OAO CORPORATION

MEMORANDUM
PER-IOM-83-G021
June 9, 1983

TO : Distribution

FROM : Alan Goldberg/OAO/400.2

SUBJECT: Meeting Notes from APL Fine Guidance Review, June 8, 1983

The JHU Applied Physics Laboratory held a Preliminary Review of their Alternative Fine Guidance System Study yesterday at the Lab. Representatives were present from MSFC (the funding center), JHU (the study contractor), GSFC, LMSC, P-E, STScI, IDT's, and others (full list attached). The presentation was divided into (1) an analysis of the present PCS problems, and (2) a review of alternate sensor concepts (viewgraphs attached).

The PCS/FGS analysis included visits to contractor and NASA sites, consultation with APL experts, and development of internal models. Problems or questions uncovered include:

- validity of 0.007 arcsec stability on 14.5 mag stars
- origin of 3x3 arcsec instantaneous FOV
- purpose of 40Hz PCS sampling
- disturbance environment: reaction wheels, etc.
- comsic ray effects on detectors and electronics
- effect of delayed launch on cosmic ray flux and aerodynamic torques
- proper use of FGS data by PCS: is 1Hz update sufficient?
- lack of DF-224 margin

The alternate sensor review consisted of reports on successful image-splitter fabrication experiments at JHU and P-E, and a survey of other technologies. Bill Fastie worked with Muffoletto Optical, producing a two part image-splitter by optically contacting two polished, uncoated quartz blocks and subsequently polishing flat the joint line. No gap can be

detected on an SEM micrograph, suggesting that the gap is less than 0.3 microns. P-E has optically contacted coated glass pieces resulting in a gap indistinguishable from the coating thickness alone. Both P-E and JHU are to build four-part quradrant splitters to a common design specification.

Other sensor technologies included near- and long-term candidates. The most promising appear to be:

optical splitters feeding PMT's
quadrant Digicon
Hybrid: optical splitter feeding a Digicon
Hybrid: diode-pair Digicons at Koesters interferometer output

The last concept is the same as one I proposed two to three years ago while at P-E. The only significant question raised on these concepts was Digicon susceptibility to magnetic fields in high-accuracy applications.

APL will concentrate on further studies of the best candidate alternatives, including technical details and system impact. The program manager, Dave Grant, and division director, George Weiffenbach, seem sincerely committed to running an open study and producing a technically and managerially useful result. The APL effort will continue through mid-October. The next review should be early August.

Alan

Alan Goldberg

Attachment

Distribution: S. Dardarian/400.2
D. White/400.2
A. Boggess/683
D. Leckrone/685

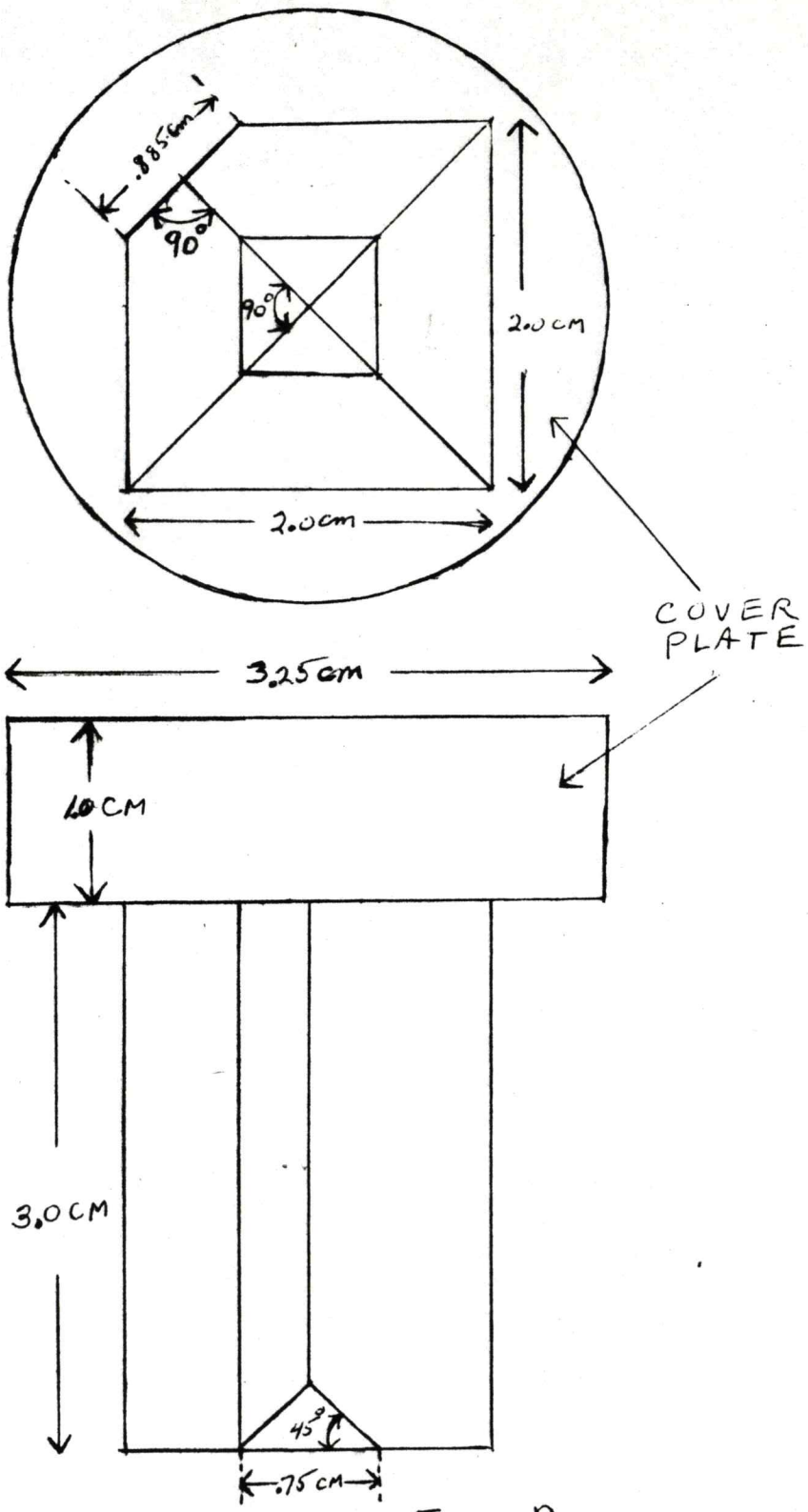
cc: G. Daelemans/OAO/400.2
B. Lambeck/OAO
T. Facey/Perkin-Elmer

/lb

Space Telescope Meeting
June 8, 1983

Attendance List

Name	Organization	Telephone
Don Cormier	LMSC, PCS Eng.	(408) 742-0865
Art Bradley	Bendix/LMSC/MOC @ GSFC	(301) 344-0874
John Humphreys	NASA/MSFC	(205) 453-2383
Charles Jones	NASA/MSFC	(203) 797-6289
Lou Montagnino	OTC/Perkin-Elmer	(203) 797-5249
Steven Kumpan	OTC/Perkin-Elmer	(203) 797-6153
Jean Olivier	MSFC	(205) 453-0519
William B. Chubb	MSFC/NASA	(205) 453-2669
Hans F. Kennel	MSFC/NASA	(205) 453-4718
Gerald J. Nurre	MSFC/NASA	(205) 453-4580
Johnathan Campbell	MSFC/NASA	(205) 453-4595/4590
Michael E. Polites	MSFC/NASA	(205) 453-2714
Jim Westphal	CALTECH	(213) 356-4800
David Grey	DGA	(617) 863-1288
William G. Fastie	JHU	(301) 338-7340
Dan Schroeder	Beloit College	(608) 365-3391
Art Reetz	NASA Hqs.	(202) 755-3340
William H. Jefferys	Univ. of Texas	(512) 471-4461
Doug Currie	Univ. of Maryland	(301) 454-3405
George Weiffenbach	JHU/APL	(301) 792-7800
Vincent L. Pisacane	JHU/APL	(301) 953-7100
M. Kane	JHU	(301) 338-7340
Tom Zaremba	JHU/APL	(301) 953-7100
Jay Dettmer	JHU/APL	(301) 953-7100x3297
R. E. Gorozdos	JHU/APL	(301) 953-7100x7129
Alain Fresneau	SI ScI	(301) 338-4800
Alan Goldberg	OAO Corp.	(301) 344-0938
Clarence Wingate	JHU/APL	(301) 953-7100x2931
Ralph M. Sullivan	JHU/APL	(301) 953-7100x3045
Tom Strikwerda	JHU/APL	(301) 953-7100x2971
Aaron Ostroff	LaRC/NASA	(804) 865-3209
Robert Gold	JHU/APL	(301) 953-7100x2181
Alan Pue	JHU/APL	(301) 953-7100x7067
Ben Hoffman	JHU/APL	(301) 953-7100x2156
Gene Hinman	JHU/APL	(301) 953-7100x480
Don Duncan	JHU/APL	(301) 953-7100x3243
J. C. Ray	JHU/APL	(301) 953-7100x523
Kim Strohbehn	JHU/APL	(301) 953-7100x3494
J. W. Hunt	JHU/APL	(301) 953-7100x2645
P. A. Newman	GSFC	(301) 344-7000x8421
Mike Femiano	NASA/GSFC	(301) 344-7000x6009
Mike Foust	JHU/APL	(301) 953-7100x617
B. F. Hochheimer	JHU/APL	(301) 953-7100x2028

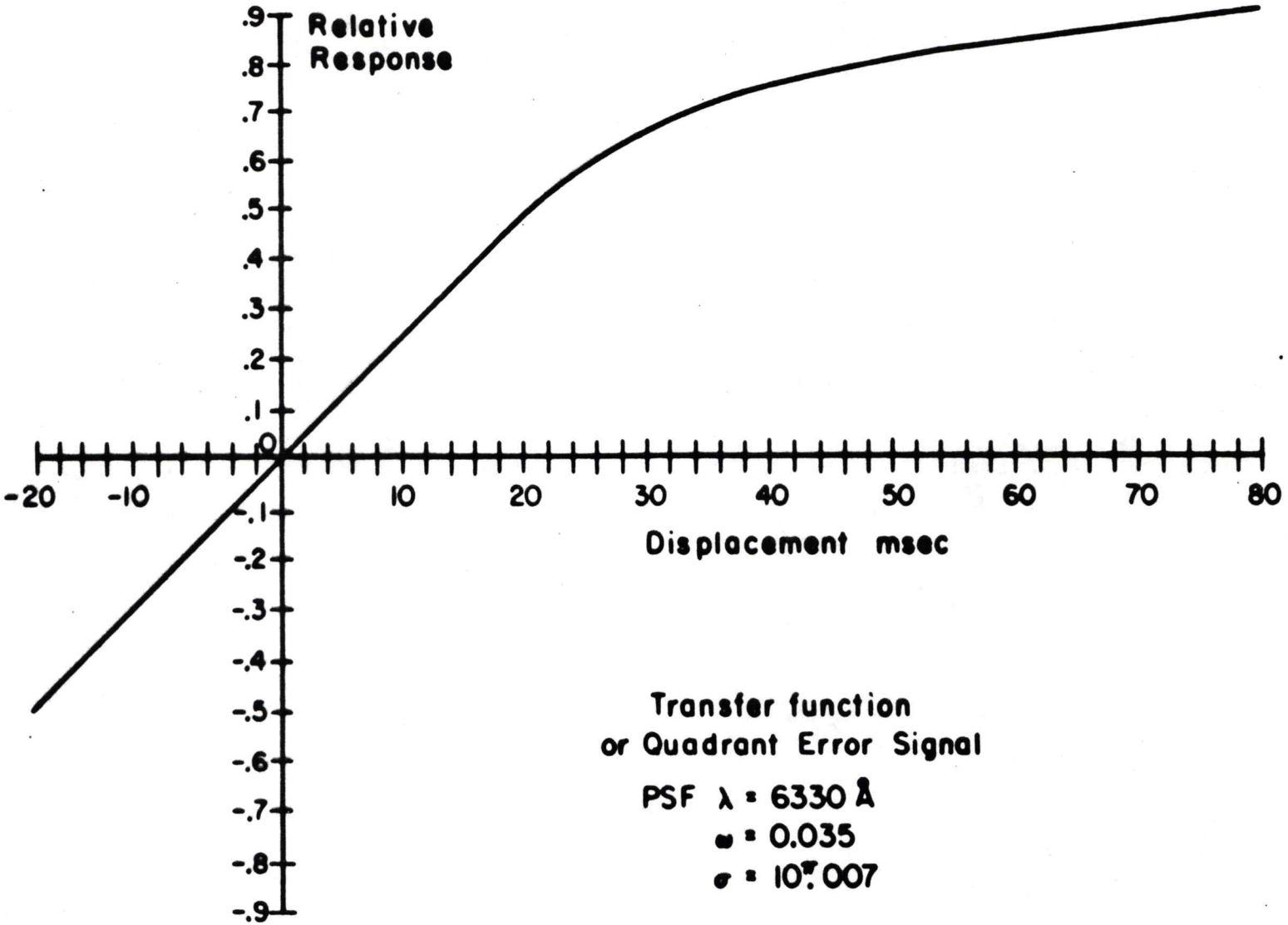


ATERIAL:
SUPRASIL

FOUR PRISM
IMMERSED QUADRANT
DIVIDER

SCALE ← 1.0CM →

WGF
5/9/83

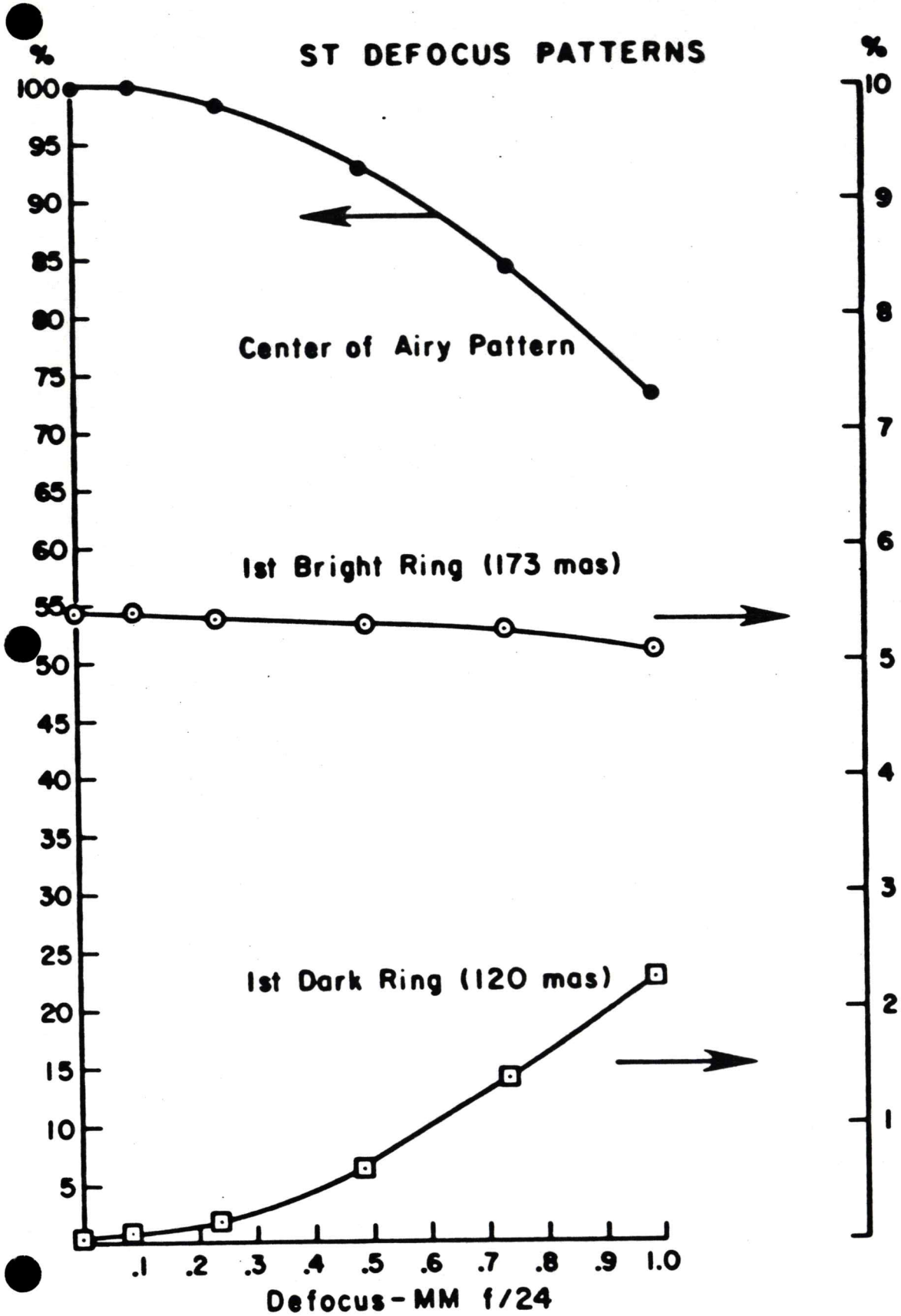


Transfer function
or Quadrant Error Signal

PSF λ = 6330 Å

ω = 0.035

σ = 10^{π}.007


ST DEFOCUS PATTERNS
%
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
%
10
9
8
7
6
5
4
3
2
1
Center of Airy Pattern
1st Bright Ring (173 mas)
1st Dark Ring (120 mas)
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Defocus - MM f/24

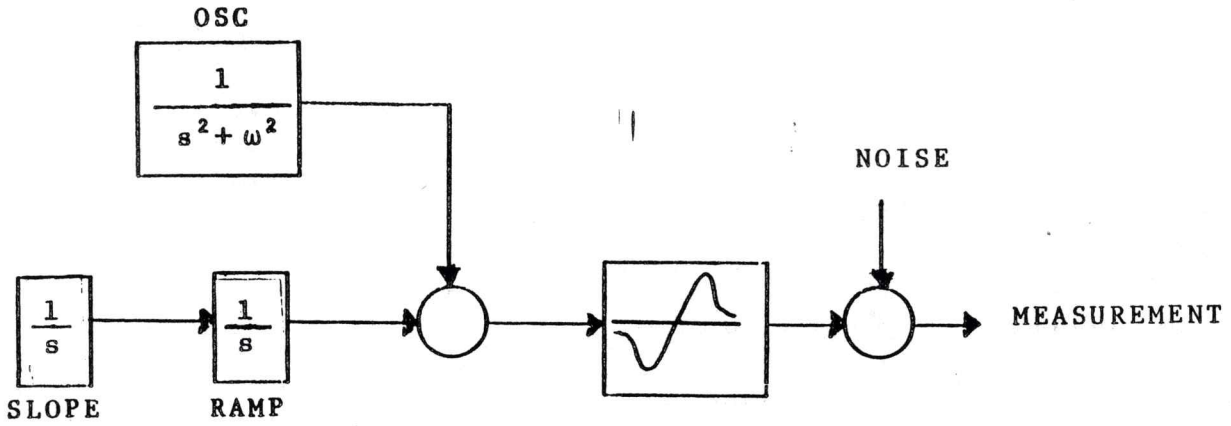
FGS Signal Processing

- Make optimal use of sensor information regardless of the particular fine guidance sensor used.

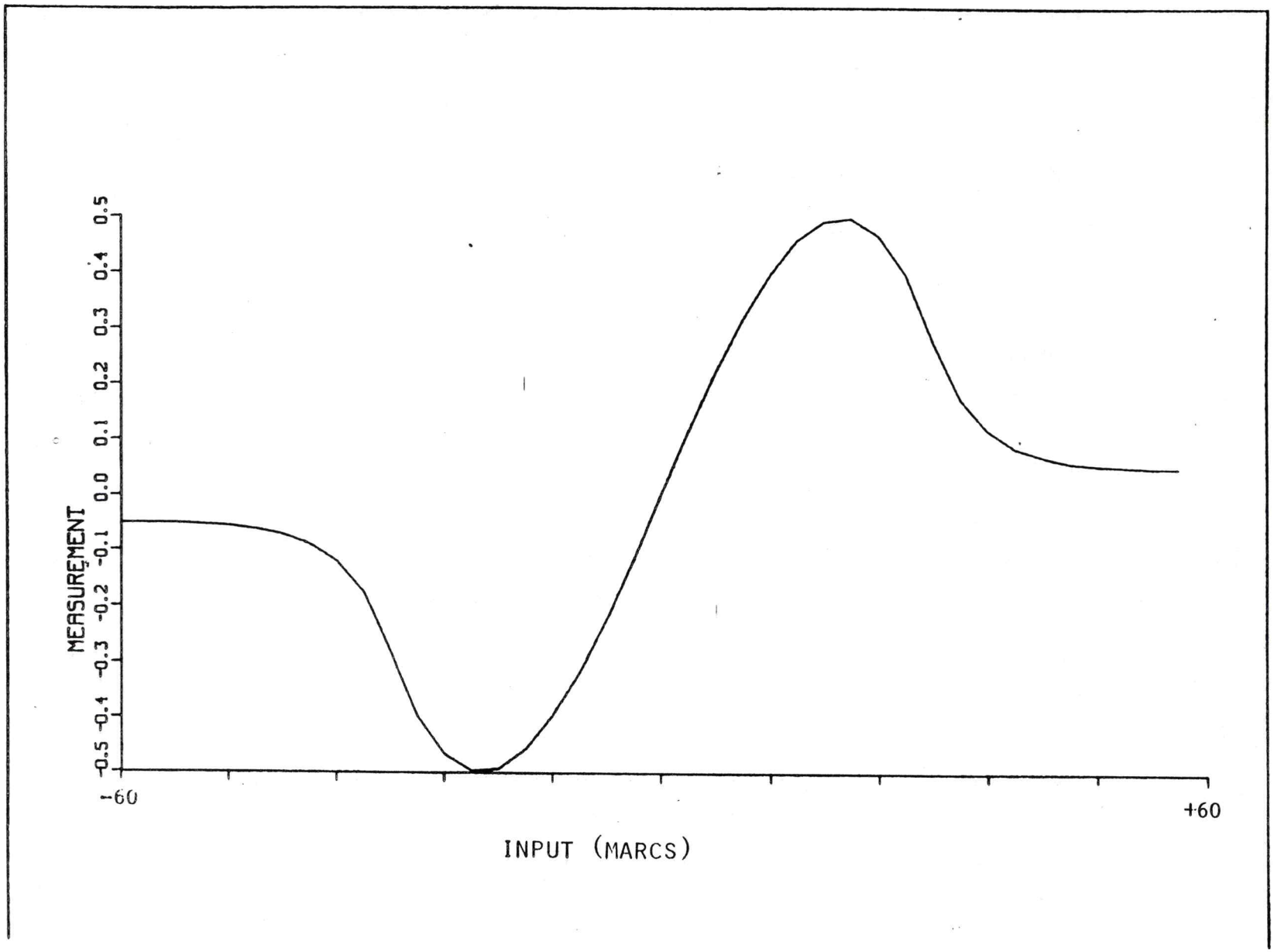
- Extend the useful range of nonlinear sensor characteristics by using prior information.

Preliminary Study

- Extend the useful range of the Koester prism interferometer via an extended Kalman filter.
- Simple signal model



- Measurements at 40 hz
- Random oscillator with rms amplitude of 10 marcs at 10 hz
- Random ramp with rms slope of 60 marcs/sec and rms initial condition of 3 marcs
- RMS additive measurement noise of 3 marcs
- Interferometer modeled as a cubic and an exponential decay
- Linearize measurement about a-priori estimate


