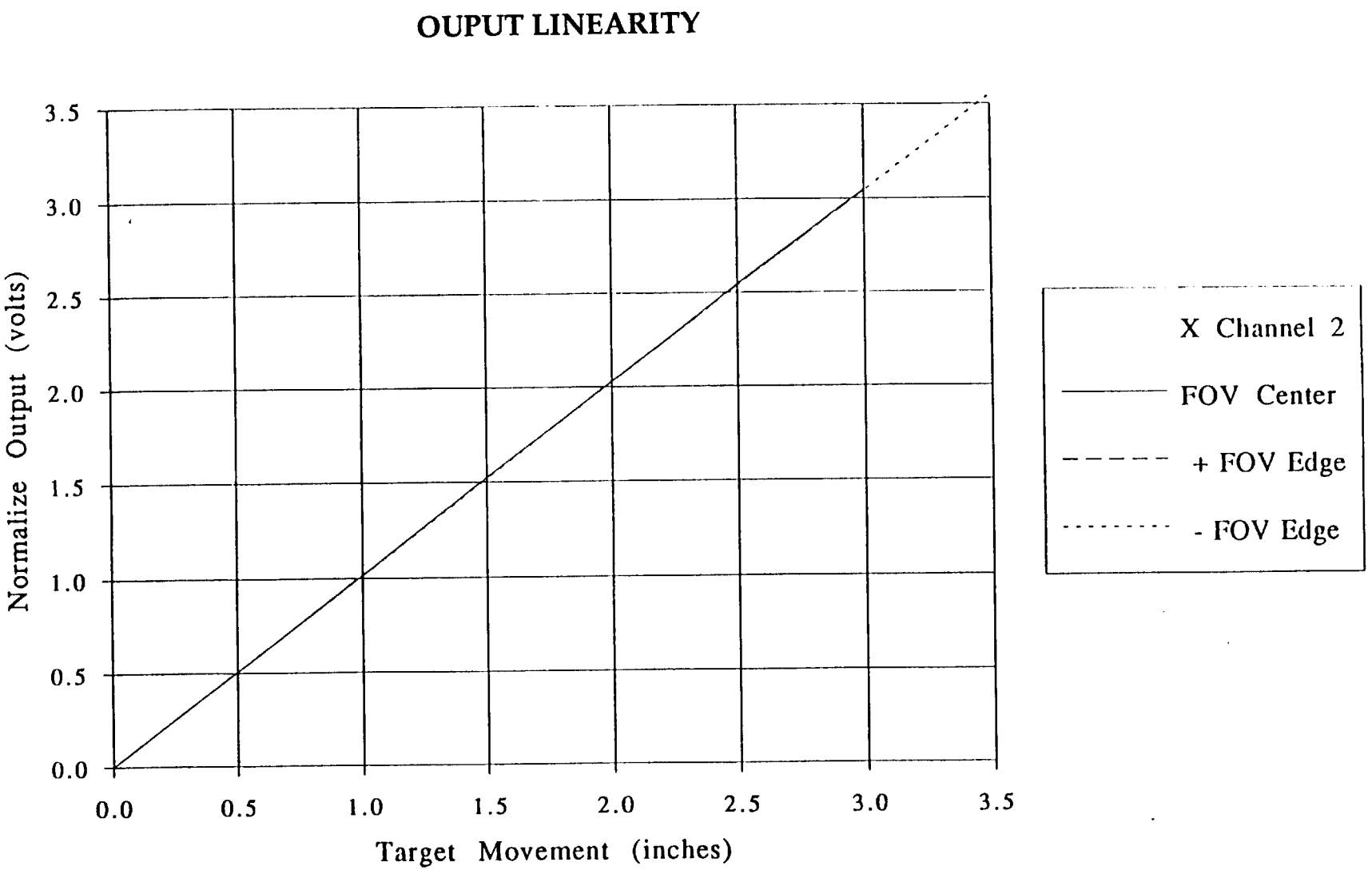
- FOV Edge
TDS Data File B:T11B0202
Update Rate: 250 Hz
X LINEARITY -FOV REPEAT

Data	X2		X2
Mean:	-5.62639	Stdev:	0.00219
Mean:	-6.13486	Stdev:	0.00225
Mean:	-6.63964	Stdev:	0.00191
Mean:	-7.14703	Stdev:	0.00193
Mean:	-7.65638	Stdev:	0.00201
Mean:	-8.16295	Stdev:	0.00243
Mean:	-8.67033	Stdev:	0.00258
Mean:	-9.17619	Stdev:	0.00216

Normalized Motion	Step Change
0.000	-
0.508	0.50847
1.013	0.50478
1.521	0.50739
2.030	0.50935
2.537	0.50657
3.044	0.50738
3.550	0.50586
Average	0.50711
Stdev	0.00154

