MODIS Algorithm Team (MAT)
Meeting Minutes, 9MAR94

ATTENDEES:

Abel, Peter	**Hoyt, Doug**
Anuta, Paul	**Knight, Edward**
Ardanuy, Phil	**Knowles, Dan**
Baden, Joan *Rapporteur*	**Kvaran, Geir**
Barker, John	**McKay, C. Albert**
Che, Nianzeng	**Montgomery, Harry** *Chair*
Crosby, David	**Gambhir, Brij**
Goldberg, Larry	**Ungar, Stephen**
Goodwin, Dave	**Weinreb, Michael**
Guenther, Bruce	**Wolfe, Robert**
	Zukowski, Tmitri J.

The next MAT meeting (March 16) has been replaced by the MODIS Calibration Plan Dry Run Review scheduled for two days, March 16 and 17. See the attached agenda for the Dry Run Review.

The next regular MAT meeting has been scheduled for Wednesday, March 30, 1994, from 9 - 11AM, in Building 22, Room G95. Contact Joan Baden for copies of presentations (286-1378). Attached is the current scheduled listing of MAT meetings for 1994 and the MAT member listing.

Michael Weinreb was the guest of this MAT meeting, discussing Thermal Calibration and problems observed with the AVHRR and GOES sensors. We thank Michael for his invaluable participation. See below agenda for details of how the actual March 9 meeting occurred.

AGENDA

MODIS Algorithm Team (MAT) Meeting
Guest: Michael Weinreb/NOAA Calibration Scientist
March 9, 1994
(9AM-12PM)
Building 16, Room 242
NASA/GSFC

9:10AM	Solar Diffuser (SD) & Solar Diffuser Stability Monitor (SDSM) (Paul Anuta)
9:40AM	The MODIS Blackbody (BB) (Dan Knowles)
10:00AM	Thermal Calibration (Michael Weinreb/NOAA/NESDIS)
11:30AM	Spectral Radiometric Calibration Assembly (SRCA) Overview
12:00PM	Adjourn

AGENDA

MODIS Algorithm Team (MAT) Meeting
Guest: Michael Weinreb/NOAA Calibration Scientist
March 9, 1994
(9AM-12PM)
Building 16, Room 242
NASA/GSFC

9:00AM	The MODIS Blackbody (BB) (Dan Knowles)
9:15AM	Solar Diffuser (SD) & Solar Diffuser Stability Monitor (SDSM) (Paul Anuta)
9:30AM	Spectral Radiometric Calibration Assembly (SRCA) Spectral Calibration (Ed Knight)
9:50AM	Radiometric Calibration (Nianzeng Che)
10:10AM	Spatial Calibration (Tim Zukowski)
10:30AM	Synthesis (Nianzeng Che)
11:00AM	Discussion
11:30AM	Adjourn

MODIS Calibration Dry Run Review
AGENDA
March 16 & 17, 1994

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MARCH 16: BUILDING 22/ROOM 271

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8AM	Executive Summary (Phil Slater)	
9AM	Chapter 1:	Introduction (Phil Slater)
10AM	Chapter 3:	Cross Calibration (Phil Slater)
11AM	Chapter 4:	Preflight solar-radiation-based calibration (Phil Slater)
12PM	BREAK FOR LUNCH	
1PM	Chapter 6:	Image-derived calibration and normalization (MCST/Barker/Ungar)
2PM	Chapter 7:	Vicarious calibration: Oceanic- Ship and buoy measurements (TBD)
3PM	Chapter 8:	Vicarious calibration: Land- Ground-based reflectance and atmospheric measurements (Phil Slater)
4PM	DISCUSSION	
5PM	ADJOURN	

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MARCH 17: BUILDING 22/ROOM G95

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8AM	Chapter 9:	Vicarious calibration: Land & water aircraft radiance measurements and atmospheric measurements (Peter Abel)
9AM	Chapter 10:	Vicarious calibration: this, that, and the other (TBD)
10AM	Chapter 11:	Vicarious calibration: Moon- Ground-based calibration of lunar radiance (TBD)
11AM	Chapter 12:	Geolocation (Robert Wolfe/Hughes/STX, Ed Masuoka/SDST)

12PM **BREAK FOR LUNCH**

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AFTERNOON OF MARCH 17(1:00PM-5:00PM)
VIDEO TELECON BUILDING 8 ROOM 206

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1PM	Chapter 2:	Preflight calibration in the laboratory (MCST/Knight)
1:15PM	Chapter 5:	Post-launch calibration using on-board calibration (OBC) systems (MCST/Knight)
1:30PM	Appendix A:	The level 1 calibration algorithms-Includes OBC Algorithms (Montgomery,Knowles, Anuta, and Zukowski@10min each, Che@20min)
2:30PM	Appendix D:	Postflight characterization (Montgomery/Maxwell)
2:40PM	Chapter 13:	Integration of independent calibration sources (Che, MCST/Barker,Abel,)

3PM **BREAK**

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Switch to AUDIO Conference in SAME ROOM: Bldg 8/Rm.206

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3:30PM **DISCUSSION** WITH SBRC VIA SPEAKER PHONE

5PM **ADJOURN**

OFFICIAL
MODIS ALGORITHM TEAM (MAT) SCHEDULED MEETINGS 1994

Day	Date	Room	Time
Wed	Feb 2	BLDG 22/G95	9-11AM
Wed	Feb 9	BLDG 22/271	9-11AM
Wed	Feb 16	BLDG 22/G95	9-11AM
Wed	Feb 23	BLDG 22/G95	9-10:30AM
Wed	March 2	BLDG 22/G95	9-11AM
Wed	March 9	BLDG 16/242	9-12PM
Wed*	**March 30**	**BLDG 22/G95**	**9-11AM**
Mon	April 4	BLDG 22/G95	9-11AM
Mon	April 11	BLDG 22/G95	9-11AM
Mon	April 25	BLDG 22/G95	8:30-10AM
Mon	May 2	BLDG 22/G95	9-11AM
Mon	May 9	BLDG 22/G95	9-11AM
Mon	May 16	BLDG 22/G95	9-11AM
Mon	May 23	BLDG 22/G95	9-10AM
Mon	May 30	BLDG 22/G95	9-11AM
Mon	June 6	BLDG 22/G95	9-11AM
Mon	June 13	BLDG 22/G95	9-11AM
Mon	June 20	BLDG 22/G95	9-11AM
Mon	June 27	BLDG 22/G95	9-11AM
Wed	July 6	BLDG 22/G95	9-11AM

*Next Meeting

MODIS Algorithm Team (MAT) 3/9/94

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Hughes/STX	7701 Greenbelt Rd., Suite 400, Greenbelt, Md. 20770
Goddard Space Flight Center	Greenbelt, Md. 20771
Ball Aerospace Sys. Div.	7500 Greenway Center Dr., Suite 700, Greenbelt, Md. 20770

Guests

SSAI(Brij Gambhir)	5900 Princess Garden Parkway, Lanham, MD 20706
NOAA/NESDIS(Michael Weinreb)	301-763-8136 or mweinreb/nesdis@telemail.nasa.gov
NOAA/NESDIS(David Crosby)	301-763-8136 or crosby@nzms.wwb.noaa.gov

MAT Presentation

MODIS Solar Diffuser/SD Stability Monitor Calibration System and Algorithms

MODIS Algorithm Team of the
MCST (MODIS Characterization Support Team)

Harry Montgomery, Manager
MODIS Instrument Characterization and Calibration

Code 925 - Sensor Development and Characterization Branch
NASA / Goddard Space flight Center, Greenbelt, Maryland 20771
FAX: (301) 286-1757

Paul E. Anuta, Edward Knight, Tom Bryant

Research and Data Systems Corporation (RDC)
7855 Walker Drive, Greenbelt, MD, 20770
FAX: (301) 982-3749

Presented by Paul E. Anuta

March 9, 1994

Outline

- Solar Diffuser Functional Description
- Solar Diffuser Stability Monitor Functional Description
- Pre-Launch SD/SDSM Calibration
- SBRC In-Flight Solar Diffuser/SDSM Calibration Equations
- Level 1-B SD/SDSM Calibration Algorithm Beta Version
- SBUV Diffuser Calibration Experience
- SSBUV Diffuser Experiment Results
- SD Calibration Concerns, Plans

SOLAR DIFFUSER PROVIDES FULL APERTURE REFLECTANCE CALIBRATION

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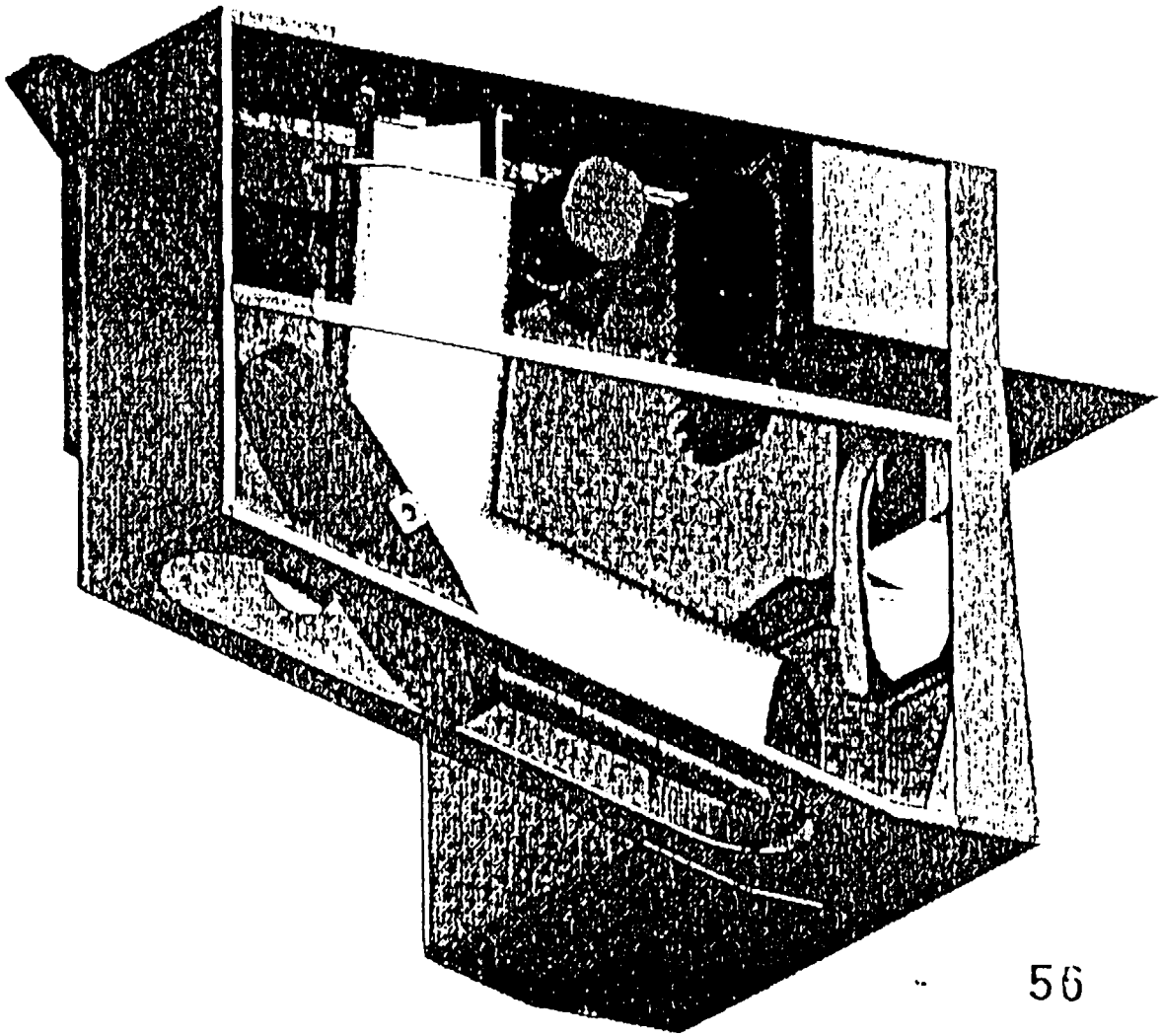