MEASUREMENT
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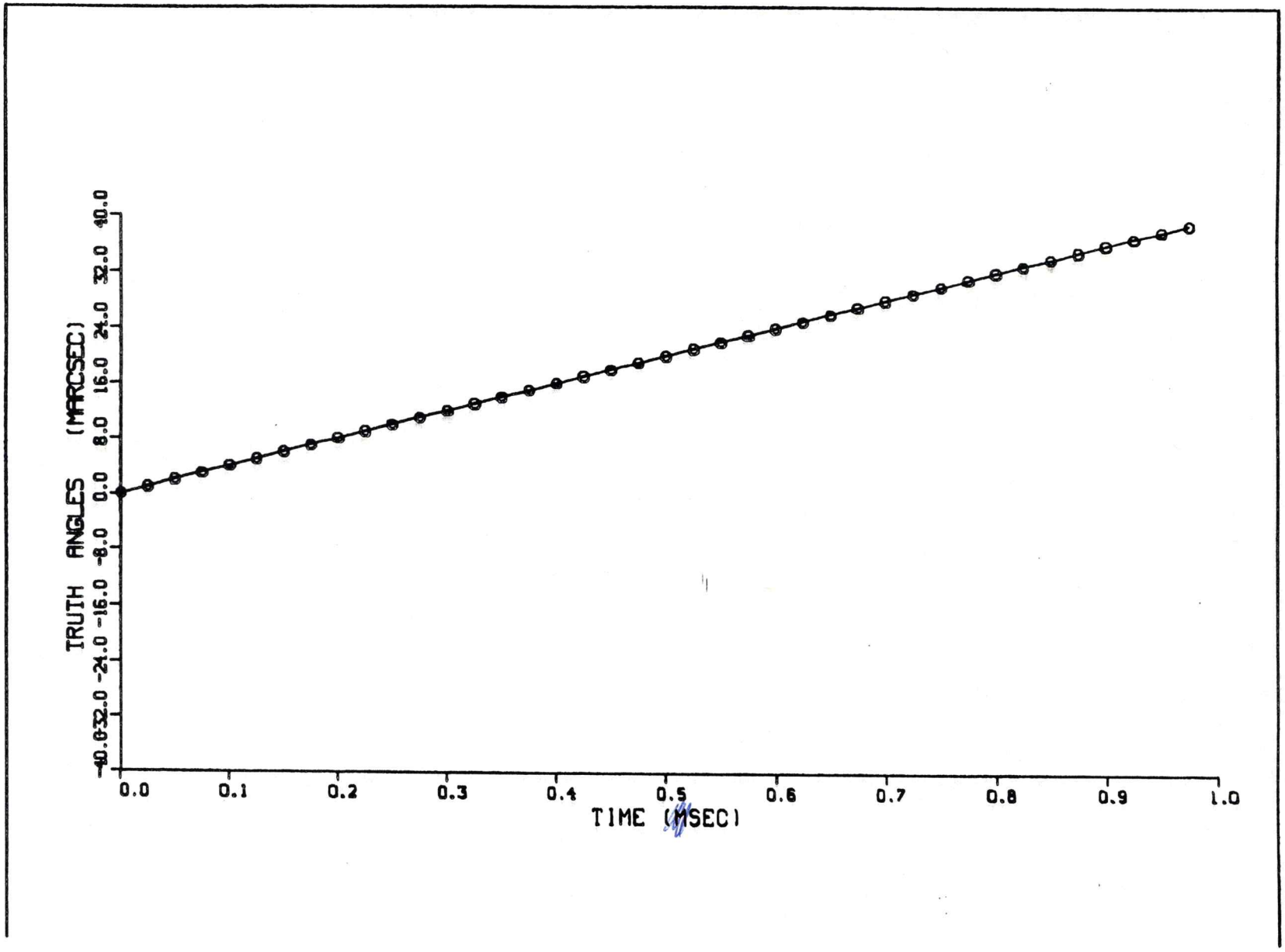
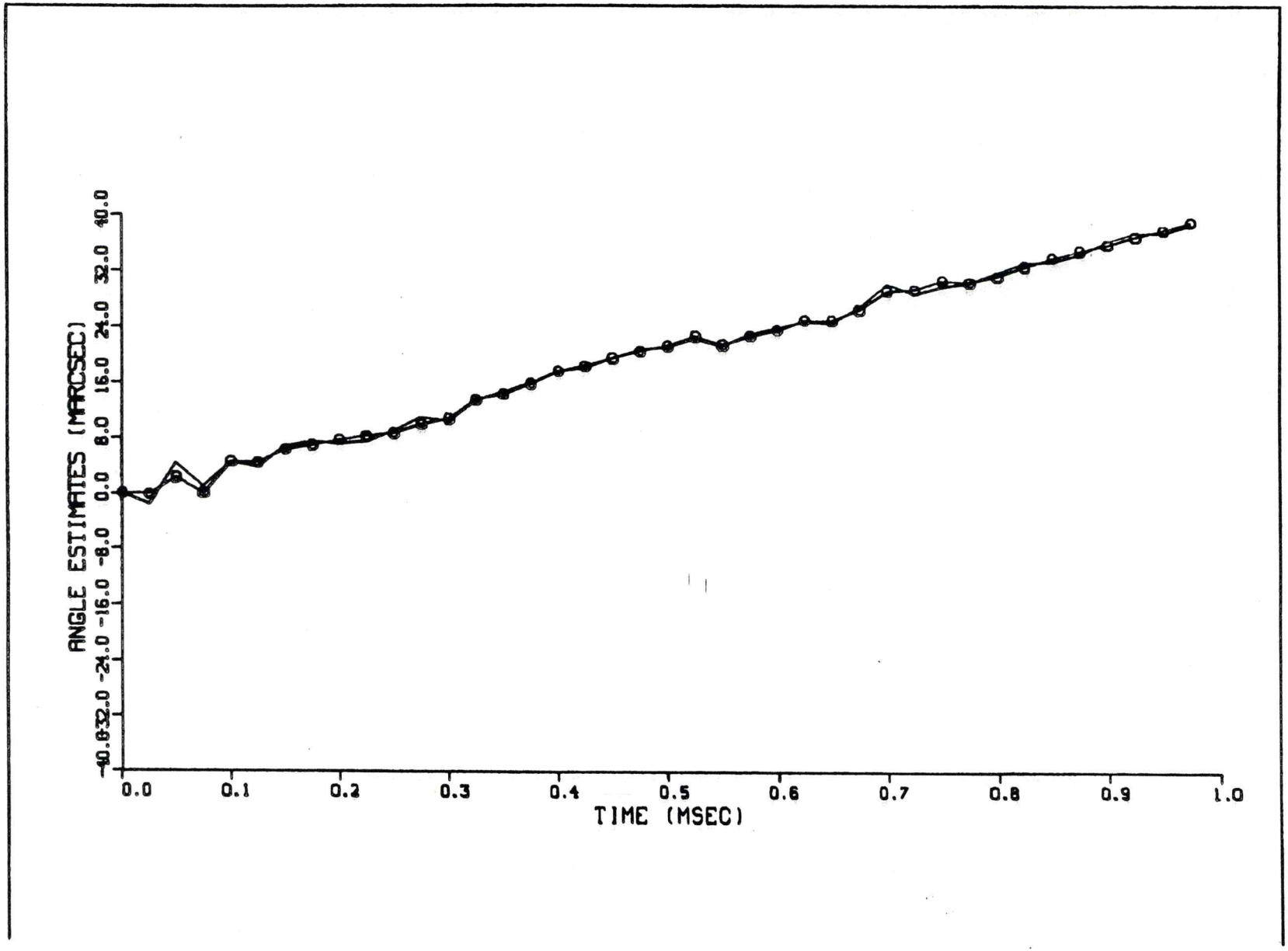
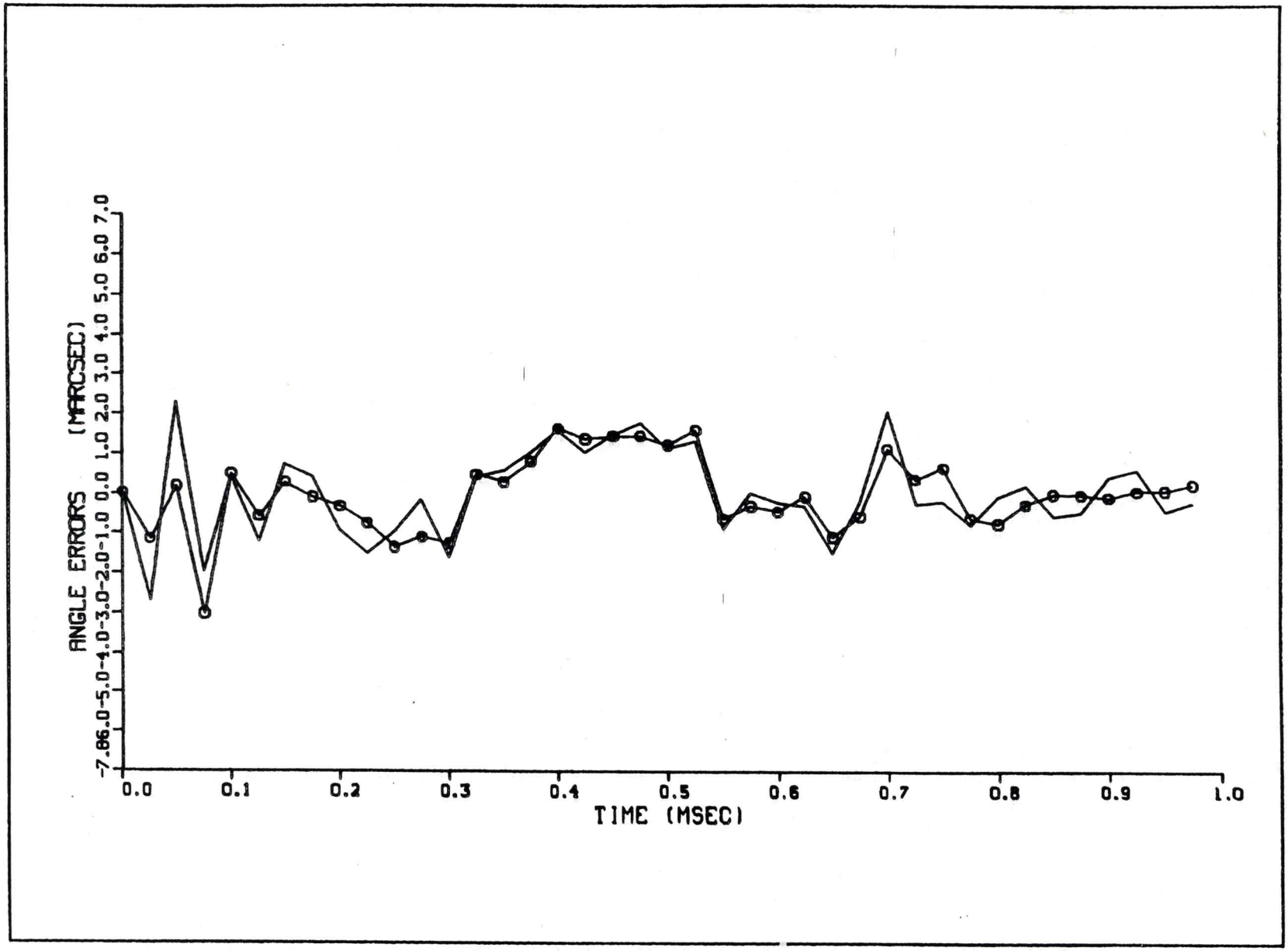
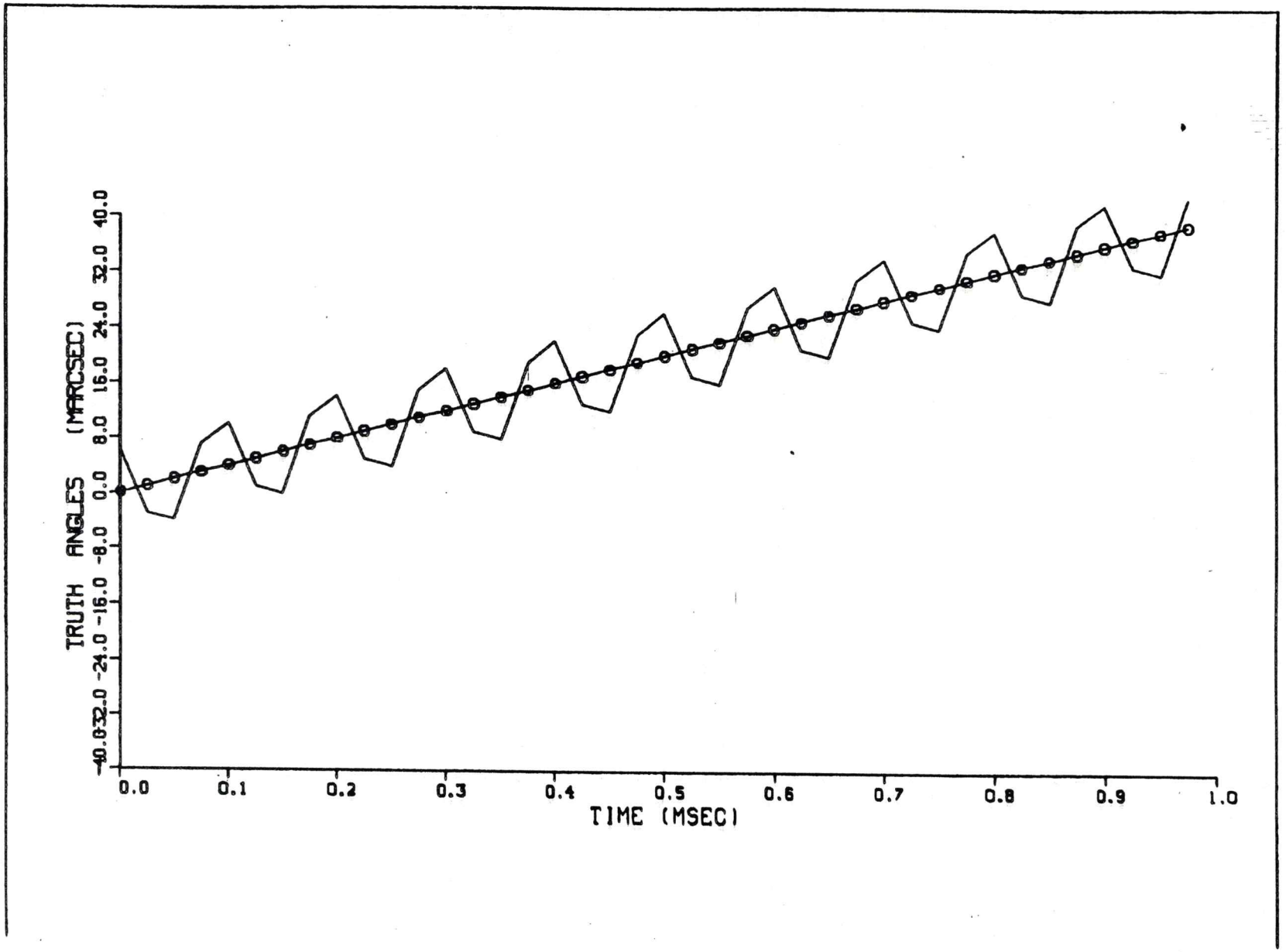
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-60
+60
INPUT (MARCS)


TRUTH ANGLES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (MSEC)

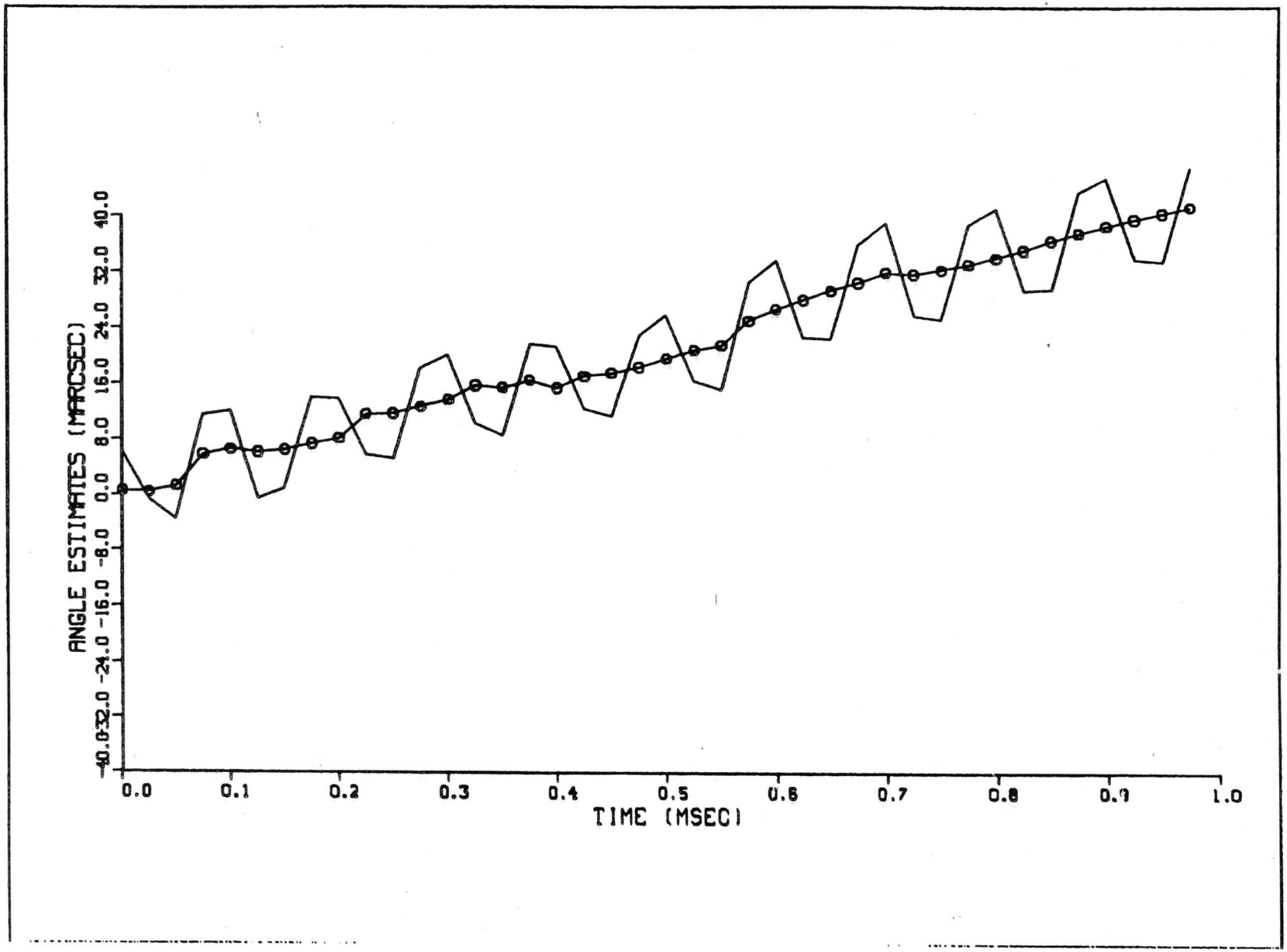

ANGLE ESTIMATES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (MSEC)


ANGLE ERRORS (MARCSEC)
-7.8 6.0 -5.0 -4.0 -3.0 -2.0 -1.0 0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
TIME (MSEC)

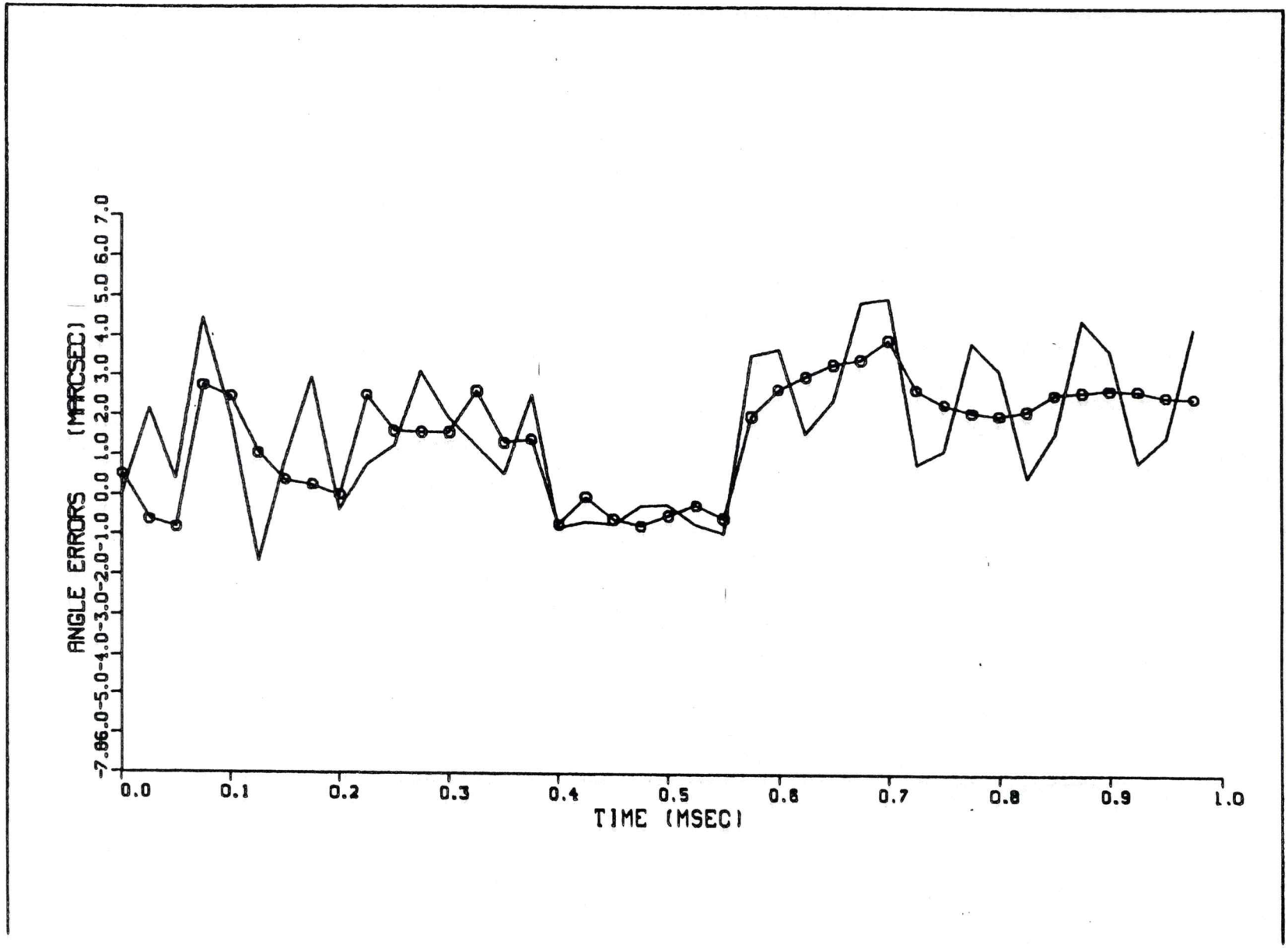
Curve 1


TRUTH ANGLES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (MSEC)

Case 2


ANGLE ESTIMATES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (MSEC)

CASE 2


ANGLE ERRORS (MARCSEC)
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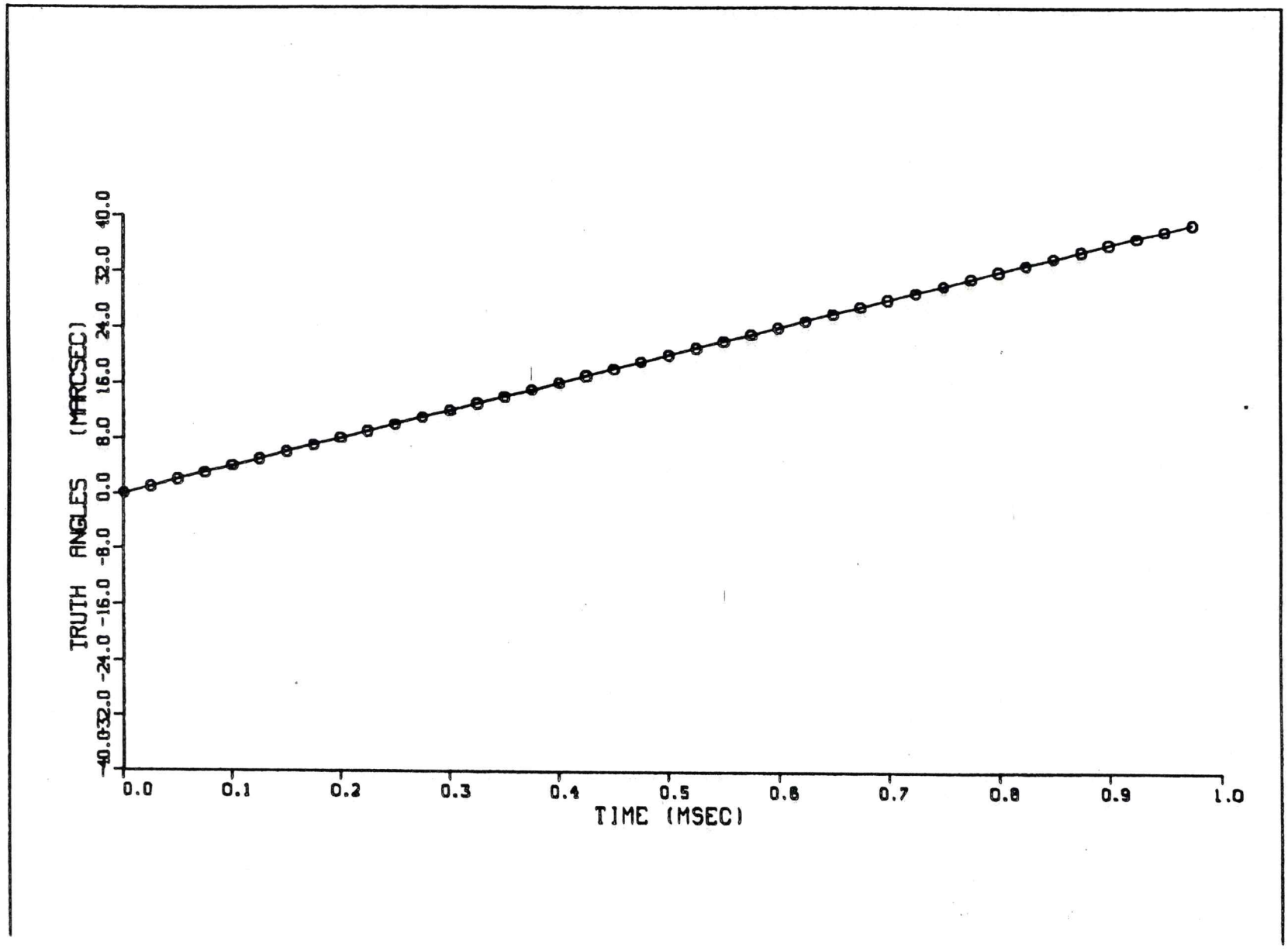
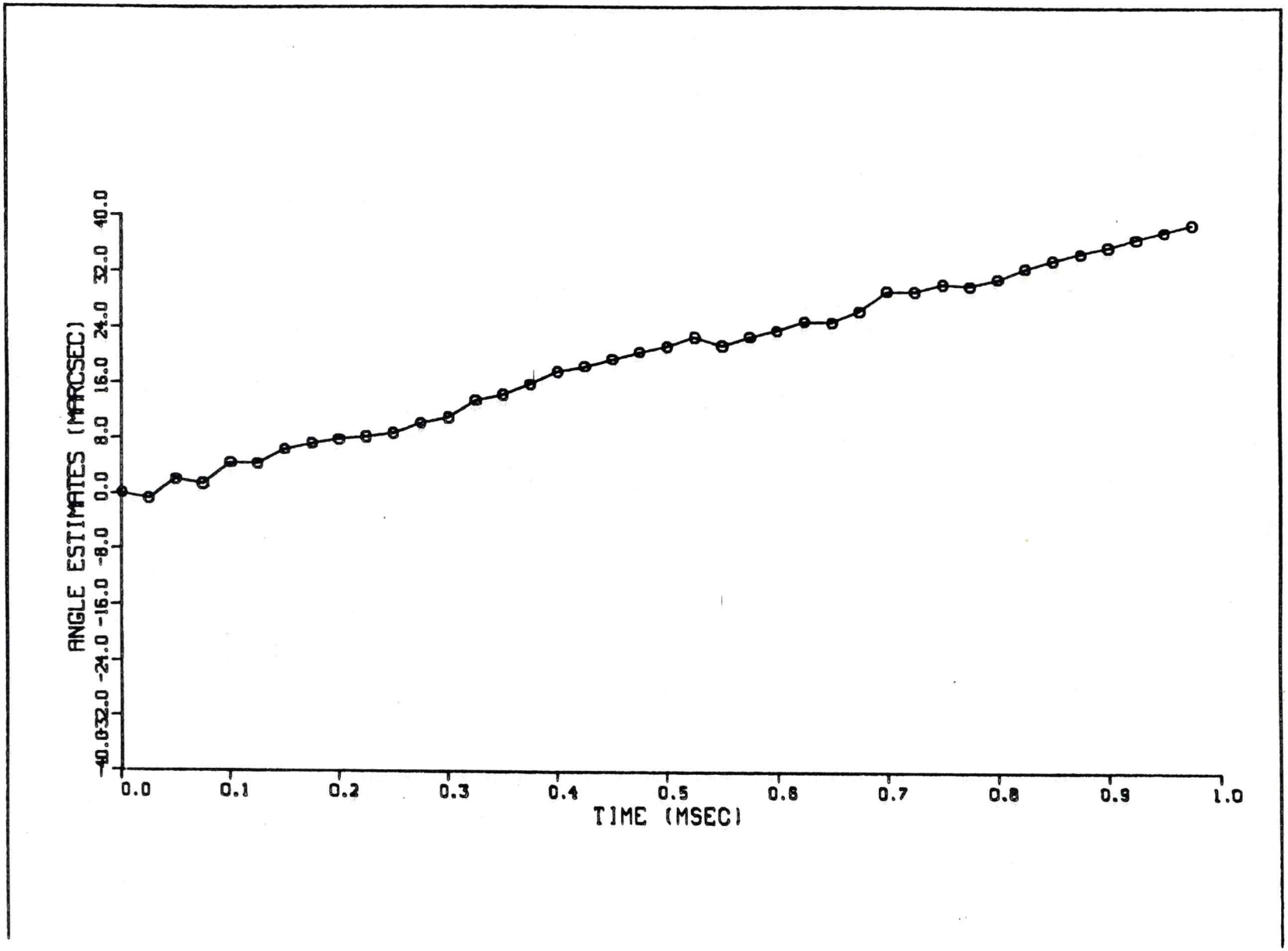
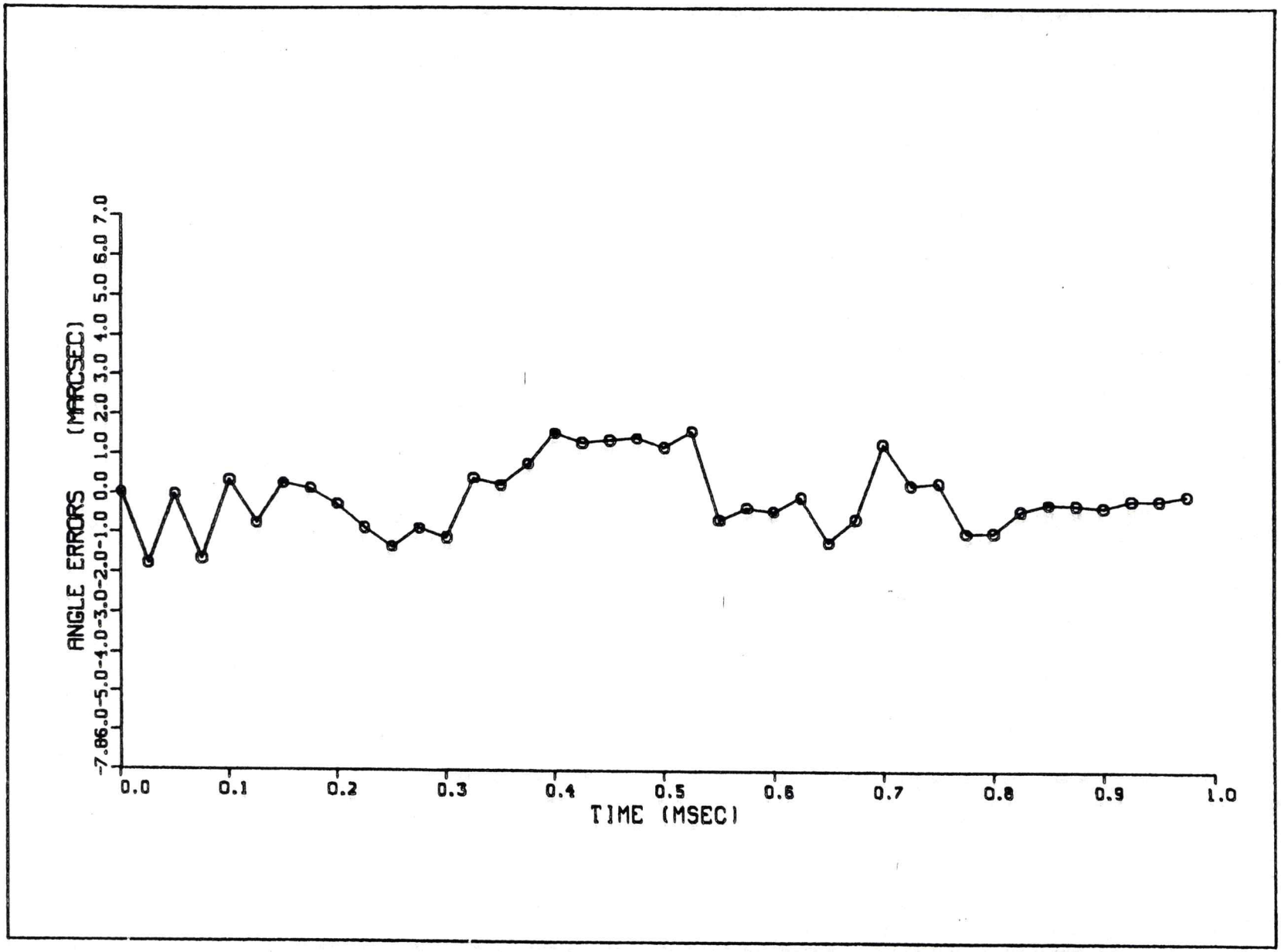
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
TIME (MSEC)


TRUTH ANGLES (MARCSEC)
-40.0 -32.0 -24.0 -16.0 -8.0 0.0 8.0 16.0 24.0 32.0 40.0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
TIME (MSEC)

Case 3


ANGLE ESTIMATES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (MSEC)

