MCLAUGHLIN

MODIS Science Team Meeting, Oct. 1 - 3, 1991. Attachment E

THE MODIS-N INSTRUMENT

Jack Engel

1 October, 1991

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PRESENTATION OUTLINE

basically technical overview

- Requirements Overview
- Baseline Design Description
- Performance of Baseline Design
- Suggested Changes to the Baseline Design

REQUIREMENTS OVERVIEW

OVERVIEW OF THE MODIS-N REQUIREMENTS

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- Spectral Coverage — 0.408 μm - 14.385 μm, 36 Bands
- Spectral Resolution — 10 nm ≤ Δλ ≤ 500 nm
- Spectral Stability — λ & Δλ stable to ≤ 2nm (VIS bands) *very stringent*
  λ & Δλ stable to ≤ 1% (all other bands)

- Spatial Coverage — ±55°, 2330 km swath at 705km
- Spatial Resolution — 250 m; 500 m; 1000 m *not high resolution*
- Spatial Registration — ≤0.1 IFOV (all bands of the same resolution) *weber alerted*
- IFOV — .354 mr, .709 mr, 1.418 mr (All ±3%)

- Radiometric Range — 0.02% ≤ rho ≤ 100%, 3K ≤ T ≤ 700K *(clouds) (fire band (21)) very broad*
- Radiometric Resolution — 12 bits *some encoded @ 10 bits*
- Radiometric Performance — 57 ≤ SNR ≤ 1111, 0.05 K ≤ NEΔT ≤ 5.0 K

- Polarization Insensitivity — ≤2%, 0.43 μm ≤ λ ≤ 2.2 μm *instrument can't polarize light by more than 2%; won't contribute to existing polarization*

- Calibration Accuracy — Absolute Calibration: ±1% λ > 3 μm; ±5% λ <3 μm;
  ±2% Reflectance (λ <3 μm)

asked to improve / think 0.6% can be done absolute calibration on-orbit

MODIS-N VIS/NIR/SWIR BANDS

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BAND	λ	IFOV	Δλ	PURPOSE (EXAMPLES)
	LAND AND CLOUD BOUNDARIES BANDS			
1	659 nm	250m	50 nm	VEG CHLOROPHYLL ABS LAND COVER TRANS.
2	865 nm	250m	40 nm	CLOUD AND VEGETATION LAND COVER TRANSF.
	LAND AND CLOUD PROPERTIES BANDS			
3	470 nm	500m	20 nm	SOIL, VEGETATION DIFFERENCES
4	555 nm	500m	20 nm	GREEN VEGETATION
5	1240 nm	500m	20 nm	LEAF/CANOPY DIFFERENCES
6	1640 nm	500m	20 nm	SNOW/CLOUD DIFFERENCES
7	2130 nm	500m	50 nm	LAND AND CLOUD PROPERTIES
	OCEAN COLOR BANDS			
8	415 nm	1000m	15 nm	CHLOROPHYLL
9	443 nm	1000m	10 nm	CHLOROPHYLL
10	490 nm	1000m	10 nm	CHLOROPHYLL
11	531 nm	1000m	10 nm	CHLOROPHYLL
12	565 nm	1000m	10 nm	SEDIMENTS
13	653 nm	1000m	15 nm	SEDIMENTS, ATMOSPHERE
14	681 nm	1000m	10 nm	CHLOROPHYLL FLUORESCENCE
15	750 nm	1000m	10 nm	AEROSOL PROPERTIES
16	865 nm	1000m	15 nm	AEROSOL/ATMOSPHERIC PROPERTIES
	ATMOSPHERE/CLOUD BANDS			
17	905 nm	1000m	30 nm	CLOUD/ATMOSPHERIC PROPERTIES
18	936 nm	1000m	10 nm	CLOUD/ATMOSPHERIC PROPERTIES
19	940 nm	1000m	50 nm	CLOUD/ATMOSPHERIC PROPERTIES

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for additional information

MODIS-N MWIR/LWIR BANDS
(CONTINUED)

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BAND	λ	IFOV	Δλ	PURPOSE (EXAMPLES)
	THERMAL BANDS			
20	3.75 μm	1000m	0.18 μm	SEA SURFACE TEMPERATURE
21	3.75 μm	1000m	0.05 μm	FOREST FIRES/VOLCANOES
22	3.96 μm	1000m	0.05 μm	CLOUD/SURFACE TEMPERATURE
23	4.05 μm	1000m	0.05 μm	CLOUD/SURFACE TEMPERATURE
24	4.47 μm	1000m	0.05 μm	TROPOSPHERIC TEMPERATURE/CLOUD FRACTION
25	4.52 μm	1000m	0.05 μm	TROPOSPHERIC TEMPERATURE/CLOUD FRACTION
26	4.57 μm	1000m	0.05 μm	TROPOSPHERIC TEMPERATURE/CLOUD FRACTION
27	6.72 μm	1000m	0.36 μm	MID-TROPOSPHERIC HUMIDITY
28	7.33 μm	1000m	0.30 μm	UPPER-TROPOSPHERIC HUMIDITY
29	8.55 μm	1000m	0.30 μm	SURFACE TEMPERATURE
30	9.73 μm	1000m	0.30 μm	TOTAL OZONE
31	11.03 μm	1000m	0.50 μm	CLOUD/SURFACE TEMPERATURE
32	12.02 μm	1000m	0.50 μm	CLOUD HEIGHT & SURFACE TEMPERATURE
33	13.34 μm	1000m	0.30 μm	CLOUD HEIGHT & FRACTION
34	13.64 μm	1000m	0.30 μm	CLOUD HEIGHT & FRACTION
35	13.94 μm	1000m	0.30 μm	CLOUD HEIGHT & FRACTION
36	14.24 μm	1000m	0.30 μm	CLOUD HEIGHT & FRACTION

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REQUIREMENTS DICTATE BASELINE DESIGN APPROACH

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Requirement	Design Approach
• Spectral Coverage and Resolution	Reflective Afocal Fore Optics Primary Spectral Separation into Four Regions *reflective enhanced silver coatings* Four Refractive Imaging Objectives *assemblies* Individual Spectral Filters for each Band
• Spatial Coverage	Continuously Rotating Scan Mirror
• Spatial Registration	Monolithic Focal Plane Assemblies (where possible) *visible & n IR* Afocal Telescope Allows Translation of Objectives *before launch* On-Orbit Registration Monitoring (SRCA) *spectral radiometric calibration assembly – they can monitor, but not change*
• Radiometric Performance	17.8cm Unobscurred Aperture *7 inch diameter* f/1.76 (VIS, NIR, SWIR/MWIR); f/1.32 LWIR *off axis reflective Gregorian telescope* 10 IFOV's (20, 40) Along Track *faster to minimize — & keep detector small, minimize heat load*
• Polarization Insensitivity *45% fold mirror/compensates for ( )*	Fold Mirror, Polarization Compensators, Optical Coatings *more detectors on track ⇒ ( )*
• Calibration Accuracy	Threefold approach - Prelaunch *rigorous*, Solar/Blackbody *visible/IR thermal* On-Orbit, Ground Truth *during plan over flights*

MCST discussions yesterday / avoid detailed discussion now

MODIS-N CUTAWAY SHOWS KEY SUBSYSTEMS

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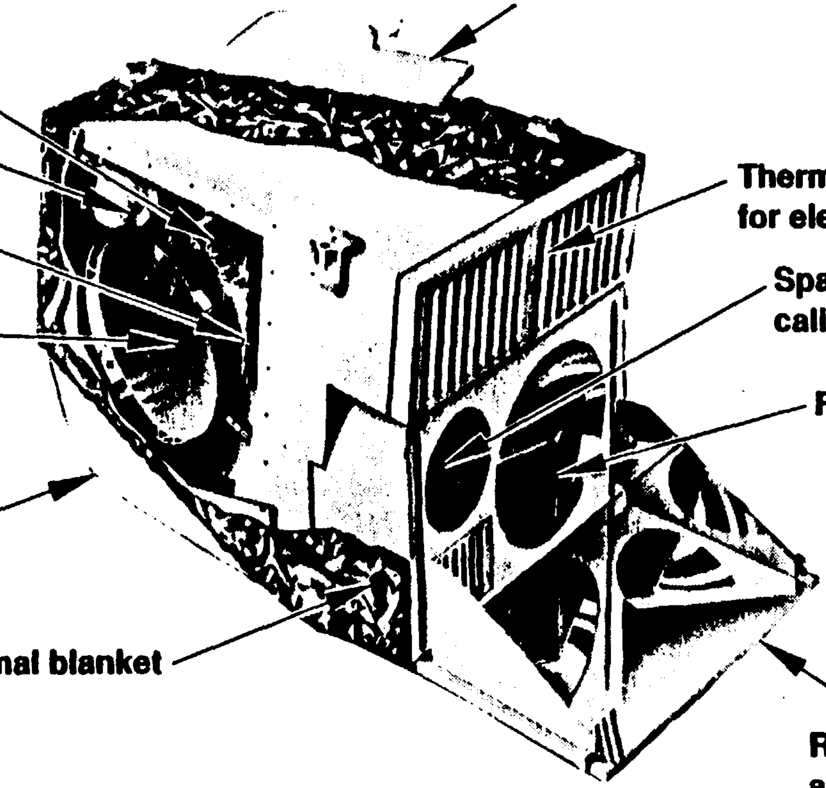