Channel Scale Factor: 1.01528 Volts/Inch

X2 Linearity ATP (Concluded)



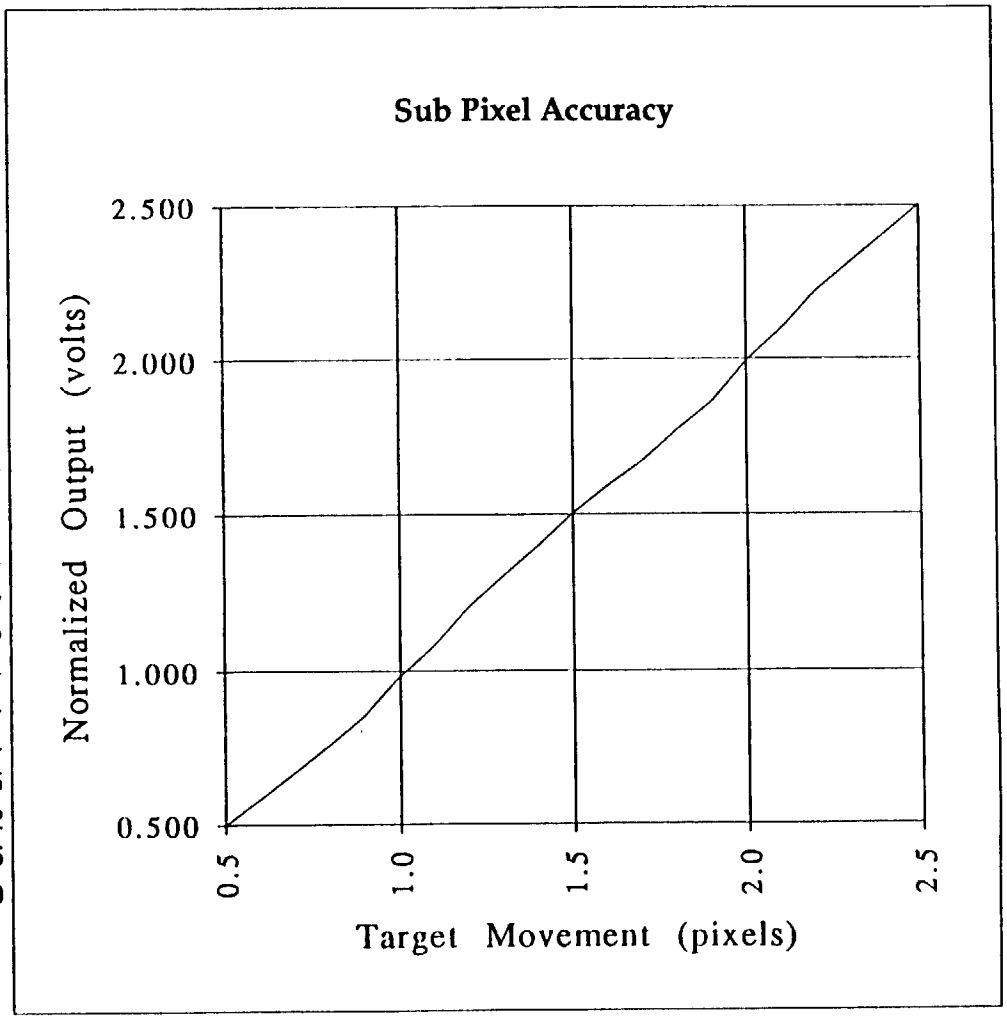
X Channel 2 Sub Pixel Accuracy Verification

TDS Data File B:T10B2235
Update Rate: 250 Hz

X2 SUB-PIXEL VERIFICATION

Data	X2		X2	Normalized Pixel	Normalized Output
Mean:	2.73442	Stdev:	0.00263	0.5	0.500
Mean:	2.72049	Stdev:	0.00129	0.6	0.583
Mean:	2.70538	Stdev:	0.00128	0.7	0.673
Mean:	2.69054	Stdev:	0.00186	0.8	0.761
Mean:	2.67479	Stdev:	0.00167	0.9	0.855
Mean:	2.65300	Stdev:	0.00180	1.0	0.984
Mean:	2.63630	Stdev:	0.00173	1.1	1.083
Mean:	2.61601	Stdev:	0.00135	1.2	1.204
Mean:	2.59962	Stdev:	0.00168	1.3	1.301
Mean:	2.58351	Stdev:	0.00143	1.4	1.397
Mean:	2.56557	Stdev:	0.00219	1.5	1.504
Mean:	2.55073	Stdev:	0.00150	1.6	1.592
Mean:	2.53719	Stdev:	0.00101	1.7	1.673
Mean:	2.51990	Stdev:	0.00153	1.8	1.775
Mean:	2.50500	Stdev:	0.00197	1.9	1.864
Mean:	2.48312	Stdev:	0.00143	2.0	1.994
Mean:	2.46635	Stdev:	0.00236	2.1	2.094
Mean:	2.44597	Stdev:	0.00168	2.2	2.215
Mean:	2.42957	Stdev:	0.00121	2.3	2.312
Mean:	2.41395	Stdev:	0.00129	2.4	2.405
Mean:	2.39803	Stdev:	0.00267	2.5	2.500