Case 3


ANGLE ERRORS (MARCSEC)
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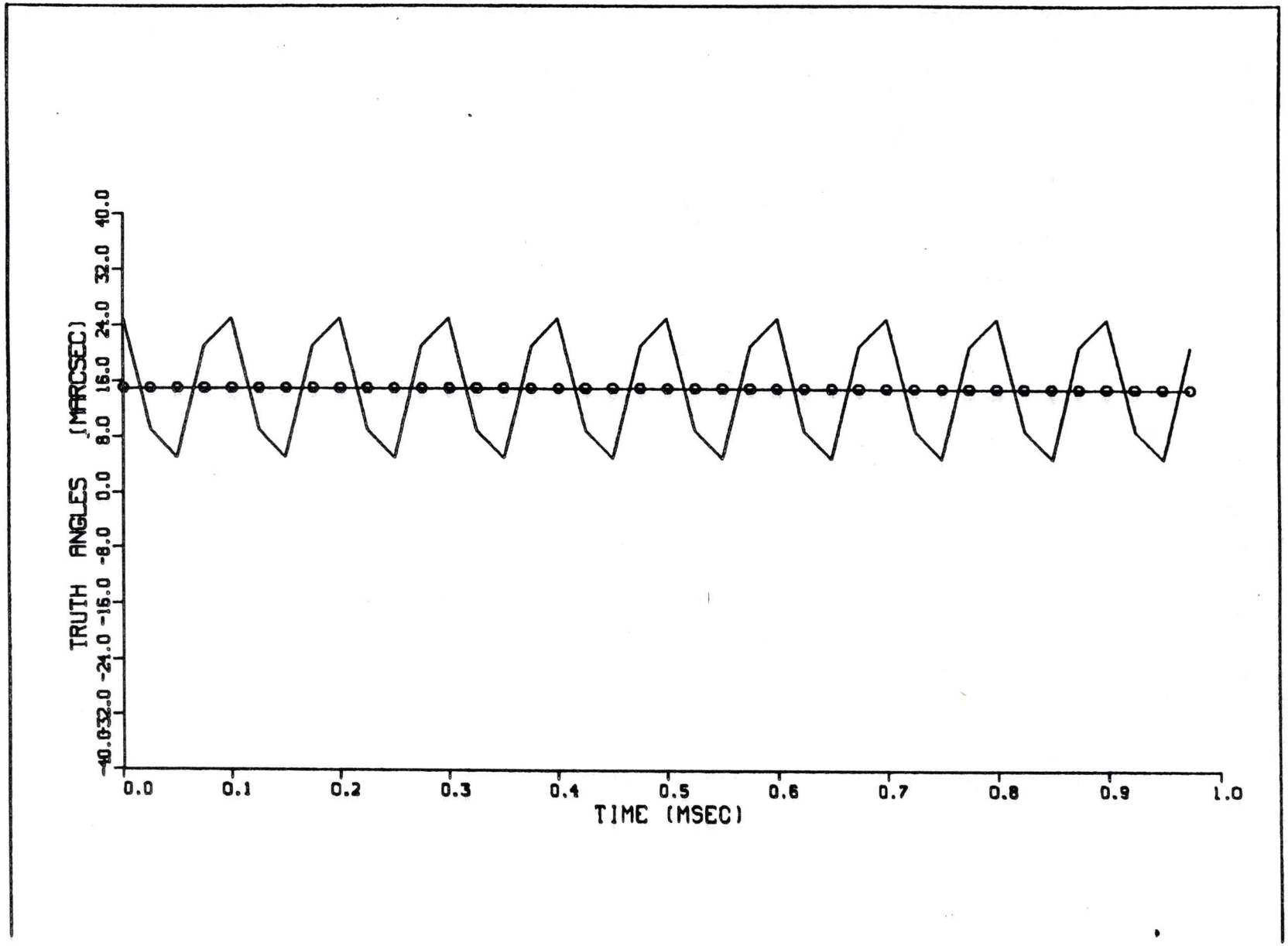
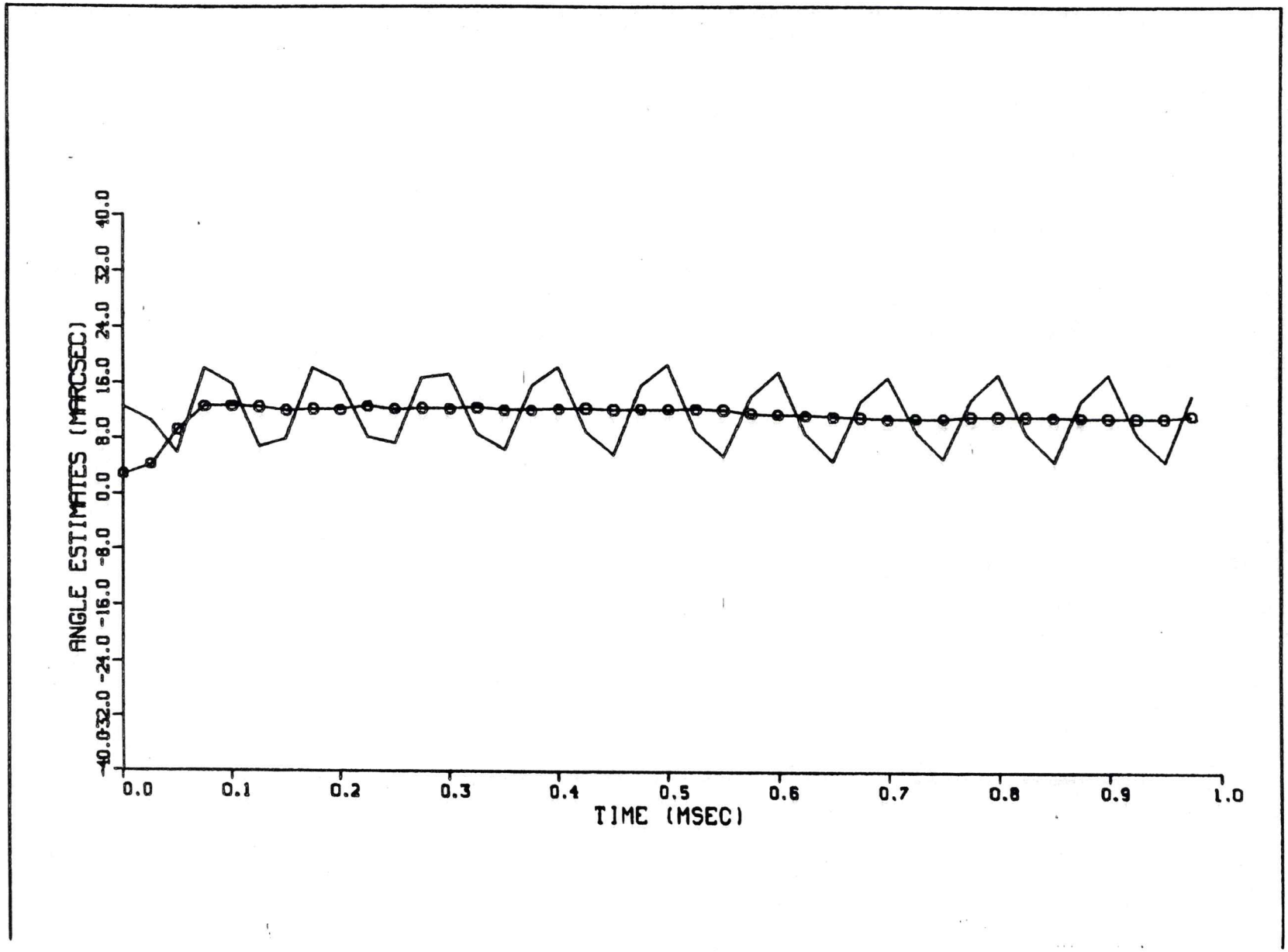
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
TIME (MSEC)

Case 3


TRUTH ANGLES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (MSEC)

Case 4


ANGLE ESTIMATES (MARCSEC)
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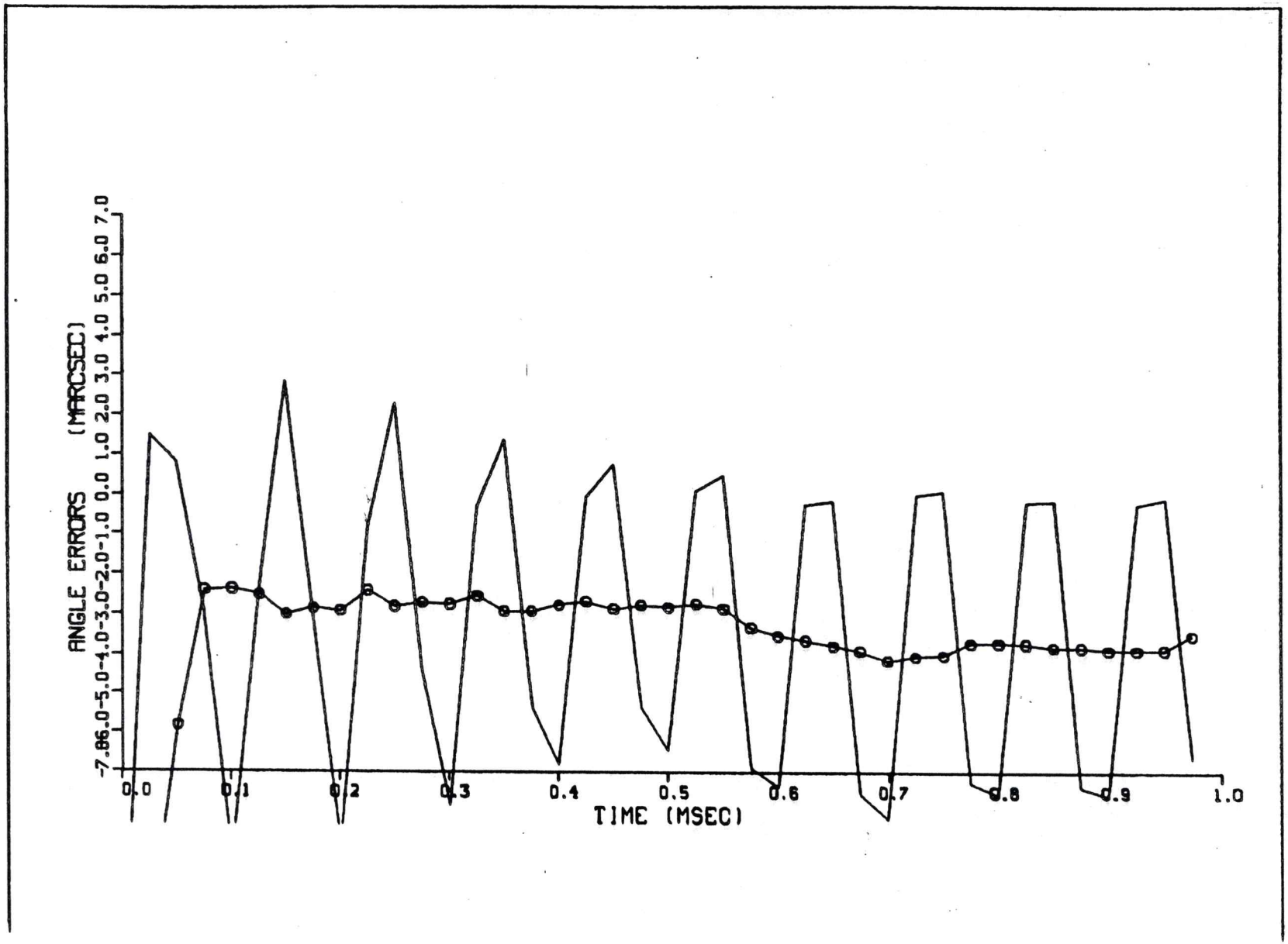
TIME (MSEC)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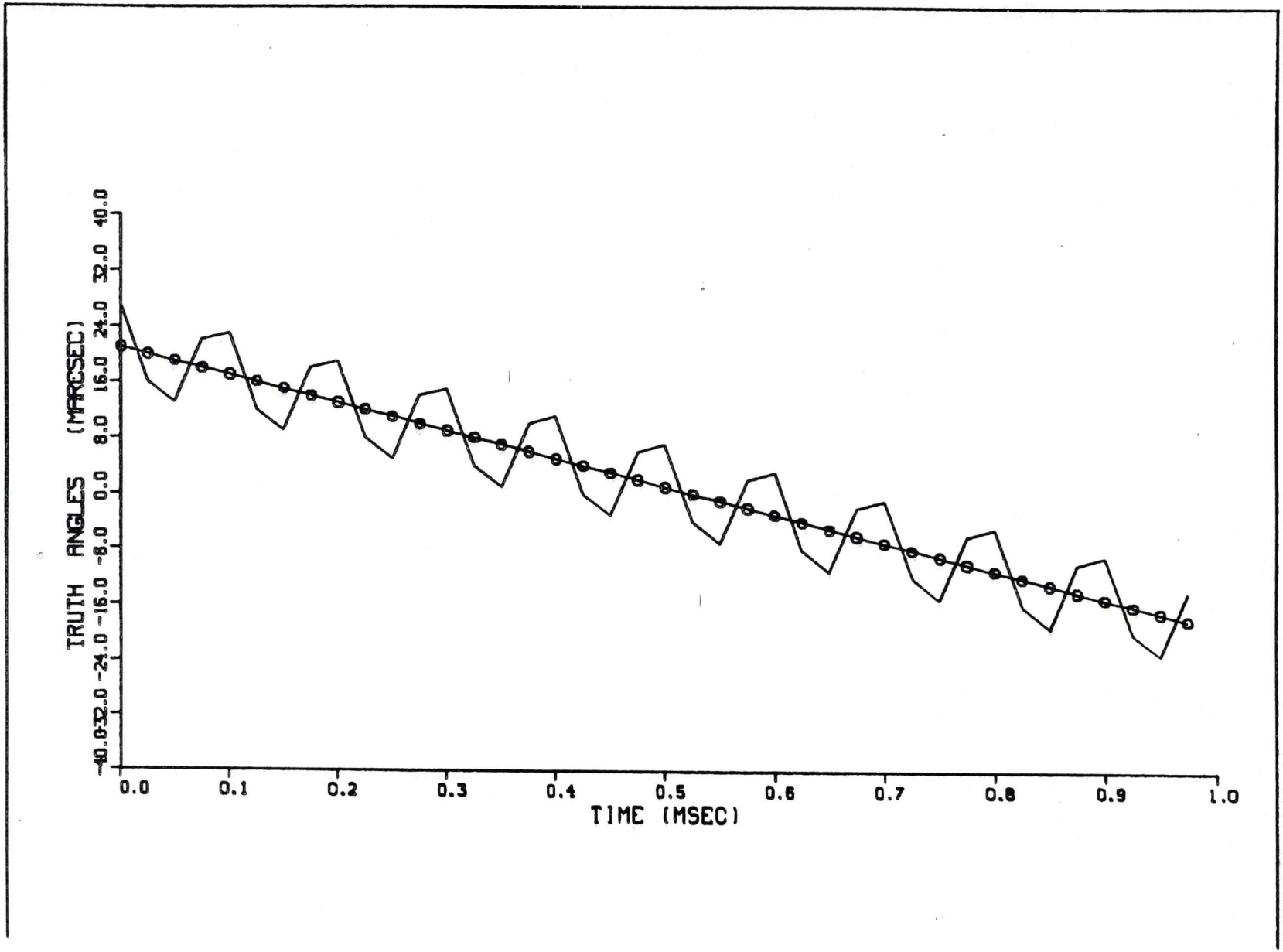
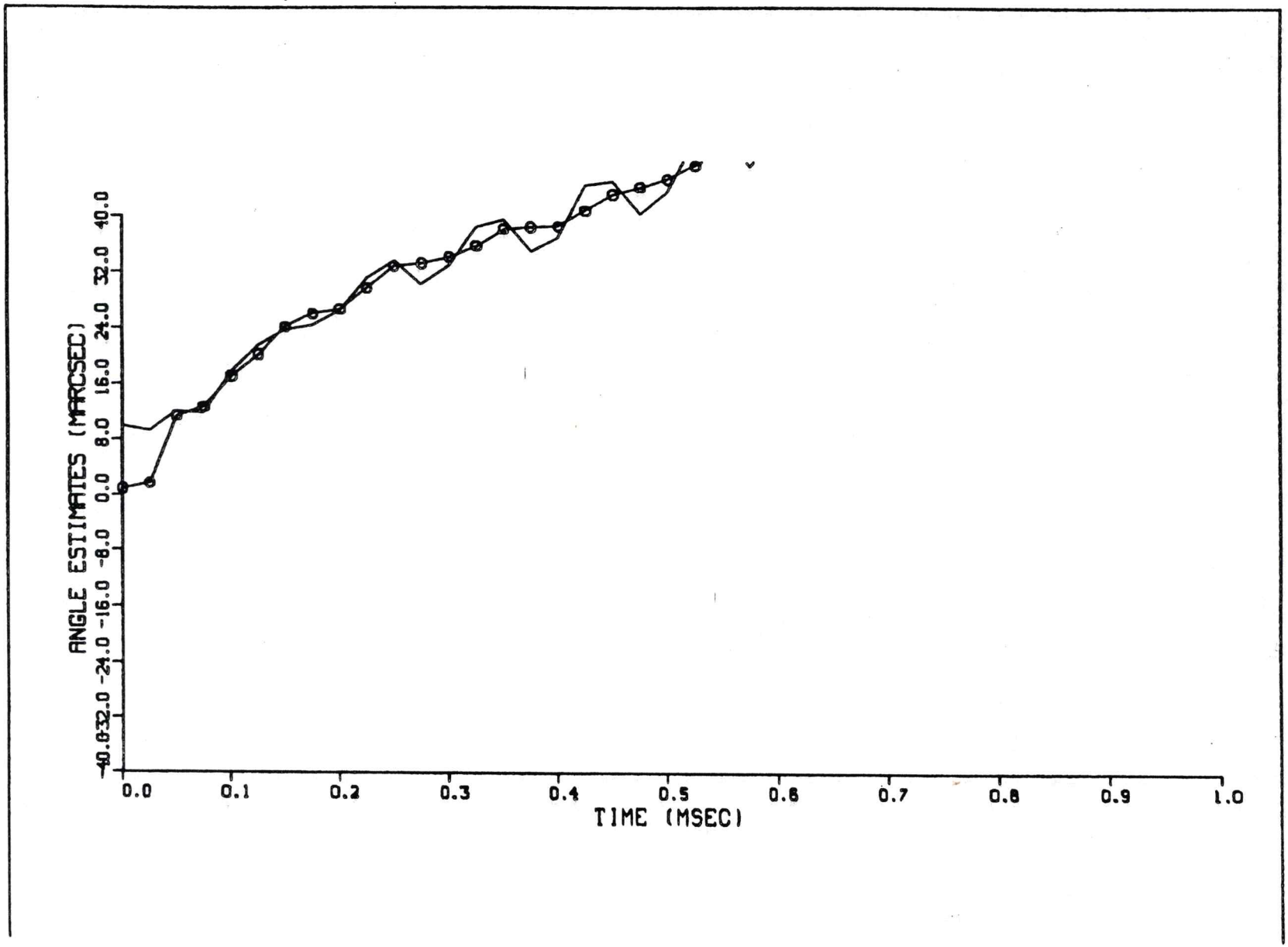
TIME (MSEC)

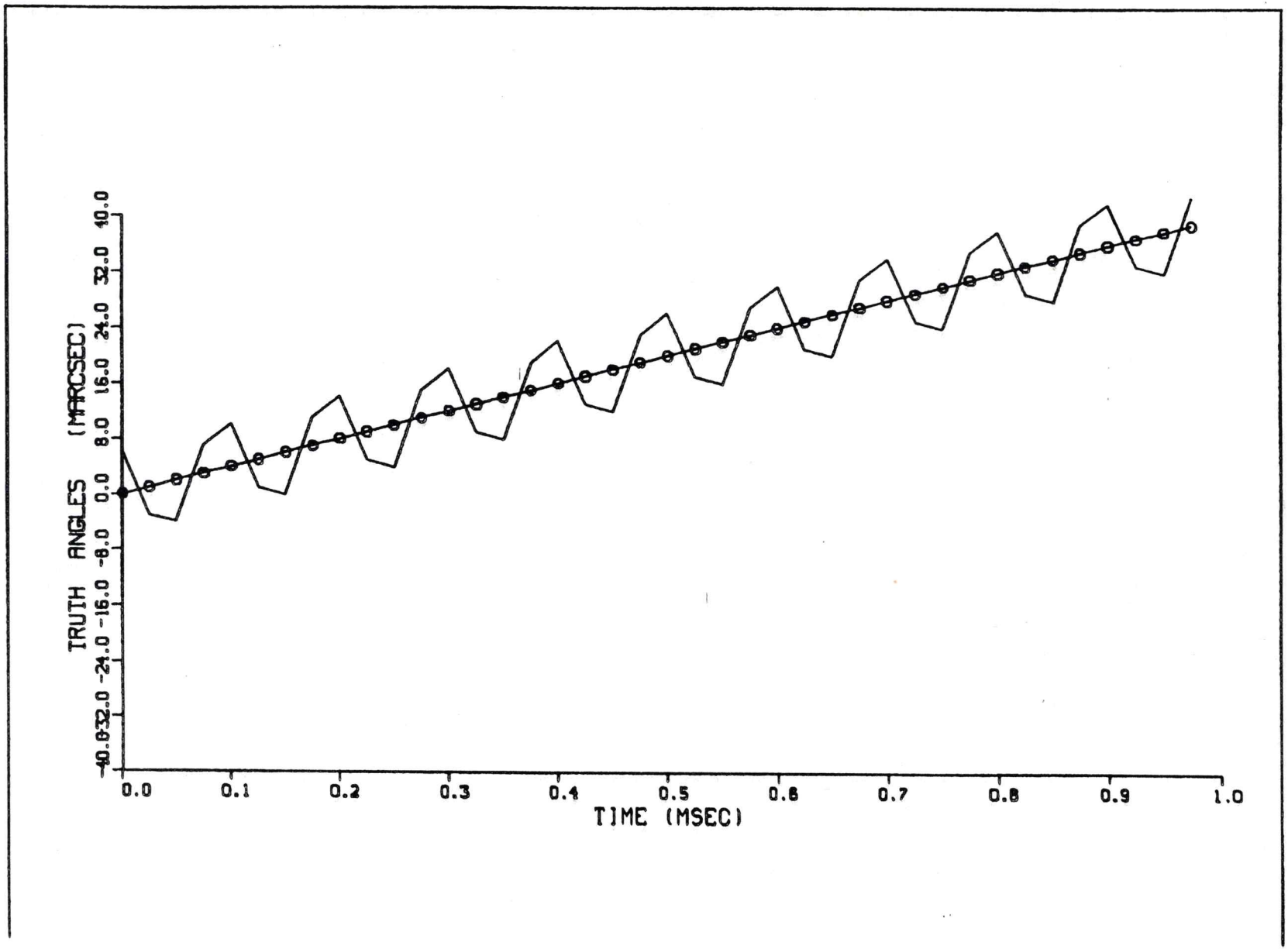
Case 4


TRUTH ANGLES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (MSEC)

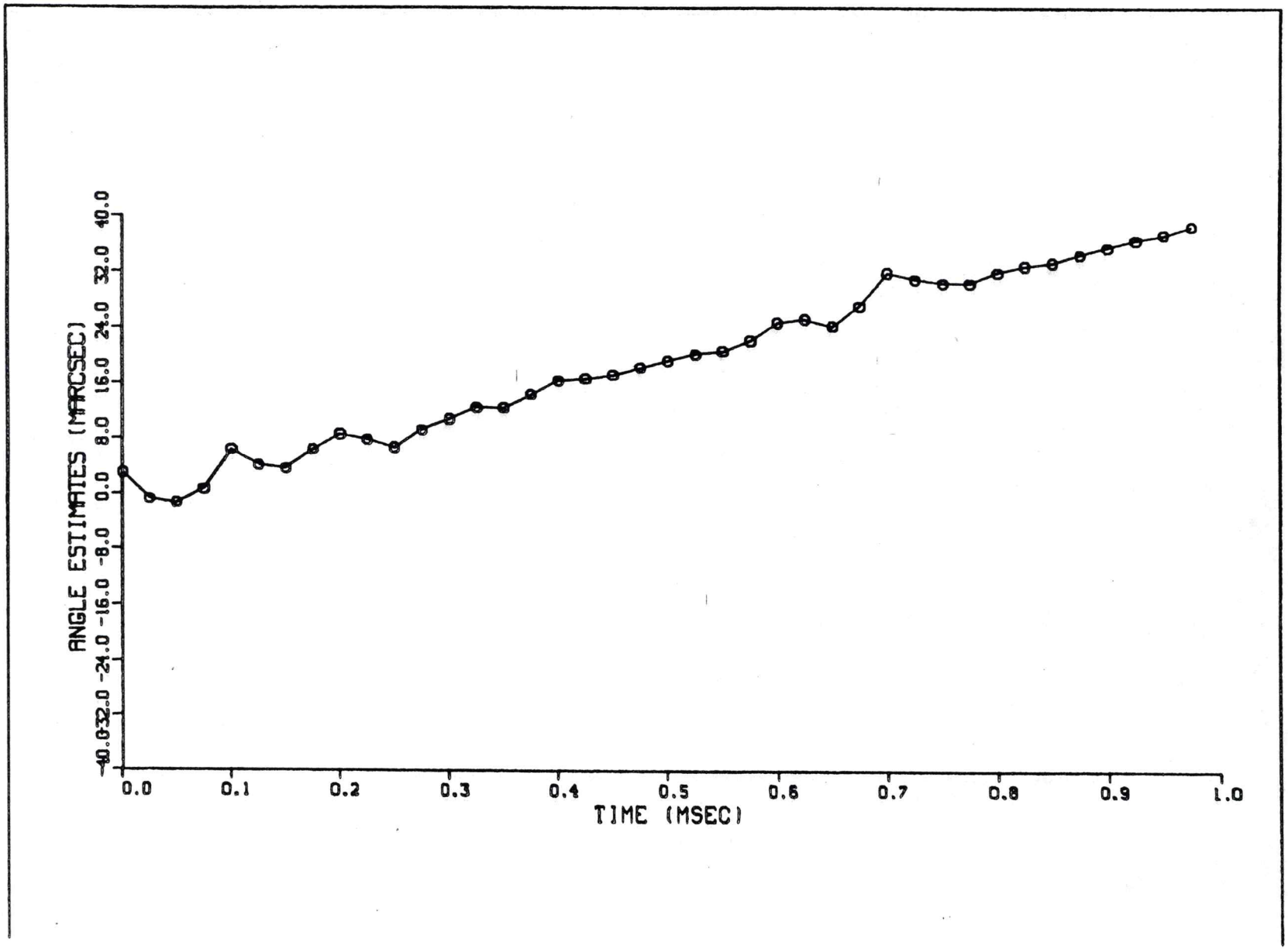
Curves


ANGLE ESTIMATES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (MSEC)

CHR 5


TRUTH ANGLES (MARCSEC)
10.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (MSEC)

case 6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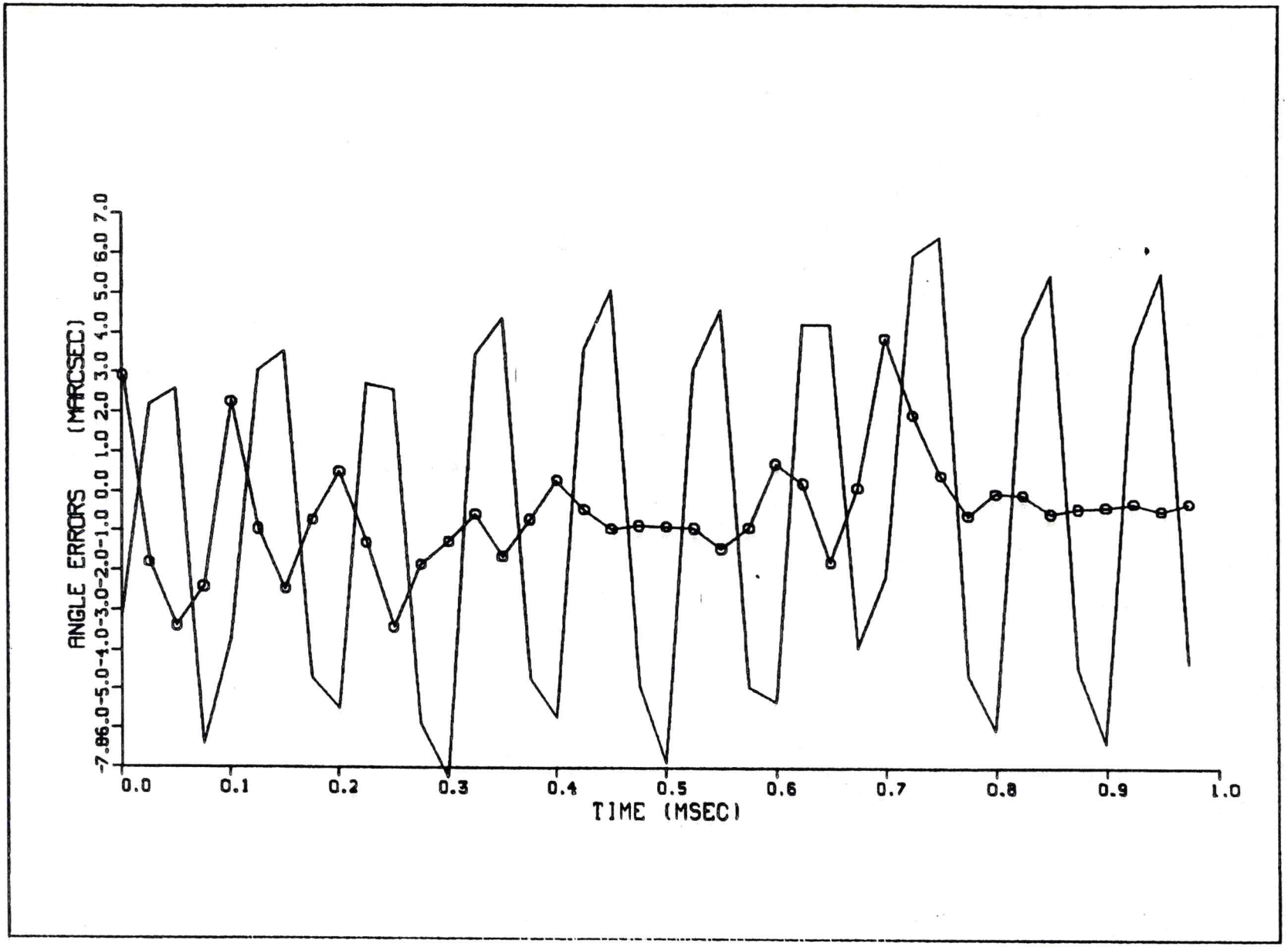
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
TIME (MSEC)

card


ANGLE ERRORS (MARCSEC)
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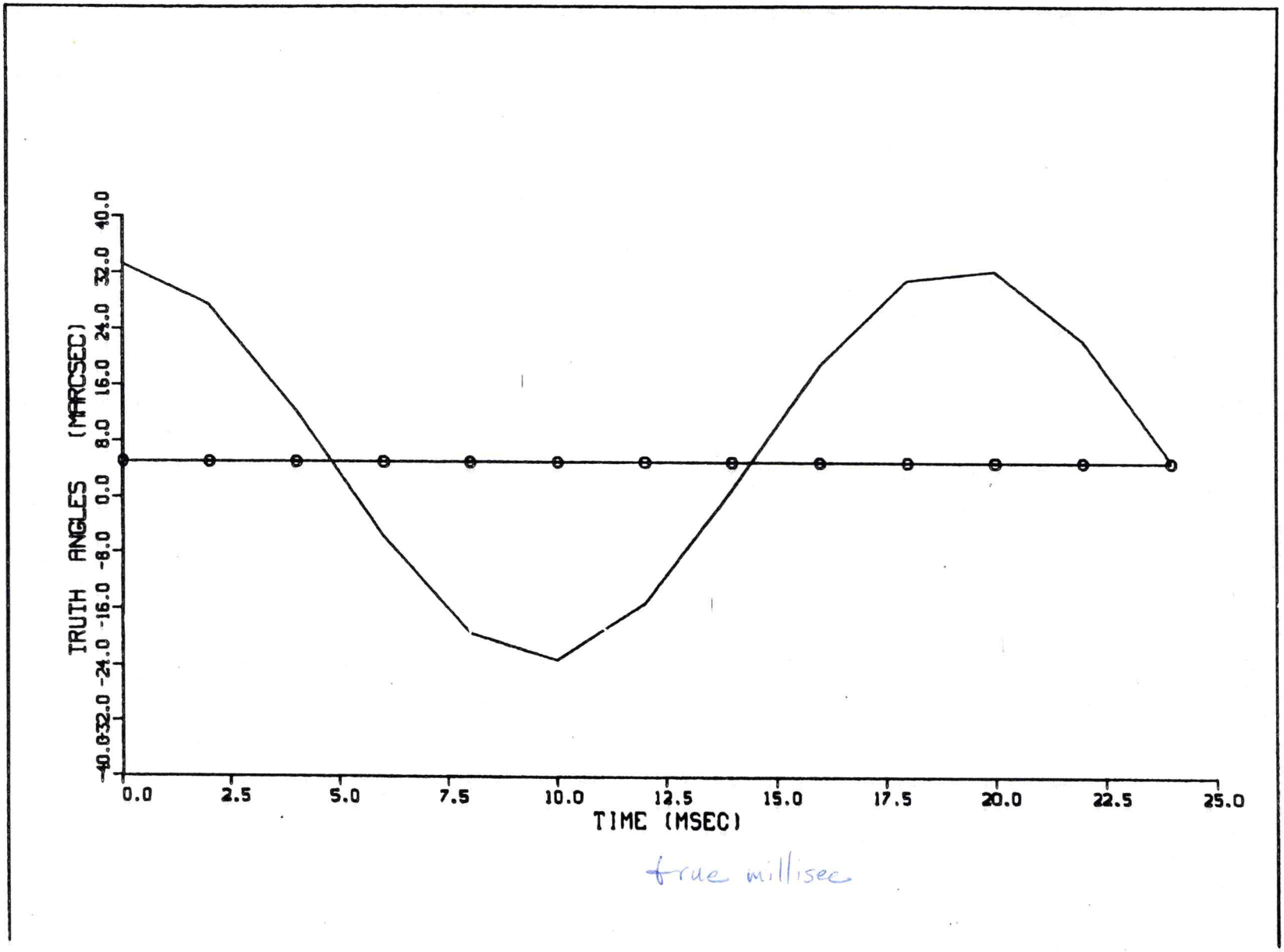
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
TIME (MSEC)

- Filter successfully tracks a ramp with good prior information.
- This demonstrates extending the useful range in a simple case.
- Range extension for a realistic case is yet to be done.
- Poor prior information hurts filter performance.
- Large prior oscillation hurts filter performance.