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SOLAR DIFFUSER DESIGN MEETS REQUIREMENTS

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TOP SYSTEM REQUIREMENTS

- ABSOLUTE 2% (1 Sigma) REFLECTANCE CALIBRATION OF VIS, NIR AND SWIR BANDS
- DIRECT SOLAR RADIANCE CALIBRATION (SUN IS BEST LONG TERM CALIBRATION SOURCE)

DERIVED REQUIREMENTS/CONSTRAINTS (SPECIFICATION 151789)

- FULL APERTURE ILLUMINATION OF MODIS FILLING 46 FOVs ALONG-SCAN (15 Useable Data Frames)
- TWO EFFECTIVE RANGES OF ALBEDO LEVELS: 0.45 to 0.59 and 0.04 to 0.05
- UNCERTAINTY IN ANGULAR ORIENTATION SHALL CONTRIBUTE $\leq$ 0.5% CALIBRATION ERROR (Δ AOI $<$ 0.15°)
- STABLE TO WITHIN 15% OVER 5 YEAR LIFE
- BRDF $\approx$ 0.315 sr-1, KNOWN TO WITHIN 1.0% OVER REFLECTANCE REGION AND TRACEABLE TO NIST TO THE EXTENT POSSIBLE
- SIGNAL CONTAMINATION: EARTHSHINE $\leq$ 0.3%; MINIMAL INDIRECT SOLAR RADIANCE
- DURATION OF SOLAR CALIBRATION: 1 MINUTE MINIMUM

SOLAR DIFFUSER AND SOLAR VIEW DOOR

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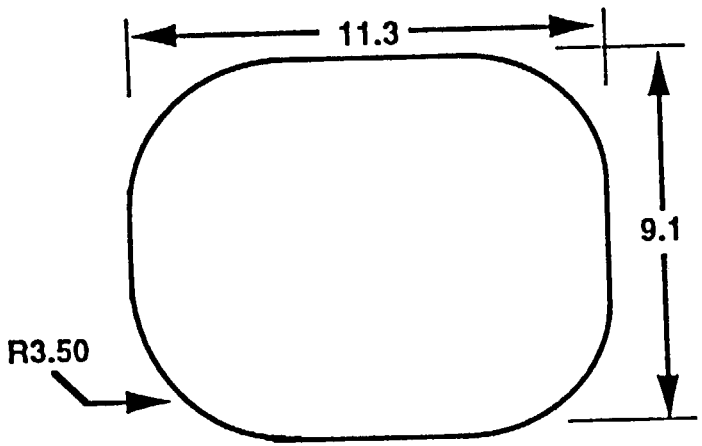

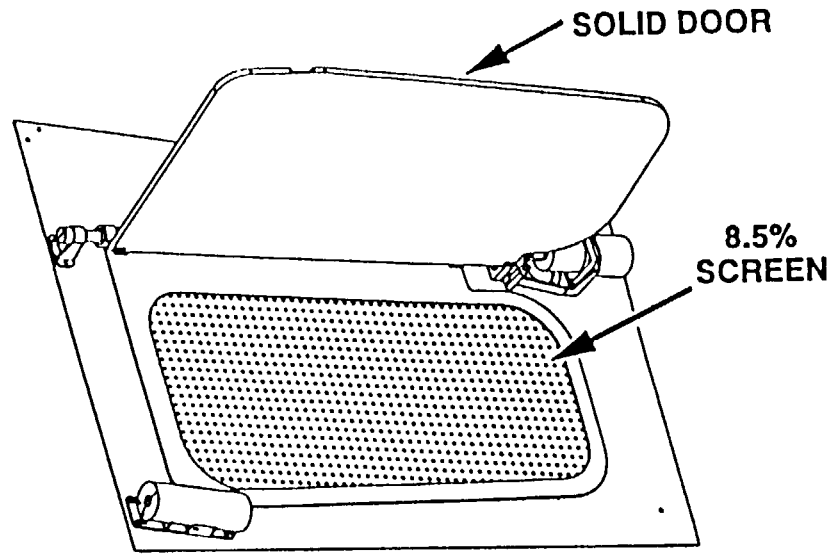

SOLAR DIFFUSER ASSEMBLY

- FULL APERTURE ILLUMINATION FILLING 46 FOVs ALONG-SCAN (15 useable frames of data)
- EFFECTIVE ALBEDO: 0.52 (0.45 to 0.59 range)
- FIXED POSITION. SOLAR AOI = 58.4° NOMINAL; 53.8° TO 63.0° RANGE
- DIFFUSER MATERIAL: SPACE-GRADE SPECTRALON (PTFE) (vacuum baked decontamination, dry nitrogen purge storage)

SOLAR VIEW DOOR ASSEMBLY

- 8.5% TRANSMITTING SCREEN USED TO ADJUST ALBEDO LEVELS
- DOOR ON SOLAR VIEWPORT MINIMIZES DIFFUSER EXPOSURE
- ALGORITHMS DEVELOPED TO MODEL VARIATIONS W/8.5% SCREEN IN PLACE DUE TO VARIATIONS IN:
  - Illumination Geometry
  - View Geometry

SOLAR DIFFUSER CALIBRATION DATA AVAILABLE ONCE PER ORBIT

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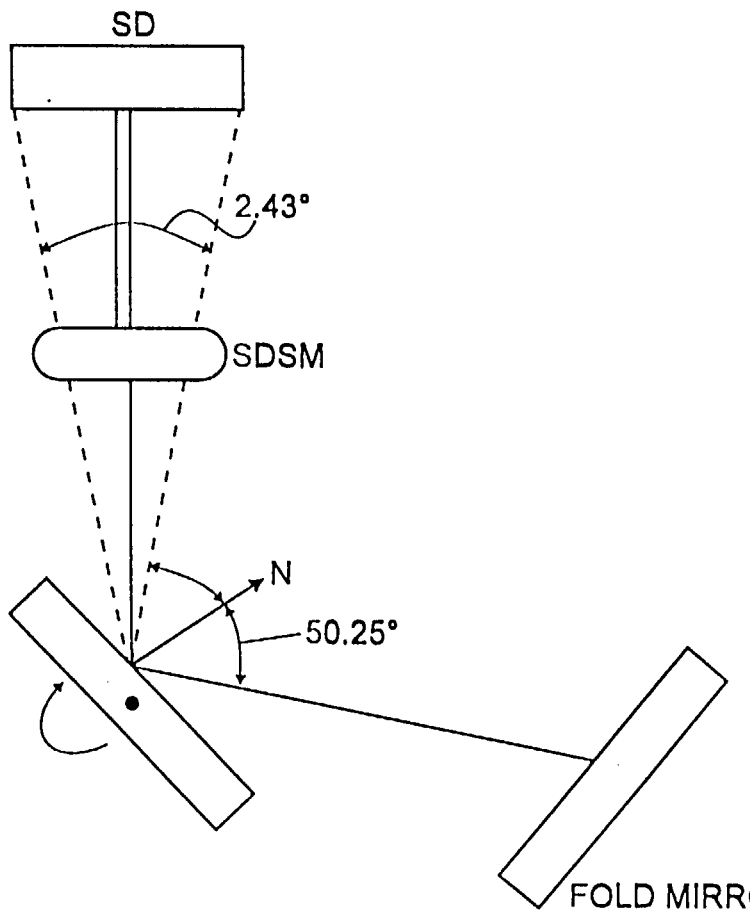
- DIFFUSER CAN BE ILLUMINATED NEAR THE NORTH POLE ONCE PER ORBIT
- SOLAR VIEW PORT SIZED TO ALLOW ILLUMINATION OF 1.3 TO 2 MINUTE DURATION
- CONTAMINATION OF CALIBRATION DATA MINIMIZED. ALLOTTED CALIBRATION PERIOD PRECLUDES SOLAR ILLUMINATION OF CLOUDS BELOW 100 Km ALTITUDE, EITHER IN DIRECT CALIBRATION PATH OR DIRECTLY BELOW SENSOR
- DIFFUSER REFLECTANCE CHANGES MONITORED BY SDSM. INFORMATION AVAILABLE WHENEVER SOLAR DIFFUSER CALIBRATION IS PERFORMED.