Mass: 190kg
Volume: 1 x 1 x 1.6m
Power: 192W
Data Rate: 10.68 mbps

one/orbit solar reflectance calibration shot

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BASELINE DESIGN

FROM PHOTONS TO DATA

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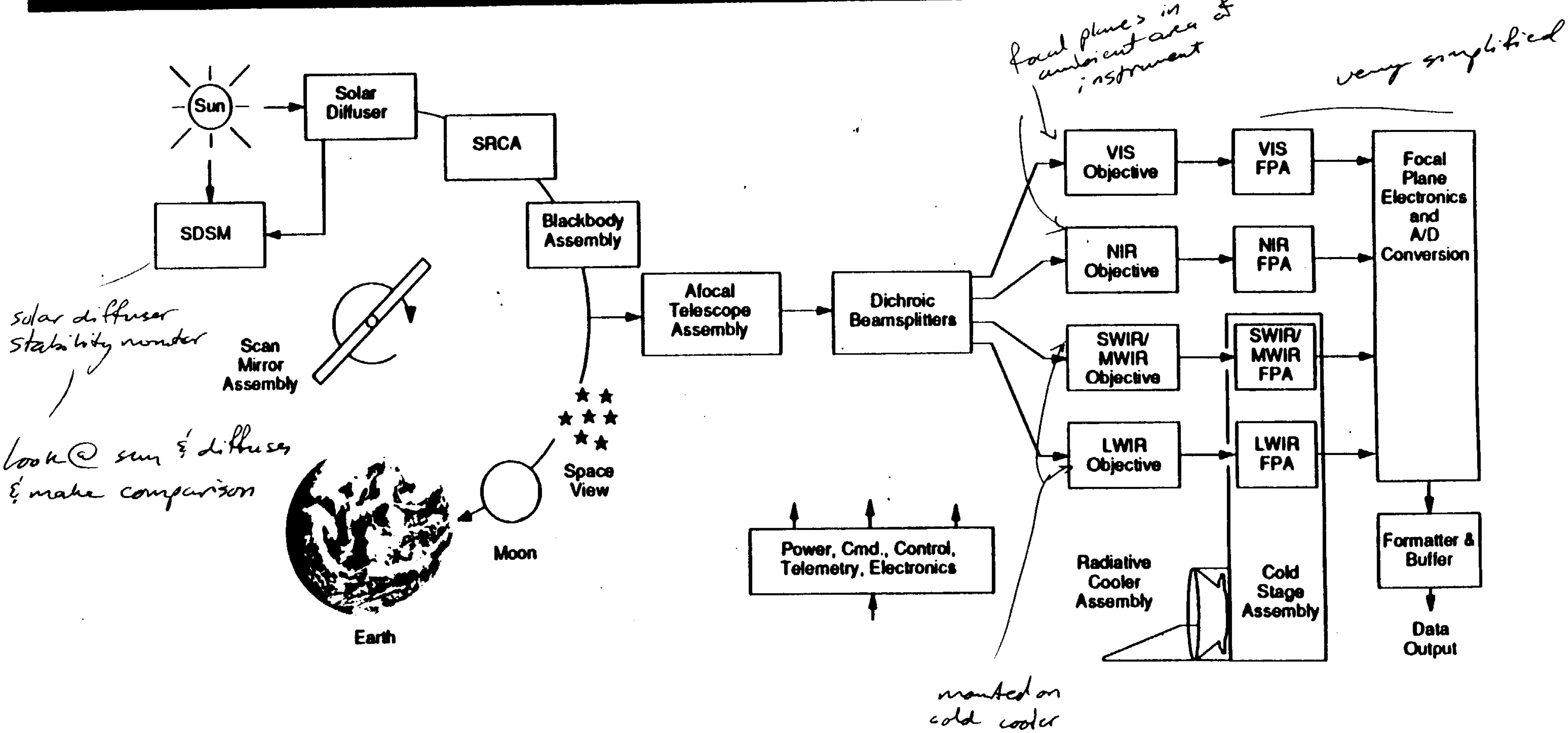

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27 Megabits raw data rate,
buffered to slow down → 10.7 megabits
+ overhead in day mode

'MODIS-N BASELINE INSTRUMENT PARAMETERS

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ORBIT	705 km, 1:30 PM ASCENDING
SWATH	±55°, 10.0 km TRACK x 2330 km SCAN
SCANNING	360° SCAN, DOUBLE SIDED, 20.4 RPM, 0.450s ACTIVE SCAN TIME
IFOV	0.354 mr (0.25 km), 0.709 mr (0.50 km), 1.418 mr (1.0 km)
TELESCOPE	2-MIRROR OFF-AXIS GREGORIAN, EPD 17.8 CM
SPECTRAL BANDS	36 FROM 0.415 μm TO 14.3 μm
SPECTRAL SEPARATION	DICHROIC BEAMSPLITTERS AND DISCRETE FILTERS
DWELL TIME	83 μs (0.25 km), 166 μs (0.50 km), 332 μs (1.0 km)
DETECTOR MATERIAL	SILICON (0.4 μm ≤ λ ≤ 0.95 μm), PV HgCdTe (1 μm ≤ λ ≤ 10 μm), PC HgCdTe (λ > 10 μm)
DETECTOR READOUT	CAPACITIVE TRANSIMPEDANCE AMPLIFIERS (CTIA)
IR DETECTOR COOLING	THEMATIC MAPPER-TYPE RADIATIVE COOLER, 85K
CALIBRATION	LABORATORY, GROUND TRUTH, ON-BOARD BLACKBODY, SOLAR DIFFUSER, SPECTRORADIOMETRIC CALIBRATOR
DATA RATE	10.68 MBPS (DAY MODE), 2.88 MBPS (NIGHT MODE)
SIZE, WEIGHT, POWER	1.0m x 1.6m x 1.0m, 190.1 kg, 192W

DICHROIC BEAMSPLITTERS SEPARATE ENERGY TO FOUR COREGISTERED OBJECTIVES AND FOCAL PLANES

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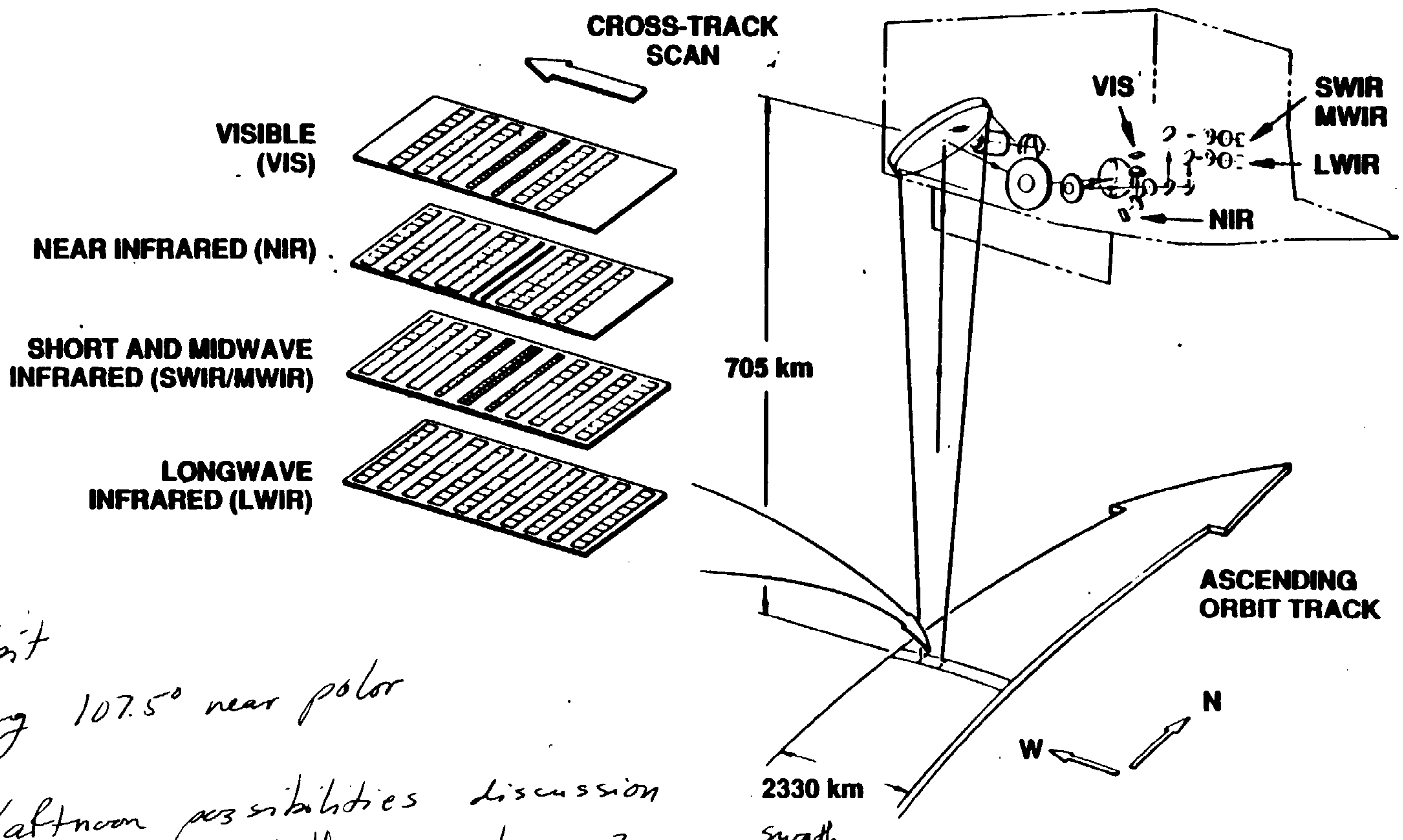

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contract orbit
ascending 107.5° near polar
orbit
morning/aftnoon possibilities discussion
makes difference whether we have 2
identical or mirror image instruments.
morn descend – identical aftnoon ascend
" ⇒ mirror images

DETECTOR NUMBERING -

DOES THE SCIENCE TEAM HAVE A PREFERENCE

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- The Landsat Thematic Mappers flying in a daylight descending orbit lay down the following pattern of data channels

Scan #1 16 16 16 16 16
15 15 15 15 15
14 14 14 14 14
13 13 13 13 13
---
9 9 9 9 9 9 9 9 9
8 8 8 8 8 8 8 8 8
---
2 2 2 2 2 2 2 2 2
1 1 1 1 1 1 1 1 1
Scan #2 16 16 16 16 16 16
15 15 15 15 15 15
etc

- How would the Science team like the detectors numbered for MODIS-N?

not @ Luckoff meeting

1 thru 10 from South to North as imaged?

or

10 thru 1 so that 1's are North Oriented in Image

Does anyone care?? — not big issue, but needs early clarification for clear communication