Output Volts per One/Tenth Pixel 0.01682



X3 Linearity ATP

X Channel 3 FOV Center
TDS Data File B:T10B2245
Update Rate: 250 Hz
X3 LINEARITY

Data	X3		X3
Mean:	0.97014	Stdev:	0.00197
Mean:	0.45958	Stdev:	0.00155
Mean:	-0.04848	Stdev:	0.00117
Mean:	-0.55510	Stdev:	0.00156
Mean:	-1.06586	Stdev:	0.00128
Mean:	-1.57578	Stdev:	0.00159
Mean:	-2.08389	Stdev:	0.00166
Mean:	-2.58950	Stdev:	0.00134

Normalized Motion	Step Change
0.000	-
0.511	0.51056
1.019	0.50806
1.525	0.50662
2.036	0.51076
2.546	0.50992
3.054	0.50811
3.560	0.50561
Average	0.50852
Stdev	0.00198

+ FOV Edge
TDS Data File B:T11B0122
Update Rate: 250 Hz
X1-X4 LINEARITY +FOV

Data	X3		X3
Mean:	9.27135	Stdev:	0.00000
Mean:	8.76268	Stdev:	0.00050
Mean:	8.25633	Stdev:	0.00149
Mean:	7.74795	Stdev:	0.00134
Mean:	7.24194	Stdev:	0.00000
Mean:	6.73142	Stdev:	0.00075
Mean:	6.22429	Stdev:	0.00168
Mean:	5.71701	Stdev:	0.00110

Normalized Motion	Step Change
0.000	-
0.509	0.50867
1.015	0.50635
1.523	0.50838
2.029	0.50601
2.540	0.51052
3.047	0.50713
3.554	0.50728
Average	0.50776
Stdev	0.00155

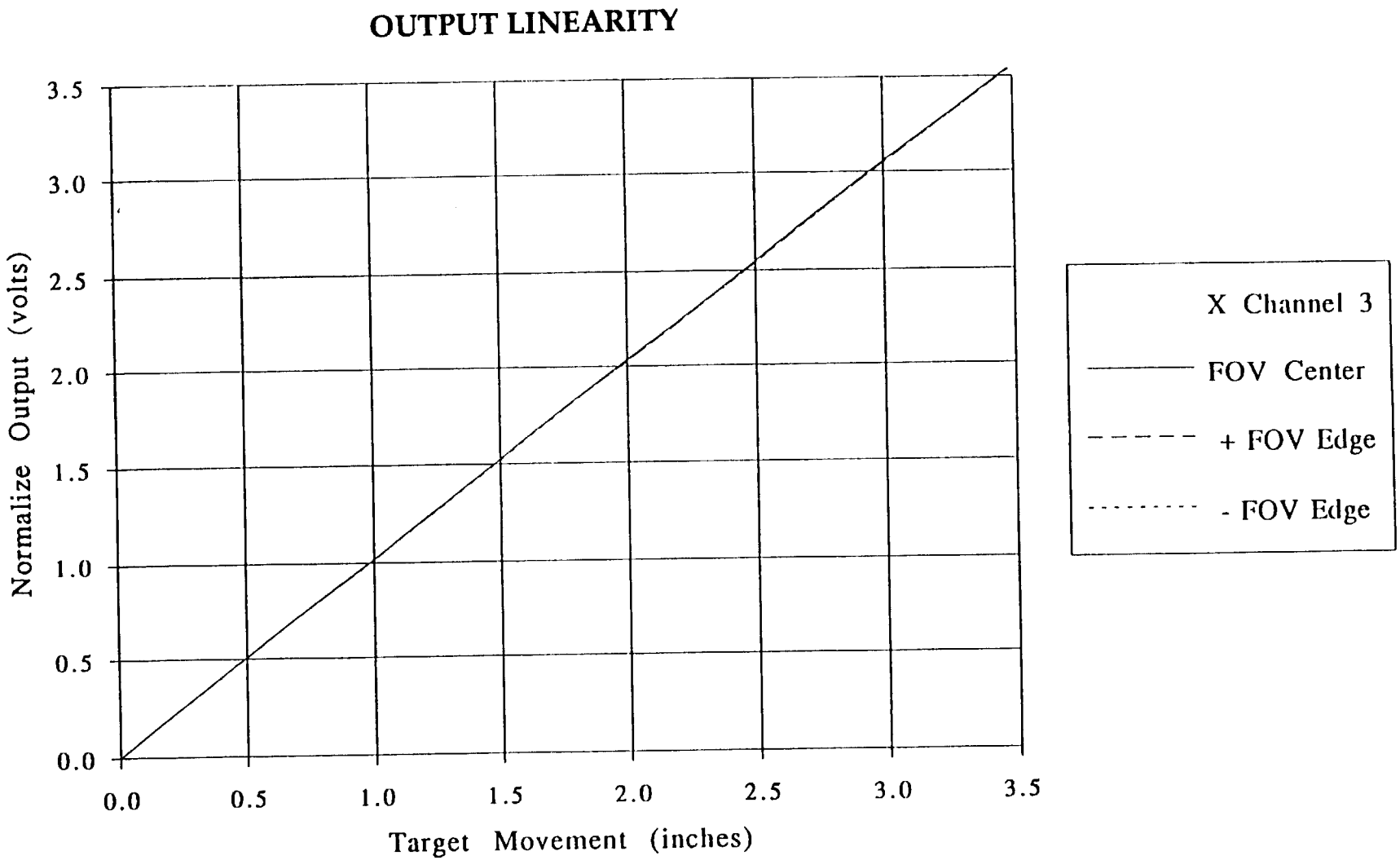
- FOV Edge
TDS Data File B:T11B0202
Update Rate: 250 Hz
X LINEARITY -FOV REPEAT