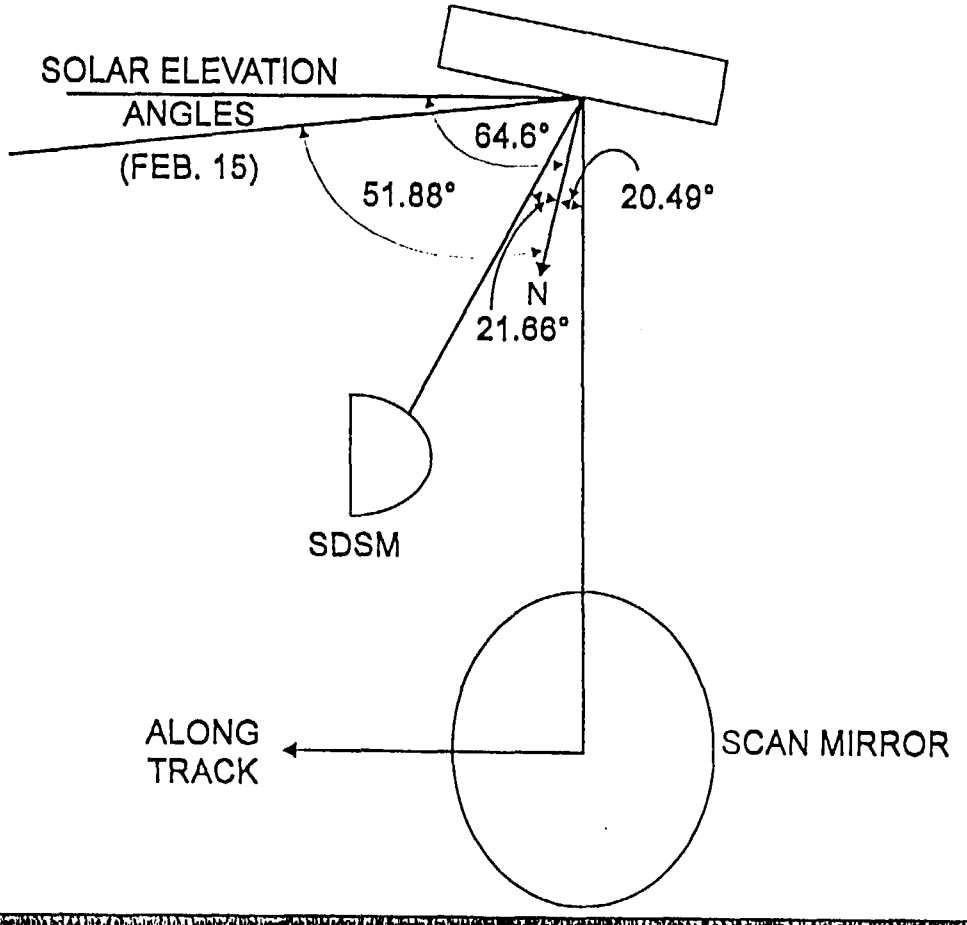
MODIS Solar Diffuser Geometry-I

FORWARD ALONG TRACK VIEW



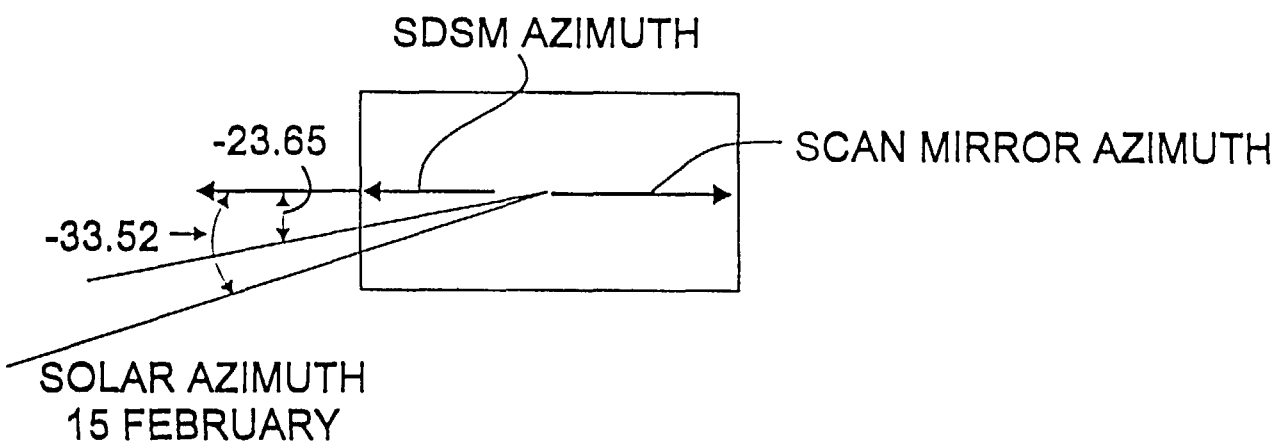
MODIS Solar Diffuser Geometry-II

ACROSS TRACK VIEW



MODIS Solar Diffuser Geometry-III

UPWARD ZENITH VIEW



SIMPLE, STABLE SDSM DESIGN MEETS REQUIREMENTS

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TOP SYSTEM REQUIREMENTS (SDSM Assembly Specification 151791)

- TRACK CHANGES IN SOLAR DIFFUSER REFLECTANCE TO 0.5% ACCURACY OVER VIS/NIR/SWIR BANDS
- SUN SHALL BE USED AS THE REFERENCE SOURCE

DERIVED REQUIREMENTS	MET BY ..... DESIGN/ACTIVITIES
Solar and diffuser illumination shall be viewed and measured similarly (results in an inherently stable design)	2 inch diameter Spectralon integrating sphere provides uniform illumination & radiometric stability Three position fold mirror used to view illumination sources: Sun; Solar Diffuser; DC Restore Simple lens at entrance port spreads solar and diffuser illumination similarly over sphere cavity wall
Reflectance region shall be monitored with 11 bands distributed across 0.4 to 1.7 μm Detector SNRs ≥ 400	11 narrow bandpass filter detectors located in integrating sphere: 9 Si; 2 Ge Direct Solar illumination is attenuated with a 2% transmitting screen; allows a single detector gain setting to be used
Solar reference signal shall be insensitive to variation in solar angle of incidence and/or be correctable	Square entrance aperture results in a simple cosine variation in effective screen transmittance with variation in AOI. Aperture dimensions are an interger multiple of screen's hole spacing.
Power consumption: ≤ 5 W Avg; 10 W Peak	Circuit design complete and breadboarded

SDSM HAS 3 VIEWS VIA ROTATING FOLD MIRROR

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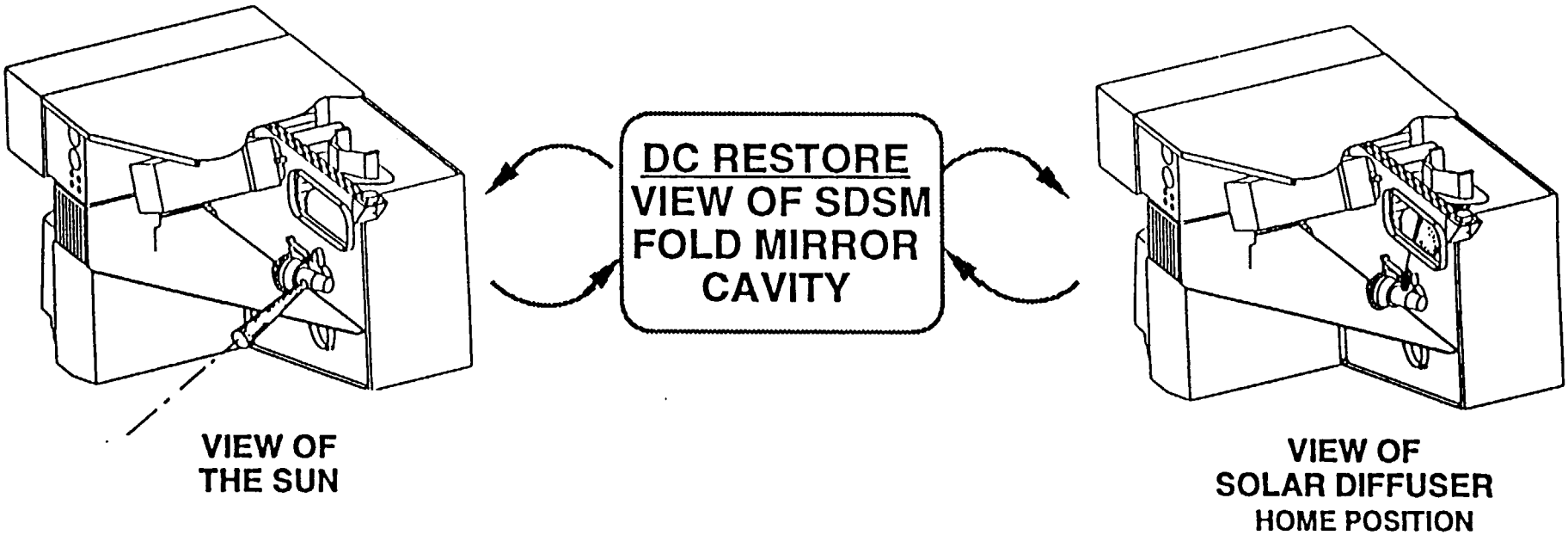

- SDSM INFORMATION AVAILABLE WHENEVER CALIBRATION USING SOLAR DIFFUSER IS PERFORMED (AVAILABLE ONCE PER ORBIT FOR A MINIMUM OF 1 MINUTE DURATION).
- MULTIPLE SAMPLES COLLECTED PER SDSM VIEW FOR ALL 11 DETECTORS.
- FREQUENCY FOR SUN AND SOLAR DIFFUSER VIEWING IS APPROXIMATELY 10 CYCLES PER MINUTE.

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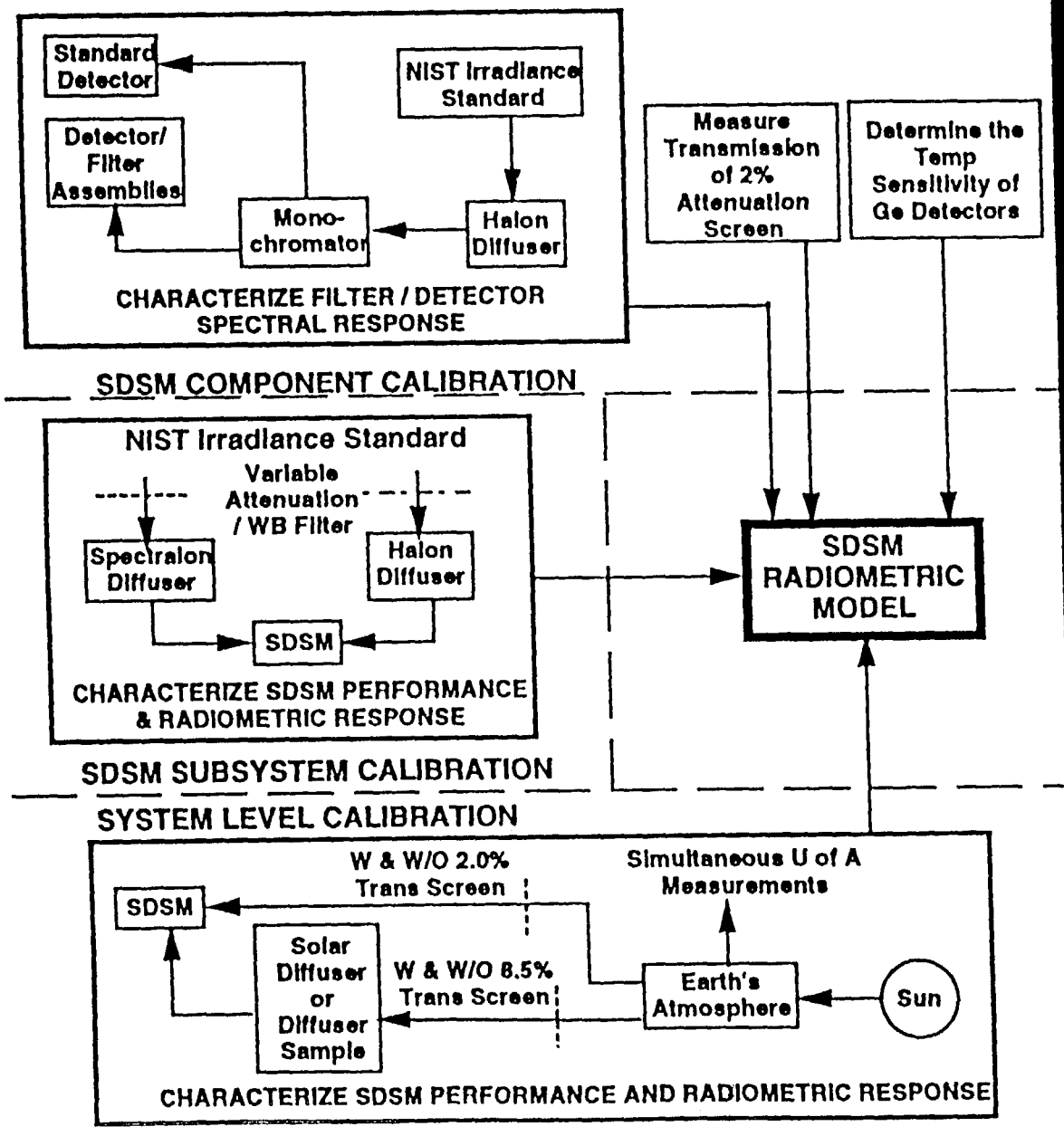
SDSM CALIBRATION & CHARACTERIZATION PLAN