MODIS-N INTERIOR VIEWS

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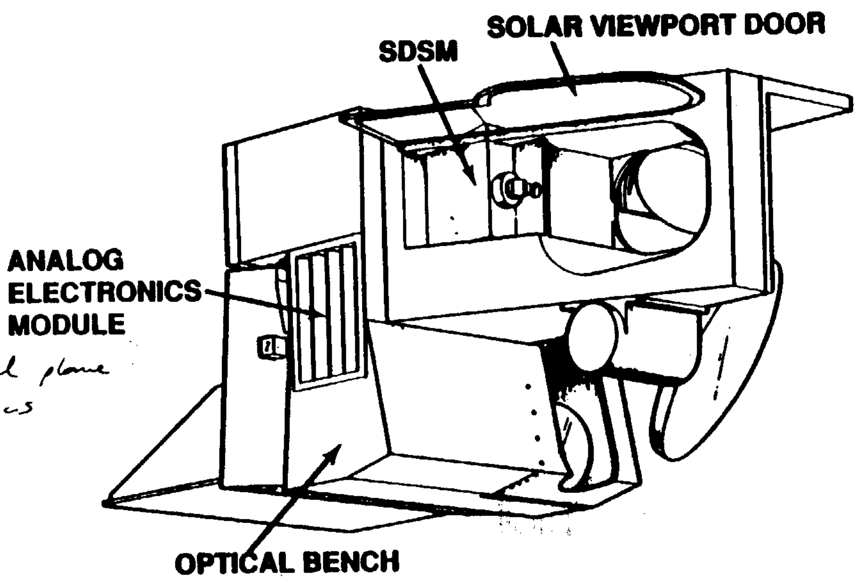
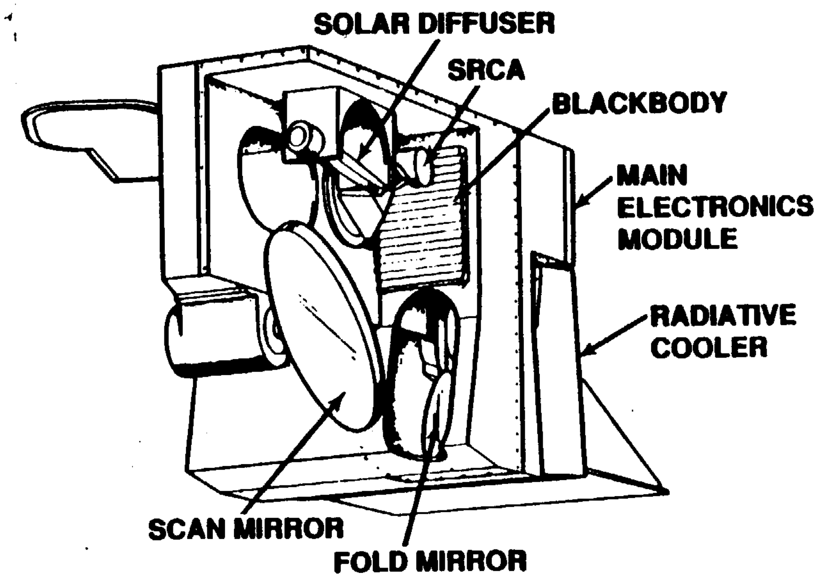
only opens when calibrating on diffuser.



some focal plane electronics



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360° SCAN ALLOWS CONTINUOUS, SEQUENTIAL VIEWS OF EARTH, SPACE AND CALIBRATION TARGETS

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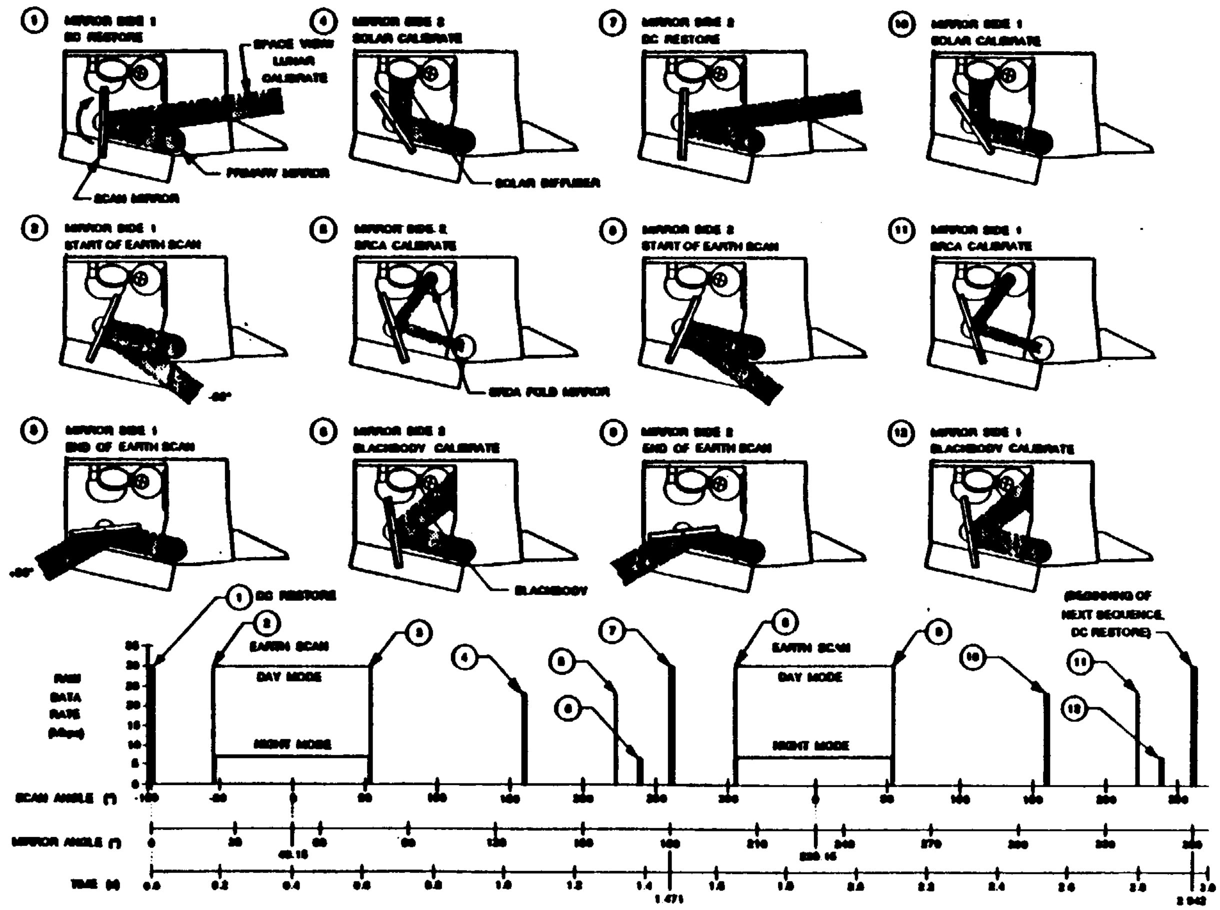

5 different targets on each scan

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MODIS-N SUBSYSTEMS

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- Mainframe Assembly (and Appendages)
- Scan Mirror Assembly
- Afocal Telescope Assembly
- Aft Optics Assembly
  - Dichroic module
  - VIS Objective module
  - VIS Focal Plane module
  - NIR Objective module
  - NIR Focal Plane module
  - SWIR/MWIR Objective module
  - LWIR Objective module
- Radiative Cooler Assembly
  - Cooler Cold Stage module
    - SWIR/MWIR Focal Plane module
    - LWIR focal Plane module
- Main Electronics Assembly
- VIS/NIR Analog Electronics Assembly
- SWIR/MWIR / LWIR Analog Electronics Assembly
- Solar Diffuser Assembly
- Solar Diffuser Stability Monitor Assembly
- Spectro-Radiometric Calibration Assembly
- Blackbody Assembly

modular approach to design of MODIS-N.
good for scheduling, assembly testing;
subsystem division - easier to handle
problems.

A MODULAR DESIGN FACILITATES ASSEMBLY INTEGRATION AND TEST

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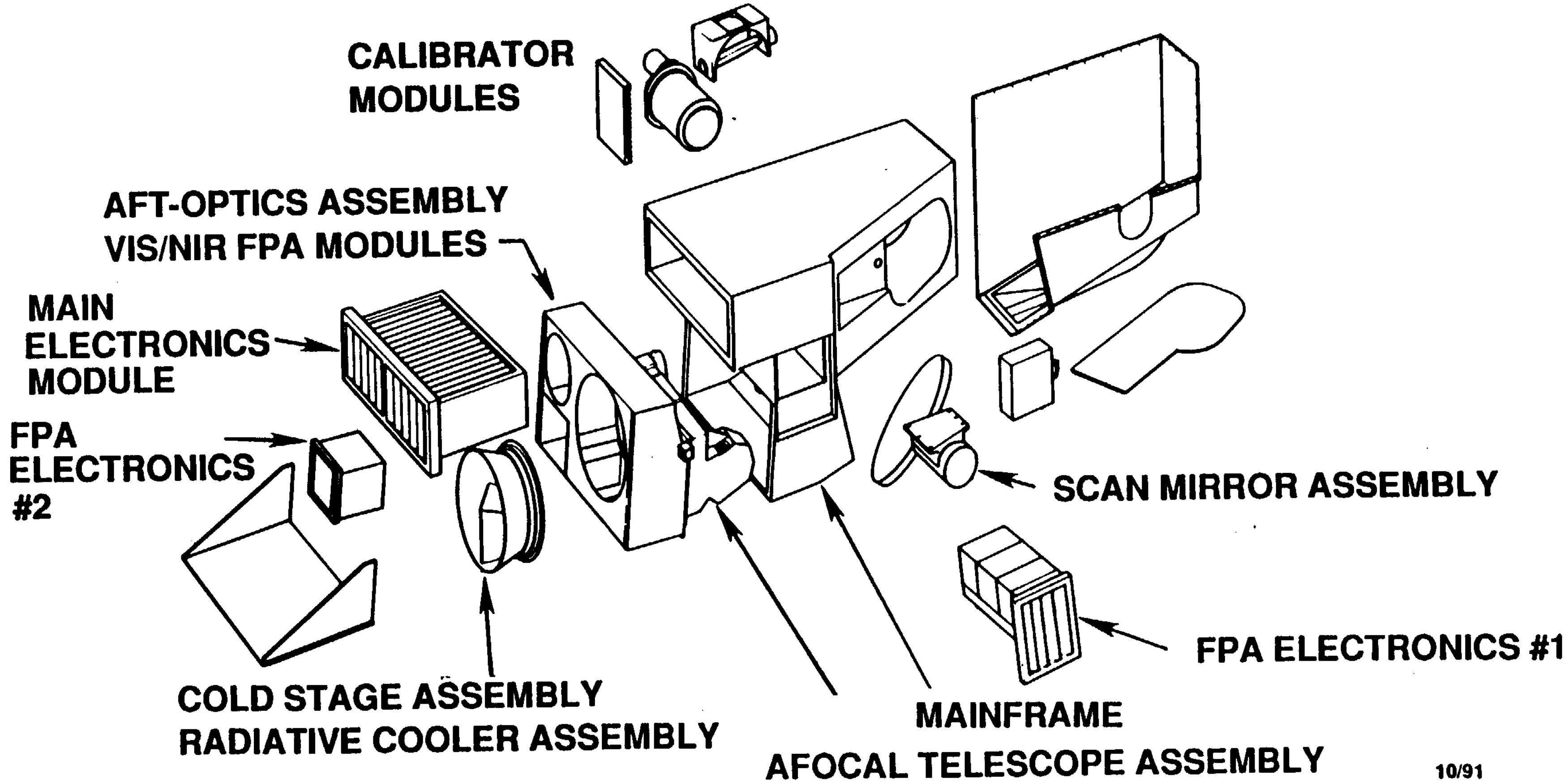