Data	X3		X3
Mean:	-5.88558	Stdev:	0.00127
Mean:	-6.39290	Stdev:	0.00135
Mean:	-6.90027	Stdev:	0.00123
Mean:	-7.40616	Stdev:	0.00135
Mean:	-7.91567	Stdev:	0.00157
Mean:	-8.42392	Stdev:	0.00125
Mean:	-8.93296	Stdev:	0.00125
Mean:	-9.43750	Stdev:	0.00210

Normalized Motion	Step Change
0.000	-
0.507	0.50732
1.015	0.50737
1.521	0.50589
2.030	0.50951
2.538	0.50825
3.047	0.50904
3.552	0.50454
Average	0.50742
Stdev	0.00175

Channel Scale Factor: 1.01580 Volts/Inch

X3 Linearity ATP (Concluded)

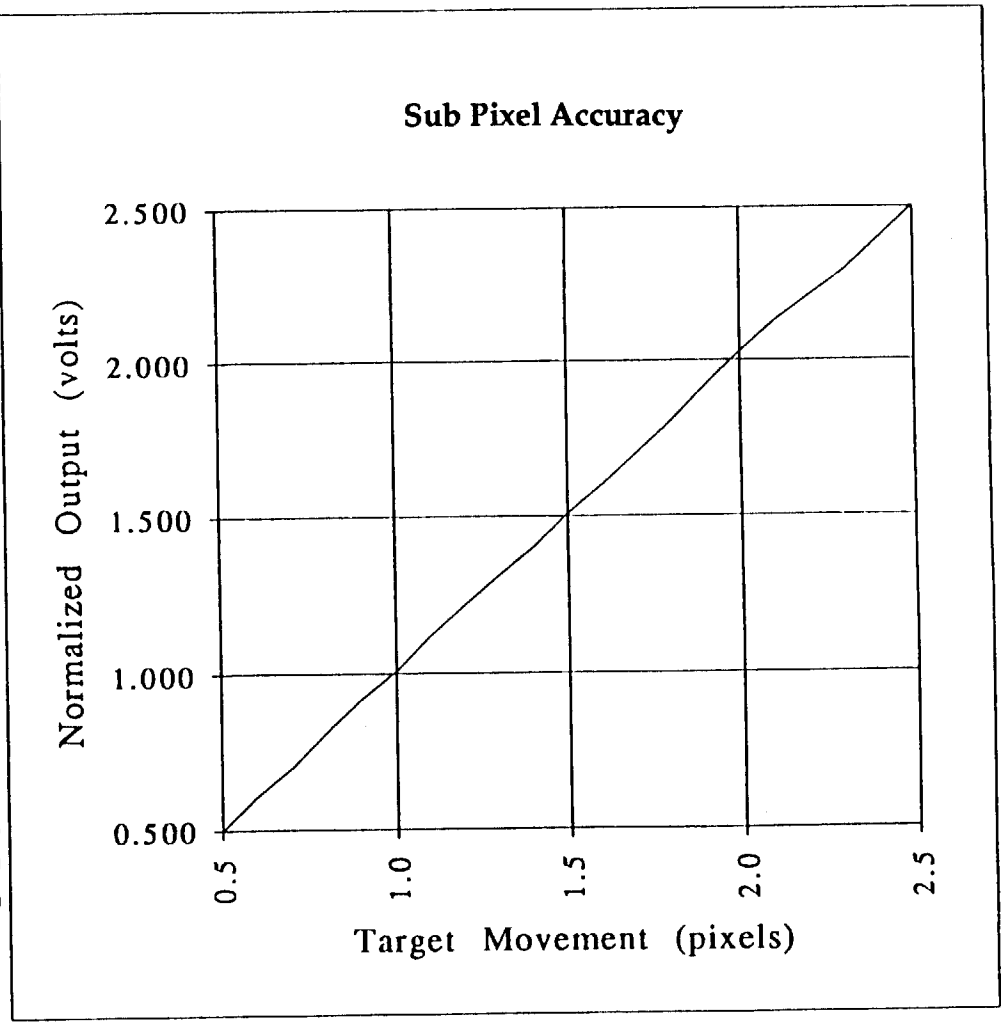


X Channel 3 Sub Pixel Accuracy Verification

TDS Data File B:T10B2339
Update Rate: 250 Hz
X3 SUB-PIXEL VERIFICATION

Data	X3		X3	Normalized Pixel	Normalized Output
Mean:	-2.55700	Stdev:	0.00121	0.5	0.500
Mean:	-2.57533	Stdev:	0.00158	0.6	0.609
Mean:	-2.59069	Stdev:	0.00130	0.7	0.701
Mean:	-2.60959	Stdev:	0.00138	0.8	0.814
Mean:	-2.62682	Stdev:	0.00175	0.9	0.916
Mean:	-2.64223	Stdev:	0.00227	1.0	1.008
Mean:	-2.66058	Stdev:	0.00191	1.1	1.118
Mean:	-2.67689	Stdev:	0.00113	1.2	1.215
Mean:	-2.69240	Stdev:	0.00144	1.3	1.307
Mean:	-2.70789	Stdev:	0.00122	1.4	1.400
Mean:	-2.72590	Stdev:	0.00190	1.5	1.507
Mean:	-2.74154	Stdev:	0.00138	1.6	1.600
Mean:	-2.75867	Stdev:	0.00139	1.7	1.702
Mean:	-2.77609	Stdev:	0.00153	1.8	1.806
Mean:	-2.79534	Stdev:	0.00156	1.9	1.921