SOLAR DIFFUSER CALIBRATION & CHARACTERIZATION PLAN

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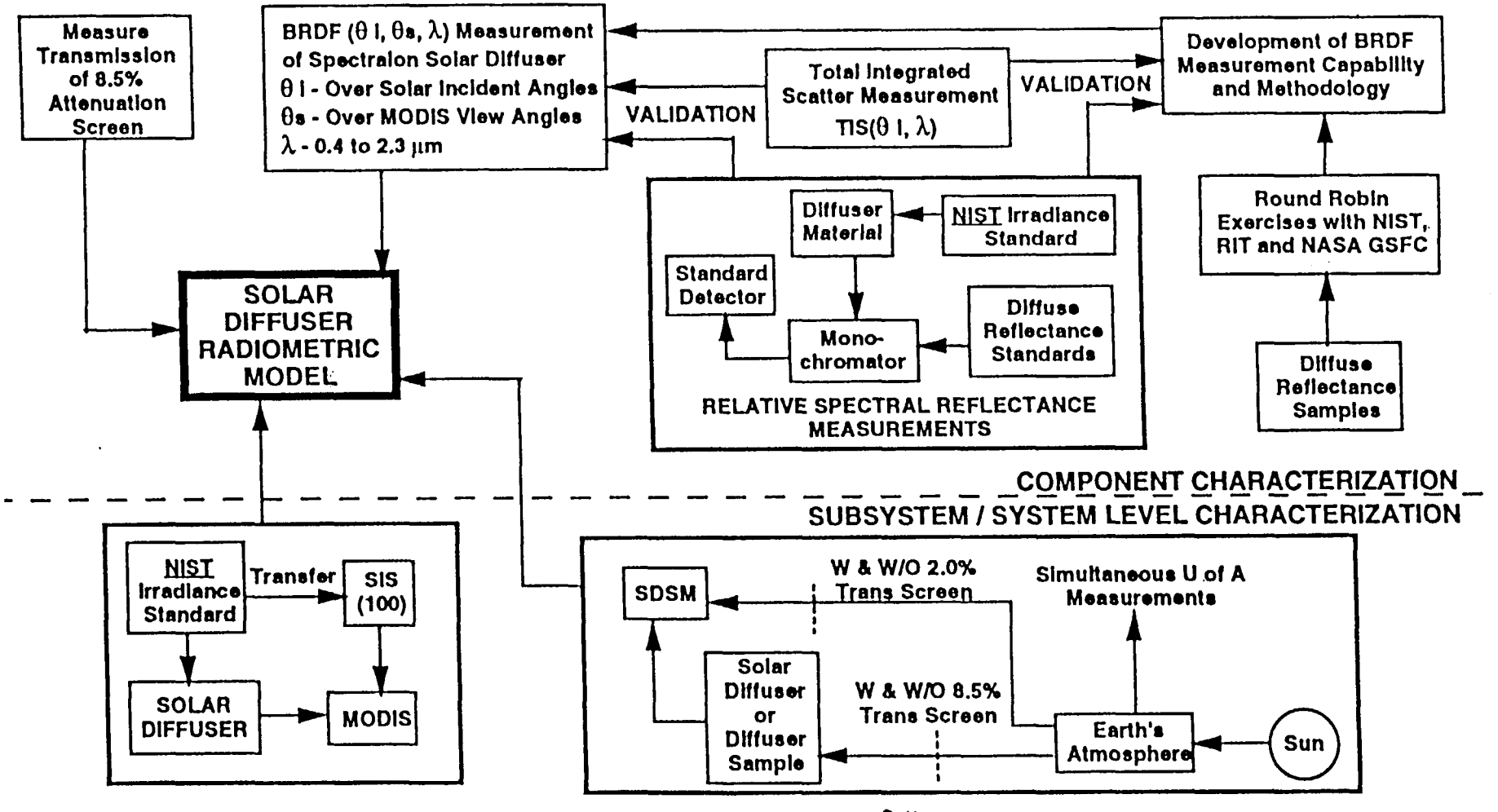


SBRC In-Flight Solar diffuser Stability Monitor (SDSM) Equations

- Last update value of solar diffuser BRDF - BRDF_prev(BB#)
- Last update value for SDSM correction factor - Fcorr_prev(BB#)
- Select calibration level: High - without screen; low - with screen
- Time of year - TOY
- Sun to diffuser angle of incidence: Øinc(F#, αhor, SL#)
- SDSM detector signals all bands dc restore function - DN_dcr(SL#, BB#)
- SDSM detector signals all bands direct sunlight - DN_sun(SL#, BB#)
- SDSM detector signals all bands solar diffuser - DN_sd(SL#, BB#)

  NOTE: DC restore signal and either direct sun or solar diffuser signals are obtained each scan line throughout the one minute used to obtain solar diffuser calibration and SDSM data.
- Calculate SDSM correction factor for each scan line set and SDSM bands:

$$\mathrm{Fcorr}(SL\#, BB\#) = \frac{DN\_sd(SL\#, BB\#) - DN\_dcr(SL\#, BB\#)}{\cos(\varnothing sun\_sd)} * \frac{\cos(\varnothing sun\_att\ scr)}{DN\_sun(SL\#, BB\#) - DN\_dcr(SL\#, BB\#)}$$

- Calculate current average SDSM correction factor for each SDSM band:

$$\mathrm{Fcorr\_current}(BB\#) = \frac{\sum \mathrm{Fcorr}(SL\#, BB\#)}{\sum SL\#}$$

SBRC In-Flight Solar Diffuser Stability Monitor (SDSM) Equations Cont.

- As this correction factor changes it needs to be applied as a correction to the solar diffuser BRDF. In principle, the following ratio will be used:

$$\frac{\text{BRDF\_current(BB\#)}}{\text{Fcorr\_current(BB\#)}} = \frac{\text{BRDF\_prev(BB\#)}}{\text{Fcorr\_prev(BB\#)}}$$

- The BRDF as given above would be at the SDSM spectral regions. BRDF for the MODIS spectral bands would be derived from these.

5.4 SDSM Required Data (TBD)

The required data includes the following variables:

- File of previous SDSM outputs
- Attenuation screen in / out
- SDSM detector signals for solar diffuser, dc restore, and direct sun viewing
- Special test wherein SDSM is used to support transfer of preflight calibration to inflight includes numerous preflight calibration files

SBRC In-Flight Solar Diffuser Calibration Equations

- Select reflectance or radiance calibration mode: same data collected but data reduction differs.
- Select calibration level: high - without screen; low - with screen
- Time of year: TOY
- Sun-to-diffuser angle of incidence: $\varnothing inc(FD\#, \alpha hor)$
- Record MODIS signals when viewing solar diffuser: DN_sd(B#, Ch#, FD#)
- Record MODIS signals when viewing space port: DN_sp(B#, Ch#, FD#)
- Calculate average space signal: $DN\_sp\_avg(B\#, Ch\#) = \frac{DN\_sp(B\#, Ch\#, FD\#)}{\Sigma F\#}$
- Calculate responsivity - radiance mode

$$RL(B\#, Ch\#, FD\#) = \frac{DN\_sd(B\#, Ch\#, FD\#) - DN\_sp\_avg(B\#, Ch\#)}{\Delta L}$$

- Calculate responsivity - reflectance mode

$$R\rho(B\#, Ch\#, F\#) = \frac{DN\_sd(B\#, Ch\#, F\#) - DN\_sp\_avg(B\#, Ch\#)}{\Delta \rho}$$

where $\Delta L(B\#, Ch\#, \varnothing inc) = BRDF(\varnothing inc, \varnothing modis) * Esun(B\#) * \cos(\varnothing sun\_sd)$

$\Delta \rho(B\#, Ch\#, \varnothing inc) = BRDF(\varnothing inc, \varnothing modis) * \cos(\varnothing sun\_sd)$

- Calculate average radiance responsivity:

$$RL\_avg(B\#, Ch\#) = \frac{\Sigma RL(B\#, Ch\#, FD\#)}{\Sigma FD\#}$$

SBRC In-Flight Solar Diffuser Calibration Equations Cont.

- Calculate average reflectance responsivity:

$$R\rho\_avg(B\#, Ch\#) = \frac{\Sigma R\rho(B\#, Ch\#, FD\#)}{\Sigma\ FD\#}$$

- Scene radiance algorithm:

$$L(B\#, Ch\#) = \frac{DN\_scene(B\#, Ch\#, FD\#) - DN\_sp\_avg(B\#, Ch\#, FD\#)}{RL\_avg(B\#, Ch\#)}$$

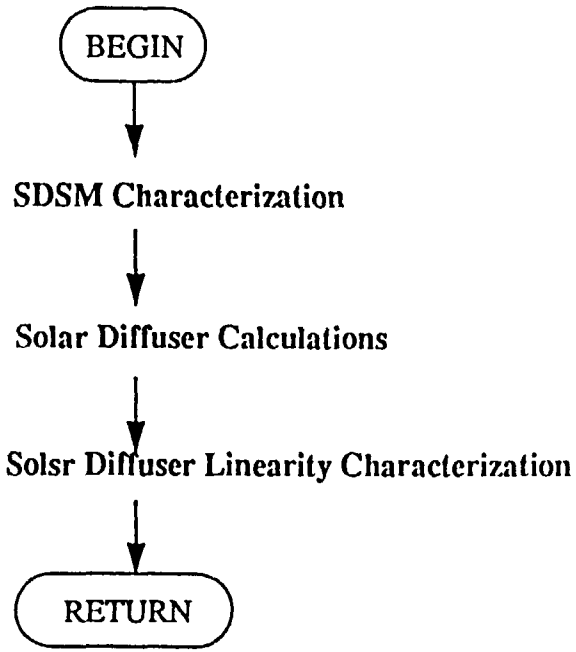
- Scene reflectance algorithm:

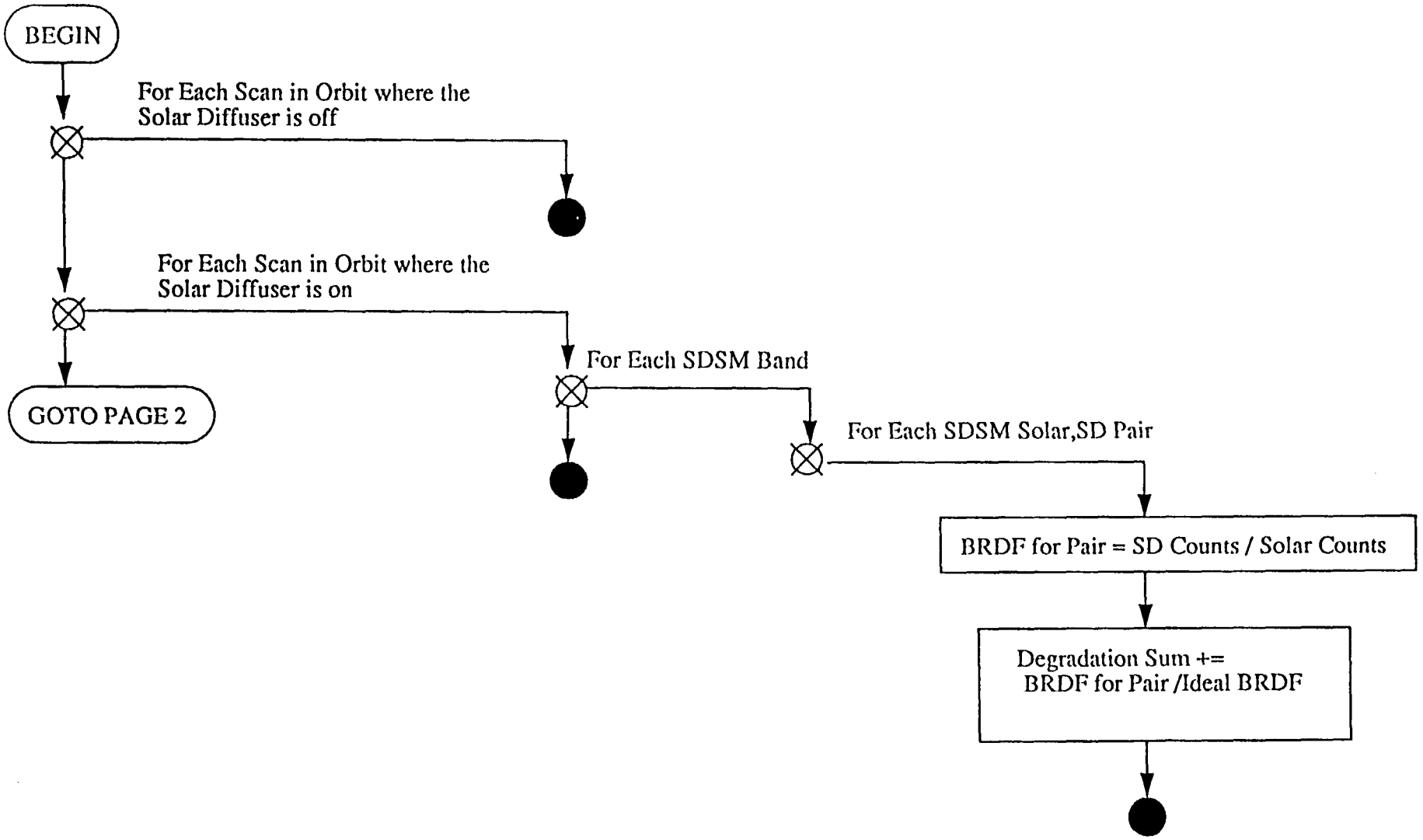
$$\rho(B\#, Ch\#) = \frac{DN\_scene(B\#, Ch\#, FD\#) - DN\_sp\_avg(B\#, Ch\#, FD\#)}{R\rho\_avg(B\#, Ch\#)}$$

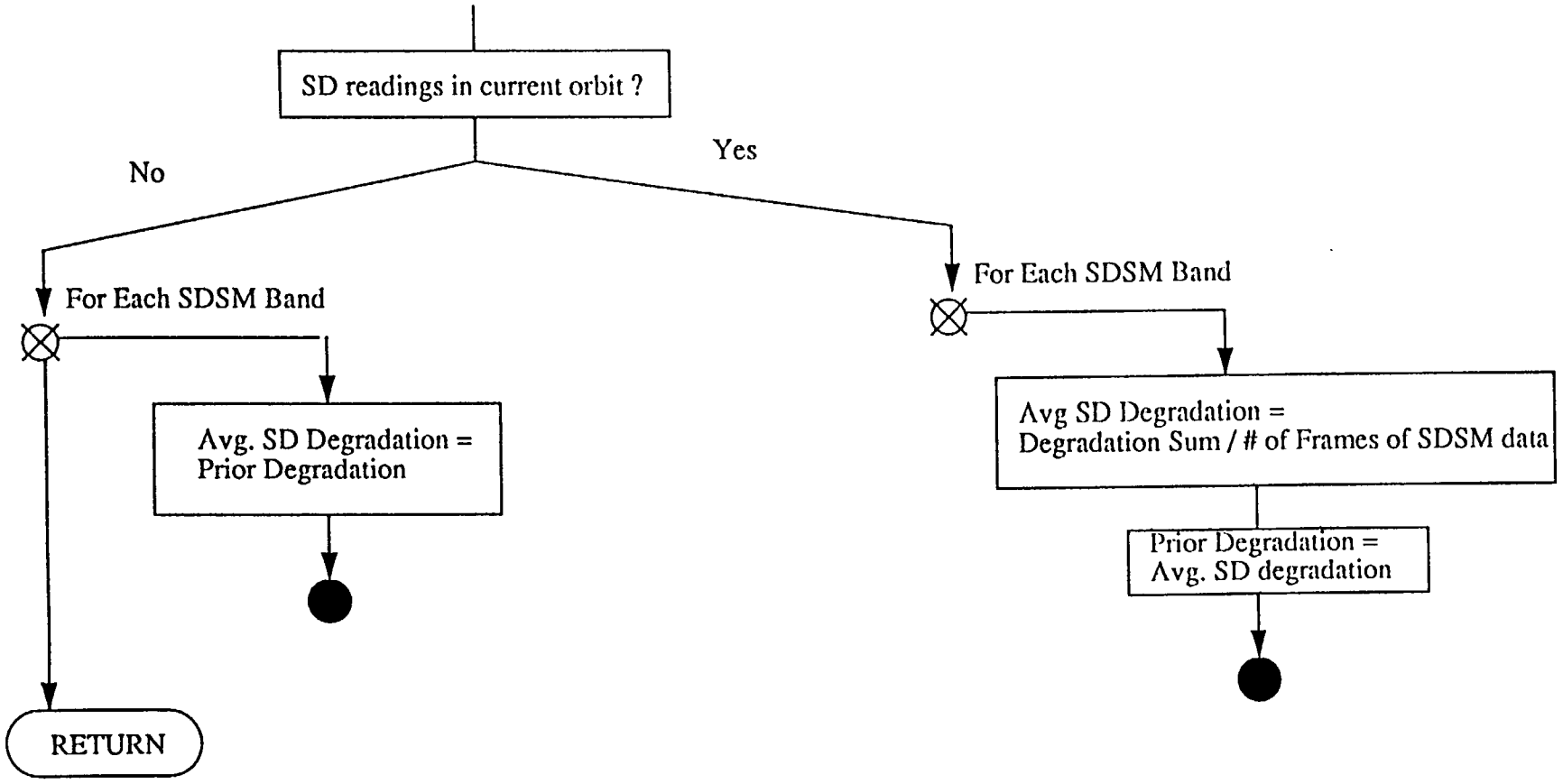
4.4 SDA Required Data (TBD)

The required data includes the following variables:

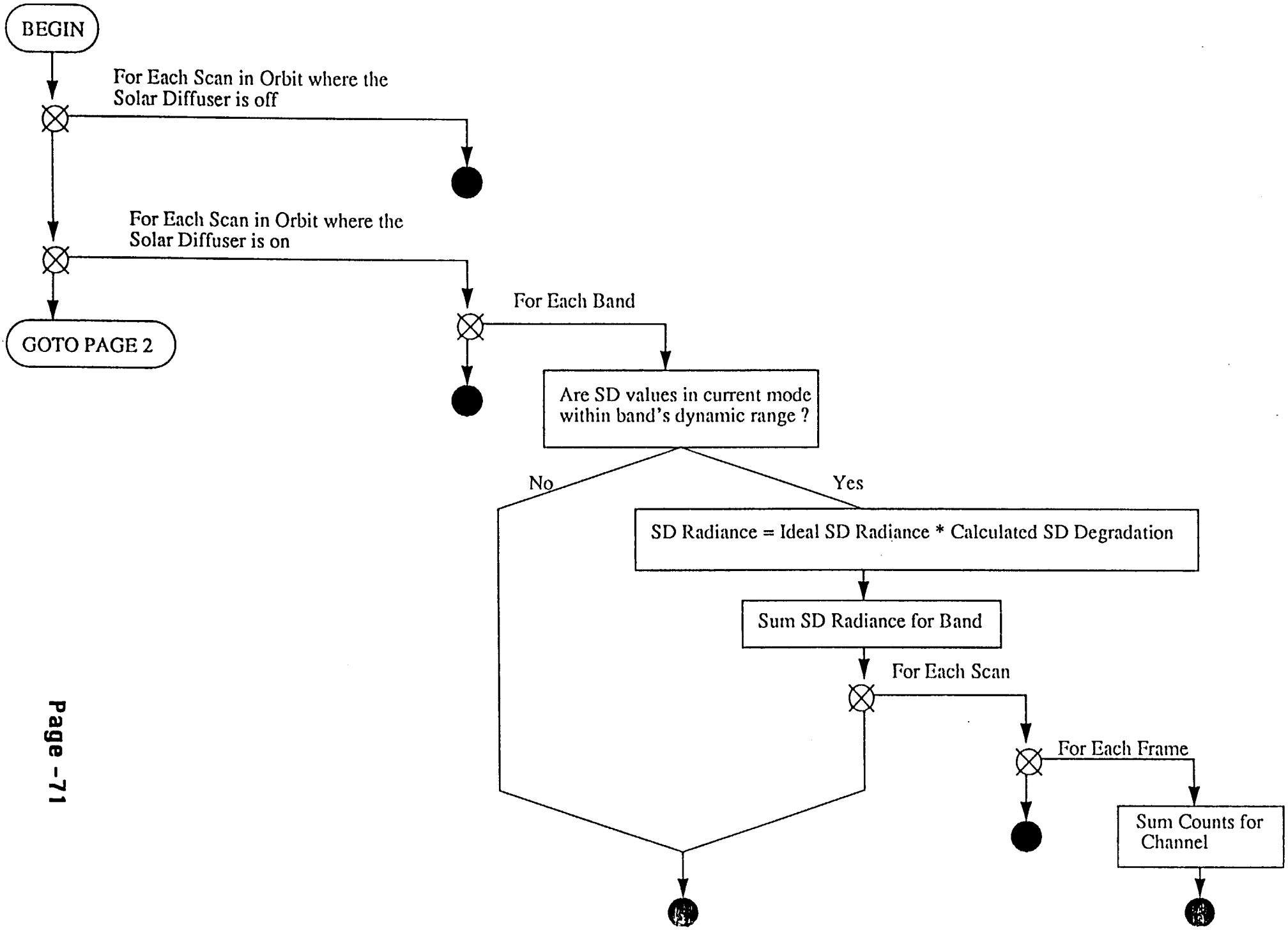
- The spectral BRDF over the region used.
- Is the attenuation screen in or out?
- The attenuation screen transmissio
- Solar spectral irradiance
- Angular relationship of sun and solar diffuser normal
- MODIS relative spectral response functions
- SDSM data to be used to correct solar diffuser BRDF, if needed


BEGIN
SDSM Characterization
Solar Diffuser Calculations
Solsr Diffuser Linearity Characterization
RETURN