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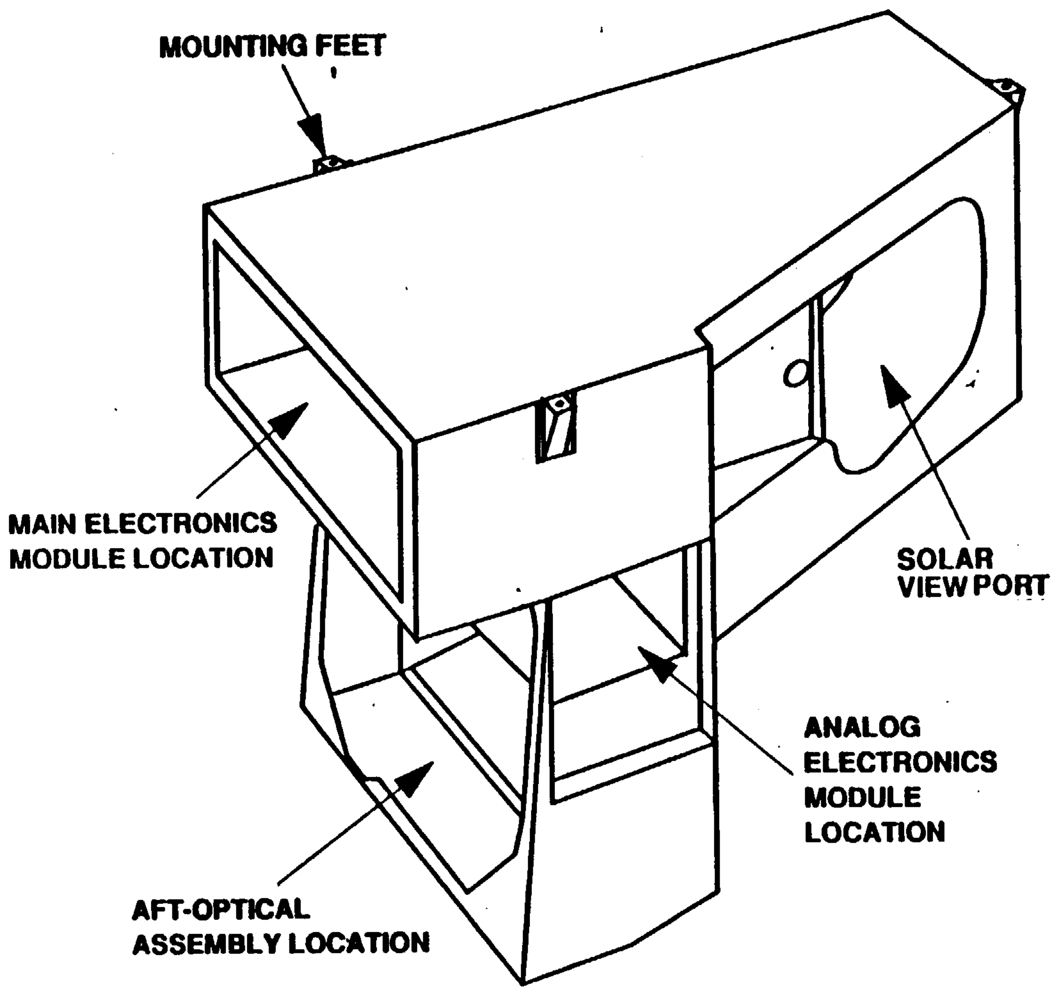

- High stiffness-to-weight ratio
- Low thermal expansion coefficient

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MODIS-N MAINFRAME IS COMPOSITE GRAPHITE-EPOXY STRUCTURE

TM experience with these type structures / problem: they absorb moisture - needs monitored & humidity control.

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TWO-SIDED BERYLLIUM SCAN MIRROR USED FOR MODIS-N

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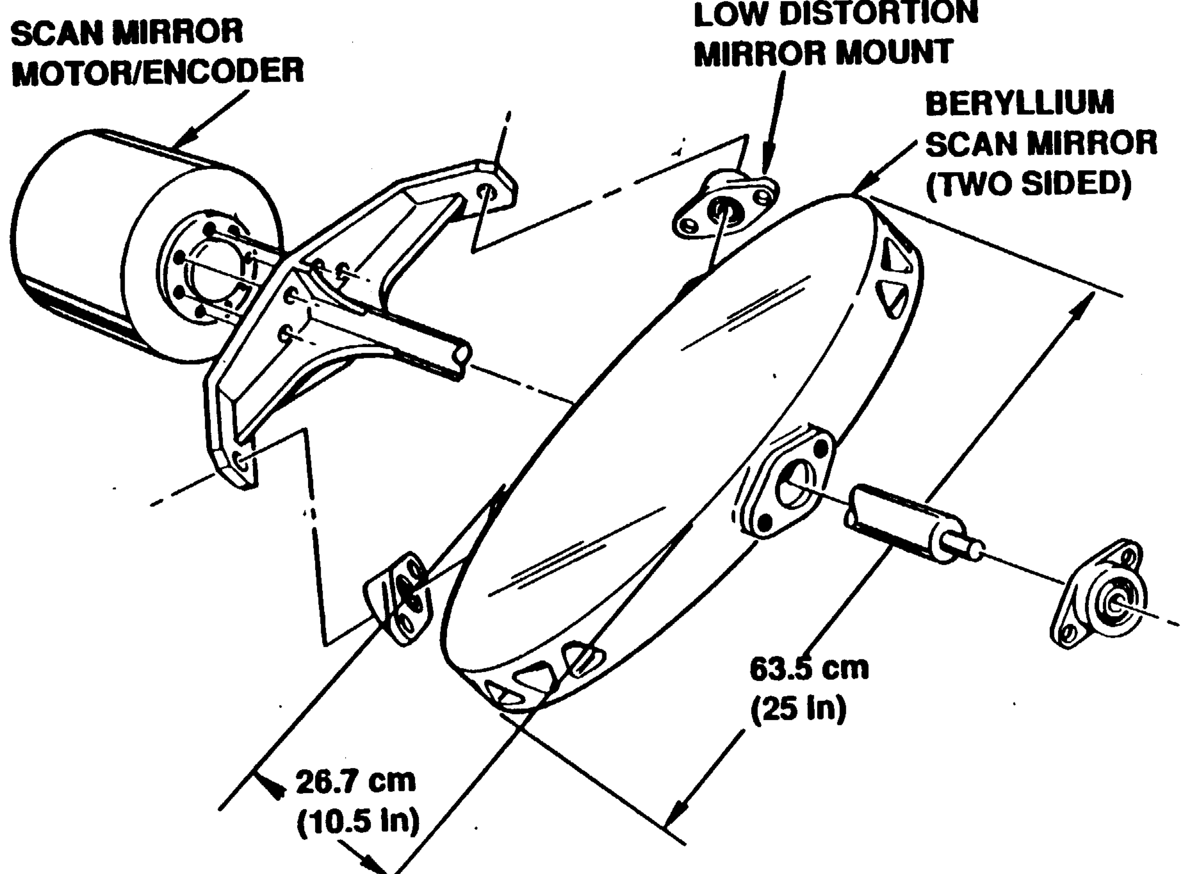

±55° requirement drives size

thickness ~ 1.5 inch, not fully determined

- DESIGN HERITAGE: VISSR/VAS, ETM

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MODIS-N TELESCOPE AND AFT-OPTICS MODULES

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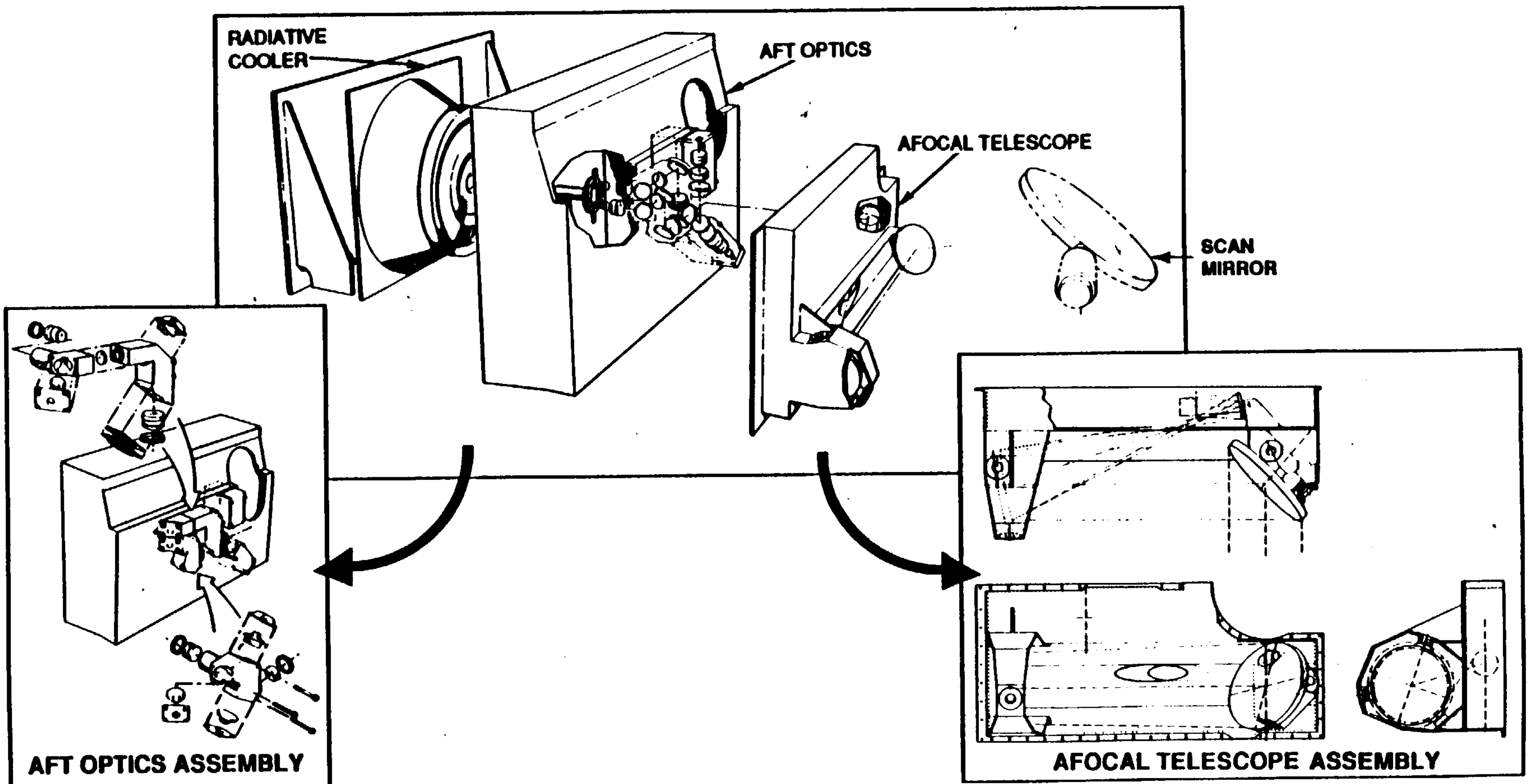