Mean:	-2.81332	Stdev:	0.00163	2.0	2.028
Mean:	-2.82970	Stdev:	0.00171	2.1	2.126
Mean:	-2.84381	Stdev:	0.00090	2.2	2.210
Mean:	-2.85780	Stdev:	0.00190	2.3	2.293
Mean:	-2.87552	Stdev:	0.00141	2.4	2.399
Mean:	-2.89247	Stdev:	0.00102	2.5	2.500

Output Volts per One/Tenth Pixel 0.01677



X4 Linearity ATP

X Channel 4 FOV Center
TDS Data File B:T11B0005
Update Rate: 250 Hz
X4 LINEARITY

Data	X4		X4
Mean:	4.65601	Stdev:	0.00255
Mean:	4.14362	Stdev:	0.00247
Mean:	3.63512	Stdev:	0.00227
Mean:	3.12705	Stdev:	0.00188
Mean:	2.62174	Stdev:	0.00144
Mean:	2.11000	Stdev:	0.00176
Mean:	1.60165	Stdev:	0.00114
Mean:	1.09238	Stdev:	0.00085

Normalized Motion	Step Change
0.000	-
0.512	0.51239
1.021	0.50850
1.529	0.50807
2.034	0.50531
2.546	0.51174
3.054	0.50835
3.564	0.50927
Average	0.50909
Stdev	0.00239

+ FOV Edge
TDS Data File B:T11B0122
Update Rate: 250 Hz
X1-X4 LINEARITY +FOV

Data	X4		X4
Mean:	9.85661	Stdev:	0.00065
Mean:	9.34883	Stdev:	0.00103
Mean:	8.84028	Stdev:	0.00100
Mean:	8.33418	Stdev:	0.00202
Mean:	7.82573	Stdev:	0.00139
Mean:	7.31796	Stdev:	0.00177
Mean:	6.81155	Stdev:	0.00061
Mean:	6.30456	Stdev:	0.00095

Normalized Motion	Step Change
0.000	-
0.508	0.50778
1.016	0.50855
1.522	0.50610
2.031	0.50845
2.539	0.50777
3.045	0.50641
3.552	0.50699
Average	0.50744
Stdev	0.00096