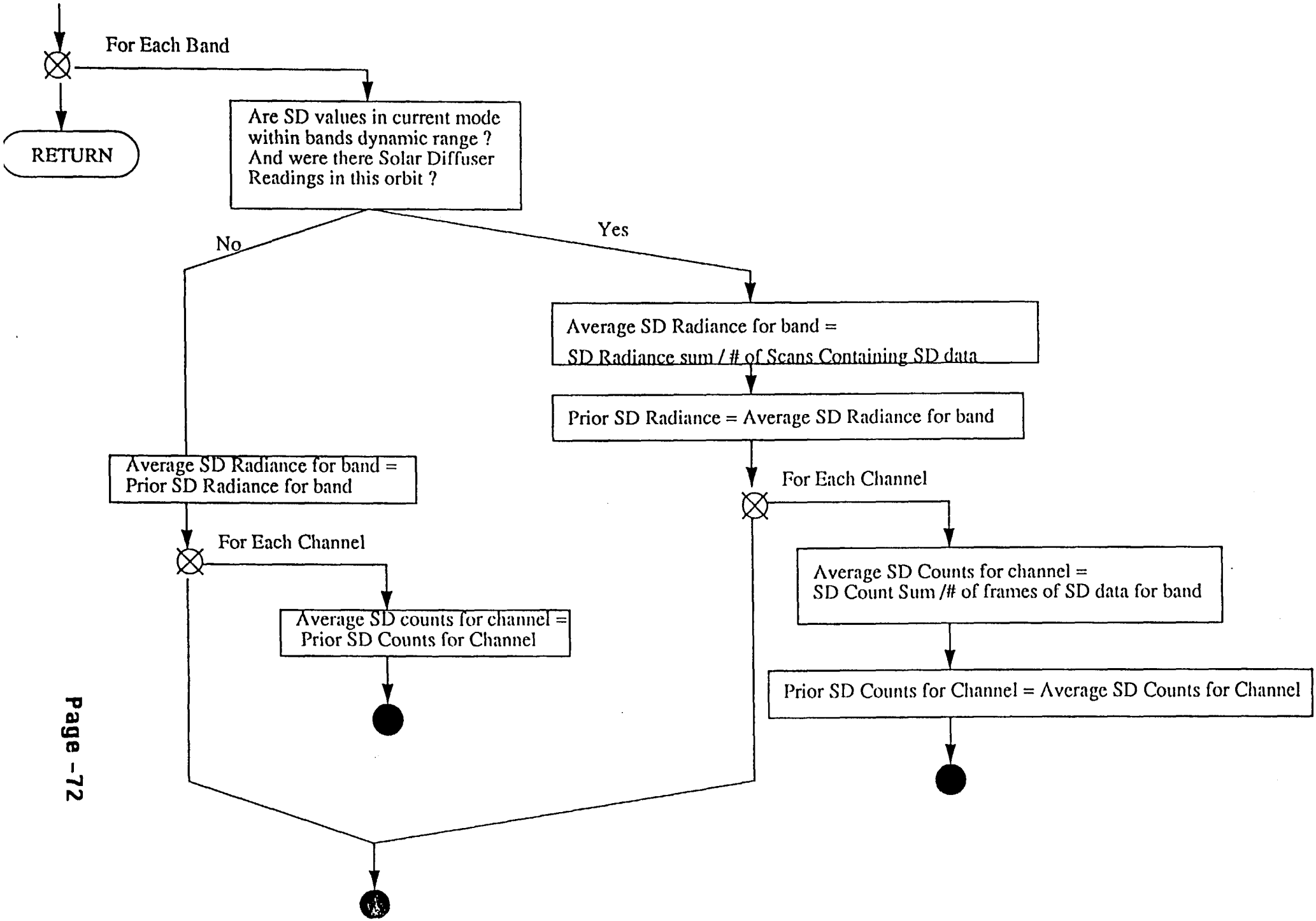

BEGIN
For Each Scan in Orbit where the Solar Diffuser is off
For Each Scan in Orbit where the Solar Diffuser is on
GOTO PAGE 2
For Each SDSM Band
For Each SDSM Solar,SD Pair
BRDF for Pair = SD Counts / Solar Counts
Degradation Sum += BRDF for Pair /Ideal BRDF


SD readings in current orbit ?
No
Yes
For Each SDSM Band
Avg. SD Degradation =
Prior Degradation
RETURN
For Each SDSM Band
Avg SD Degradation =
Degradation Sum / # of Frames of SDSM data
Prior Degradation =
Avg. SD degradation

Solar Diffuser Calculations Page 1



Solar Diffuser Calculations Page 2



Experience With SBUV Solar Diffuser Calibration

from Cebula (1988)

- Ground aluminum diffusers used in SBUV series
- Contaminant sources: Outgassing from satellite
  Direct solar radiance
  Solarization of contaminants
- Solar irradiance stable to 4%
- SBUV Instrument wavelength range: 250 to 340 nm
- Reflectance typically degraded 40% in 5 years (600 hrs. of exposure)
- Negative Exponential Model Established:

$$F\lambda = F\lambda(t_0)P(t_0)e - r\lambda E(t)e^{-S'\lambda t}e^{-\delta}\lambda G(\lambda) \quad \text{accurate to 2\%}$$

- SBUV/2 on NOAA–11 diffuser degrading linearly in first 4 years
- Observed degradation with time even when not exposed to Sun

Shuttle Diffuser Experiment Results

from Hilsenrath (1993)

- Three Missions with SBUV Payload – SSBUV: August 91, March 92, April 93
- Two Materials: Roughened Aluminum
  Polytetrafluroethylene (PTFE) also called Spectralon and Halon
- No In–Flight Data from samples
  - Reflectance and surface chemical composition measured before and after flights
- Exposure Times:

Flight	Sun View	Earth View
SSBUV-3	3.3 hours	60.0 hours
SSBUV-4	5.2 hours	82.5 hours
SSBUV-5	9.2 hours	106.5 hours

- Shuttle Contaminants: Silicones, Hydrocarbons
- Results: Reflectance Degradation Ratio: Post-flight/Pre-flight

	Alumunimum			Spectralon		
MISSION	300 nm	600 nm	900 nm	300 nm	600 nm	900 nm
SSBUV-3	0.96	0.98	0.98	0.87	1.00	1.00
SSBUV-4	0.73	0.94	0.97	0.85	1.00	1.00
SSBUV-5	0.975	0.99	1.00	0.925	1.00	1.00

- Conclusions: Ground Aluminum less sensitive to reflectance change than Spectralon in UV. Small to non-existent change occurred above 400 nm for both materials.

MCST SD Algorithm Development Plans

- Solar illumination geometry/radiometry simulator being developed to predict MODIS output from SD view as function of orbit position, attitude, time of year, etc.

- Solar spectrum characterization evaluation

- Statistical analysis and trending operations for BRDF degradation characterization and MODIS SD observations

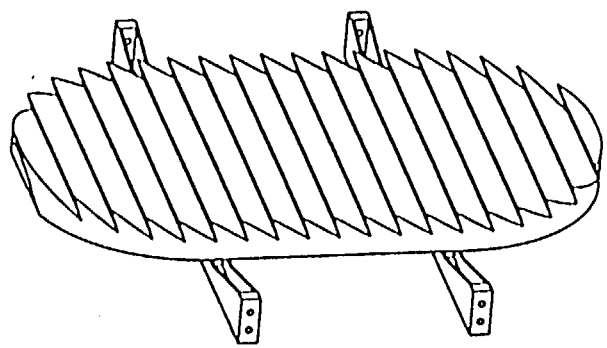
- Modification of BRDF over observation period (1 min.)

- Interpolation of 11 SDSM spectral locations to 20 MODIS band wavelengths (currently nearest neighbor)

- Characterize 8.5% screen projection on SD

The MODIS On-Board Blackbody

Calibration Overview



Dan Knowles Jr.

MODIS Algorithm Team Meeting
9 Mar, 1994

Blackbody Design
GSFC Top System Requirements

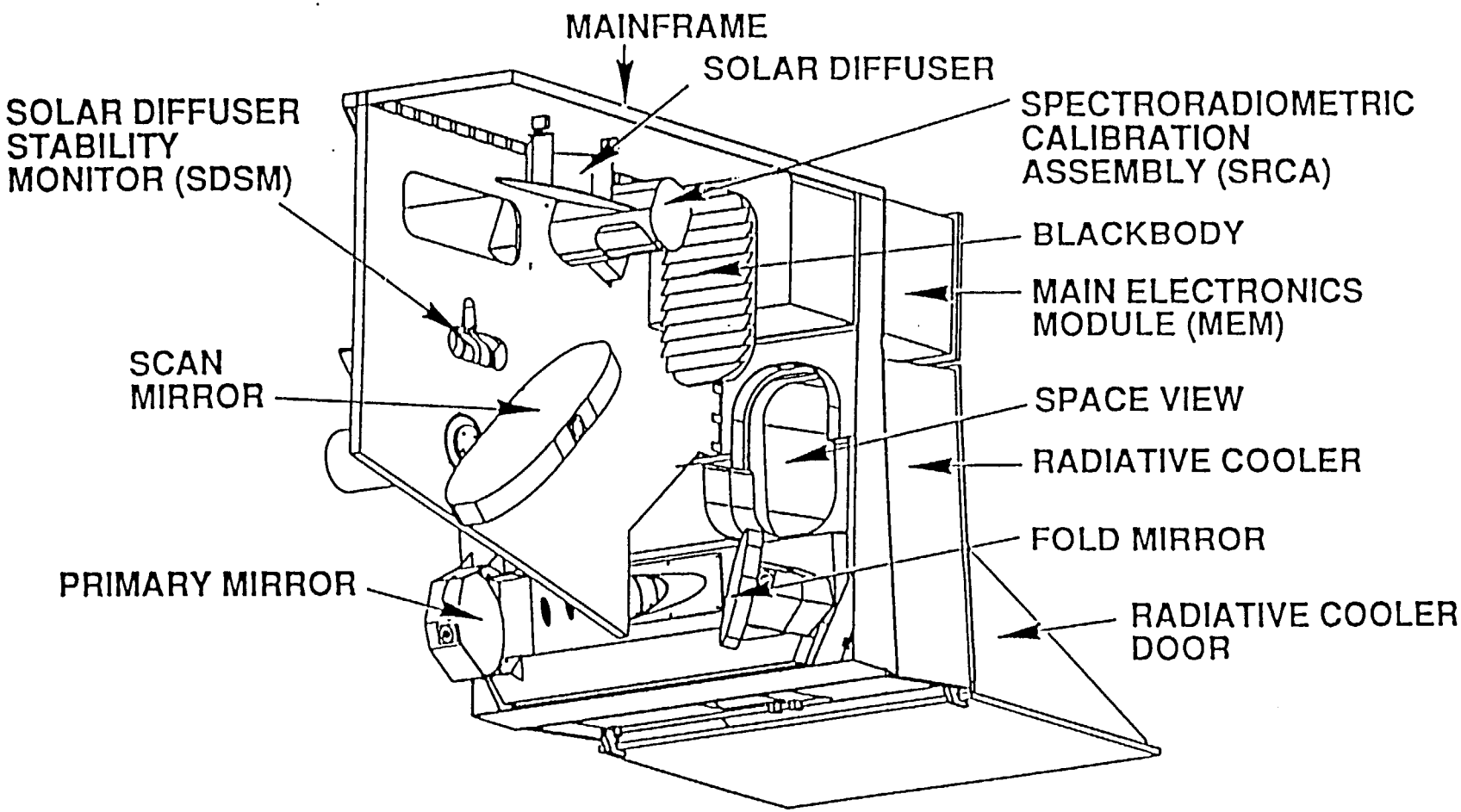
- Absolute 1% (1 sigma) radiometric calibration of MWIR and LWIR bands (0.75% for band 20; 0.5% for bands 31, 32)