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OPTICAL DESIGN UTILIZES REFLECTIVE AFOCAL TELESCOPE WITH FOUR REFRACTIVE OBJECTIVE ASEMBLIES

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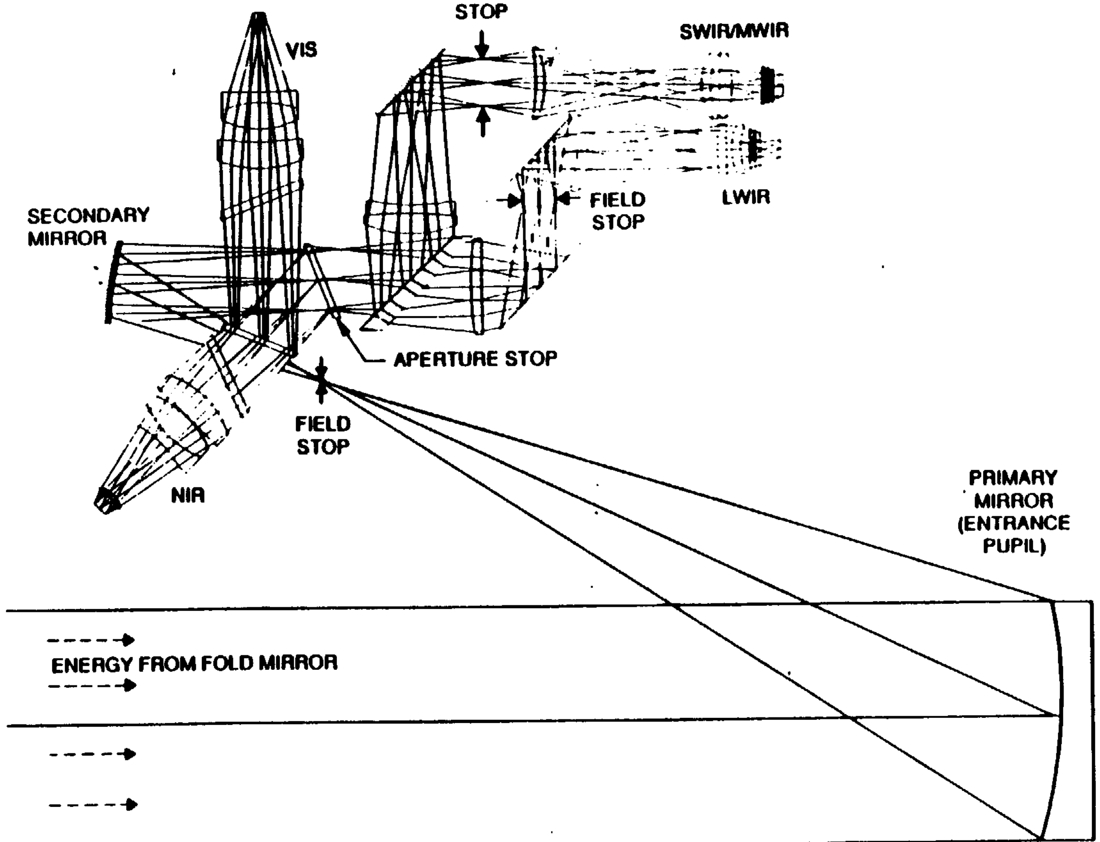
ray tracing of how 4 focal planes are focused



(SCAN MIRROR AND FOLD MIRROR NOT SHOWN)

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OPTICAL SCHEMATIC SHOWING ORIENTATION OF FOCAL PLANES

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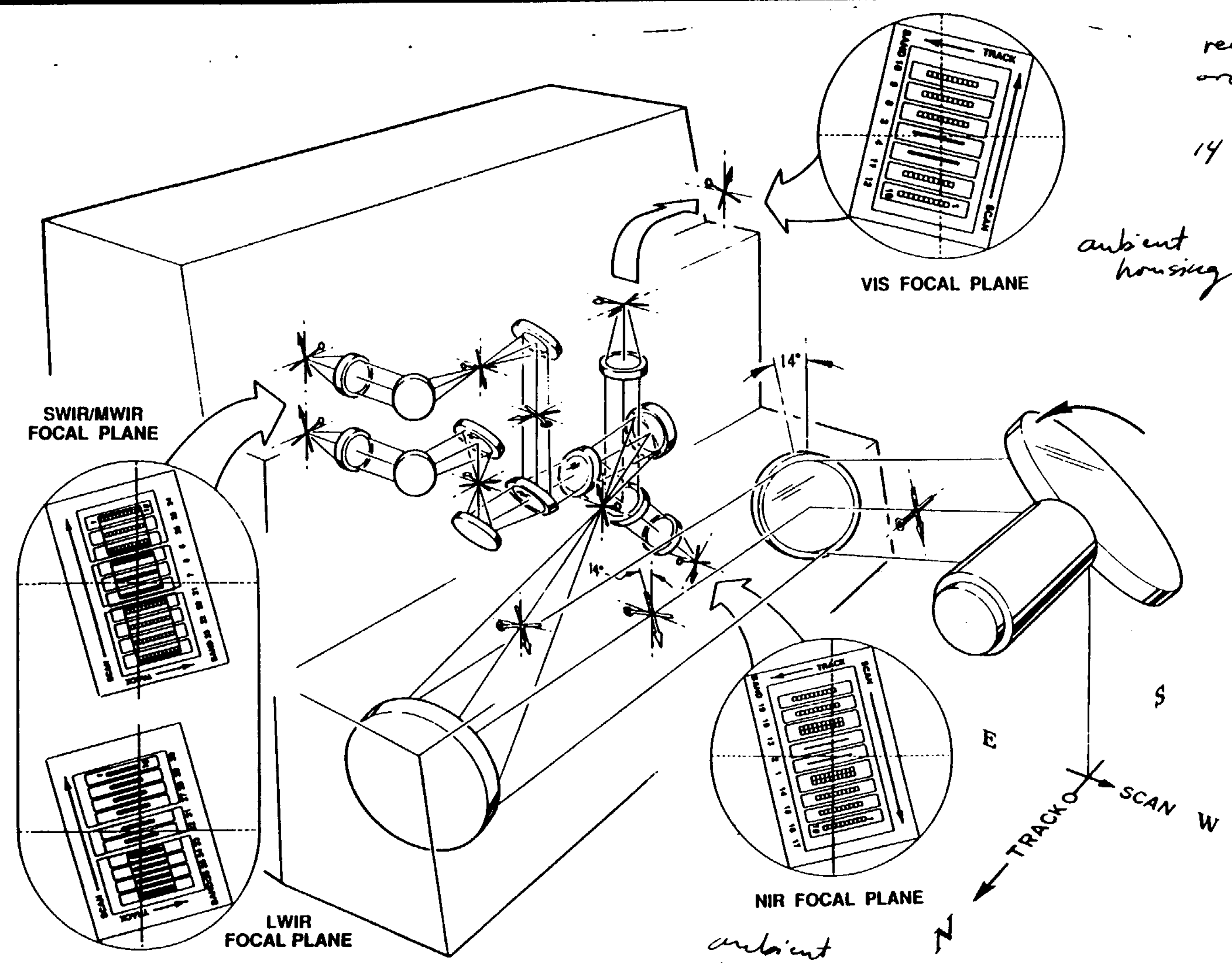
recent chart - to understand orientation of focal planes

14° - .129° orientation



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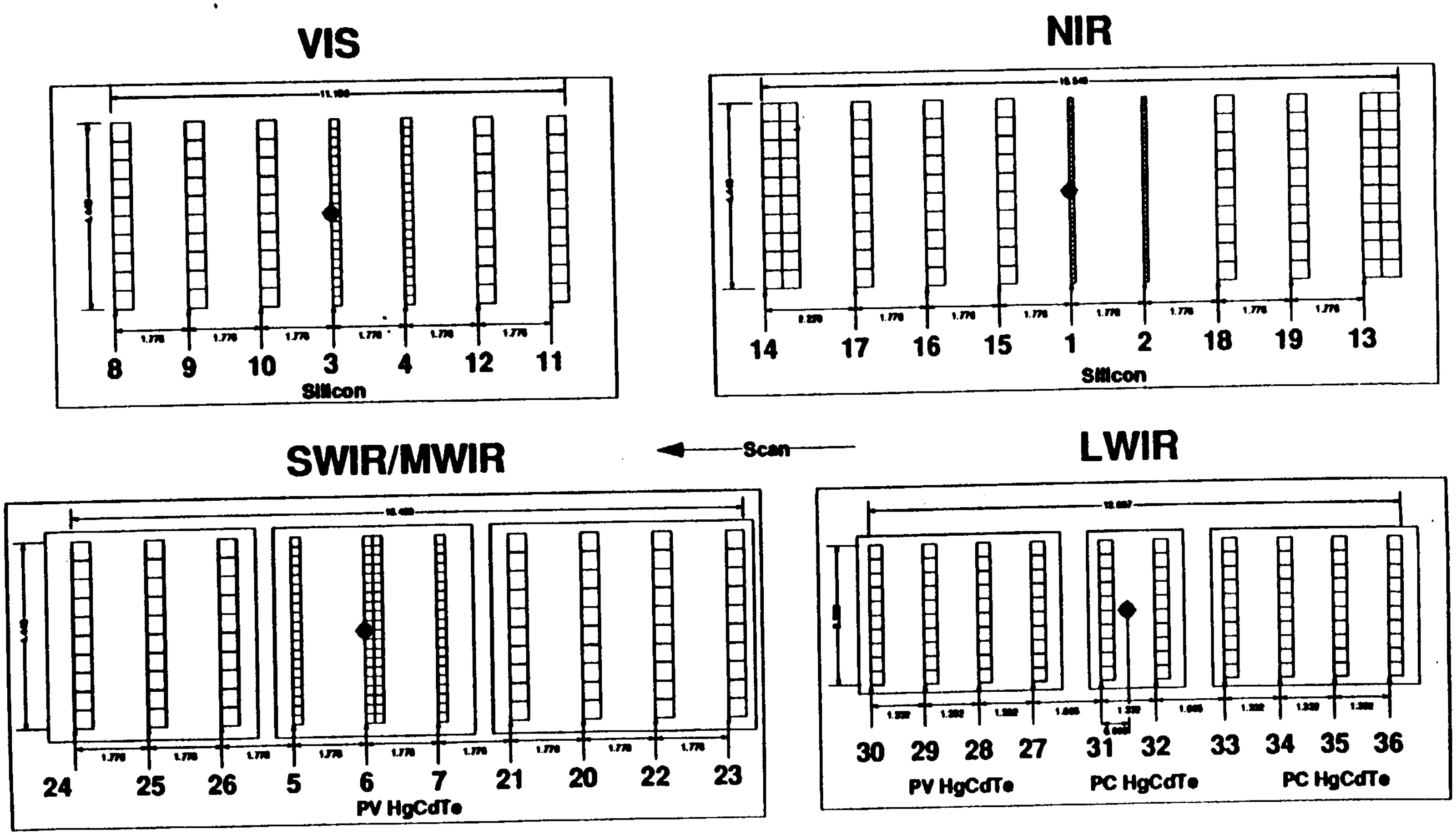
noted some differences w. next chart
still in process of evaluating where each individual band will reside on sensor.