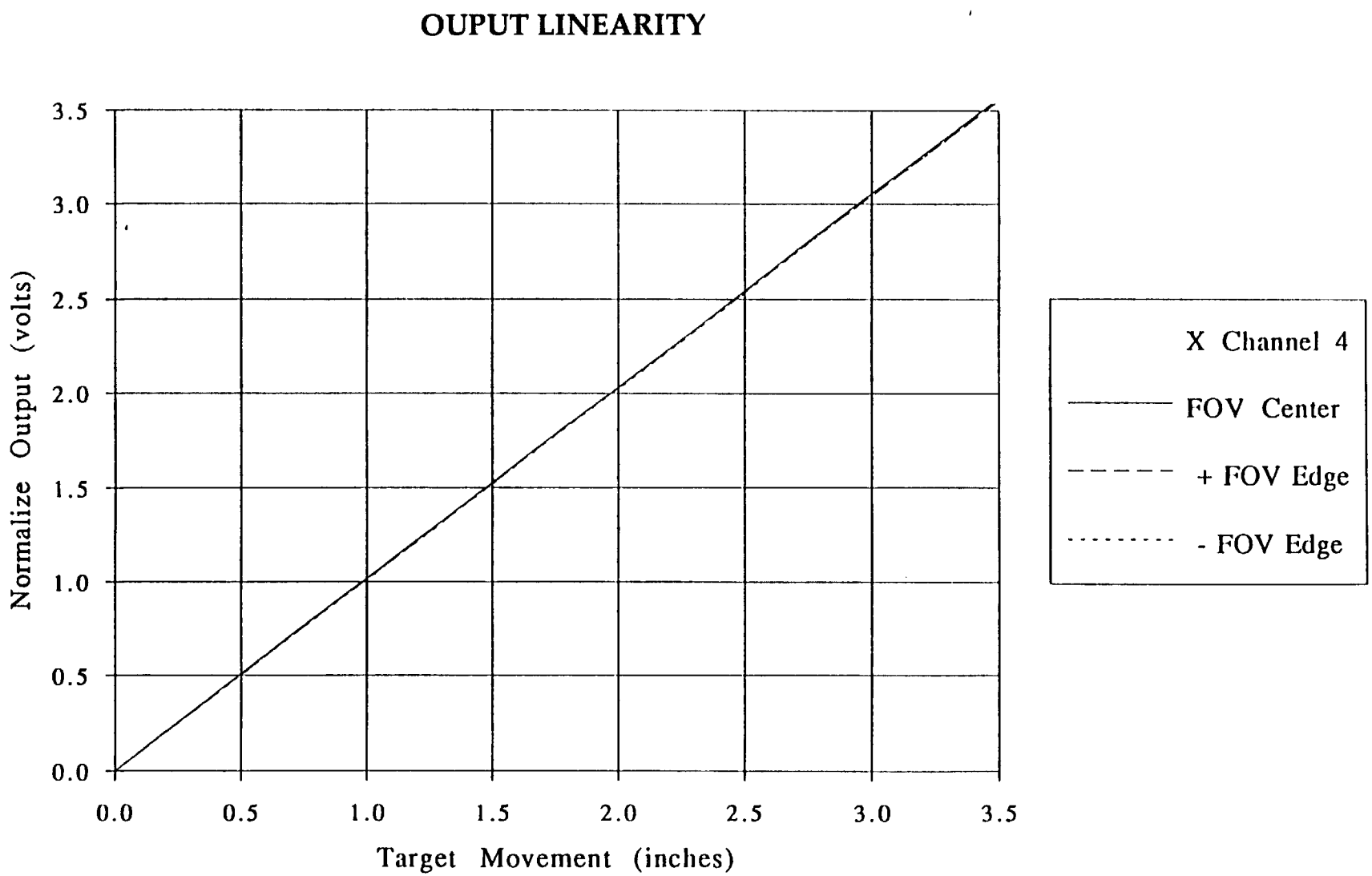
- FOV Edge
TDS Data File B:T11B0202
Update Rate: 250 Hz
X LINEARITY -FOV REPEAT

Data	X4		X4
Mean:	-5.28874	Stdev:	0.00187
Mean:	-5.79274	Stdev:	0.00129
Mean:	-6.30004	Stdev:	0.00153
Mean:	-6.80794	Stdev:	0.00209
Mean:	-7.31575	Stdev:	0.00198
Mean:	-7.82276	Stdev:	0.00219
Mean:	-8.33305	Stdev:	0.00226
Mean:	-8.83713	Stdev:	0.00173

Normalized Motion	Step Change
0.000	-
0.504	0.50400
1.011	0.50730
1.519	0.50790
2.027	0.50781
2.534	0.50701
3.044	0.51029
3.548	0.50408
Average	0.50691
Stdev	0.00223

Channel Scale Factor: 1.01563 Volts/Inch

X4 Linearity ATP (Concluded)