- DC restoration view for all bands

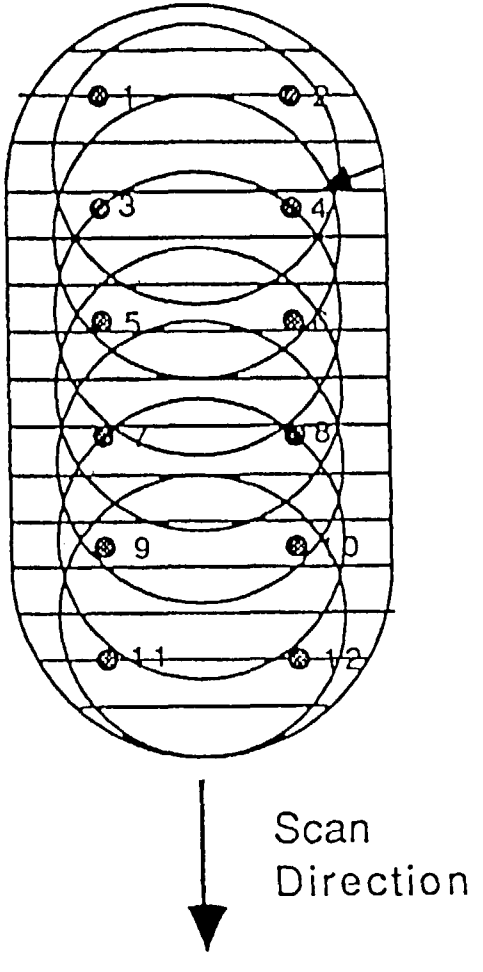
SBRC Derived Requirements (Spec 151790)

- Full aperture illumination filling 46 IFOVS along-scan
- Emittance $\geq$ 0.992 known to within 0.004 for 3.5 - 14.4μm
- Temperature knowledge $\leq$ 0.1K for 280K to 320K
- Ambient and 315K temperature control modes
- Temperature sensors' calibration traceable to NIST
- No direct or indirect solar radiance; minimize earth shine on blackbody
- Power consumption: $\leq$ 30W average; $\leq$ 40W peak.