High Frequency Jitter Problem

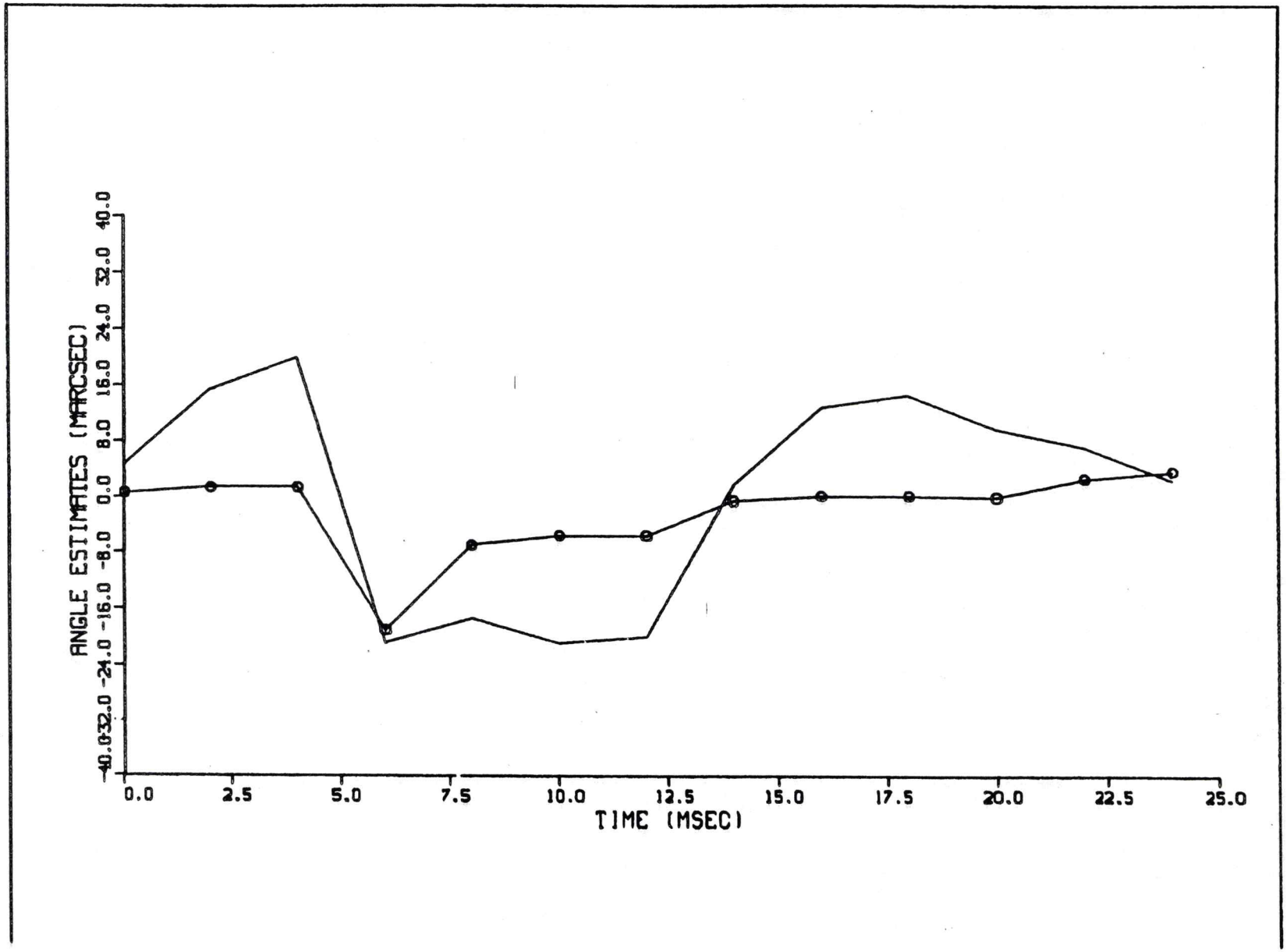
- High frequency jitter does not average to zero due to the nonlinear measurement characteristic.

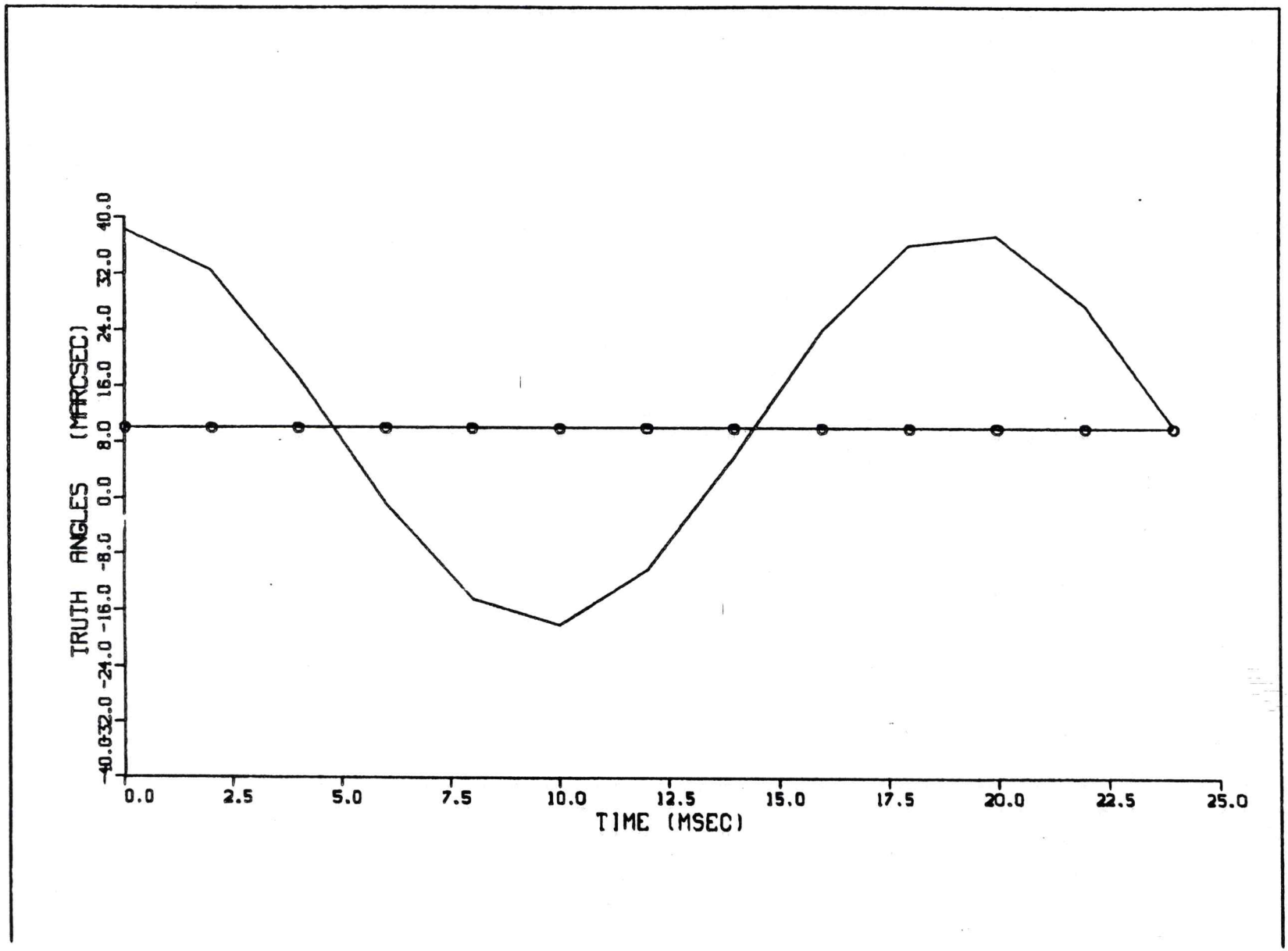
- Extended Kalman filter running at a higher rate (1 msec) does not perform well due to higher noise.



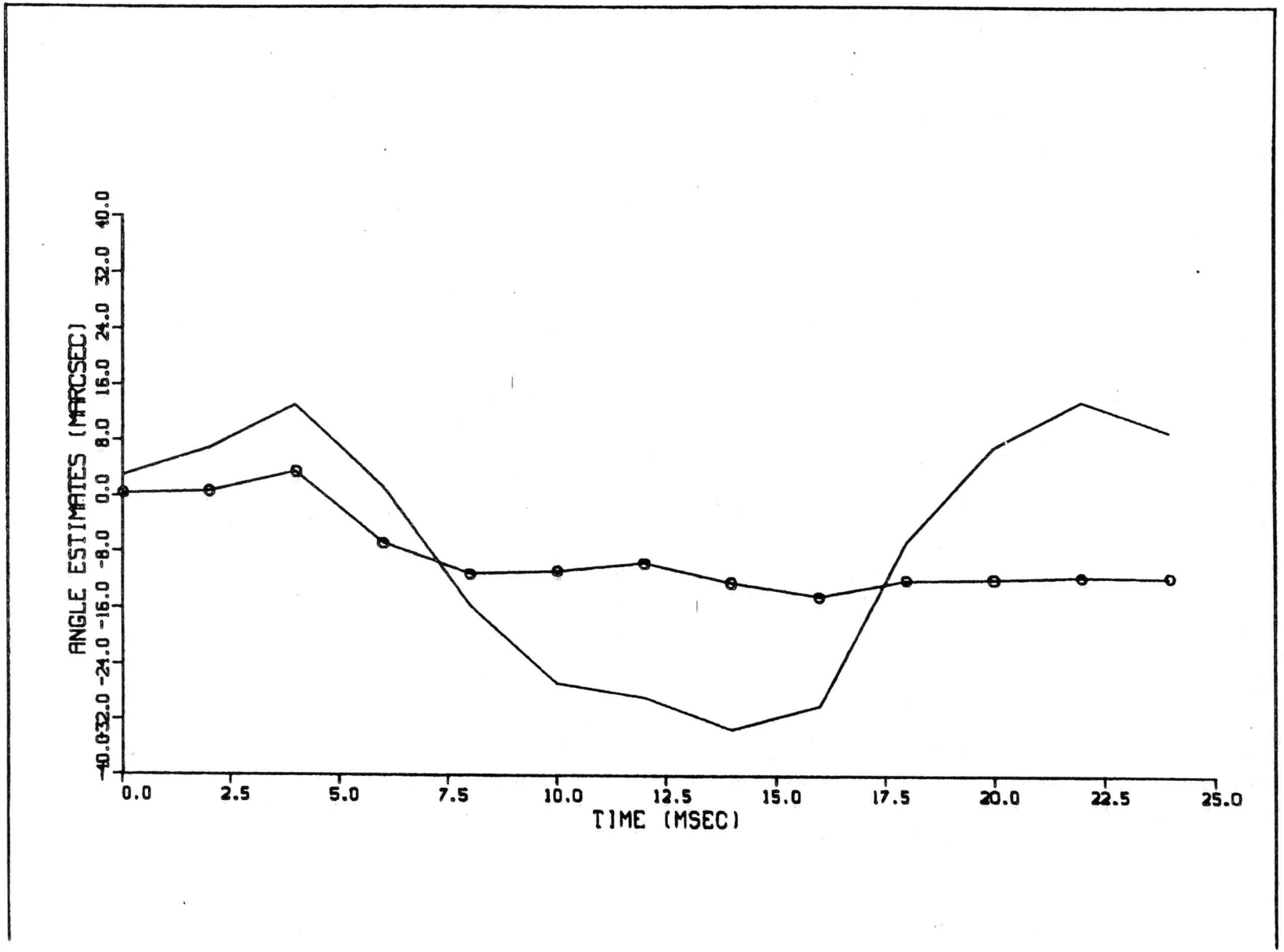
true millisec

C1337


ANGLE ESTIMATES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
TIME (MSEC)


TRUTH ANGLES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
TIME (MSEC)

Case 8


ANGLE ESTIMATES (MARCSEC)
40.0
32.0
24.0
16.0
8.0
0.0
-8.0
-16.0
-24.0
-32.0
-40.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
TIME (MSEC)

case Y

Further Work

- Evaluate suboptimal extended Kalman filters for use with current and proposed sensors based on realistic single-axis model.

- Suboptimal filters will be selected using a detailed linearized single-axis model.

- Filters will be evaluated using a detailed single-axis model.

AGENDA

Space Telescope Alternate Fine Guidance System Study

Preliminary Review - 8 June 1983

0900 - Welcome	- G. C. Weiffenbach
0905 - Overview	- W. G. Fastie
0910 - APL Program Mission Statment	- D. G. Grant C. Jones
0930 - Space Telescope System Overview and APL Simulation Methodology	- M. D. Griffin
1000 - PCS/FGS Control Configuration	- A. Pue
1030 - Break	
1045 - Disturbance Torque Environment	- J. C. Ray
1105 - Cosmic Ray Environment	- R. Gold
1125 - On-Board Processors	- J. Dettmer
1145 - Discussion	
1200 - Lunch	
1245 - Source Model	- T. E. Strikwerda

Alternate Sensor Concepts

1300 - Summary	- D. G. Grant
1315 - Optical Splitters and Optical Testbed	- W. G. Fastie
1400 - Break	
1415 - Electronic Sensors Digicons Image Dissectors Solid State Scanned Arrays	- T. E. Strikwerda
1500 - Signal Processing	- K. Strohbehn
1515 - Summary	- D. G. Grant
1530 - Discussion	
1600 - Adjourn	

APL PROGRAM

RATIONALE: DEVELOP AN ALTERNATIVE ST FINE GUIDANCE SYSTEM FOR CONSIDERATION IN THE EVENT THE EXISTING INTERFEROMETER SYSTEM DEMONSTRATES MARGINAL PERFORMANCE

DURATION: APRIL 15, 1983 – OCTOBER 15, 1983

ORGANIZATION:

SPONSOR: MARSHALL SPACE FLIGHT CENTER

PRINCIPAL INVESTIGATOR: WILLIAM G. GASTIE, THE JOHNS HOPKINS UNIVERSITY

PROGRAM MANAGER: DAVID G. GRANT, APPLIED PHYSICS LABORATORY

PROGRAM ENGINEER: MICHAEL D. GRIFFIN (APL)

PROGRAM SCIENTIST: THOMAS E. STRIKWERDA (APL)

Co-I's Art Code
Jim Westphal
Jim Gunn

MSFC Contr Rep. John Humphries

APL PROGRAM

MISSION: DEVELOP THE PRELIMINARY ENGINEERING DESIGN OF AN ALTERNATE FINE GUIDANCE SYSTEM

GUIDELINES:
- SATISFY SCIENTIFIC REQUIREMENTS
- MORE FORGIVING PERFORMANCE CHARACTERISTICS
- MINIMUM DISTURBANCE TO EXISTING FGS
- MINIMUM SCHEDULE/COST PERTURBATION
- NONINTERFERENCE WITH MAINSTREAM EFFORT

TECHNICAL APPROACH: UNRESTRICTED

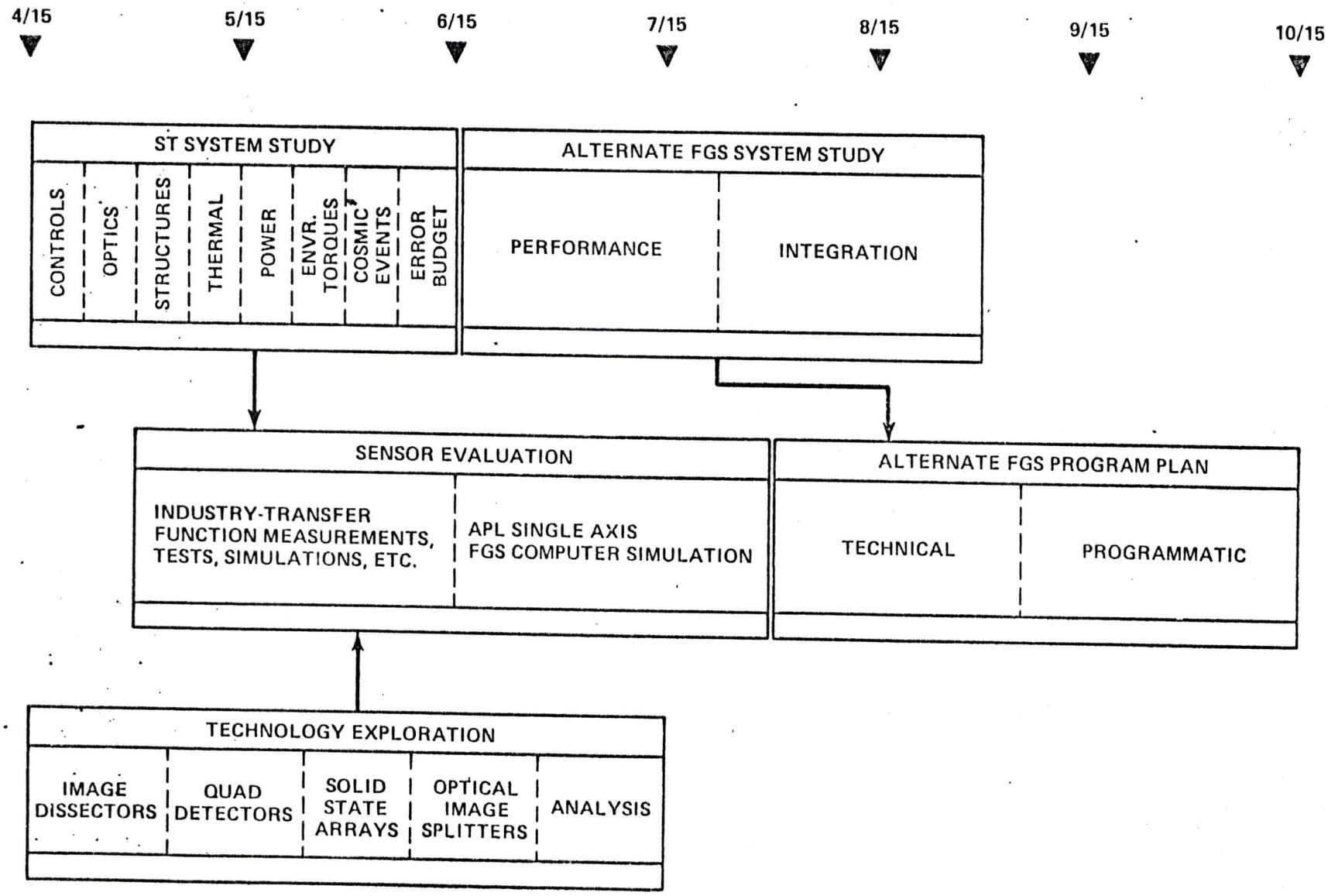
APL PROGRAM

DELIVERABLES: ALTERNATE FINE GUIDANCE SYSTEM PROGRAM PLAN

a. TECHNICAL
   - PRELIMINARY ENGINEERING DESIGN
   - NEW SENSOR PERFORMANCE VERIFICATION
   - SYSTEM PERFORMANCE VERIFICATION
   - PRELIMINARY INTEGRATION PLAN

b. PROGRAMMATIC
   - INDUSTRY DEVELOPMENT TEAM FOR FLIGHT-QUALIFIED UNITS
   - ST PRINCIPAL CONTRACTORS COMPLETE KNOWLEDGE OF
     - ALTERNATE FGS SYSTEM CONSEQUENCES
     - SYSTEM INTEGRATION ISSUES
   - PROGRAM SCHEDULE AND COST ESTIMATES

APL PROGRAM


4/15
5/15
6/15
7/15
8/15
9/15
10/15
ST SYSTEM STUDY
CONTROLS
OPTICS
STRUCTURES
THERMAL
POWER
ENVR. TORQUES
COSMIC EVENTS
ERROR BUDGET
ALTERNATE FGS SYSTEM STUDY
PERFORMANCE
INTEGRATION
SENSOR EVALUATION
INDUSTRY-TRANSFER FUNCTION MEASUREMENTS, TESTS, SIMULATIONS, ETC.
APL SINGLE AXIS FGS COMPUTER SIMULATION
ALTERNATE FGS PROGRAM PLAN
TECHNICAL
PROGRAMMATIC
TECHNOLOGY EXPLORATION
IMAGE DISSECTORS
QUAD DETECTORS
SOLID STATE ARRAYS
OPTICAL IMAGE SPLITTERS
ANALYSIS

Space Telescope System Study

Purposes:

To understand the system requirements and operating environment for an alternate FGS.

To provide an independent study of potential problem areas and recommendations for ST.

Study Emphasis:

Complexity of ST system required focusing on any area primarily in terms of its relation to pointing stability and control problems.

System Integration Constraints

- Dynamic range for interface with PCS?
- Power margin?
- Mass/volume limits in FGS box?
- Cost, schedule, space qualification?
- Integration time, suitability for acquisition?
- Processing requirements – interface with FGE/PCS?
- Noise, sensitivity, spectral response?

move 1 pass later

Space Telescope System Study

Alternate Sensor Technologies

Image Dissectors – e.g. IUE Fine Error Sensor.

CCD/CID solid state arrays.

Optical splitter / FGS PMTs in quadrant mode.

Digicon in quadrant mode, with/without optical splitter.

Signal processing to assist interferometer.

FGS Optical System Properties

What is needed to form an image in the FGS?

What will the image quality be?

Guide Stars

Availability? Magnitudes? Spectral type?

Science Requirements on Pointing Control

Nominal stability requirement .007 arcsec for 24 hours using 14.5 magnitude guide stars.

Jitter spec seems to be 10% of Airy disk for original 3 meter telescope in UV. Reduction to 2.4 meters cuts guide star photons by 33% and increases diffraction spot size by 20%.

PCS/FGS configuration and performance.

Acquisition sequence for dim stars a problem.

3 arcsec star selector FOV size specification?

- sky background at 23rd magnitude, using safety factor of 100?
- SSS scan rate in coarse track mode?
- "guarantee" 1 guide star in ~~pupil~~ instantaneous FOV?

If ~~pupil~~ size is larger, slew accuracy/drift and acquisition time is more forgiving.

Is 40 Hz FGS internal rate required for sensor with larger dynamic range?

Disturbance Environment

Reaction wheels – statistical performance summary given. Is this the right measure of performance?

High gain antenna a significant jitter source. Microstrip phased arrays instead?

Cosmic ray environment may be more severe than expected based on analysis seen so far.

Solar array damping times – operations impact?

Star selector servos – jitter in spec?

Disturbance Environment (Cont'd.)

"ISOTHERMAL"

Thermal effects – analysis seems okay. Blanket performance a bit optimistic. Sensitivity study? No other problems, pending FGS cover plate fix.

Structure – low frequency damping coefficients? Graphite/epoxy water retention/outgassing? APL has had experience at the arcsec level with this material (MAGSAT).

Environmental torques/wheel speeds/momentum dumping capability – impact of later launch on aero torques needs to be assessed.

Disturbance Environment (Cont'd.)

Gyro noise – present quieting measures have been very effective, but DRIRU-2 is 6–8 db quieter. Is this important in the present system?

Gyro drift – FGS samples used in 1 Hz average for inertial updates. Is better/more frequent update possible or desirable? FGS/PCS filtering? Full state filter around gyro?

Photon noise – a problem for acquisition and tracking on dim stars – loss of lock potential. Sample filtering? Lower FGS rate?

Computer Systems

No margin for on-orbit "work arounds" in DF-224. In-flight reprogramming has saved many missions.

Considerable margin in FGE for new algorithms. No data storage margin. Expense of changes is an obvious drawback.

FGE radiation susceptibility may be a problem. Radiation-hardened parts not currently used.

Space Telescope System Study

Simulation Approach

PCS/FGS simulation is required to analyze system performance of sensors with new gain/pointing error signal characteristics.

1-DOF simulators are adequate for initial work.

Six-month time frame does not permit development of PCS/FGS simulation capability at APL.

NASA/MSFC (Poultes) and NASA/GSFC (Feminano) had 1-DOF models which were available for APL use/modification/updates.

3 axis model: H. Kennel MSFC

Latest configuration/hardware data will be included and simulation model "played back" to NASA/Lockheed/PE for verification.

ST performance will be studied with new sensor in updated 1-DOF model.

POINTING CONTROL SYSTEM ANALYSIS

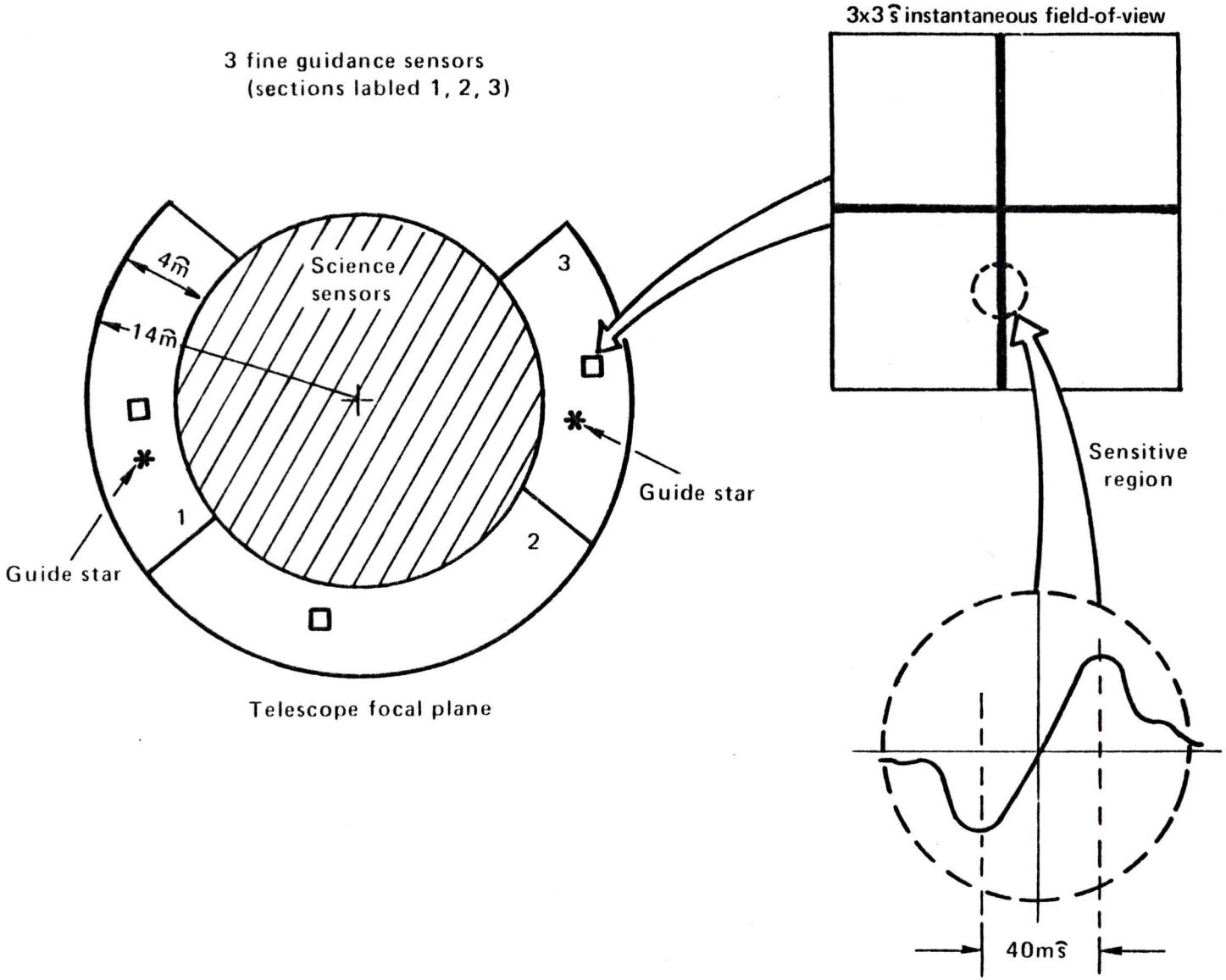
- Fundamental control strategy
- Offset tracking and motion compensation
- Observer design
- Vehicle control
- Single plane system model
- Planned work

BASIC CONTROL PHILOSOPHY

OBJECTIVE: Align specified scientific instrument boresight to data star line-of-sight

TECHNIQUE: Track nearby guide stars and offset science instrument boresight to data star line-of-sight