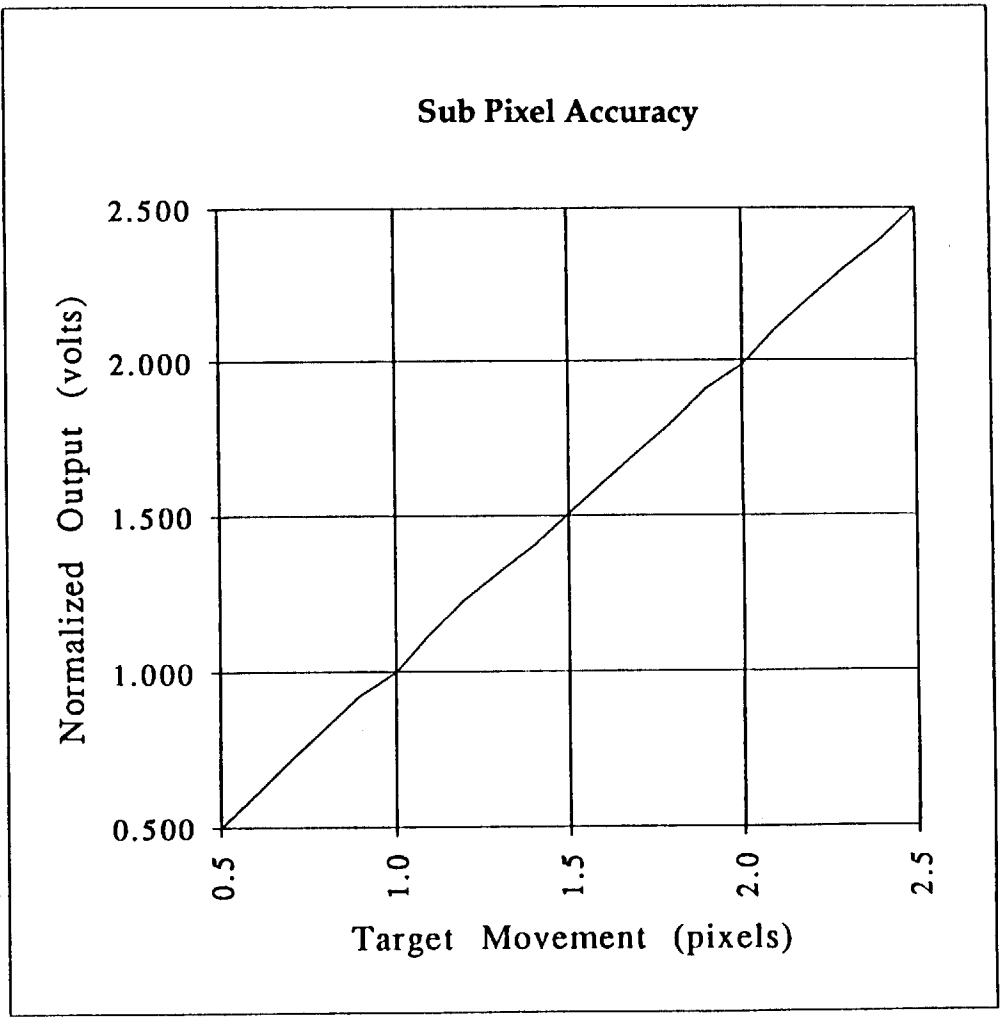


X Channel 4 Sub Pixel Accuracy Verification

TDS Data File B:T11B0022
Update Rate: 250 Hz
X4 SUB PIXEL VERIFICATION

Data	X4		X4	Normalized Pixel	Normalized Output
Mean:	4.58596	Stdev:	0.00132	0.5	0.500
Mean:	4.56771	Stdev:	0.00153	0.6	0.608
Mean:	4.54901	Stdev:	0.00126	0.7	0.718
Mean:	4.53154	Stdev:	0.00107	0.8	0.821
Mean:	4.51386	Stdev:	0.00216	0.9	0.926
Mean:	4.50155	Stdev:	0.00000	1.0	0.998
Mean:	4.48061	Stdev:	0.00162	1.1	1.122
Mean:	4.46254	Stdev:	0.00136	1.2	1.229
Mean:	4.44790	Stdev:	0.00127	1.3	1.315
Mean:	4.43308	Stdev:	0.00132	1.4	1.403
Mean:	4.41584	Stdev:	0.00172	1.5	1.505
Mean:	4.39831	Stdev:	0.00160	1.6	1.608
Mean:	4.38148	Stdev:	0.00114	1.7	1.708
Mean:	4.36471	Stdev:	0.00127	1.8	1.807
Mean:	4.34677	Stdev:	0.00192	1.9	1.913
Mean:	4.33428	Stdev:	0.00101	2.0	1.986
Mean:	4.31423	Stdev:	0.00172	2.1	2.105
Mean:	4.29702	Stdev:	0.00140	2.2	2.206
Mean:	4.28022	Stdev:	0.00112	2.3	2.306
Mean:	4.26509	Stdev:	0.00107	2.4	2.395
Mean:	4.24729	Stdev:	0.00143	2.5	2.500

Output Volts per One/Tenth Pixel 0.01693



Acceptance Demonstration

- BMT
  - Displacement range (Both planes)
  - Displacement accuracy
  - Coverage of all targets
  - Update rate
  - Correct output data

- TDS
  - Displacement range (Both planes)
  - Displacement accuracy
  - Coverage of all targets
  - Update rates
  - Correct output data

February 21, 1992 - Friday

Depart for MFSC from Jeffco airport 9:00 am MST
Arrive Huntsville Airport 12:30 CST
Unload aircraft into NASA provided van

Arrive MFSC and unload equipment, unpack, and inspect for damage

February 22, 1992 - Saturday

Arrive MFSC 8:00 am.
Carry equipment to CASES level.
Begin equipment electrical checkout on floor (bench).