MODIS-N FOCAL PLANE LAYOUT AND MATERIALS 8/28/91



□ 444 µm x 436 µm (1 km)

□ 333 µm x 327 µm (1 km)

□ 222 µm x 218 µm (0.5 km)

▫ 111 µm x 109 µm (0.25 km)

◆ Location of Optical Axis

CAD DRAWINGS SHOW FILTER MOUNTING AND ASSEMBLY

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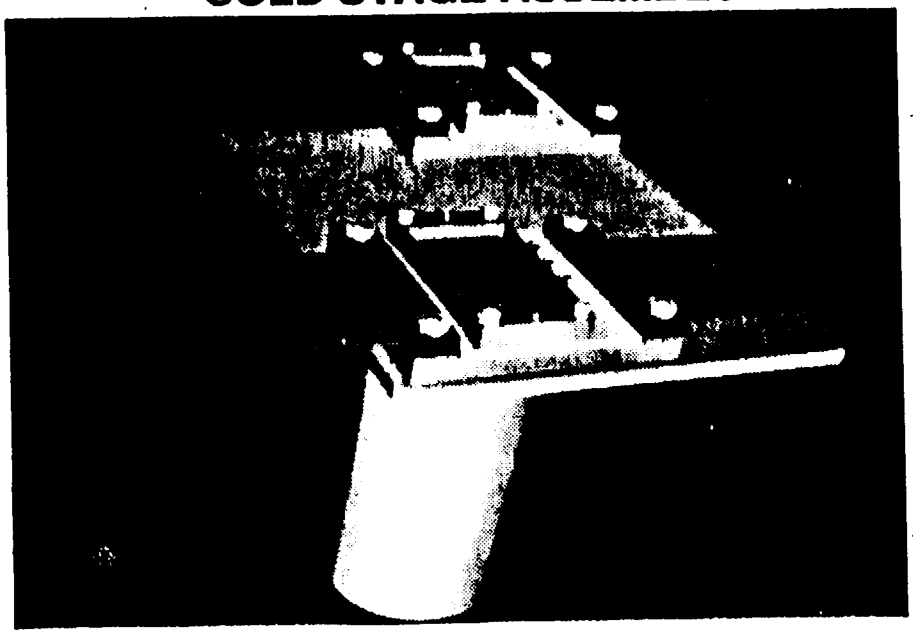
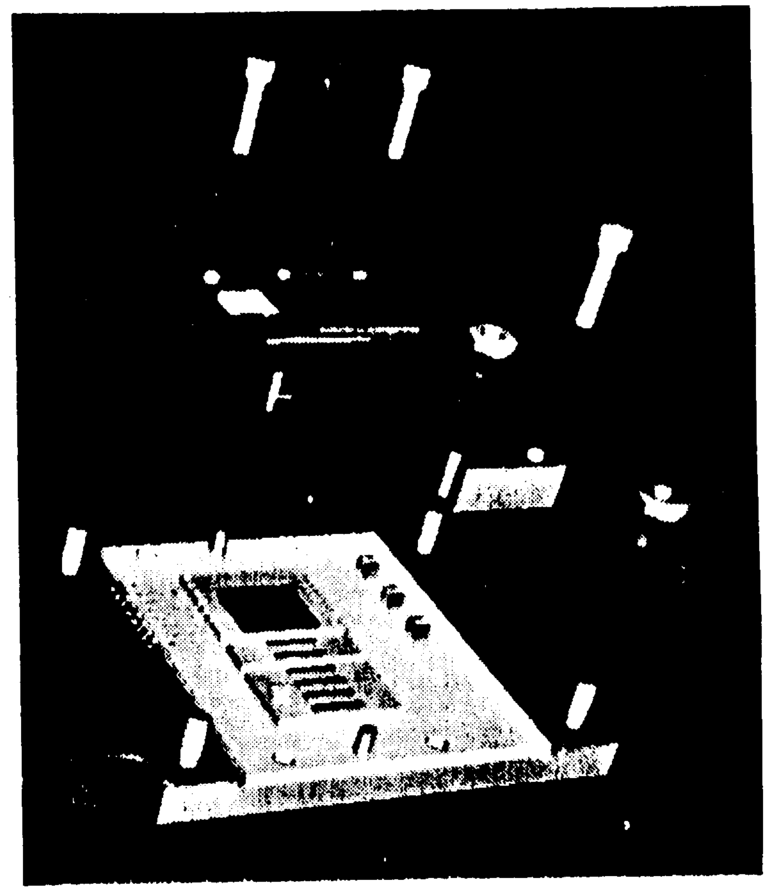
COLD STAGE ASSEMBLY



VIS, NIR

FILTER MOUNTING CONCEPT



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shows focal plane packaging philosophy. trying to do duplications

BUFFERED DATA RATE: 10.7 MBPS

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BANDS	IFOV (m)	WORDS/sec (EACH BAND)	BITS/WORD	TOTAL DATA RATE MBPS
8-32	1000	30,127	12	9.038
3-7	500	120,509	12	7.231
1,2	250	482,204	12	11.569
33-36	1000	30,127	10	1.205
			TOTAL RAW DATA	29.043 MBPS

lots of data from these

- 15 megabit memory buffers data to 10.7 MBPS (day), 2.9 MBPS (night) with overhead

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how data rate is accumulated

FDDI encoding

night rate ~ 3 megabits / lots of margin involved

MODIS-N IN-FLIGHT CALIBRATORS

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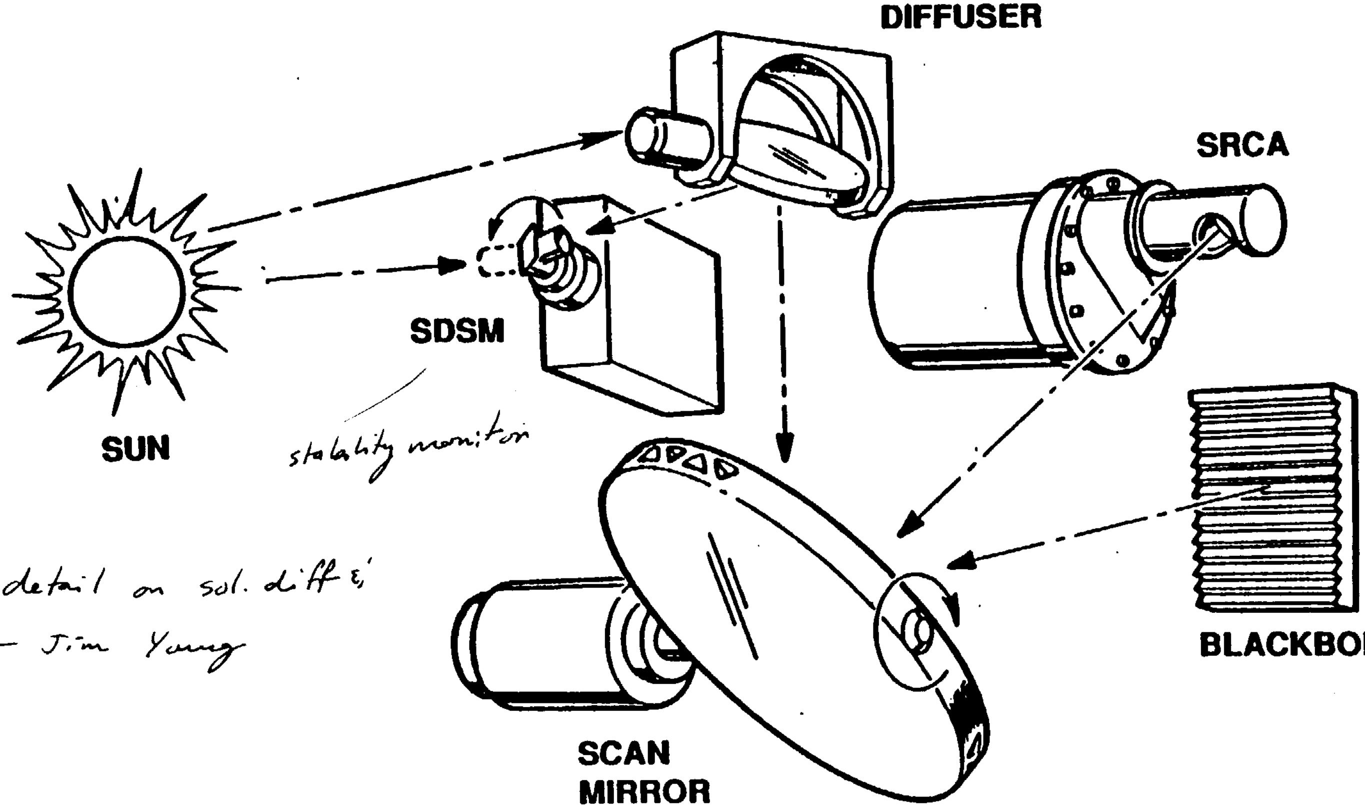

volunteered more detail on sol. diff & SDSM ; or see Jim Young

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PERFORMANCE OF BASELINE DESIGN

pertains to "As Proposed" Design

PERFORMANCE OVERVIEW FOR REVIEW BY THE MODIS-N SCIENCE TEAM

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- **Spectral Requirements - Multiple optical vendors have indicated that all of the spectral requirements can be achieved.**