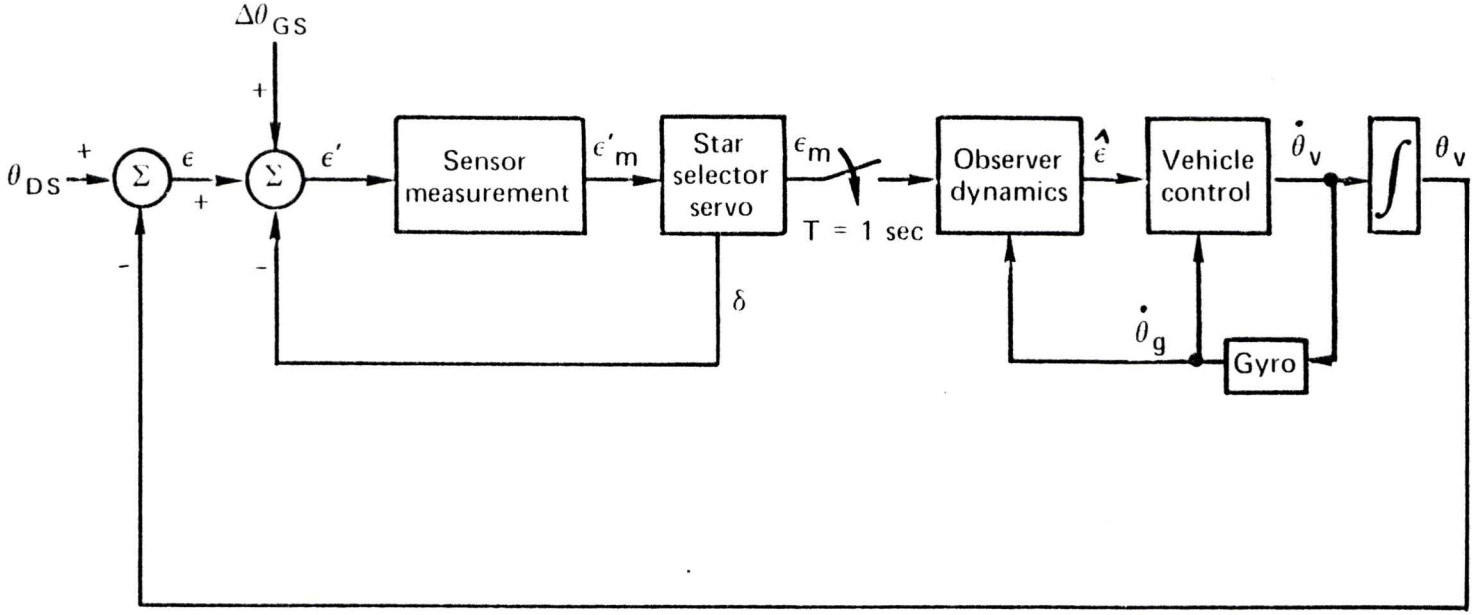
FINE GUIDANCE SENSOR FIELD-OF-VIEW

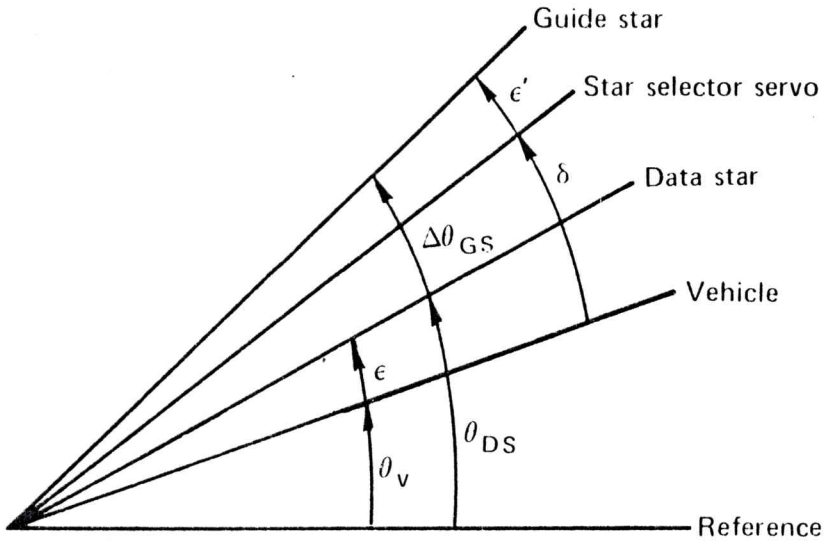


FINE-LOCK CONTROL STRATEGY

- Star selector servo loop maintains guide star within limited interferometer field-of-view
- Servo encoder and known guide star offset combined to measure pointing error to data star
- Blending of measured pointing error at low frequency and integrated gyro rate at high frequency used to control vehicle attitude

CONTROL FUNCTIONAL BLOCK DIAGRAM





Required:

$\theta_v = \theta_{DS}$

$\delta = \Delta\theta_{GS}$

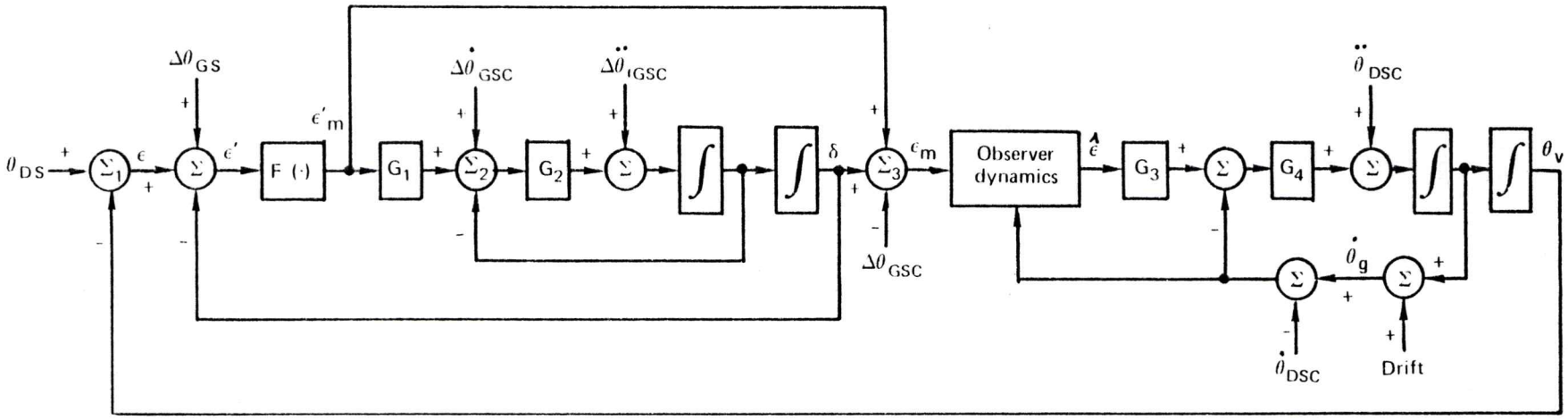
OFFSET TRACKING

- Must account for guide star/data star offset, including velocity aberration

- Control system should feedforward compensate for known motion due to velocity aberration rather than rely on feedback

PHOTON NOISE

OFFSET TRACKING AND MOTION COMPENSATION



F (·) ≡ Sensor measurement characteristic

G_1, G_2, G_3, G_4 ≡ Compensation networks

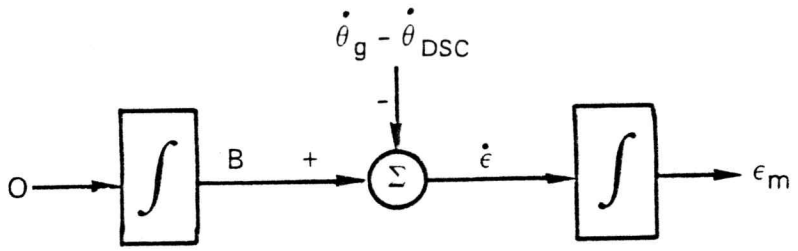
GYRO NOISE

OBSERVER DYNAMICS

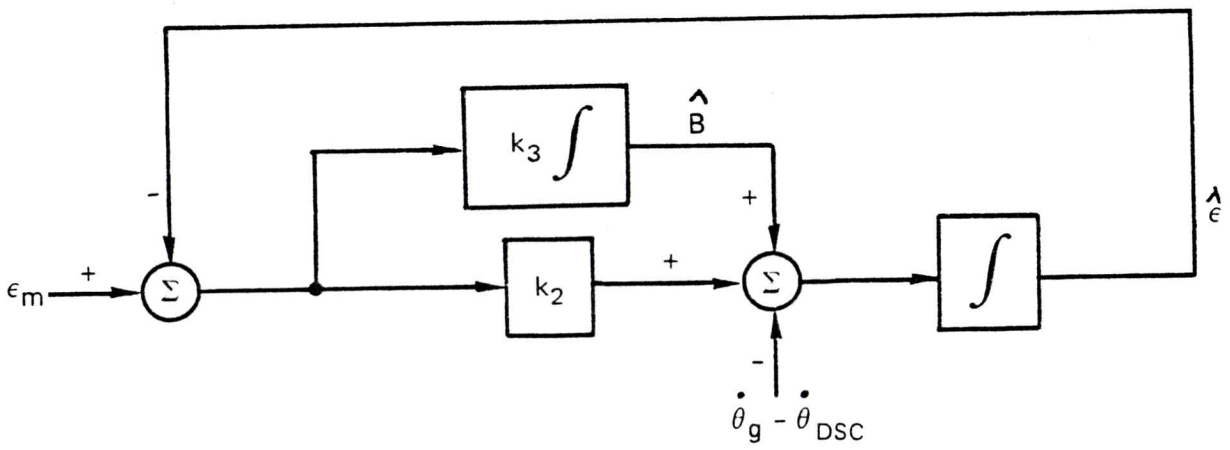
- Model measurement process as attitude error due to gyro bias

$$\left.\begin{aligned} \dot{\epsilon} &= \dot{\theta}_{DS} - \dot{\theta}_V \\ \dot{\theta}_g &= \dot{\theta}_V + B \end{aligned}\right\} \Longrightarrow \quad \dot{\epsilon} = \dot{\theta}_{DS} - \dot{\theta}_g + B$$

OBSERVER MODEL AND DYNAMICS



(a) Gyro drift - pointing error model

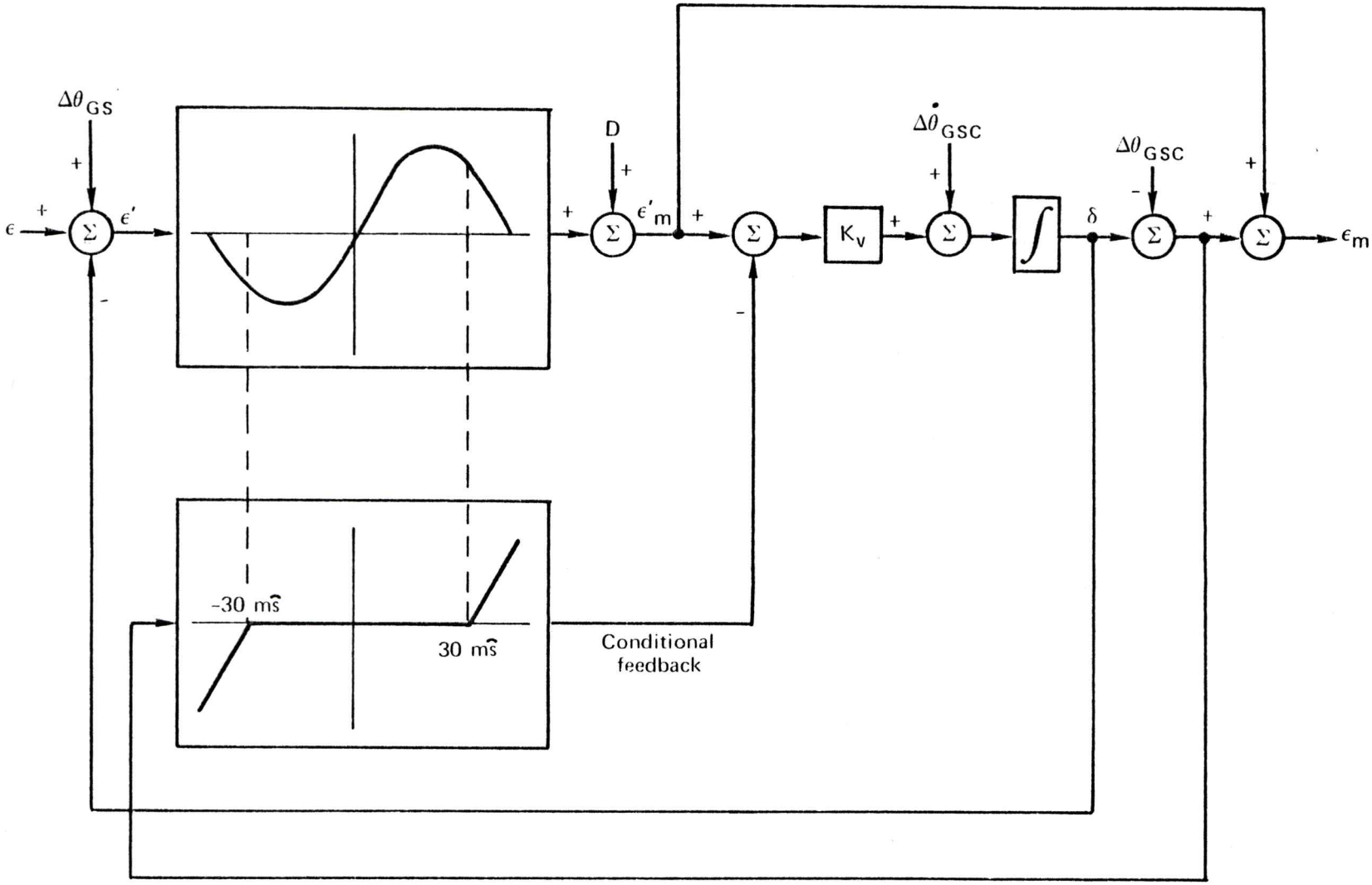


(b) Closed loop observer

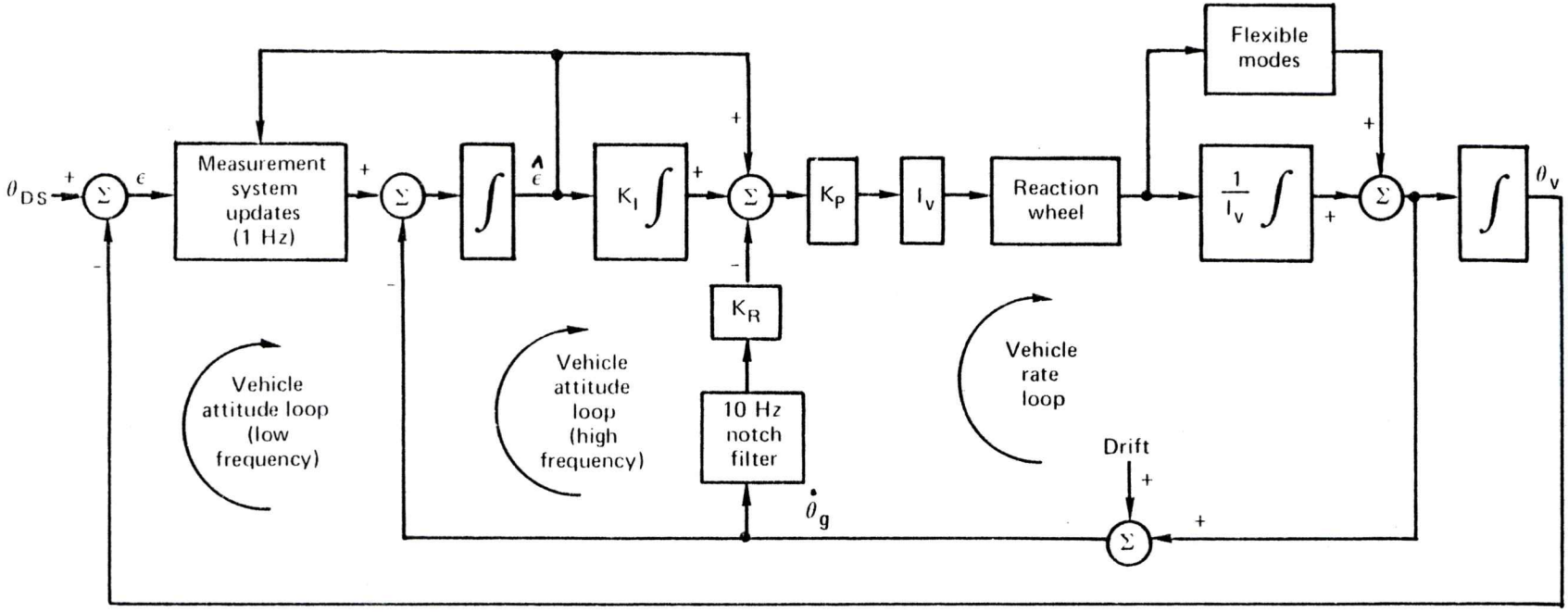
SOME OBSERVER FEATURES

- Estimated and true pointing error will differ due to random noise and unmodeled vehicle dynamics
- Assumes sensor characteristic is within linear range

EARLY CONCEPT FOR LOSS-OF-LOCK SENSITIVITY REDUCTION



VEHICLE CONTROL



PLANNED WORK

- Simulation study assessing pointing and loss-of lock performance of alternative sensor versus the current sensor
- Analysis of error sources and their propagation to pointing error
- Analysis of control loop bandwidth requirements
- Three dimensional description of pointing control system operation

Space Telescope
Disturbance Torque Analysis

- External torques:
  - Gravity gradient
  - Magnetic
  - Aerodynamic
  - Solar
- Torque → momentum → wheel speed → vibration
- Magnetic momentum dumping effectiveness determines LOS jitter due to wheel speed
- Disturbances also affect PCS performance

830607 JCRay

Space Telescope
Momentum Control Simulation

- Assume ST inertial (PCS working perfectly) :

  momentum = $\int$ torque

- Currently, model:
  - gravity gradient torque
  - CP magnetic momentum dumping
  - aero torque (MSFC coefficients)

- Plan:
  - implement ME law (others?) MINIMUM ENERGY
  - independent aero torque model EFFECT OF LATER LAUNCH
  - evaluate wheel speed performance (statistics, spectra, histories, ...)
  - disturbance profiles for PCS simulation

830607 JCRay

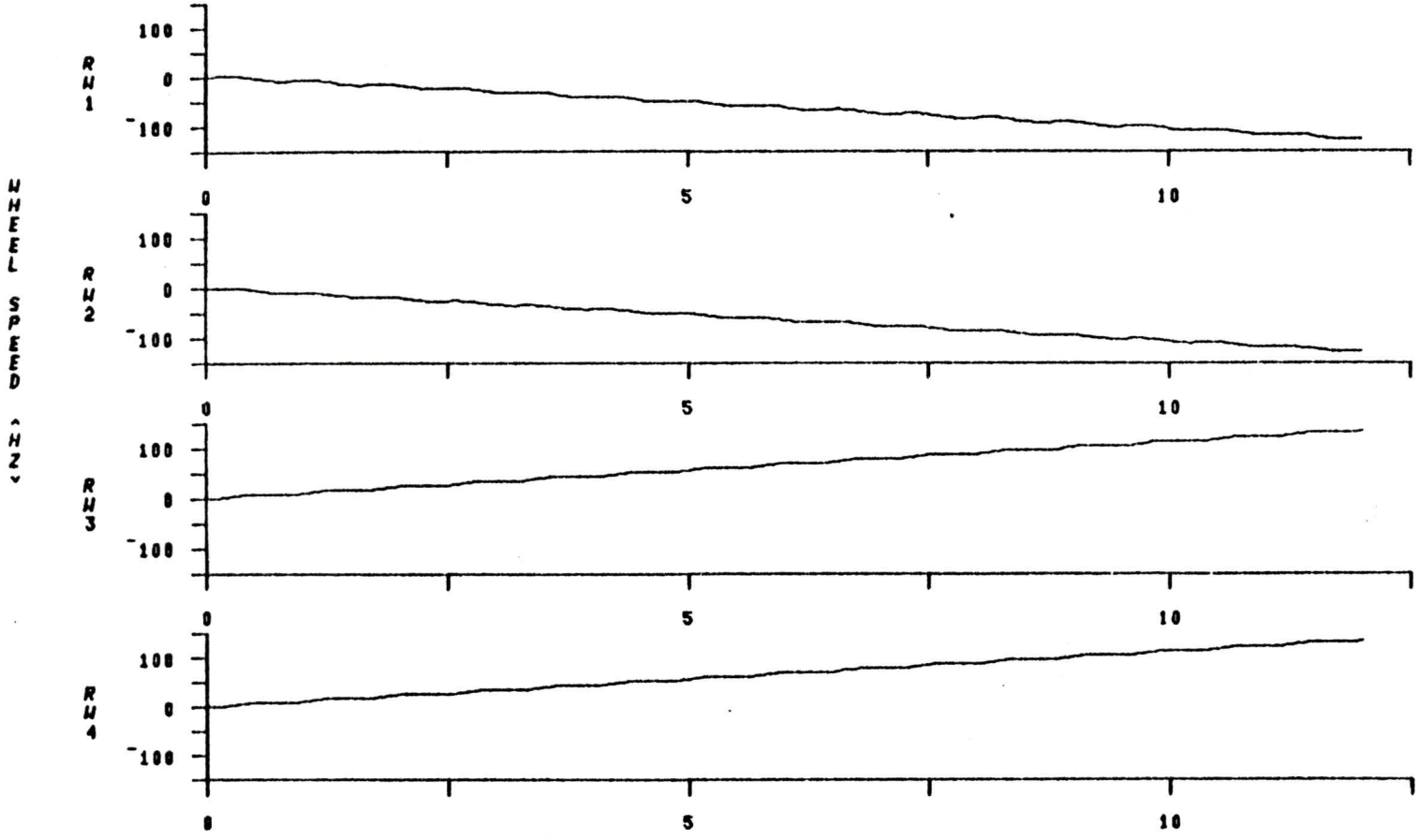
MAX GRAV GRAD TORQUE

(NO MOMENTUM DUMPING)

S.T. WHEEL SPEED

CASE NAME: ST1
INITIAL CONDITIONS:
EPOCH: YEAR=1984, DAY= 1
BODY MOM. (NMS) = .000 .000 .000
MAG. TORQUE GAIN = 0

BODY ORIENTATION (INERTIAL):
RIGHT ASCENSION (DEG) = 90.000
DECLINATION (DEG) = 73.500
ROLL ANGLE (DEG) = .000
SA ANGLE (DEG) = 0.000



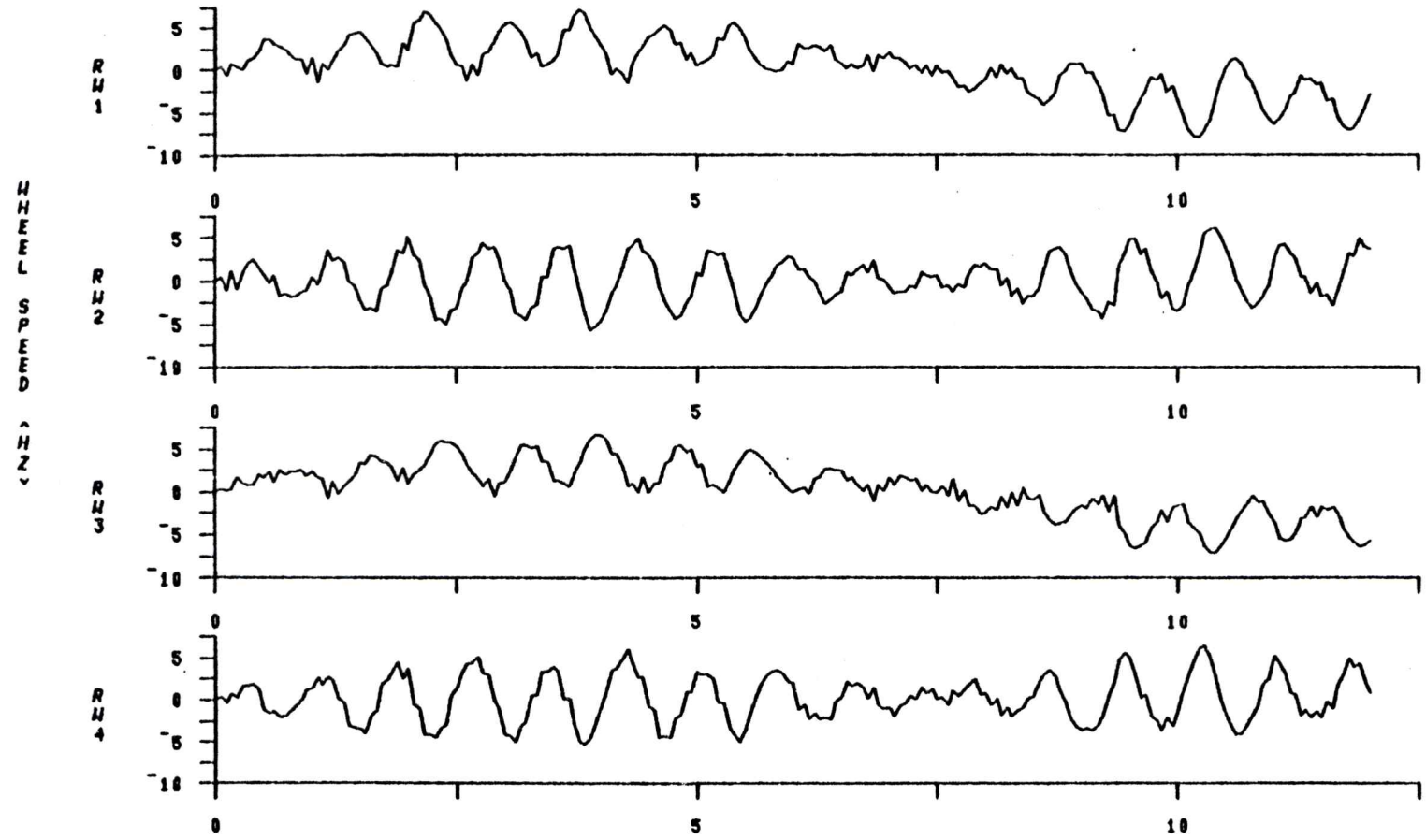
12:09 PM EDT 6/7/83 2330 STSIM

(CP DUMPING; NO AERO TORQUES)

S.T. WHEEL SPEED

CASE NAME: TEST6
INITIAL CONDITIONS:
EPOCH: YEAR=1984, DAY= 1
BODY MOM. (NMS) = .00 .00 .00
MAG. TORQUE GAIN = 750

BODY ORIENTATION (INERTIAL):
RIGHT ASCENSION (DEG) = 90.00
DECLINATION (DEG) = 73.50
ROLL ANGLE (DEG) = .00
SA ANGLE (DEG) = 90.00



$\omega_{MAX} \approx 7.5$ Hz

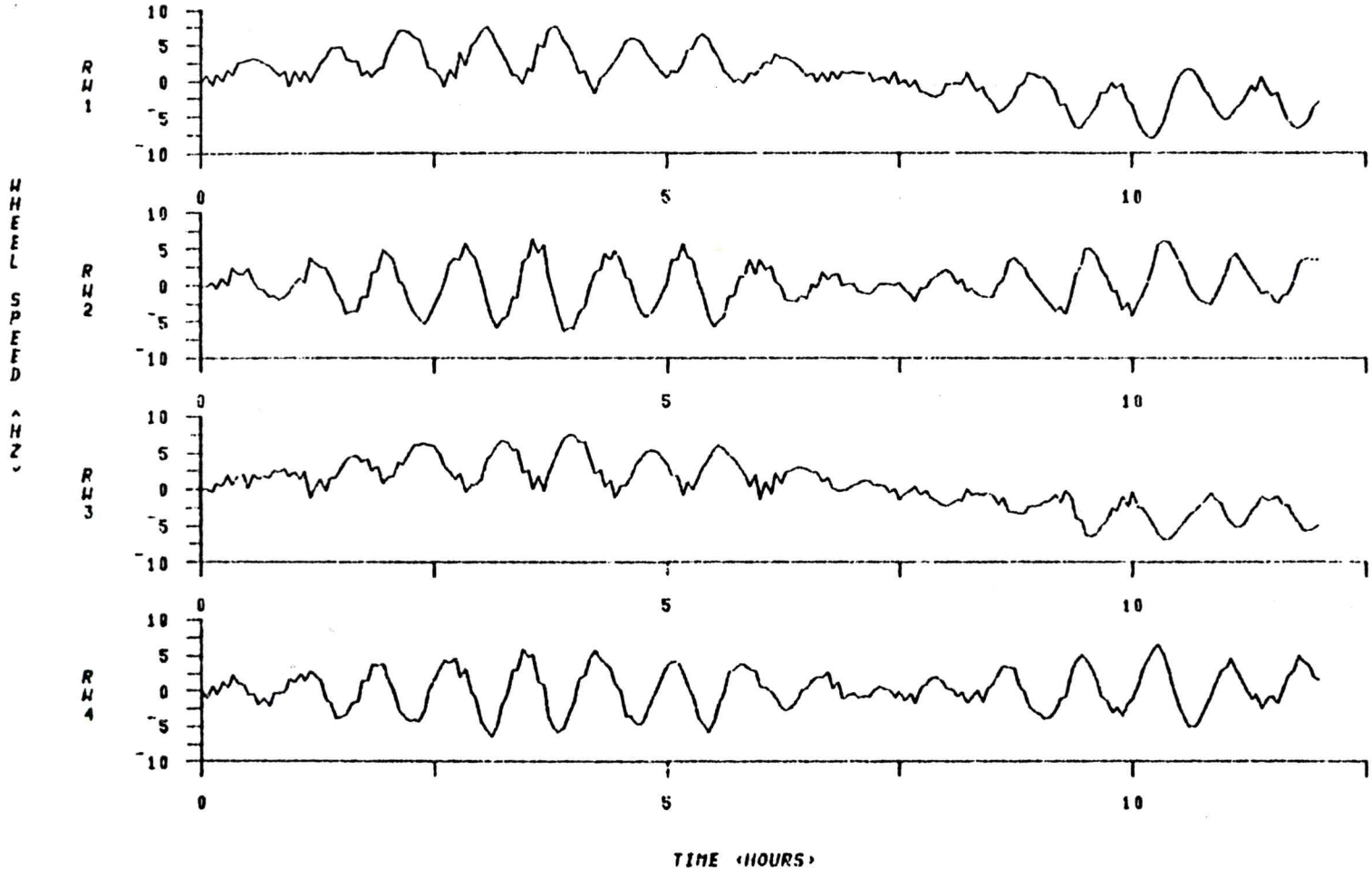
11:46 AM EDT 6/7/83 2330 STSIM

(CP DUMPING; W/AERO TORQUES)

S.T. WHEEL SPEED

CASE NAME: TEST5
INITIAL CONDITIONS:
EPOCH: YEAR=1984, DAY= 1
BODY MOM. (NMS) = .00 .00 .00
MAG. TORQUE GAIN = 750

BODY ORIENTATION (INERTIAL):
RIGHT ASCENSION (DEG) = 90.00
DECLINATION (DEG) = 73.50
ROLL ANGLE (DEG) = .00
SA ANGLE (DEG) = 90.00