1. Hook up the TDS sensor heads to the electrical chassis, power up system on the "bench," and verify signal response.

2. Hook up the BMT sensor heads to the electrical chassis, power up system on the "bench," and verify signal response.

February 24, 1992 - Monday

Install the TDS targets to MFSC system power supply and verify the operation of each light source.

Drill 7/32" diameter clearance hole for mounting pad on each illuminator.

Position three TDS targets on the tip plate (mechanically locate to within 0.1" of the final alignment position). Position the fourth TDS target on the Target array center for alignment purposes only.

Power up the TDS illuminators and verify operation.

Install mounting brackets for electrical chassis (BMT and TDS).

Install electrical chassis in the mounting brackets on the side of the MPESS and wire for power.

Install cabling to the sensor heads.

February 25, 1992 - Tuesday

Assemble lens assemblies for each sensor head.

Install TDS and BMT mounting brackets to detector plate.

Mount the TDS sensors to the mounting brackets (less cylinder lens).

Install the cables to each sensor head mount for strain relief.

Hook up the oscilloscope to the TDS output sync and target position signals.

Power the illuminator on the center of the target array for the TDS system.

Adjust alignment of each sensor to the center of the field without the cylinder lens assembly.

Adjust sensor focus as necessary to stop lens to f/16 to avoid saturation of the signal.

Reposition the TDS illuminator to within 0.1" of its final position on the tip plate.

Install the cylinder lens assembly.

Adjust each illuminator to final position for minimal DC voltage signal. These "zero" voltages will be come the final mechanical position of the TDS illuminators. Temporarily epoxy the TDS illuminators into place.

February 26, 1992 - Wednesday

Drive the Boom assembly and note any position changes after settling. Adjust illuminator positions as necessary. Several iterations of the Boom motion may be necessary.

Determine the permanent location of the TDS targets and affix permanently.

Operate the TDS for final checkout and document the functional performance.

Interface with customer analog ports for verification of static positions.

February 27, 1992 - Thursday --- February 28, 1992 - Friday

Hook up the digital interface to the Ball-supplied test computer.

Hook up the oscilloscope and set best focus on each sensor lens system. Note: The cylinder lens and secondary illuminators are attached to each sensor assembly.

Check that the positions of the targets correspond to a reasonable position and the delta pixels for the initial data set of each sensor output is reasonable.

Check that 37 targets are present for each system.

Check that all signal levels from each target to each sensor are comparable to the test data obtained at the Ball facility.

Excite the boom for a brief period and note each position change (if any). Note the amount of relative change each time the boom is excited. Determine if this is a significant change or negligible.

Assuming minimal change, remove cylinder lens on one head and rotate sense head to image the target line on the array. Replace the illuminator and cylinder lens assembly. Adjust the primary illuminator for maximum signal. Repeat for each sense head.

If significant change, consult with MFSC personnel as to how to address the problem.

Perform tests to verify proper operation of the RAMS system.

Begin interface with customers data acquisition system.

Monday, March 2 through ??

Troubleshoot and staff as necessary to verify RAMS operation.

NASA

Report Documentation Page

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7. Author(s)
Hugh W. Davis

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Marshall Space Flight Center, AL 35812

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15. Supplementary Notes

16. Abstract

CASES (Controls, Astrophysics and Structures Experiment in Space) is a proposed experiment to collect x-ray images of the galactic center and solar disk with unprecedented resolution. This requires precision pointing and suppression of vibrations in the long, flexible structure that comprises the 32-m x-ray telescope optical bench. Two separate electro-optical sensor systems are provided for the ground test facility (GTF). The Boom Motion Tracker (BMT) measures eigenvector data for post-mission use in system identification. The Tip Displacement Sensor (TDS) measures boom tip position and is used as feedback for the closed-loop control system that stabilizes the boom. This report summarizes the development and testing of the BMT and TDS systems.

17. Key Words (Suggested by Author(s))
Boom Motion Tracker, Tip Displacement Sensor, RAMS (Remote Attitude Measurement Sensor), CSI (controls-structure interaction), CASES (Controls, Astrophysics and Structures Experiment in Space), position sensor, unobtrusive sensing, LSS (large space structures), flexible structures.

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