- **Spectral Band Registration (SBR) Requirements - The proposal identified this as a critical area. Recent analysis since that time indicates that the "residual" optical distortions are quite large.**
  - **Meeting the requirement with the baseline requires focal plane displacements to compensate for the nominal optical distortions.** — with XY translation of each spectral band; some resid. left
  - **Residual optical distortions dominate SBR in the track direction.**
  - **We meet the ±0.1 IFOV requirement, but with minimal margin.**
  - **More on this subject will follow.**

  fair amount [illegible] distortion — good design form, but design deficiency is

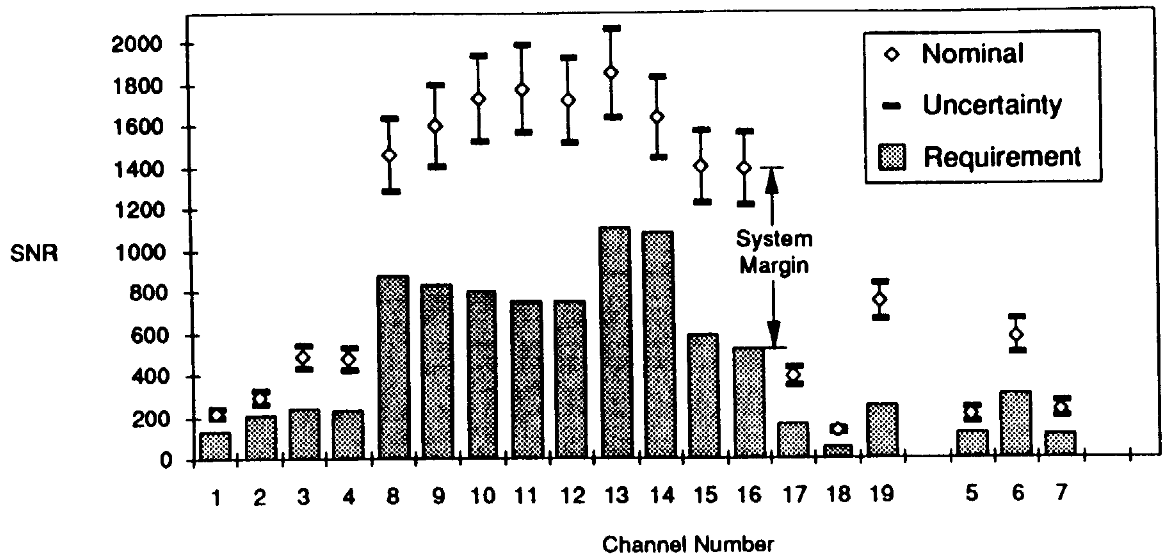
- **SNR & NEΔT will be met with significant margins (except for band 21; Fireband NEΔT specified at 300K)** — more to follow 20 has same spec as 21 / unsure why 20 & 21 specified @ same temperature

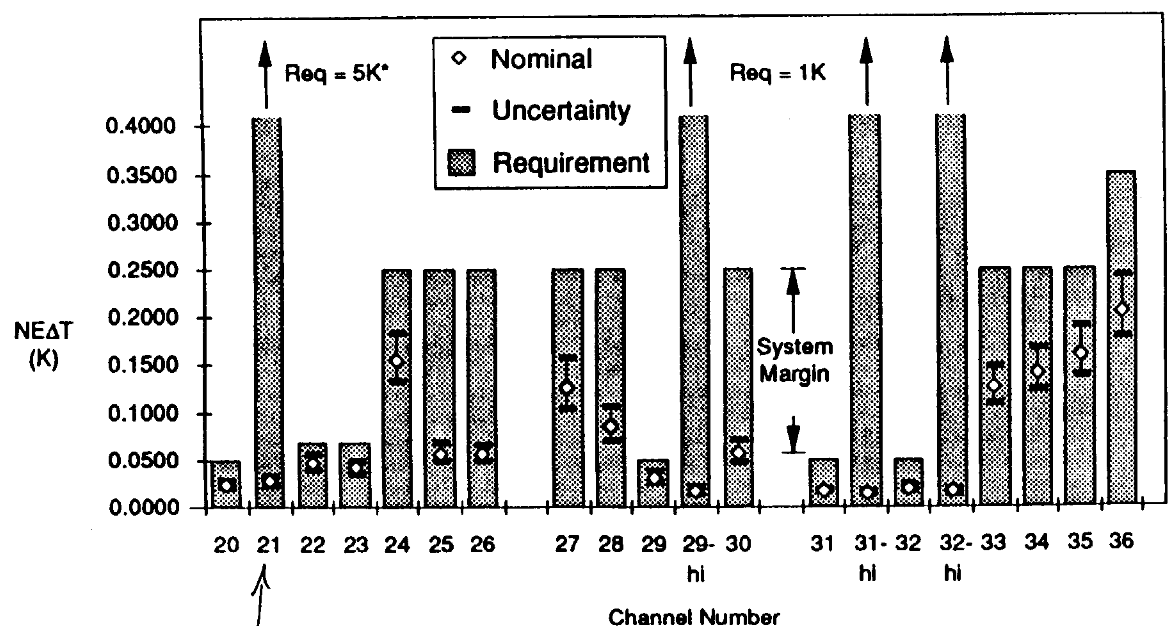
- **MTF Margins > 22% at Nyquist**

- **Polarization Insensitivity of ≤ 2% for angles up to ± 45° and 0.43 μm ≤ λ ≤ 2.2 μm can be achieved.**
  will be difficult / area of possible relief

- **Calibration Accuracy - These requirements are probably achievable, but very difficult.**

TM accuracies requ. 10% / got 6% — these tougher on MODIS





* Band 21 Predicted NET Shown for 700 K Scene Temperature. NET @ 300K = 9.5K, NET @ 335K = 3.1K

tough spec also

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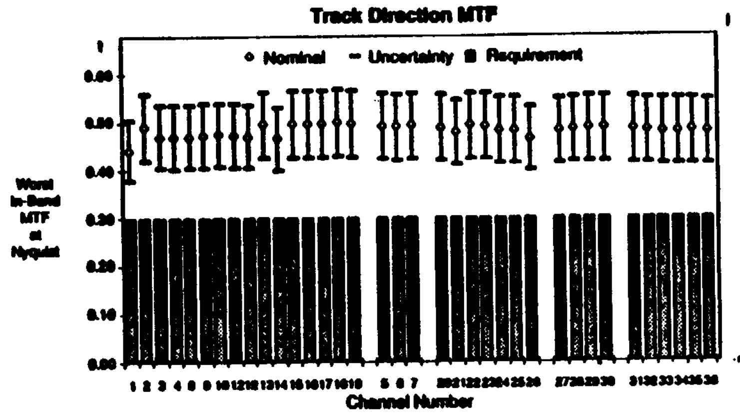
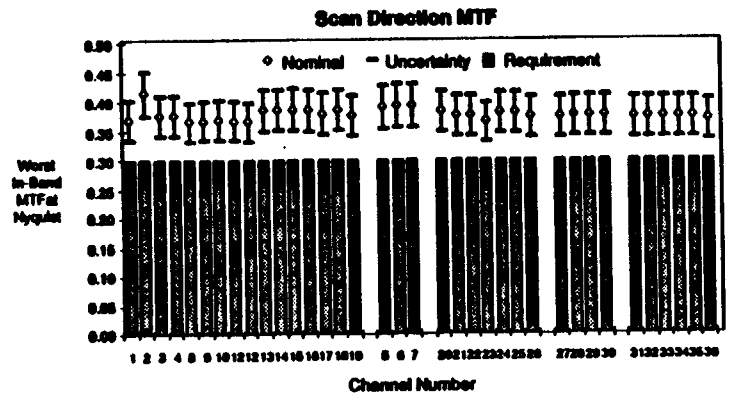
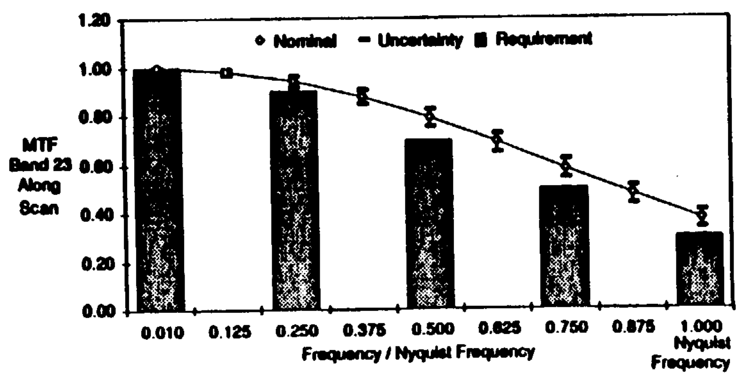
THE PREDICTED SNR & NEΔT MARGINS ARE SIGNIFICANT

Vince – question band 1.6 TDI







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PREDICTED MTF MARGINS GREATER THAN 22% AT NYQUIST FREQUENCY

very consistent now, but may find non-ideal IFOV's later

only variation due to optical differences

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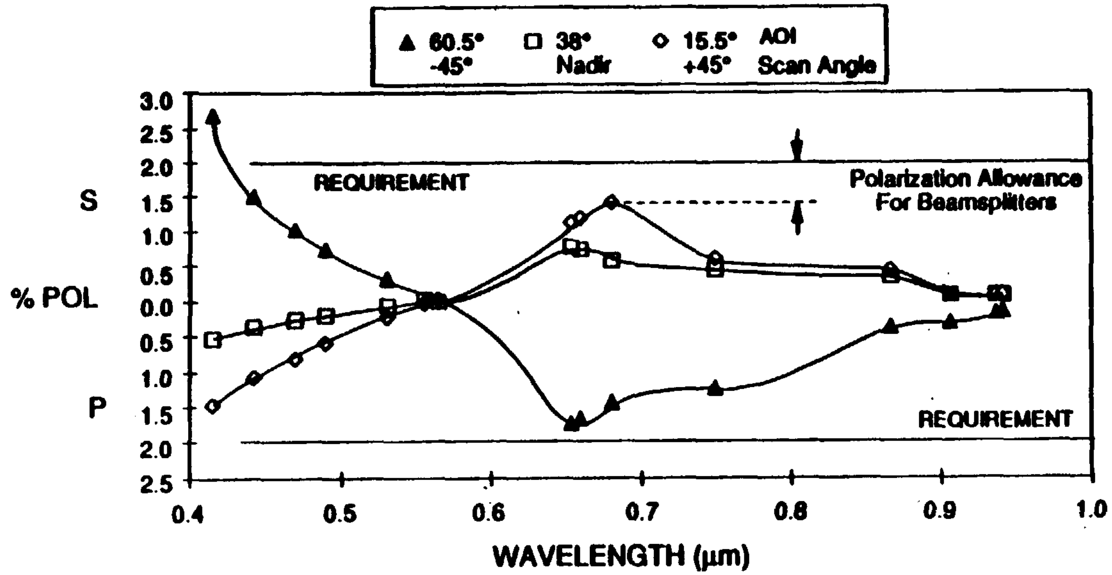

enhanced

- **SILVER COATED MIRRORS**
- **45° FOLD MIRROR COMPENSATES FOR MOST OF SCAN MIRROR STATIC POLARIZATION**
- **LOW POLARIZATION DICHROICS**
- **POLARIZATION COMPENSATOR PLATES**