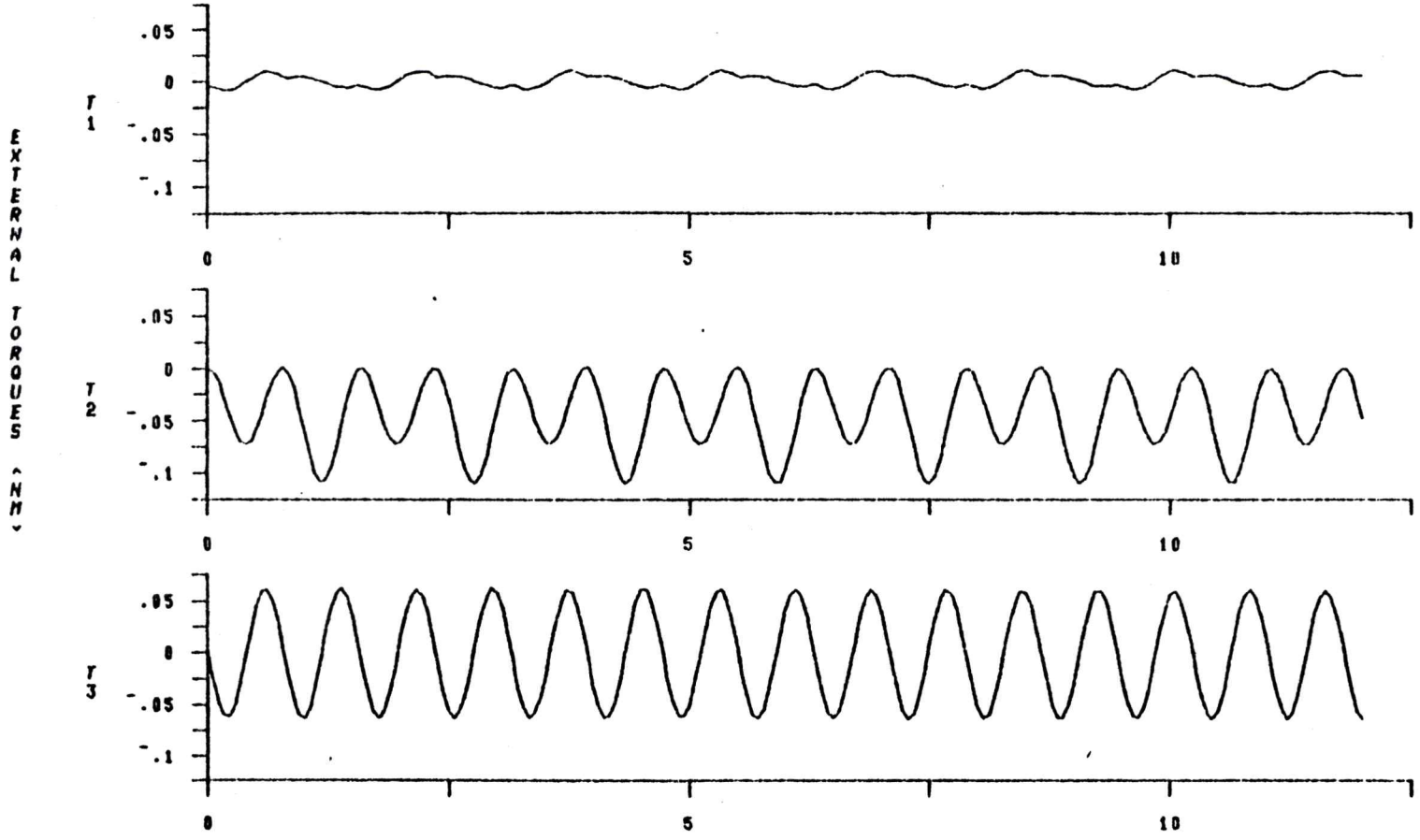
10:45 AM EDT 6/7/83 2330 STSIM

NO RWA OR MAG TORQ FAILURES MODELLED YET

S.T. EXTERNAL TORQUES

CASE NAME: TEST5
INITIAL CONDITIONS:
EPOCH: YEAR=1984, DAY= 1
BODY MOM. (NMS) = .00 .00 .00
MAG. TORQUE GAIN = 750

BODY ORIENTATION (INERTIAL):
RIGHT ASCENSION (DEG) = 90.00
DECLINATION (DEG) = 73.50
ROLL ANGLE (DEG) = .00
SA ANGLE (DEG) = 90.00

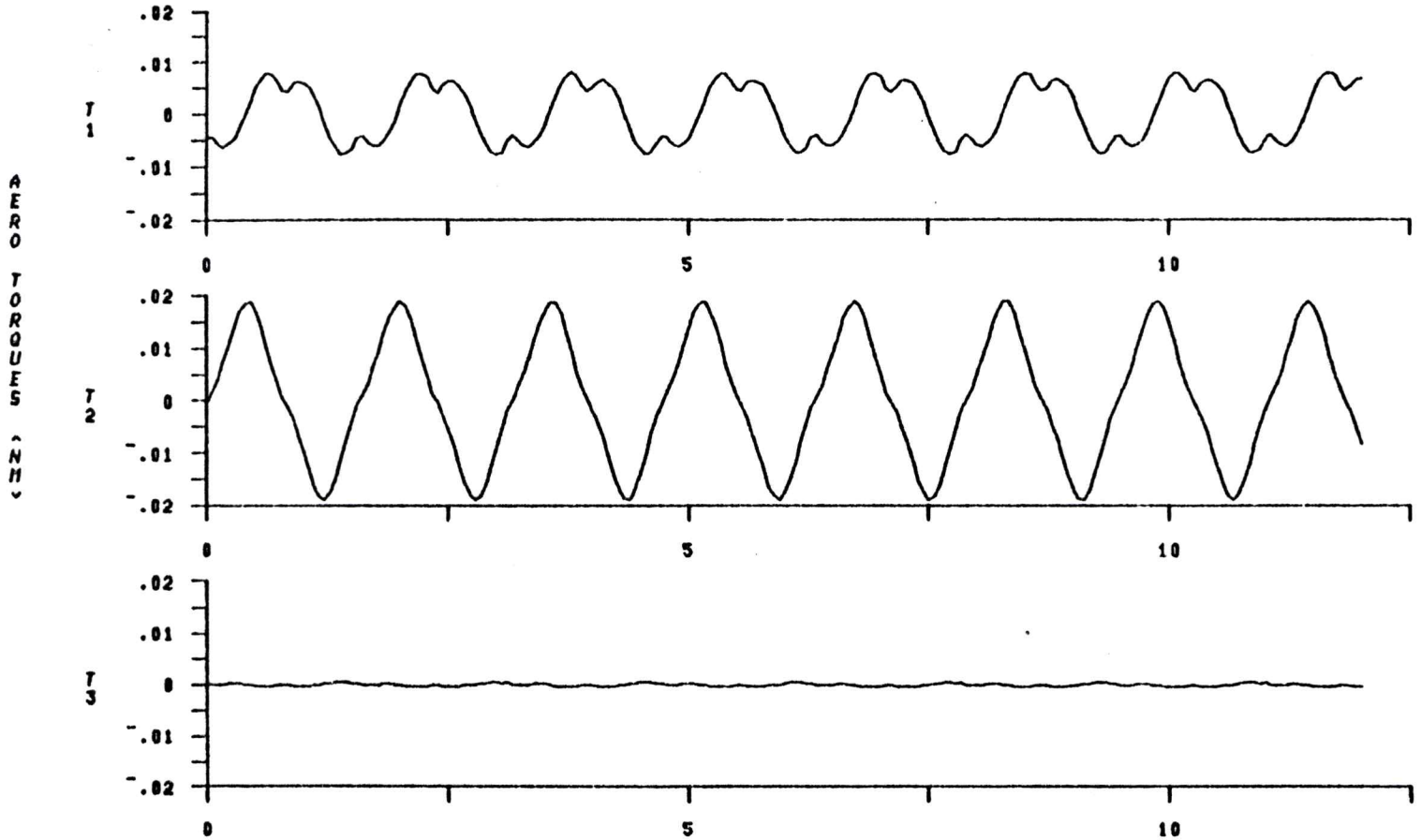


10:48 AM EDT 6/7/83 2330 STSIM

S.T. AERODYNAMIC TORQUES

CASE NAME: TEST5
INITIAL CONDITIONS:
EPOCH: YEAR=1984, DAY= 1
BODY MOM. (NMS) = .08 .08 .08
MAG. TORQUE GAIN = 750

BODY ORIENTATION (INERTIAL):
RIGHT ASCENSION (DEG) = 90.00
DECLINATION (DEG) = 73.58
ROLL ANGLE (DEG) = .00
SA ANGLE (DEG) = 90.00

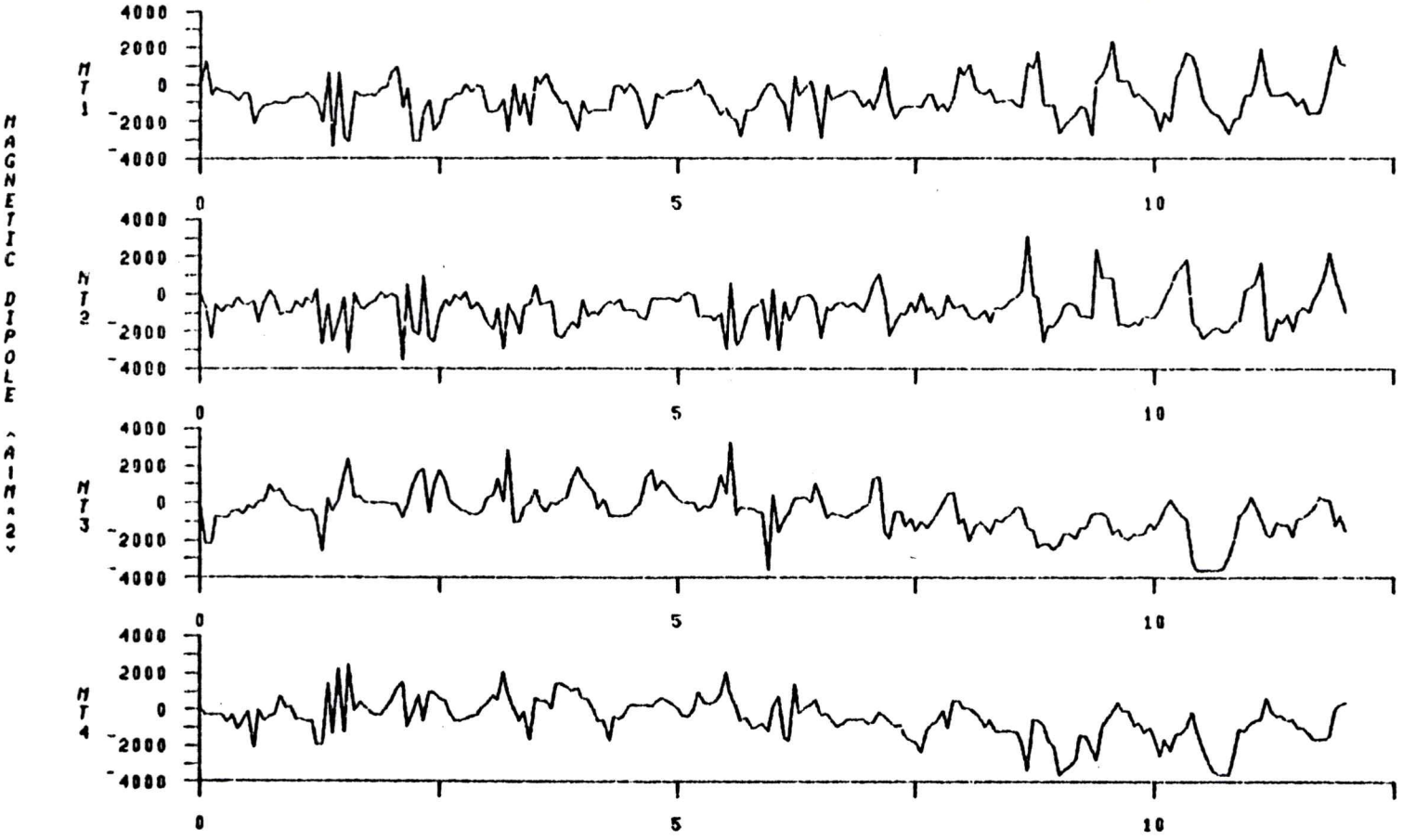


3:52 PM EDT 6/7/83 2330 STSIM

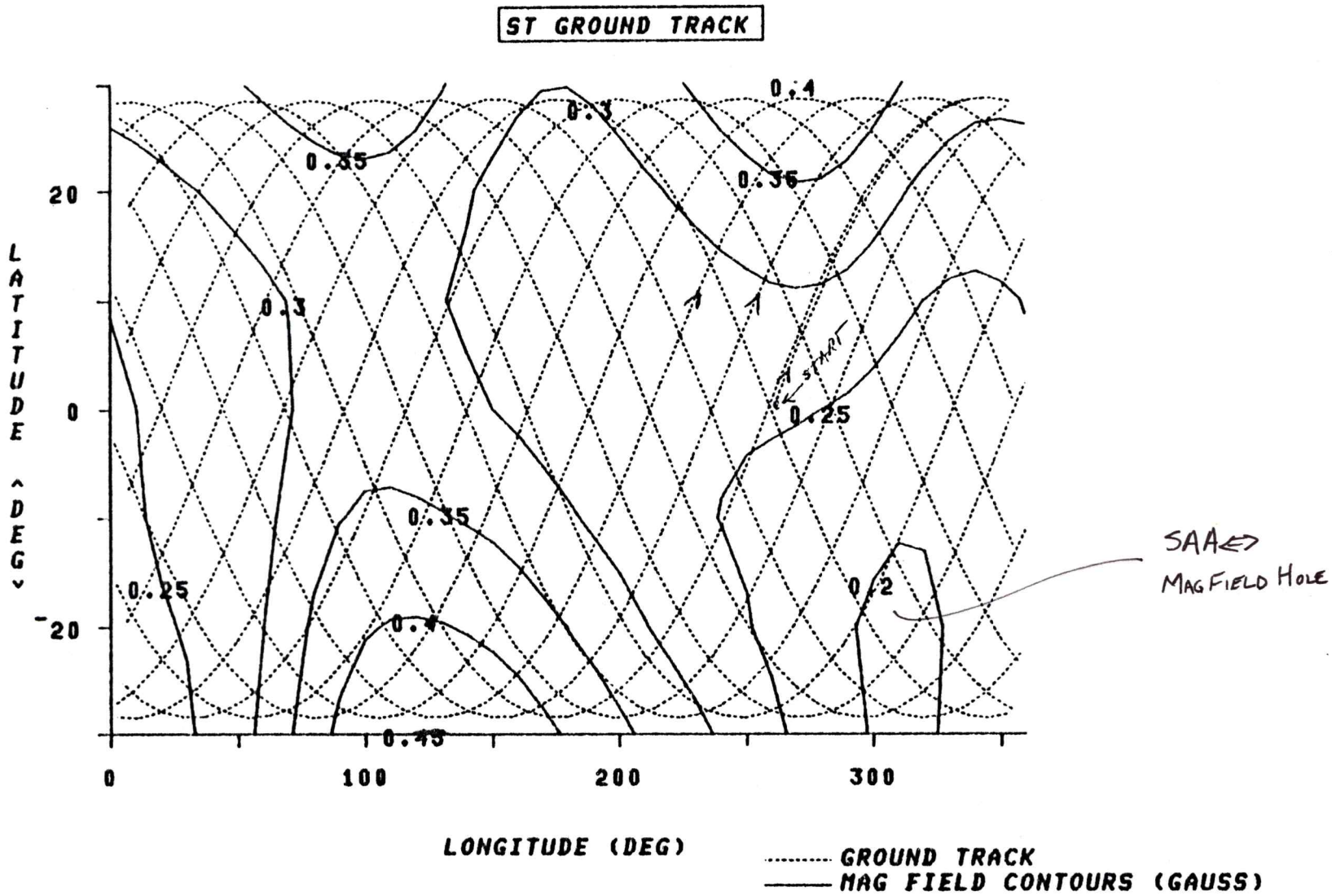
S.T. DIPOLE MOMENT OF MAGNETIC TORQUERS

CASE NAME: TEST5
INITIAL CONDITIONS:
EPOCH: YEAR=1984, DAY= 1
BODY MOM. (NMS) = .00 .00 .00
MAG. TORQUE GAIN = 750

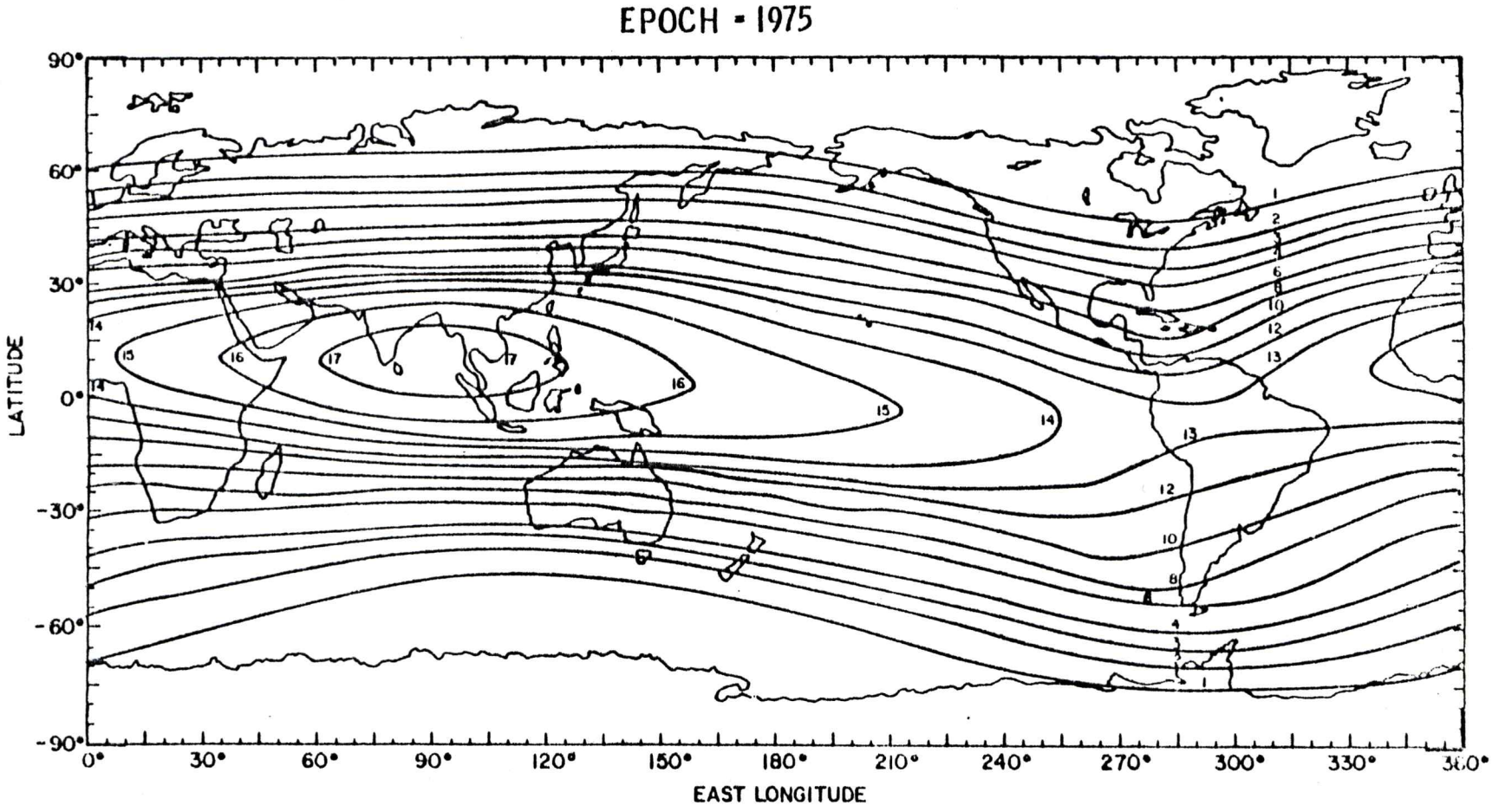
BODY ORIENTATION (INERTIAL):
RIGHT ASCENSION (DEG) = 90.00
DECLINATION (DEG) = 73.50
ROLL ANGLE (DEG) = .00
SA ANGLE (DEG) = 90.00



10:47 AM EDT 6/7/83 2330 STSIM

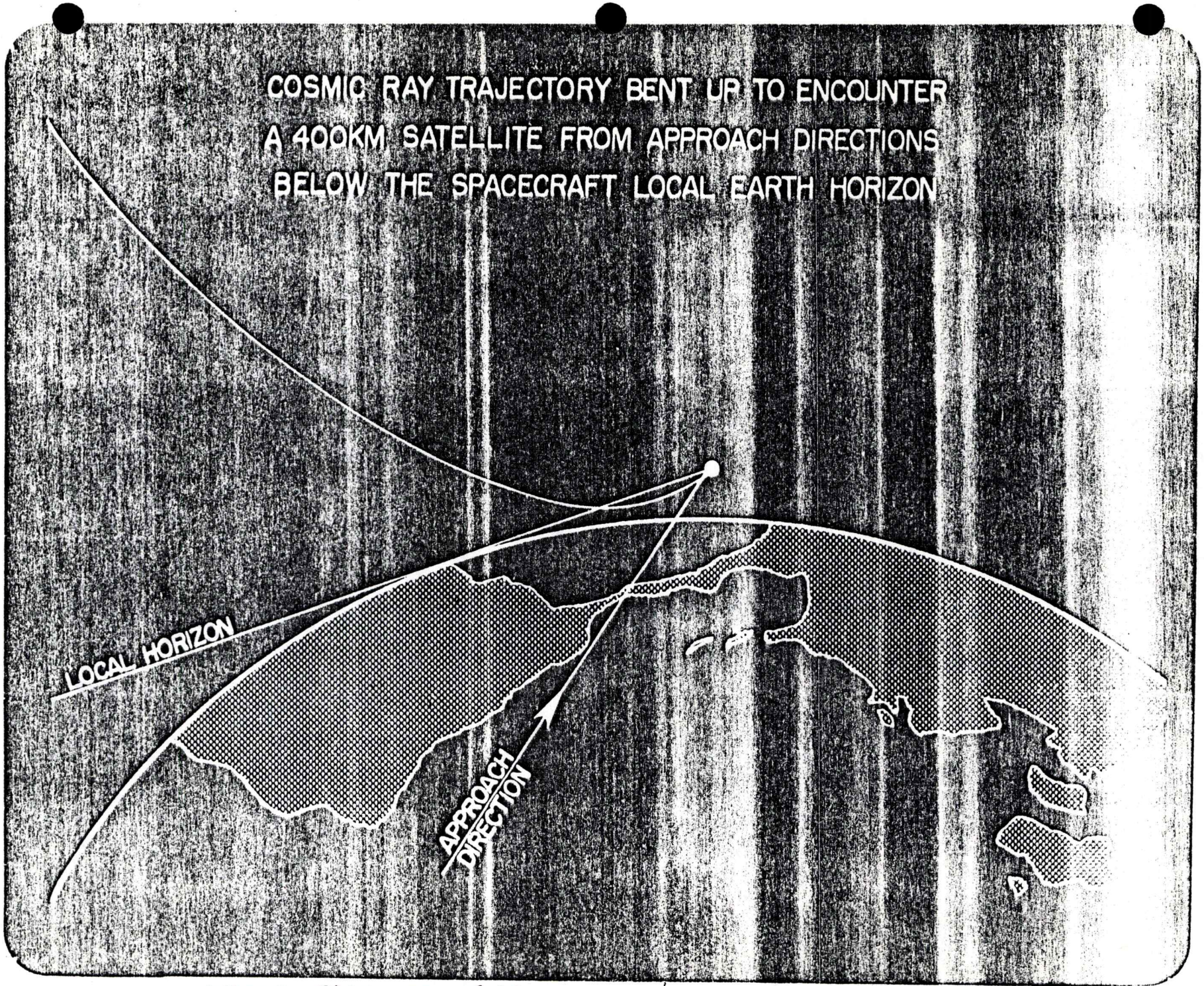


3:35 PM EDT 6/7/83 2544 SCOPE



MINIMUM ENERGY COSMIC RAY ENERGY (GeV) WHICH CAN REACH SURFACE.

Cherenkov
Fluorescence
Direct excitation



CHARGED PARTICLES SPIRAL IN FROM BELOW

COSMIC RAY ACCESS TO A SPACECRAFT

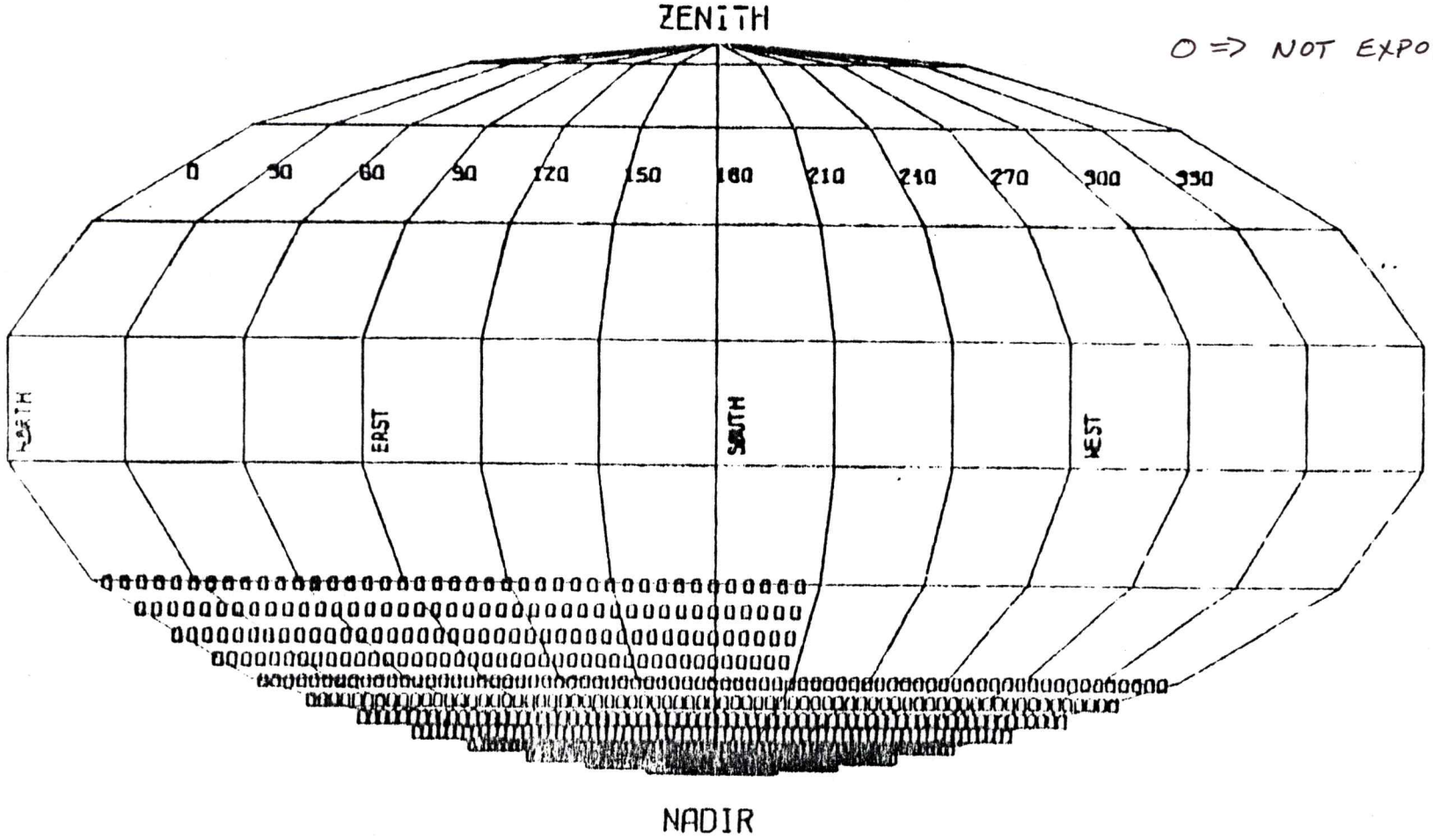
ORTHOGRAPHIC PROJECTION

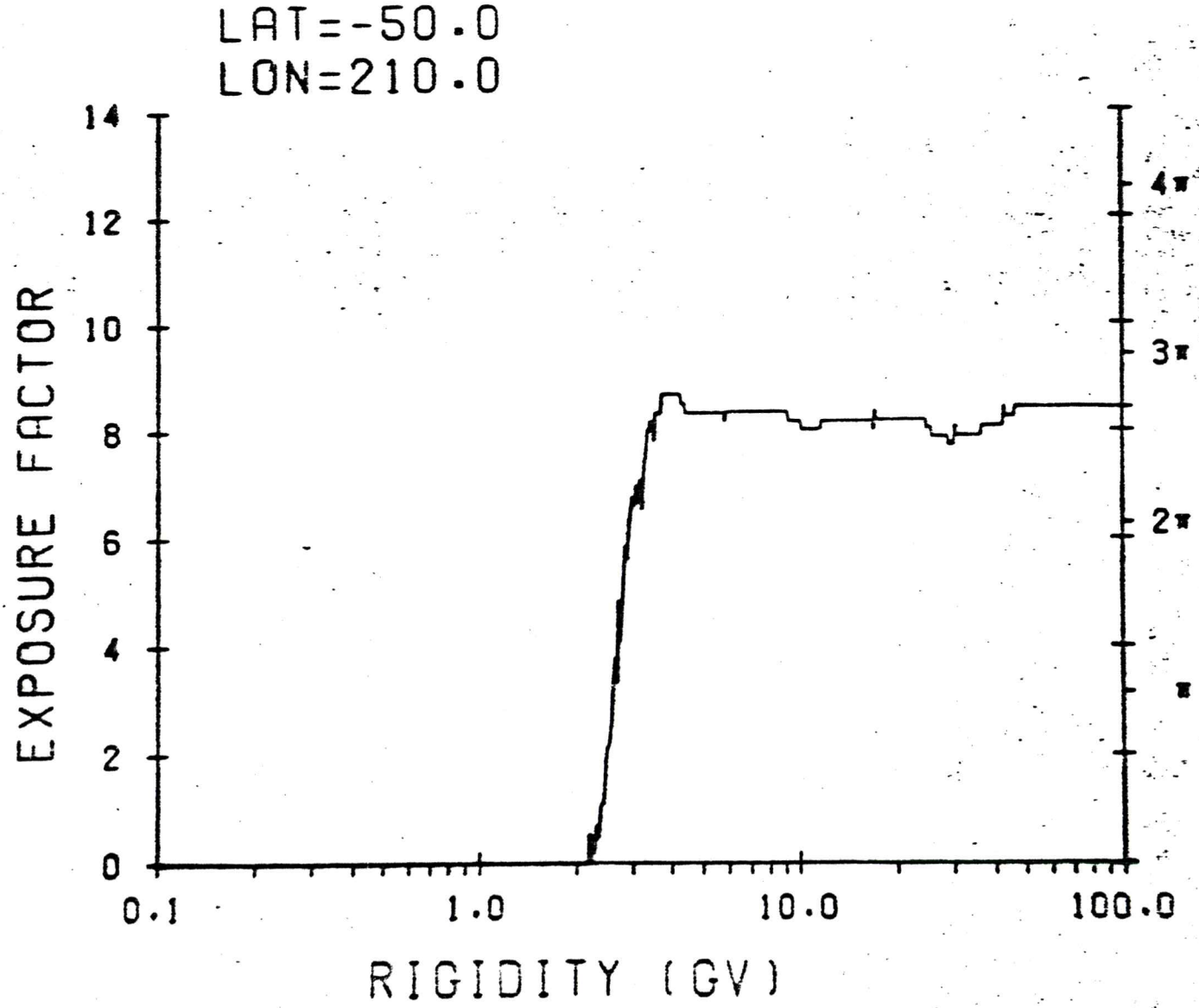
ALT = 400 KM

LAT = -10.

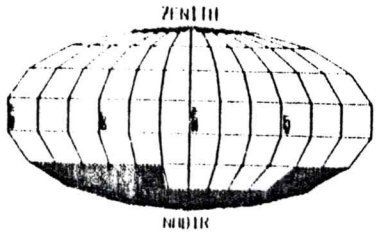
LON = 0.

AT SOME E




LAT=-50.0
LON=210.0
EXPOSURE FACTOR
14
12
10
8
6
4
2
0
4π
3π
2π
π
0.1
1.0
10.0
100.0
RIGIDITY (GV)

LAT = 40. LØN = 0.



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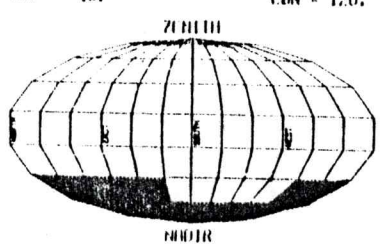

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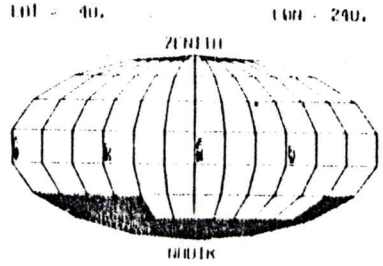

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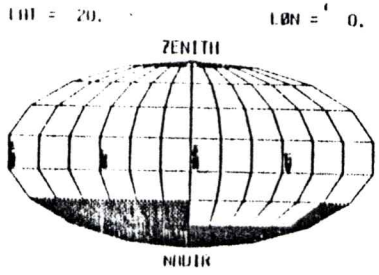
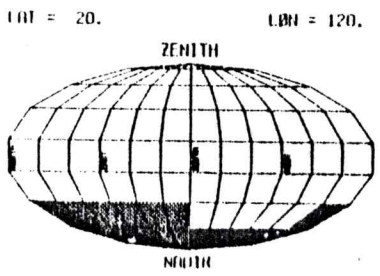
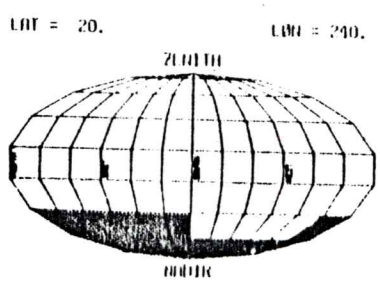


LAT = 20. LØN = 120.



LAT = 20. LØN = 240.



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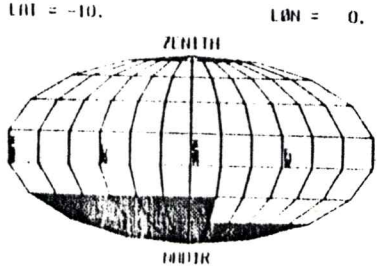
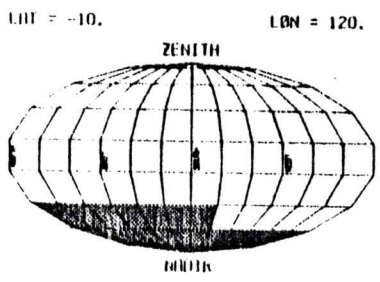
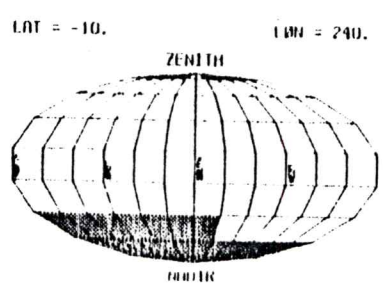


LAT = -10. LØN = 120.



LAT = -10. LØN = 240.



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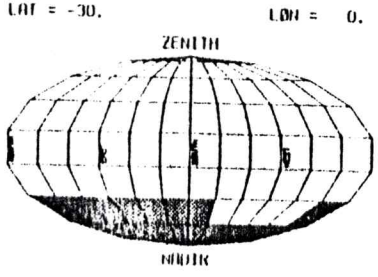
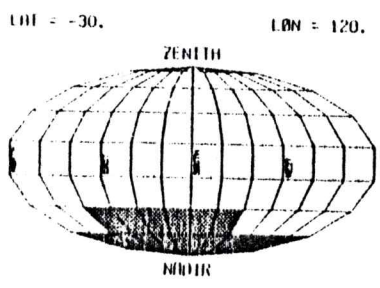
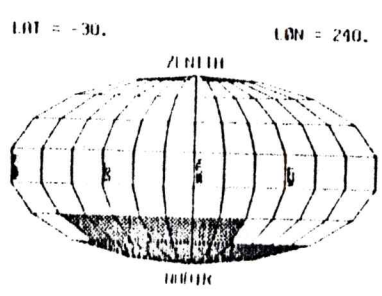
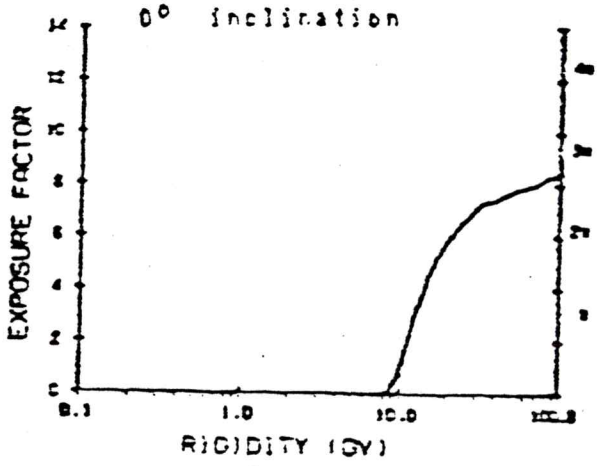


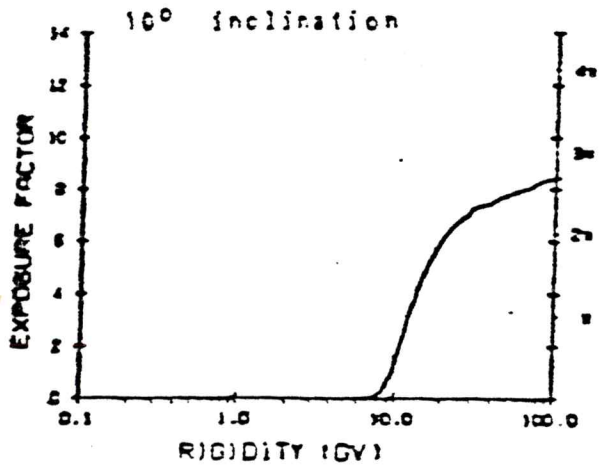
LAT = -30. LØN = 120.

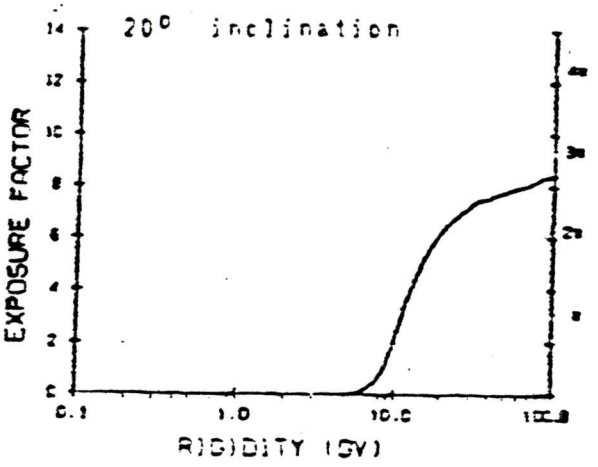


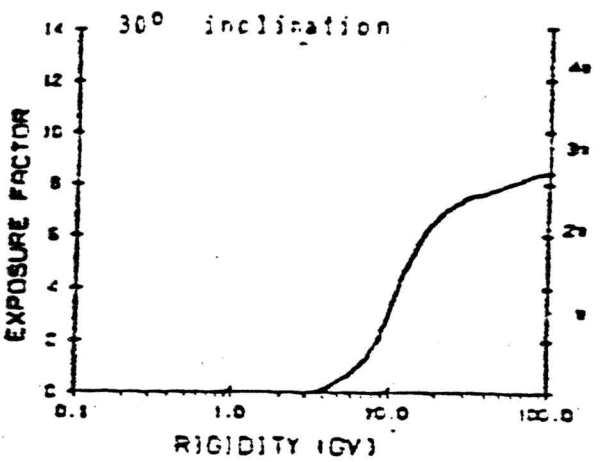
LAT = -30. LØN = 240.

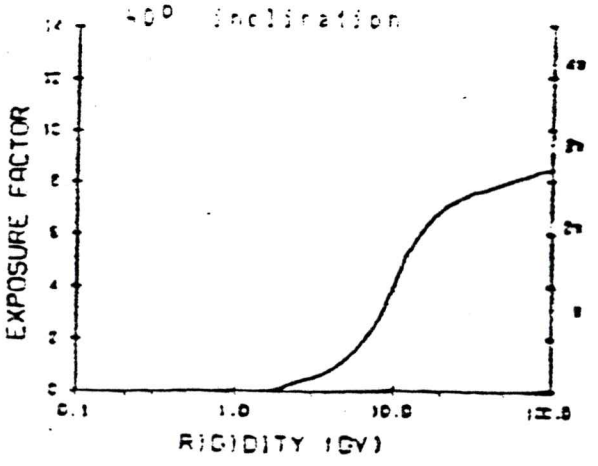


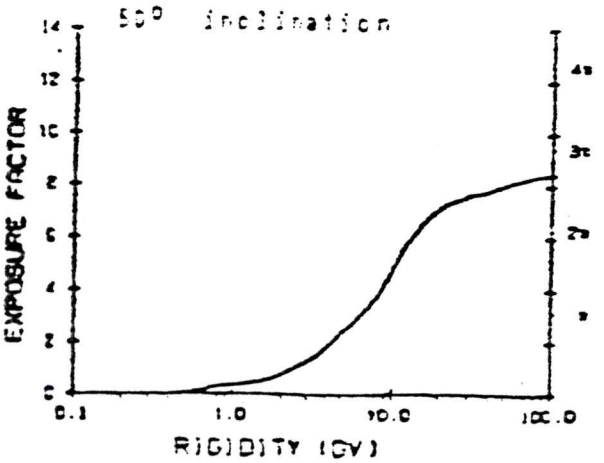

0° inclination
EXPOSURE FACTOR
RIGIDITY (GV)

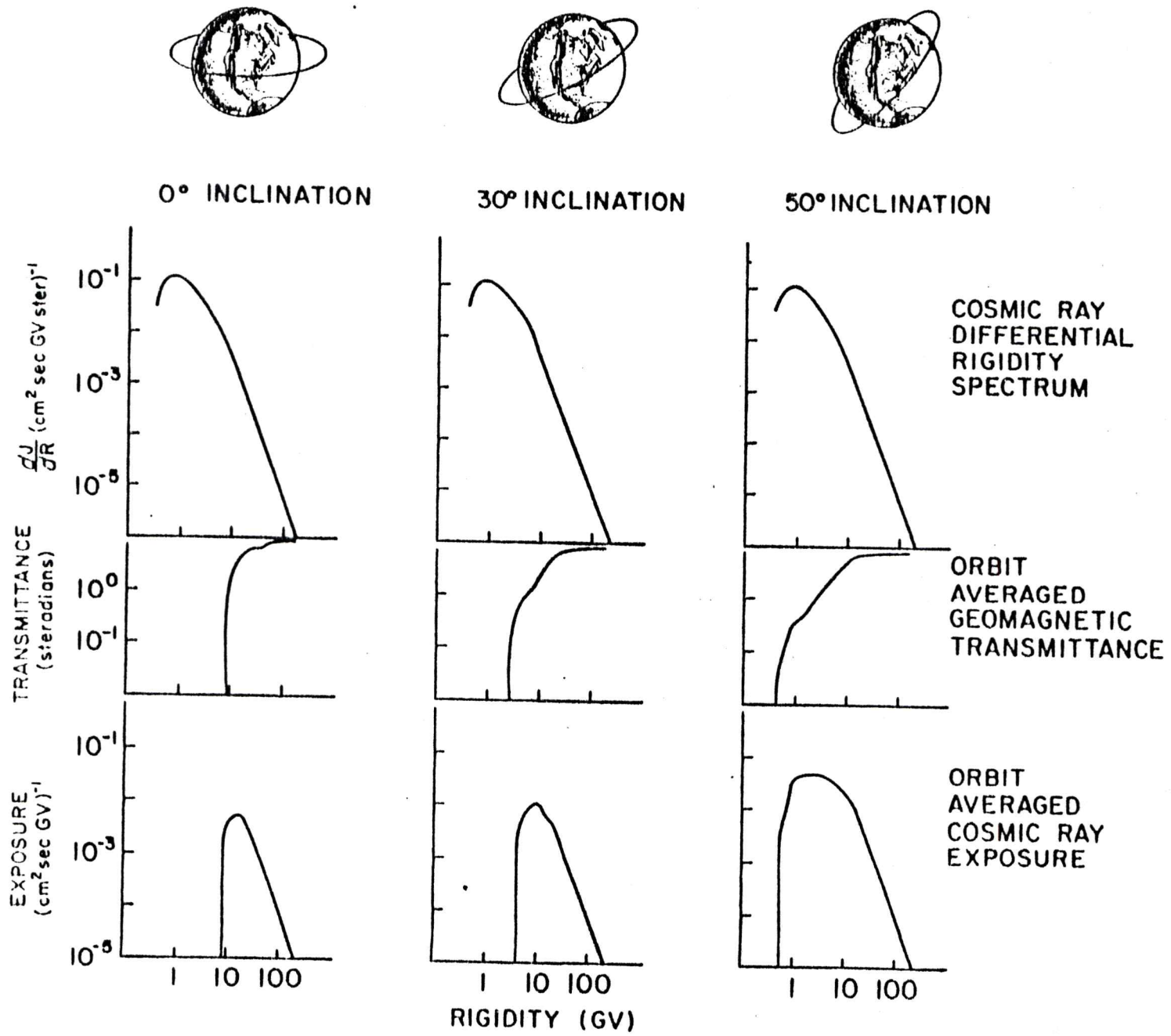

10° inclination
EXPOSURE FACTOR
RIGIDITY (GV)


20° inclination
EXPOSURE FACTOR
RIGIDITY (GV)


30° inclination
EXPOSURE FACTOR
RIGIDITY (GV)

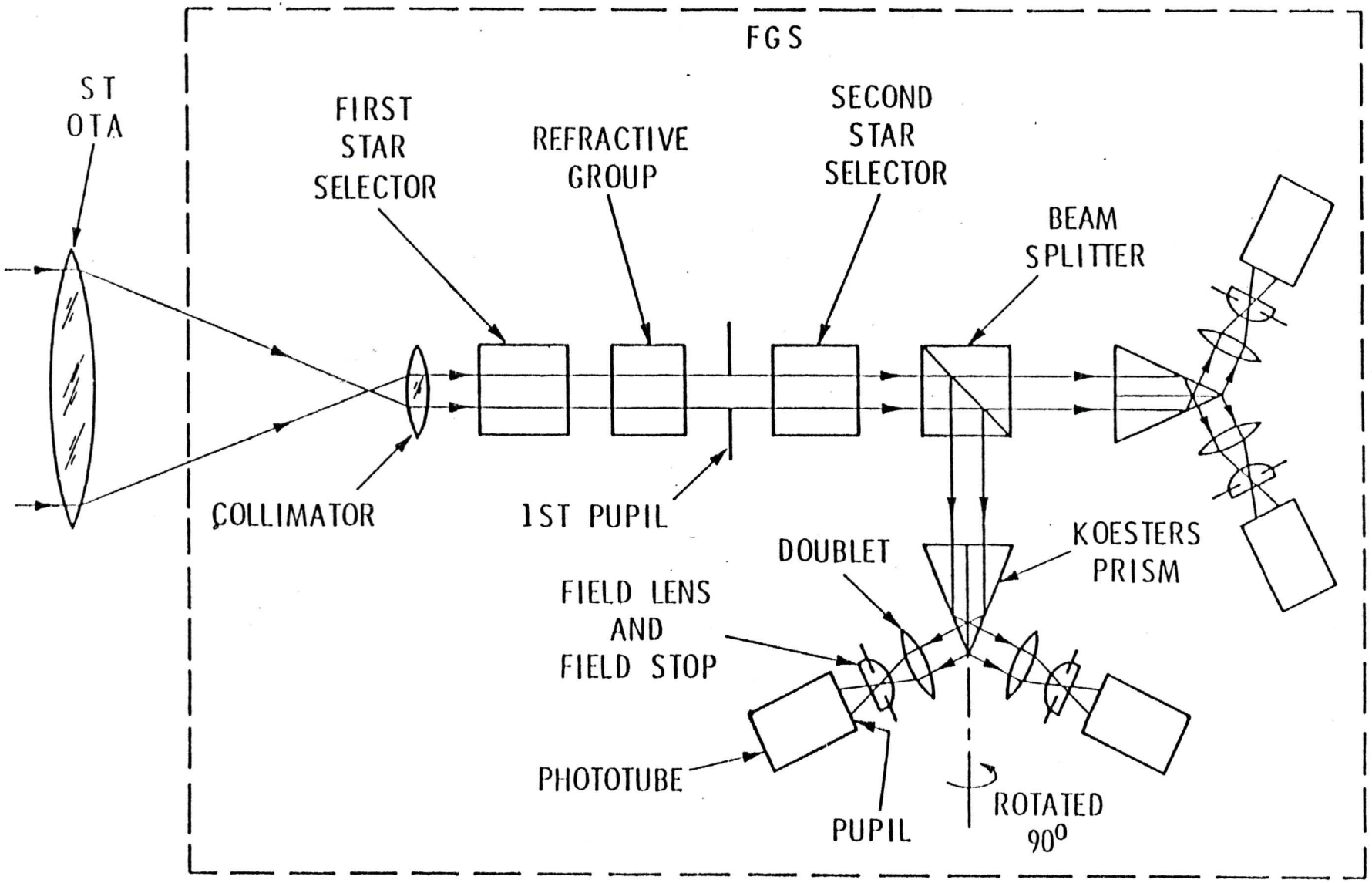

40° inclination
EXPOSURE FACTOR
RIGIDITY (GV)


50° inclination
EXPOSURE FACTOR
RIGIDITY (GV)



$J \propto \frac{\cos^4(\lambda_{MAG})}{r^2}$ (?)

SIMPLIFIED FGS OPTICAL SCHEMATIC



PCS Computer Review

- PCS required to have at least 20% memory and execution time margin for on orbit changes
- 71.4% execution time used (Jan 83)
- 86.9% memory used (Jan 83) <u>exceeds spec</u>
- Memory margin solutions being investigated:
  - Remove functions
  - Use spare memory board
  - Add external storage

PCS Computer Review

- PCS/FGS Interface has growth potential
- Spare command slots already allocated
  - 4 all commandable every 25ms period
  - 11 one commandable per 25ms period
- No spare data slots allocated
- PCS & FGS hardware capable of supporting 16 additional data words every 25ms

FGE Review

- No specification for FGE memory margins (Firmware prohibits on orbit changes)

- FGE memory used:
  - 44% 1802 program
  - 53% 1802 data
  - 64.2% 2900 program
  - 70.0% 2900 8 bit data
  - 95.3% 2900 24 bit data

- Shortage of spare 24 bit data memory locations may hamper future changes

FGE Review

- No specification for FGE execution time margin (Firmware prohibits on orbit changes)
- FGE 2900 execution time is mode dependent:
  - 13.0% SSM
  - 13.2% Fine mode
  - 13.4% Fine lock (no FEA start)
  - 18.0% LOS
  - 18.4% Fine lock
  - 20.8% LOS (turns)
  - 22.8% Search
  - 31.6% Coarse track
- FGE 2900 is thermal limited at ??%
- Growth to 31.6% in any mode without thermal risk

FGE Review

- FGE 2900 processor is power cycled at 40 Hz due to thermal dissipation limit

- 6.3 Billion power cycles in 5 years

- Power cycling may lead to failure
  - Needs further investigation
  - Electromigration ?

FGE Review

- No specification for FGE radiation susceptibility
- No radiation hardened devices currently in FGE
- Preliminary review – Identify
- Further study – Analyze

FGE Review

- FGE soft errors
  - Probabilistic events
  - Device variations
  - Effects are location dependent
  - No permanent damage
- Potential soft error prone devices:
  - 93L422 Bipolar RAM
  - 2901B Bipolar ALU — NOT MUCH EFFECT, IT'S USUALLY OFF!
  - 6551 CMOS RAM (heavy ions)
  - 4000 series CMOS logic (heavy ions)
  - TTL Bipolar logic (heavy ions)
- Potential solutions:
  - Less susceptible devices
  - Immune devices
  - Error detection/correction
  - Operational

FGE Review

- FGE latchups
  - Probabilistic events
  - Device variations
  - Permanent damage

- Potential latchup prone devices:
  - 6551 CMOS RAM (heavy ions)
  - 6611 CMOS PROM (heavy ions)

- Potential solutions:
  - Immune parts
  - External device protection

FGE Review

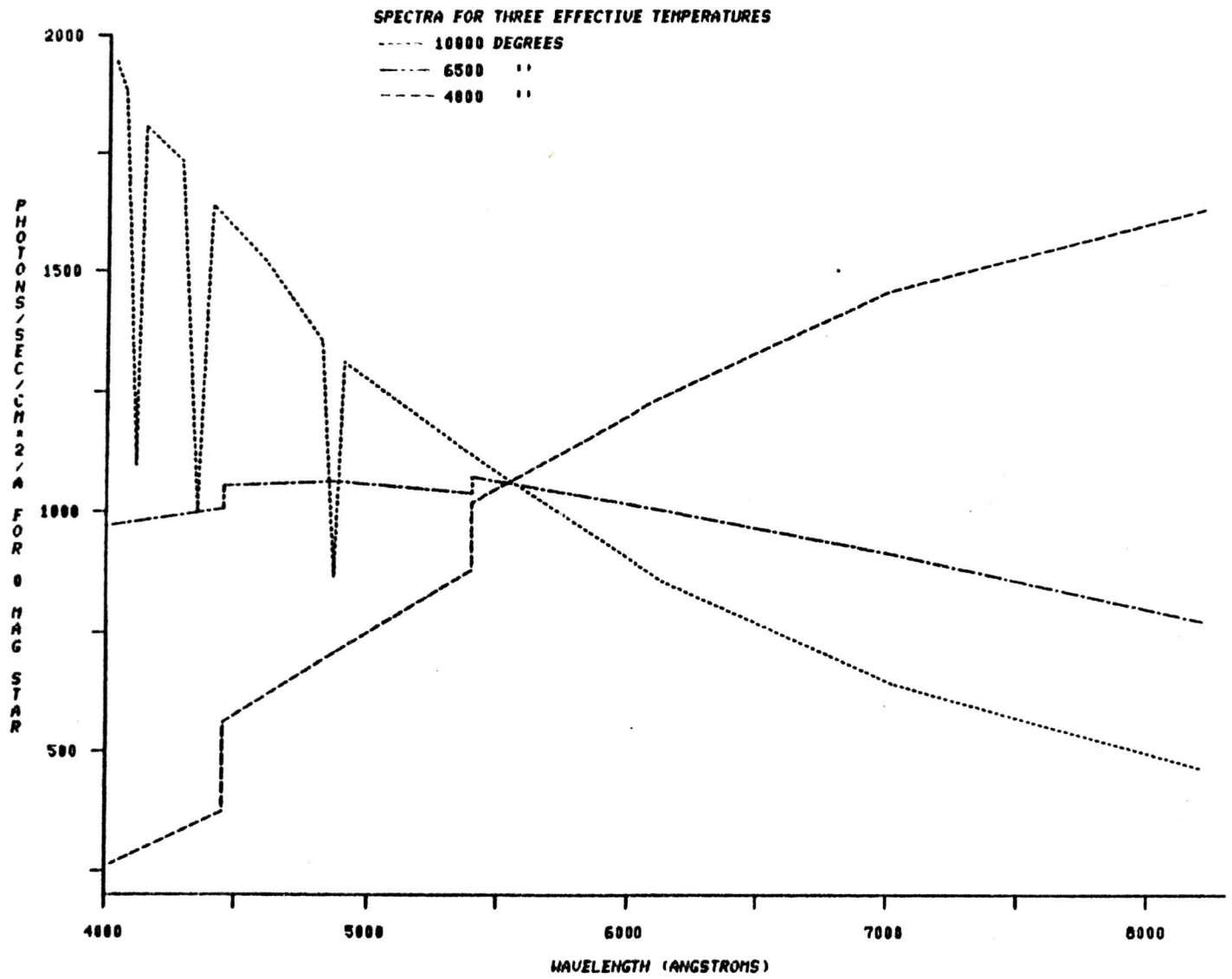
- FGE total radiation dose
  - Device variation
  - Degradation building to failure
  - Permanent damage

- Expect 1.8K Rad over 5 years with shielding

MAY REPRESENT AN EARLY ESTIMATED LAUNCH DATE → SOLAR CYCLE PROBLEM.

- Potential total dose prone devices:
  - 6551 CMOS RAM (less than 6K Rad)
  - 1802 CMOS microprocessor (as low as 1.3K Rad)
  - 4000 series CMOS logic (as low as 7K Rad)

- A solution is to use radiation hardened devices


SPECTRA FOR THREE EFFECTIVE TEMPERATURES
10000 DEGREES
6500 ''
4000 ''
2000
1500
1000
500
PHOTONS/SEC/CM**2/A FOR 0 MAG STAR
4000
5000
6000
7000
8000
WAVELENGTH (ANGSTROMS)

APL PROGRAM
ALTERNATE SENSOR CONCEPTS

TECHNOLOGY	RESOURCE
OPTICAL IMAGE SPLITTER	JHU – W. FASTIE PERKIN-ELMER – R. JONES, S. KUMPAN ITEK – C. MORSER
QUADRANT DETECTOR	SAI – R. GINEVAN
IMAGE DISSECTORS	ITT – L. WUELLNER
SOLID STATE SCANNED ARRAYS	BALL AEROSPACE – R. CLEAVINGER JPL – R. STANTON
SIGNAL PROCESSING	APL – K. STROHBEHN

APL PROGRAM
ALTERNATE SENSOR CONFIGURATION

GUIDE STAR IMAGE SENSORS

- DO NOT DEPEND ON KOESTERS PRISMS
- REQUIRE FORMATION OF NEAR DIFFRACTION LIMITED STAR IMAGE

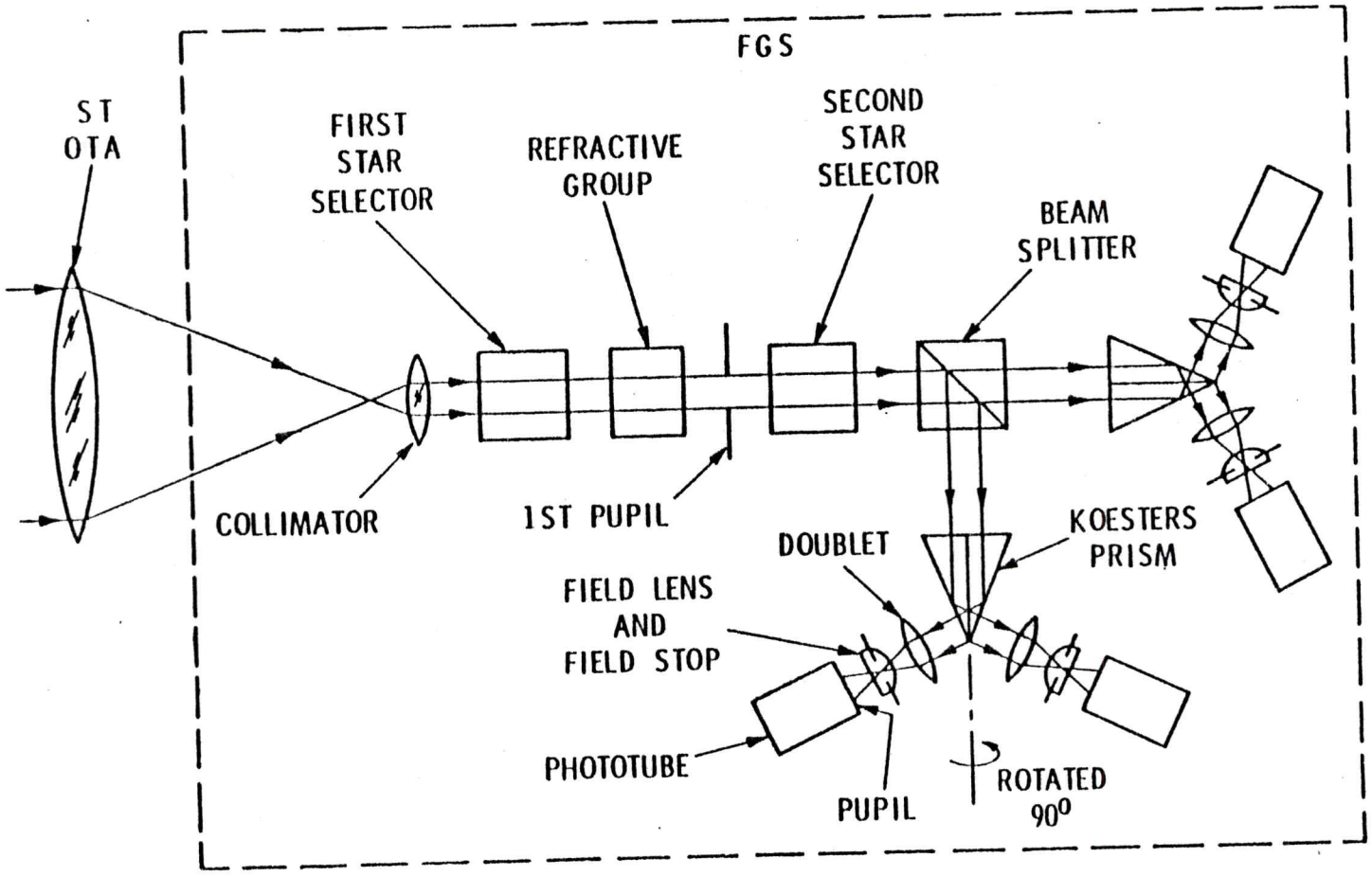
TECHNOLOGY	CONFIGURATION
OPTICAL IMAGE SPLITTER	IMAGE FGS FIELD OF VIEW ONTO QUADSPLITTER. USE EXISTING PMT's. PROCESS FOR ACQUISITION AND FINE LOCK
QUADRANT DETECTORS	IMAGE FGS FIELD OF VIEW ONTO DIGICON QUAD DETECTOR. USE EXTENDED QUAD RING TO FACILITATE ACQUISITION. PROCESS FOR ACQUISITION AND FINE LOCK
HYBRID OPTICAL SPLITTER, QUADRANT DETECTOR	IMAGE FGS FIELD OF VIEW ON QUAD SPLITTER WHICH IS MOUNTED ON A QUAD DETECTOR DIGICON. PROCESS FOR ACQUISITION AND FINE LOCK
IMAGE DISSECTOR	IMAGE FGS FIELD OF VIEW ONTO IMAGE DISSECTOR. SCAN FIELD OF VIEW OVER APERTURE FOR ACQUISITION. DO FINE LOCK IN ACQUISITION WINDOW
CCD, CID ENHANCED CID	IMAGE FGS FIELD OF VIEW ONTO ARRAY. PROCESS FOR ACQUISITION AND FINE LOCK