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BETTER THAN ±2% POLARIZATION INSENSITIVITY IS PREDICTED BETWEEN 0.43 µm AND 2.2 µm

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SPECTRAL BAND REGISTRATION BASELINE PERFORMANCE

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- Summary of Registration evaluated at Top, Center, and Bottom of Field: (after translation to accommodate nominal optical distortions)
  - We meet the requirements, but just barely - some random contributors are not fully understood at this time.

    launch shift in cool vs. ambient bands not fully understood.
  - Scan Direction Registration of Corresponding Detector Elements:

    anticipate in scan direction
    - ±0.07 IFOV (Driven by random errors associated with EFL, Detector Misalignment, Optical Axis Misalignment, Thermal and Mechanical Stability, Launch shifts, etc.)

      ability to lock in place

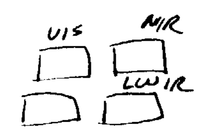
      cool down performance usually very repeatable - still needs error budget
  - Track Direction Registion of Corresponding Detector Elements:
    - ±0.10 IFOV (Driven by residual optical distortion + random errors)

      minimally meeting this
  - Many of the random errors will not contribute to within focal plane registration errors. EFL, mask dimension, and SCA-to-SCA errors will.

    how sensor chip assemblies

- Plots of baseline data are available

referred back to



band rearrangements likely to be close

mercury-cadmium-telluride
limit ~ 0.6 inch in size
3 sensor chip assemblies expected

SPECTRAL BAND REGISTRATION (CONTINUING ACTIONS)

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- We will continue to work to reduce the anticipated mis-registration to increase our margin against the specified requirements.
  - We will work with the engineers for each subsystem to attempt to significantly reduce the random contributors to the registration uncertainty.
  - We will continue to evaluate minor variations in the optical design which might lessen the residual distortions.

objective assemblies

increase focal lengths to . . .

SUGGESTED CHANGES TO THE BASELINE DESIGN

another package on specifications concerns.

BASELINE CHANGES FOR REVIEW BY THE MODIS-N SCIENCE TEAM

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- **D.C Restoration on the Blackbody instead of on cold Space.**
  - **Several Advantages:**
    - **No need to avoid restoring on the moon. The moons presence might be quite difficult to accurately predict. Moon now occurs during Calibration period.**
    - **Calibration occurs on space view immediately following d.c. restore. If we were to restore on space, the blackbody calibration occurs on other side of mirror after viewing the solar diffuser and SRCA.**
    - **Calibration accuracy is unaffected by the change.**

has been evaluated - more logical way to do it / urges consideration
eats into dynamic range / they'll allow 3-4 % leeway in range
vs (?) any immediate problem ?

- **The nominal instrument operating temperature in the vicinity of the aft optics will be designed to be 293K.**

instrument in same thermal behavior as on-orbit

  - **It would be desirable to operate the entire instrument (with the exception of the SRCA) at a 100% duty cycle.**
    - **Maintain maximally stable thermal environment.**
    - **Average power increases from 192w to 220w vs. requirement of 225w.**

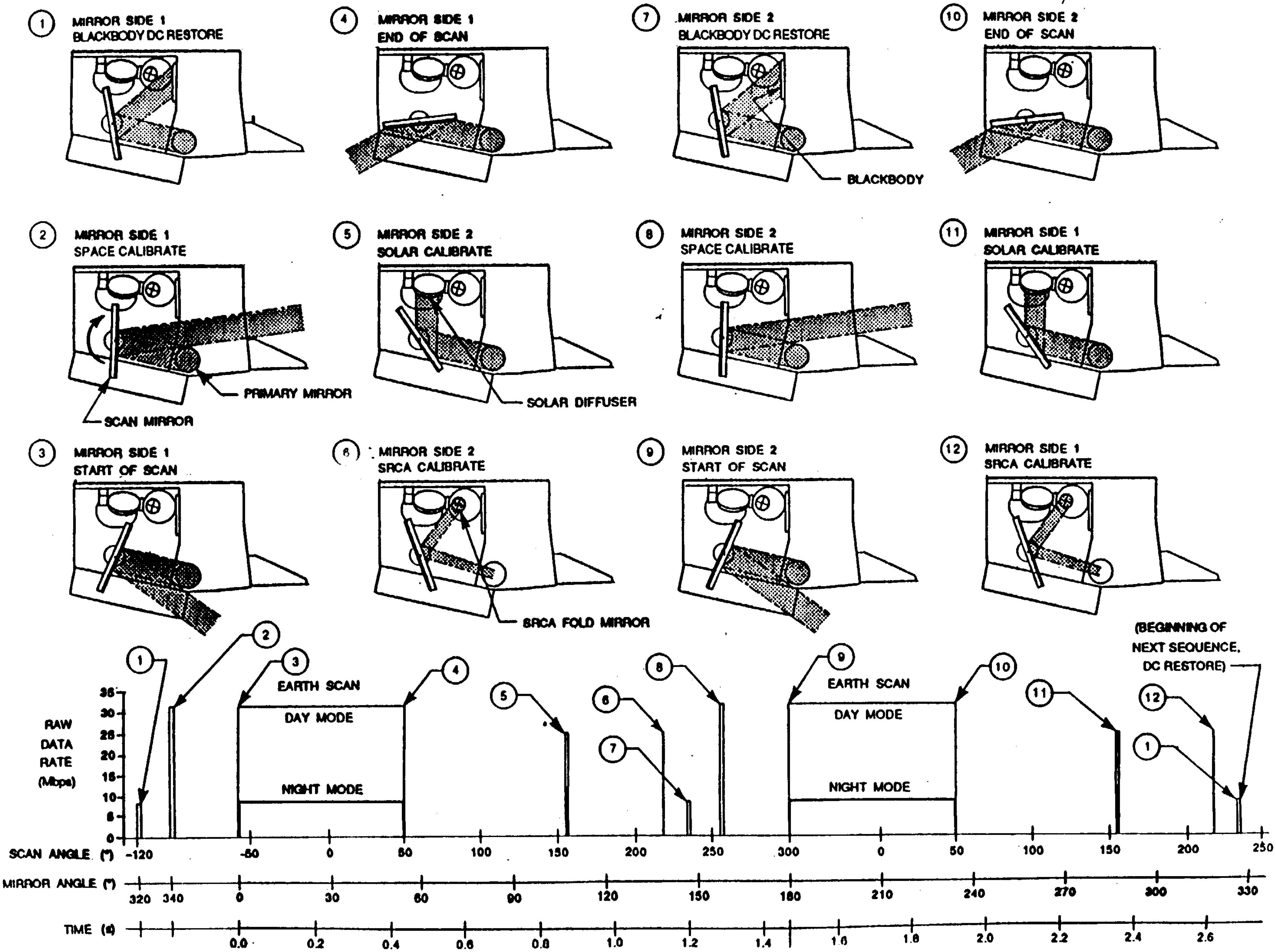
thinks would behoove us [redacted] pay power penalty   expects to save 20-30

BB seen by opposite side of mirror

opportunity to occassionally callibrate on moon / presence difficult to know precisely
need precise attitude / orbit / moon location

DC restore on BB - trying to point out advantage

SCANNING SEQUENCE WITH CONTINUOUS ROTATION OF MIRROR



BASELINE CHANGES FOR REVIEW BY THE MODIS-N SCIENCE TEAM (Cont'd)

HUGHES

SANTA BARBARA RESEARCH CENTER
a subsidiary

- Relocation of the VIS & NIR analog electronics functions to the "Growth" volume that has a prime view of space for optimum heat transfer. separate into 2 boxes

  Four benefits to the design:

  1) Provides extremely stable thermal environment for VIS & NIR electronics ≤1°C at 100% d.c.
  2) Significantly reduces the power dissipated in the "Analog Electronics Module" which gets a solar load on its radiating surface during a portion of each orbit.
  3) Provides adequate volume in each assembly for a reasonable growth, if necessary. (Another way of expressing this advantage would be to say that a lower risk packaging technology can be used.)
  4) Reduces the cable lengths from the VIS and NIR focal planes from approximately two feet to approximately one foot.

  Phil Slater - notes possible optical crosstalk problem

- Reduced Field Angles and Increased Effective Focal Lengths (slower f/#'s) for each of the Imaging Objectives

  1) Field angles are reduced by minimizing the spacing between spectral bands. (3 IFOV's instead of 4)
  2) Focal lengths are increased by simultaneously increasing detector sizes.
  3) These changes improve optical performance (SBR) and reduce physical size for easier packaging.
  4) Slight reduction in radiometric performance & requires multiple stripe filters per substrate.

  will try to maintain no more than 2 filters per substrate

BASELINE CHANGES FOR REVIEW BY THE MODIS-N SCIENCE TEAM (Cont'd)

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- We are re-evaluating the use of TDI in bands 6, 13 & 14. The benefit does not justify the complexity in all cases. As an alternative, we are considering the use of non-linear gain to improve the performance at Ltyp for these bands. (piecewise linear)
- We are also considering the use of non-linear gain in band 29 to improve our margin. We are currently predicting an NEΔT of 0.041K against a requirement of .05K, a 22% margin.
  - Why do Bands 29, 31, and 32 require an NEΔT of 0.05K when the other LWIR bands only require an NEΔT of 0.25K or greater?

wants re-evaluation

SUMMARY STATEMENTS

- The Modis-N requirements are very challenging.

- We believe our Baseline Design is a near optimum solution to the MODIS-N requirements.

- Our Baseline Design meets most requirements with significant margins.

- We will continue to try to optimize the design through modest changes to the Baseline.