APL PROGRAM
ALTERNATE SENSOR CONFIGURATION

INTERFEROMETER ENHANCEMENT

- DOES NOT DISTURB KOESTERS PRISMS
- MAINTAINS ACCURACY WHILE DIMINISHING PROBABILITY OF LOSS OF LOCK

TECHNOLOGY	CONFIGURATION
HYBRID TWO-CHANNEL OPTICAL SPLITTER, TWO-CHANNEL DIGICON	USE LIGHT EXITING KOESTERS PRISMS AND FORM IMAGES. REPLACE PMT's WITH SPLIT-FACE DIGICONS, AXIS NORMAL TO KOESTERS PRISM AXIS. SYNTHESIZE QUAD DETECTOR AND USE AS CATCH BASIN IN ALTERNATE AXIS
SIGNAL PROCESSING	OPTIMAL FILTERING



Simplified FGS Optical Schematic

Space Telescope Alternate Sensors

Image Splitters

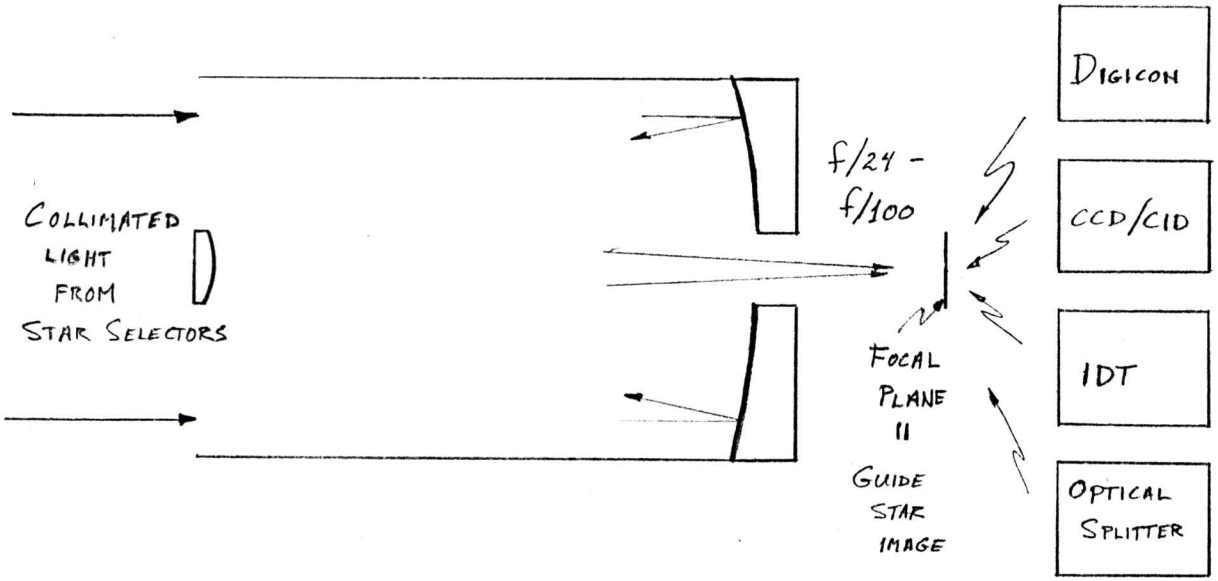
- Optical Splitters
- Digicon with quadrant diode array
- Image dissector tube
- CCD / CID array
- Combination devices

Interferometer Modifications

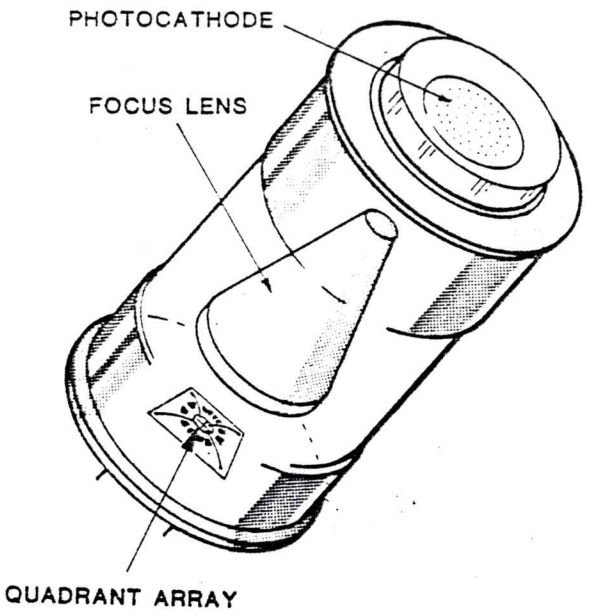
- Interferometer output imaged onto Digicon

NATIONAL
42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE

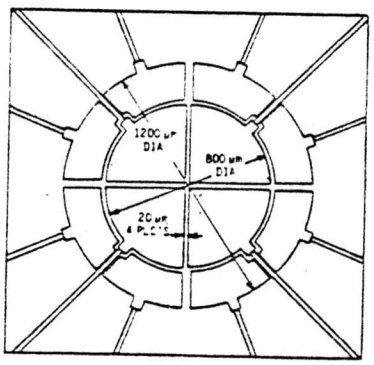
ALTERNATE SENSORS



QUADRANT DIGICON



UNENCAPSULATED VIEW



QUADRANT ARRAY
CONFIGURATION

Space Telescope Alternate Sensors

Digicon

- Flexible diode array geometry
- Low dark noise
- S–20 photocathode
- Simple operation / stable / small size
- Excellent single photon detection
- Space qualified
- High–voltage supply (15 kV) not a problem

Digicon – Disadvantages

Some light lost in "gaps" between diodes

Dynamic range is limited

Beam spread from cathode to diode (12 microns)

SPACE TELESCOPE FGS

Component Weight & Power Estimate

Quadrant Digicon

Size	2" d x 3"
Weight	4 lb. (with mount)

HVPS

Size	3-1/4" x 4-1/2" x 3"
Weight	3 lb.
Power	300 mw

Charge Amplifier Assembly

Size	2" d x 2"
Weight	1 lb.
Power	200 mw

Signal Processer

Size	5 " x 3" x 3"
Weight	5 lb.
Power	300 mw

LVPS

Size	3-1/4" x 4-1/2" x 2"
Weight	3 lb.
Power	

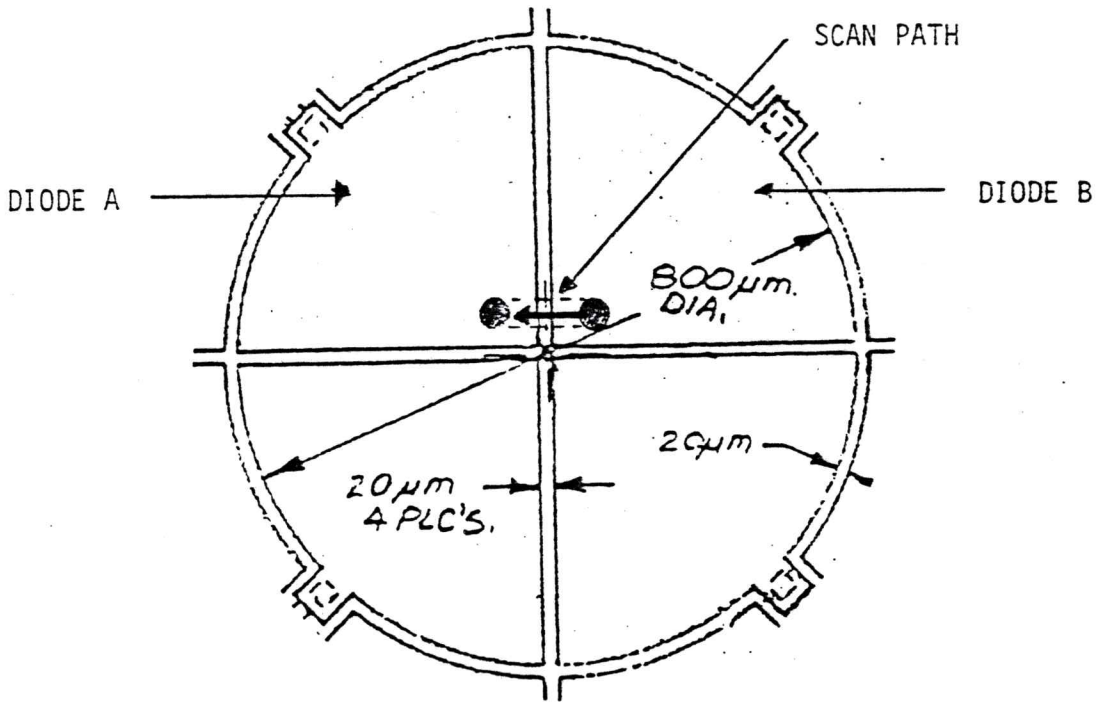
Microprocesser

Size	5" x 8" x 4"
Weight	7 lb.
Power	7 watt

TOTAL

Power	<9 watt, 28 VDC
Weight (Components)	<20 lb.

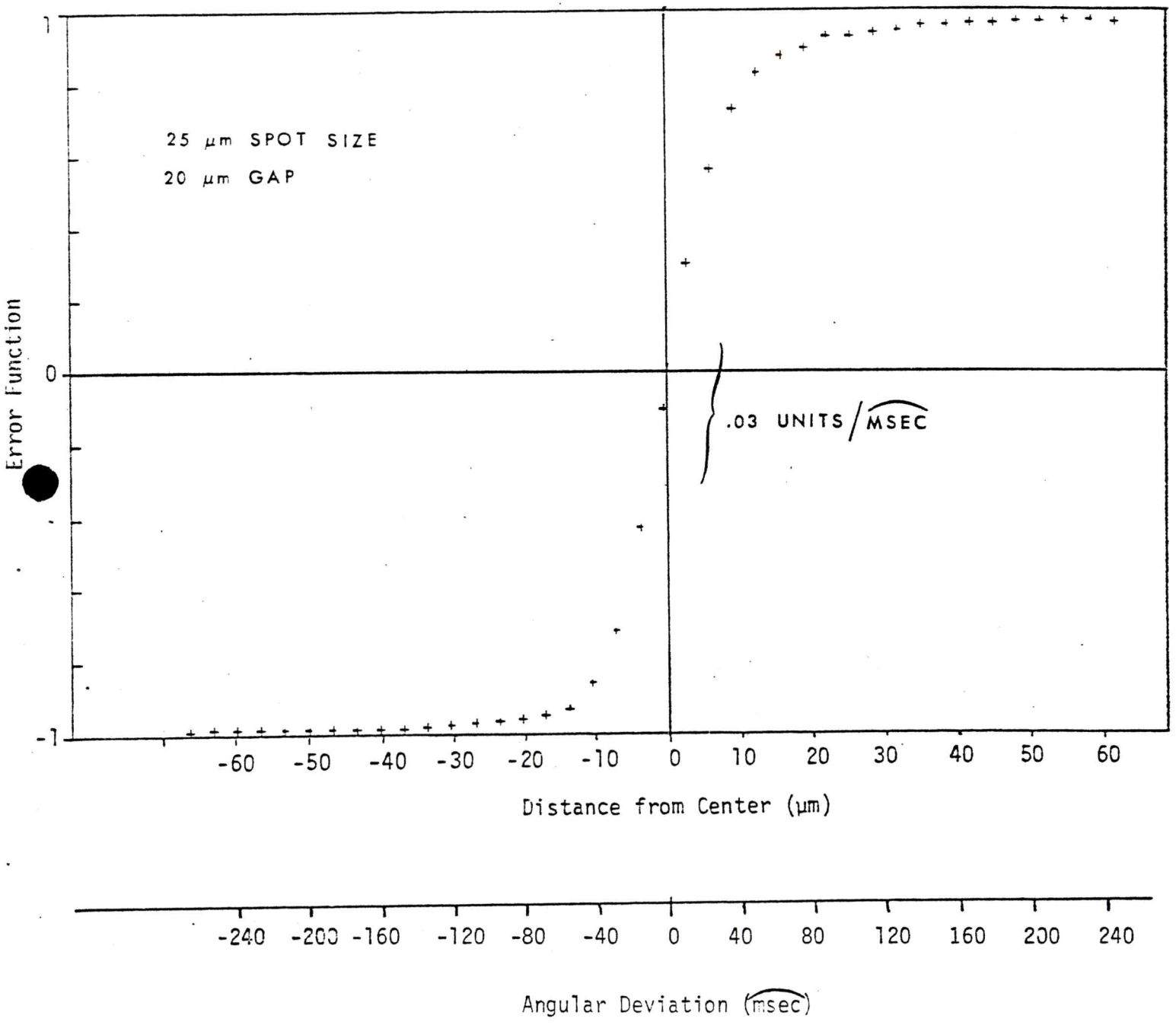
QUAD TUBE SCAN GEOMETRY



SPOT DIAMETER APPROXIMATELY 25 µm.

ELECTRONIC VISION & SYSTEMS DIVISION

QUAD TUBE SCAN—ERROR FUNCTION (A-B)/(A+B)



NATIONAL
42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE

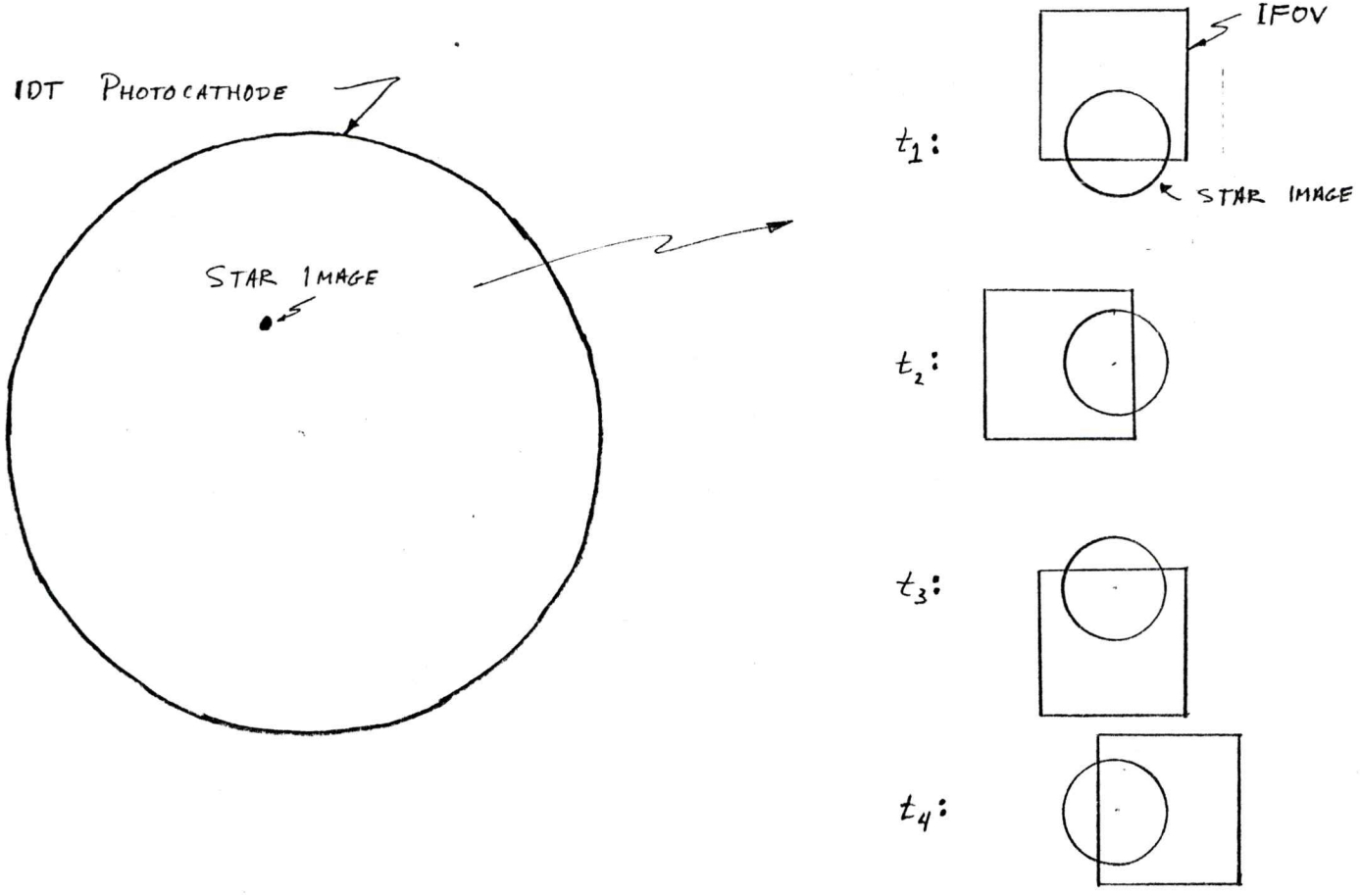


IMAGE DISSECTOR TUBE

Space Telescope Alternate Sensors

Image Dissector Tube

- Proven design and extensive flight experience
- Low noise – no cooling required
- Large dynamic range
- S–20 photocathode
- Random access of any photocathode area

Space Telescope Alternate Sensors

Image Dissector Tube – Disadvantages

Low efficiency (non–integrating)

Acquisition complicated and/or time consuming

Extensive electronics required

NATIONAL
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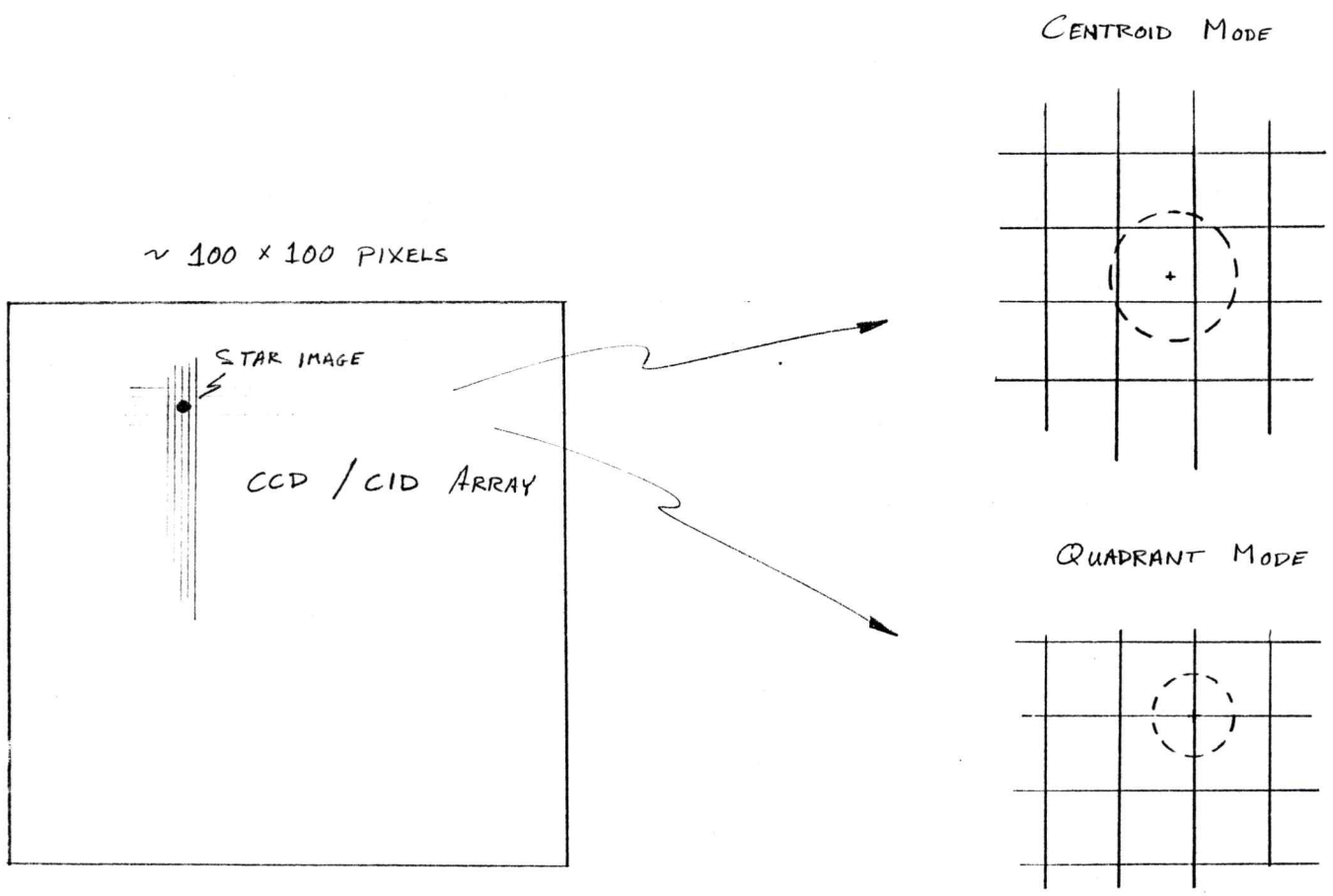
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE



CCD / CID CONCEPT

Space Telescope Alternate Sensors

CCD / CID Arrays

- Integrating devices
- Good quantum efficiency
- Compute image centroid or use quadrant mode
- Random access (CID)
- Non-destructive readout (CID)

Space Telescope Alternate Sensors

CCD / CID Arrays – Disadvantages

- Large dark noise and/or readout noise
- Extensive circuitry required
- New technology – not space qualified

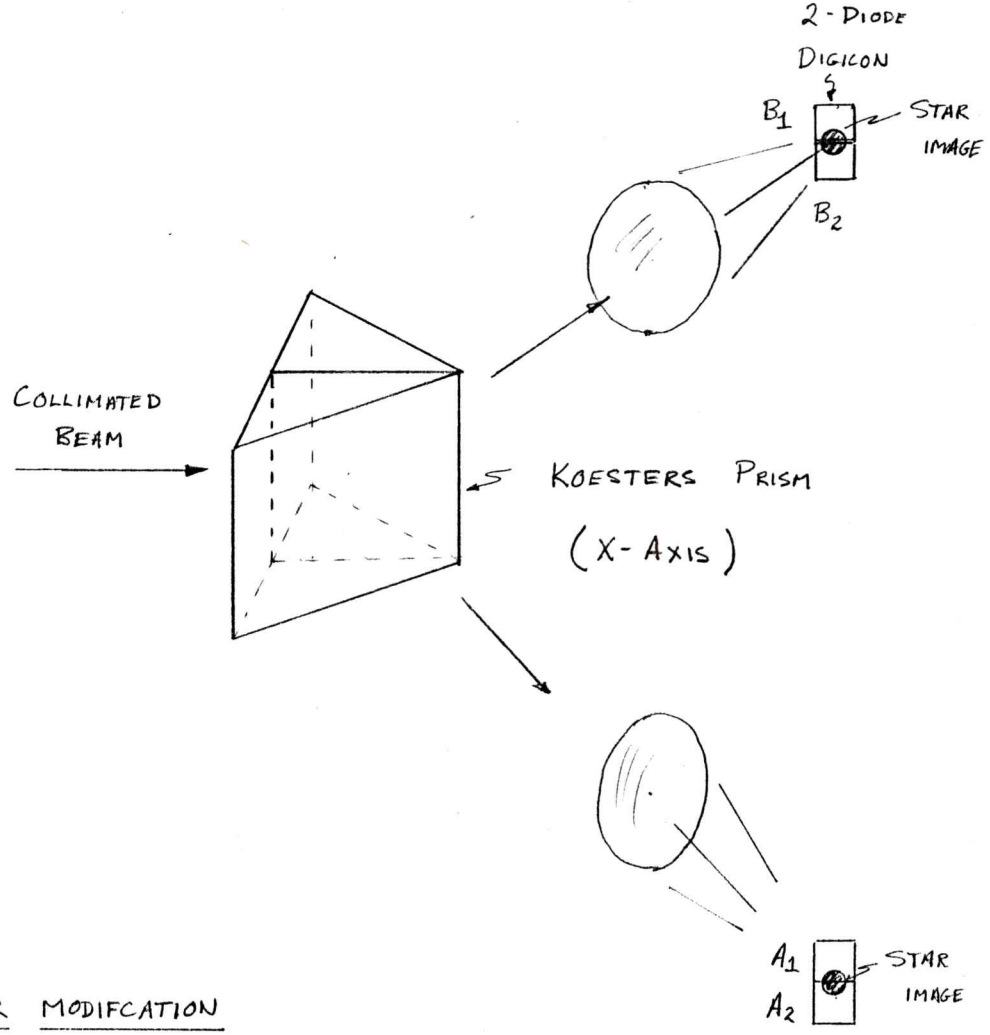
NATIONAL | 42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
Made in U.S.A.

X AXIS FINE ERROR SIGNAL =

$$= \frac{(A_1 + A_2) - (B_1 + B_2)}{(A_1 + A_2) + (B_1 + B_2)}$$

Y AXIS COARSE ERROR SIGNAL =

$$= \frac{(A_1 + B_1) - (A_2 + B_2)}{(A_1 + B_1) + (A_2 + B_2)}$$



INTERFEROMETER MODIFCATION

Space Telescope Alternate Sensors

Interferometer Output Imaged onto Digicon

Maintains most of existing hardware

Maintains interferometer tranfer function

No loss of lock problem

Space Telescope Alternate Sensors

Interferometer Output Imaged onto Digicon–

Disadvantages

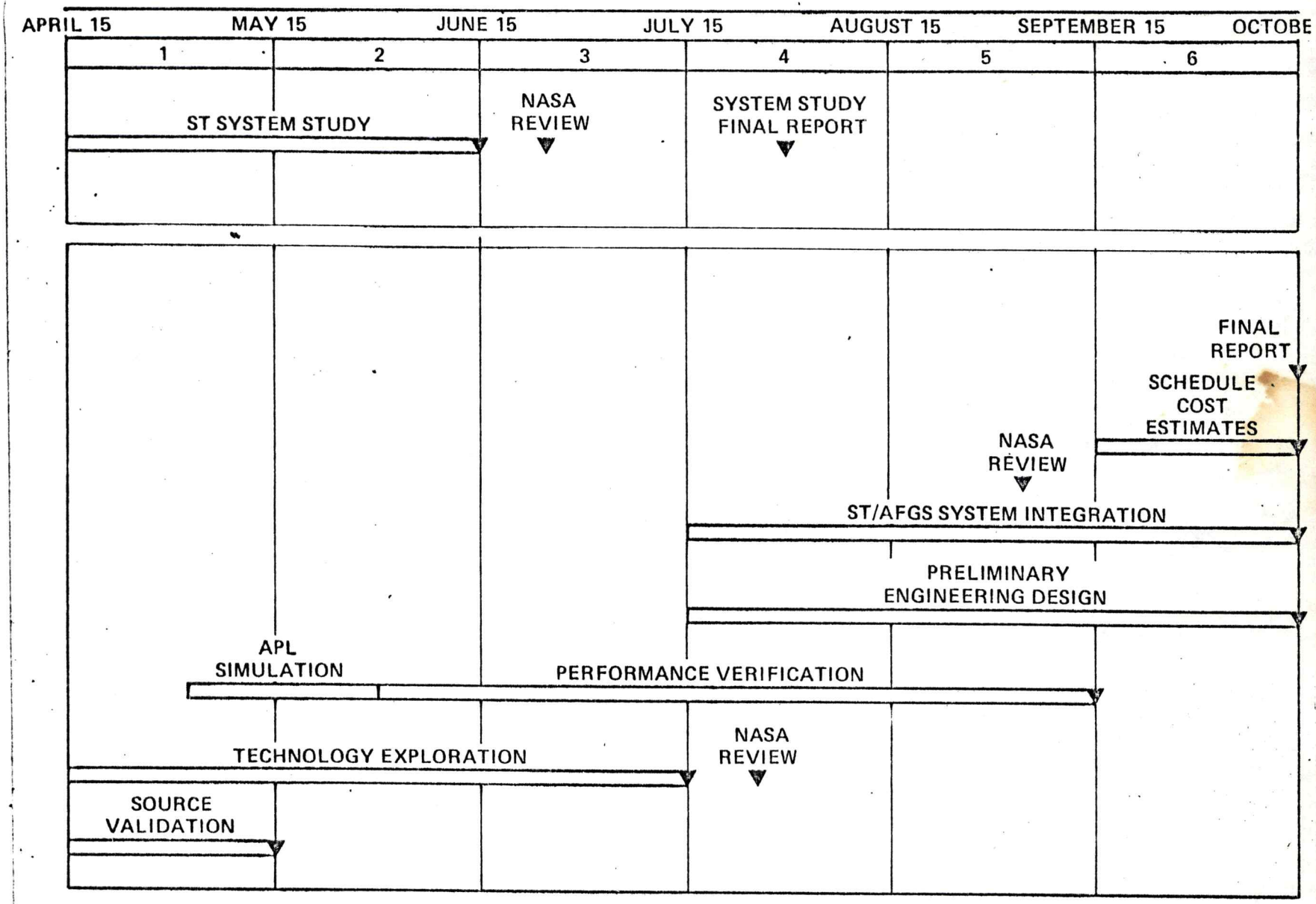
Complicated design

Alignment of optics is critical

APL PROGRAM SUMMARY

- ST SYSTEM STUDY ESSENTIALLY COMPLETED, FINAL REPORT PUBLISHED IN JULY 1983
  - COSMIC RAYS
  - ENVIRONMENTAL TORQUES
  - CONTROLS CONFIGURATION DEFINITION
  - OPTICS
- SENSOR EVALUATION WILL FOCUS ON
  - DIGICON QUADRANT DETECTOR
  - OPTICAL SPLITTERS
  - HYBRID CONFIGURATIONS
  - SIGNAL PROCESSING

APL PROGRAM


APRIL 15
MAY 15
JUNE 15
JULY 15
AUGUST 15
SEPTEMBER 15
OCTOBE
1
2
3
4
5
6
ST SYSTEM STUDY
NASA REVIEW
SYSTEM STUDY FINAL REPORT
FINAL REPORT
SCHEDULE COST ESTIMATES
NASA REVIEW
ST/AFGS SYSTEM INTEGRATION
PRELIMINARY ENGINEERING DESIGN
APL SIMULATION
PERFORMANCE VERIFICATION
TECHNOLOGY EXPLORATION
NASA REVIEW
SOURCE VALIDATION