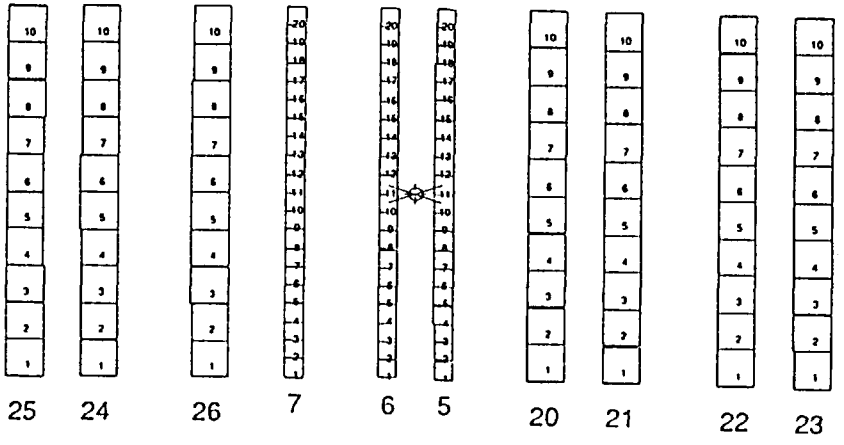
Physical Layout in Object Space



Focal Plane Scan of Blackbody

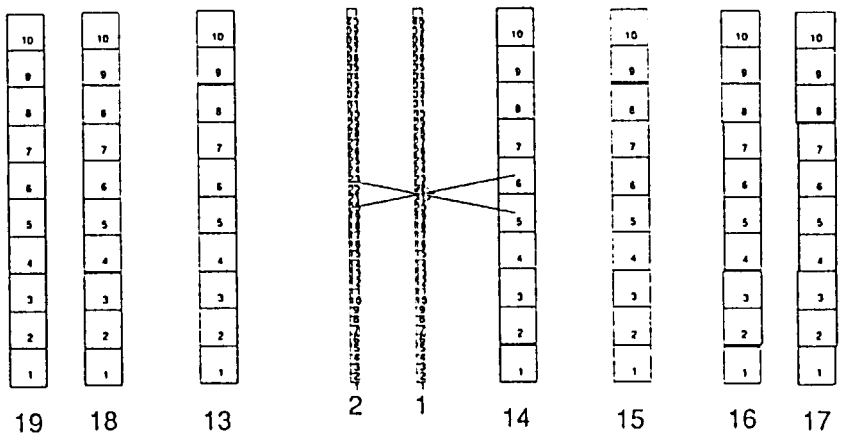


SMWIR FPA



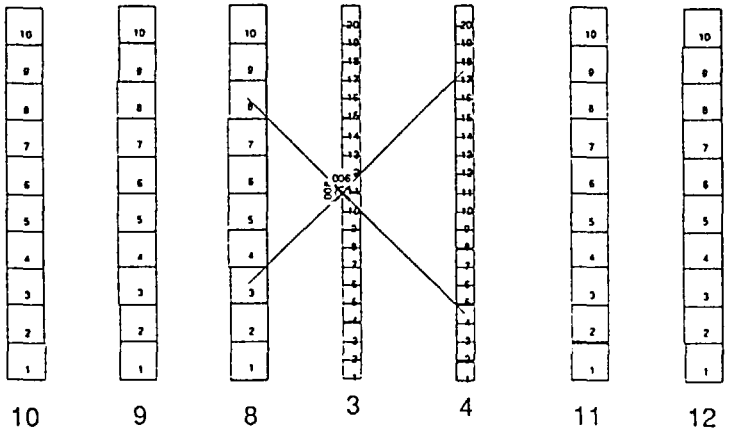
Scan ---->

NIR FPA



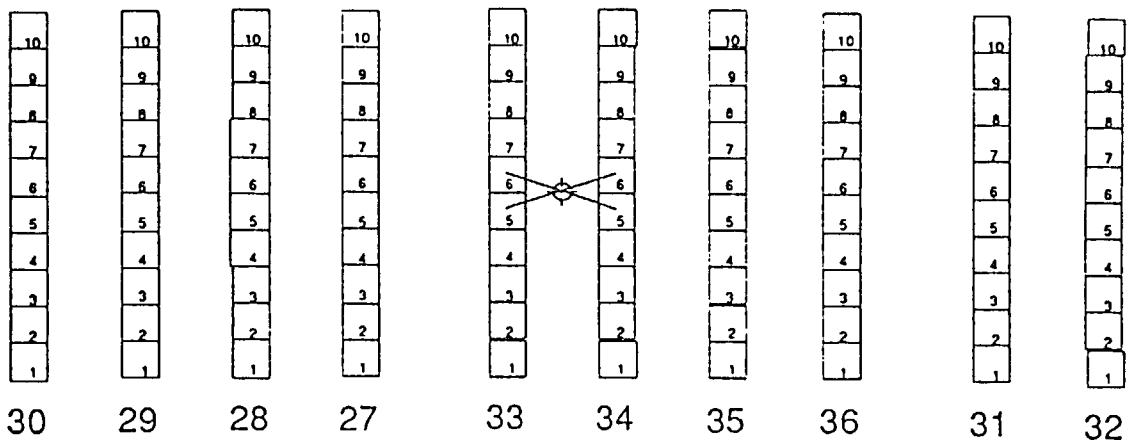
Scan ---->

VIS FPA



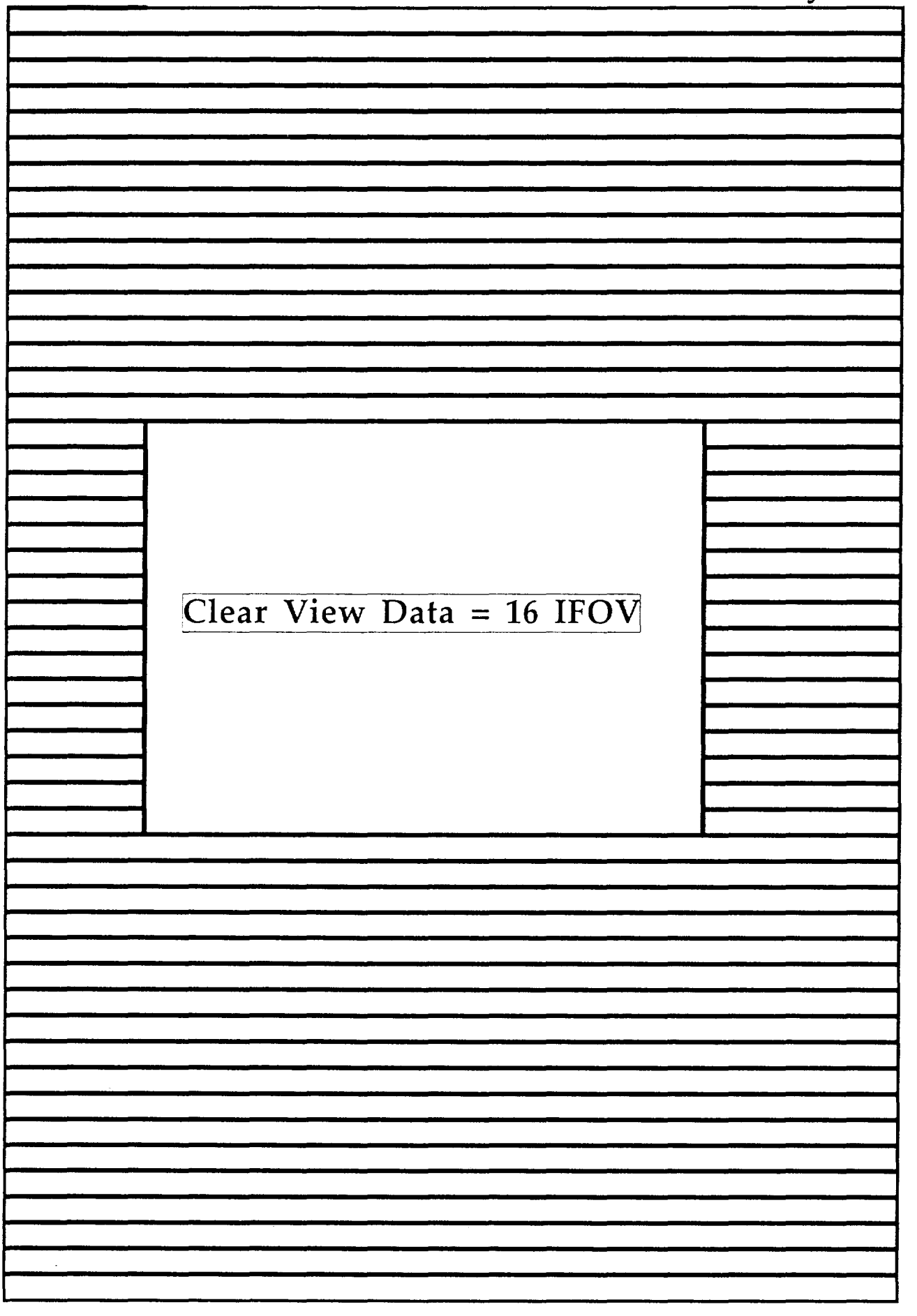
Scan ---->

LWIR FPA



Scan ---->

Scan Of MODIS Focal Planes Across Blackbody

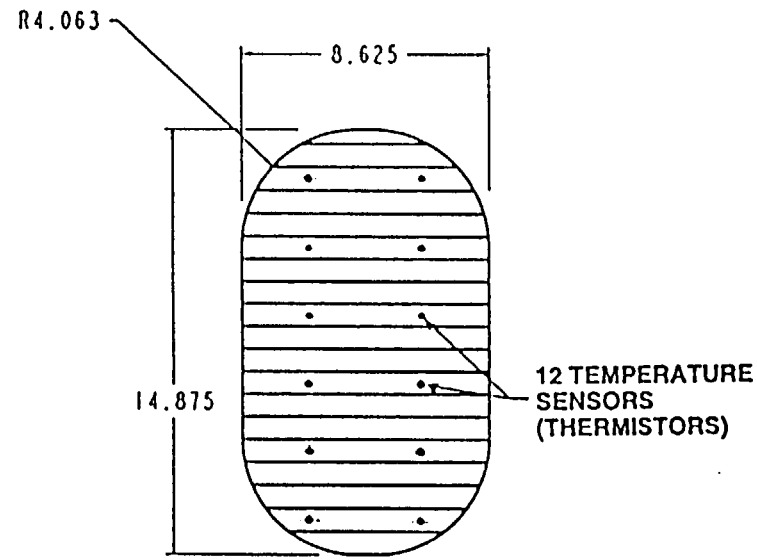


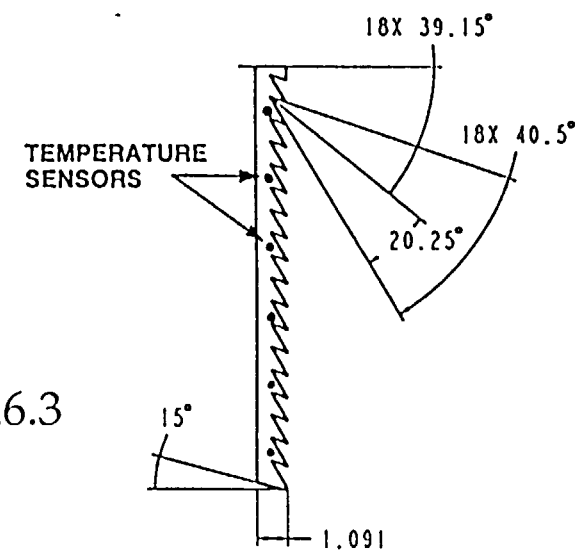
MODIS Blackbody Spatially Aligned Temperature Data Grid

	CH10	CH9	CH8	CH7	CH6	CH5	CH4	CH3	CH2	CH1
FD1										
FD2										
FD3										
FD4										
FD5										
FD6										
FD7										
FD8										
FD9										
FD10										
FD11										
FD12										
FD13										
FD14										
FD15										

Blackbody Parameter Summary

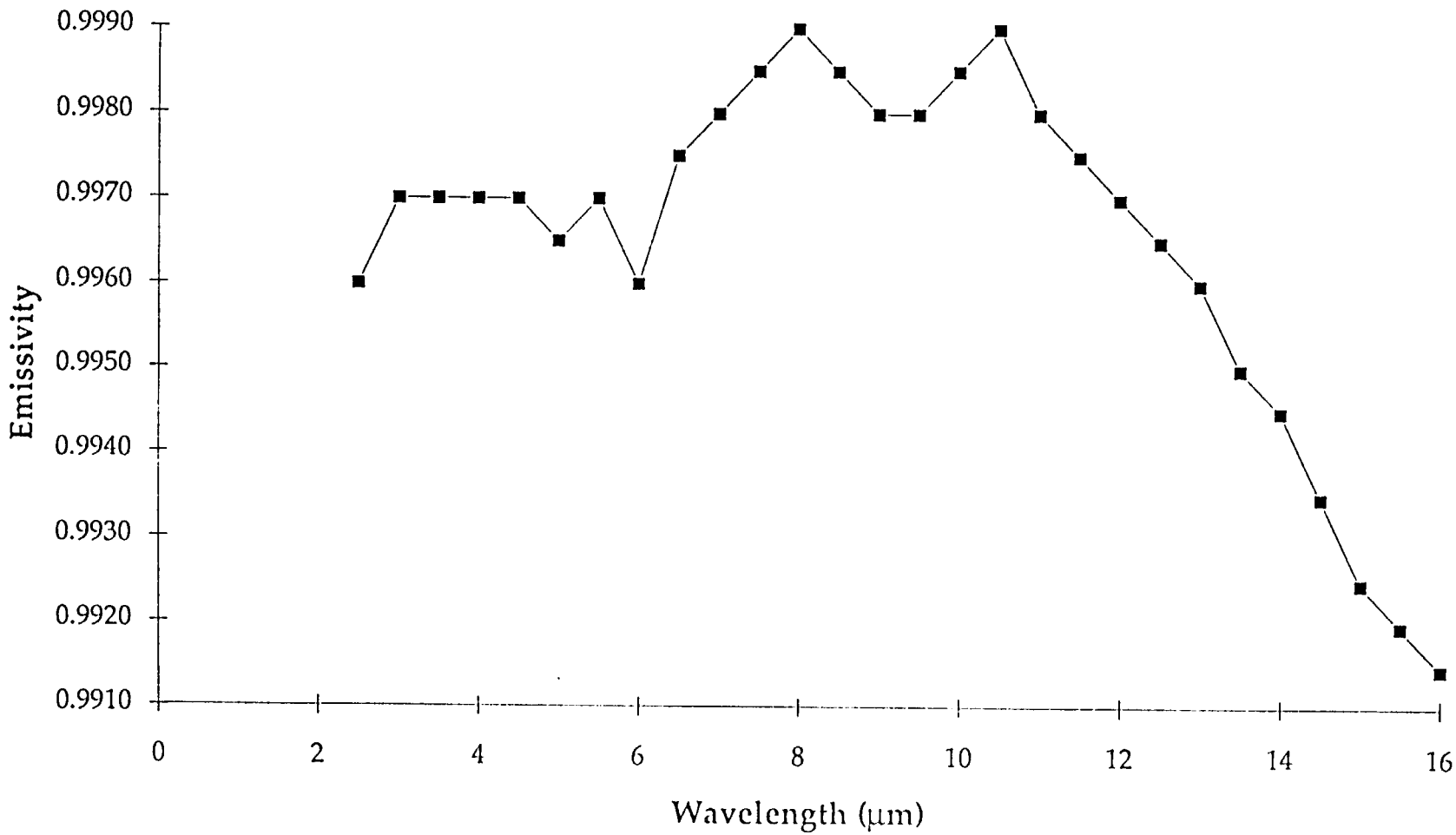
Material - anodized aluminum
Height - 14.875"
Width - 8.625"
Thickness - 1.091"
Weight - 8.3 lbs
Heaters - 4
Thermistors - 12 "bead in glass" thermistors
Blackbody "heat up" (285 - 315) - 130 minutes
Blackbody "cool down" (315 - 285) - 100 minutes
View Angle Range "clear view" - (230.750 - 232.050)
Number of Frames of "clear view" Data - 15
Included Groove Angle - 40.5
Index View Angle - 284
Nominal Blackbody View angle - 231.4
Angle of Incidence on Scan Mirror for Nominal View - 26.3





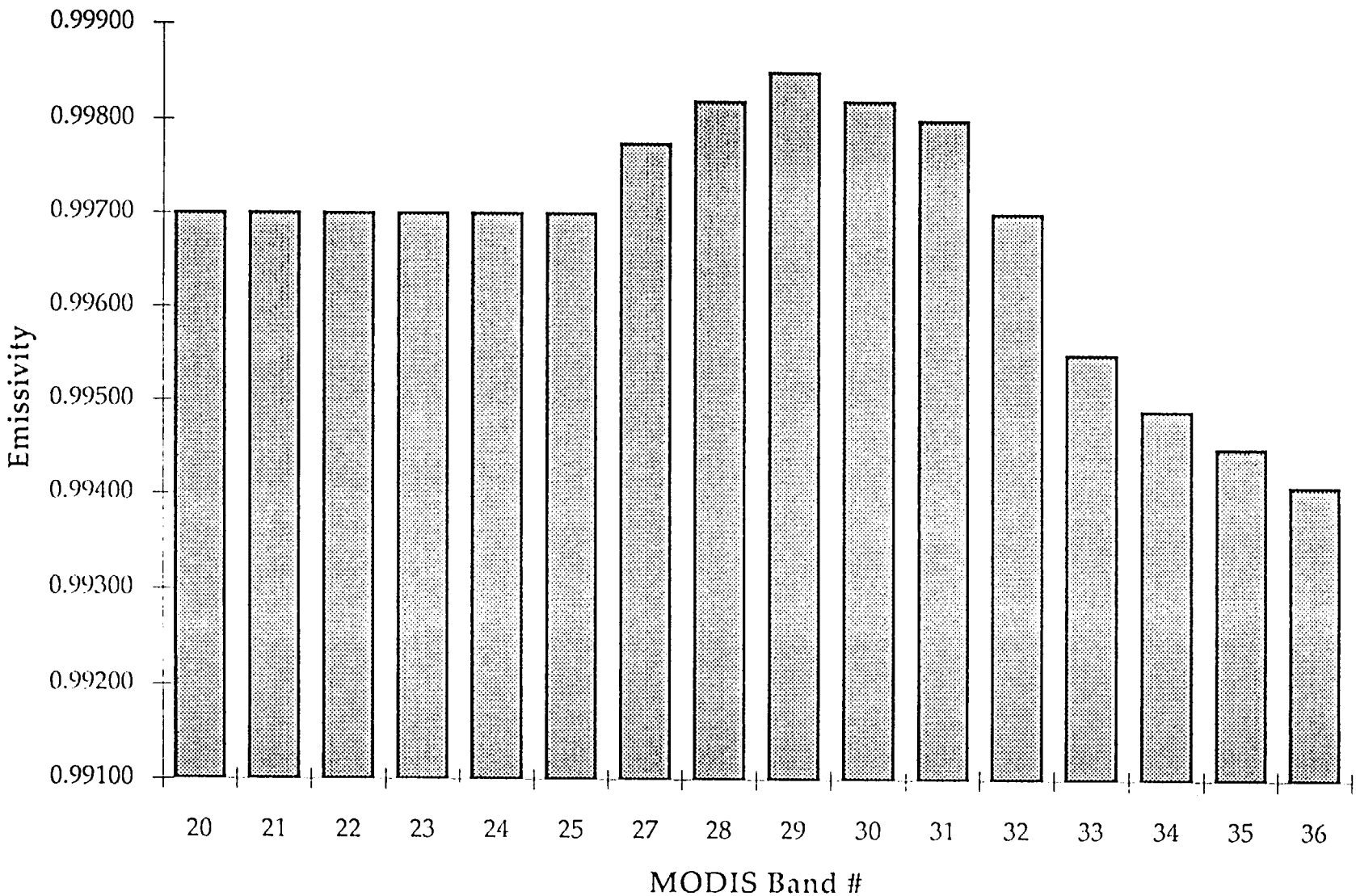
MODIS Blackbody Emissivity vs Wavelength

- Calculation based on type II anodized aluminum data applied to the SBRC emissivity equation



Emissivity vs MODIS Band

- Calculation based on type II anodized aluminum data applied to the SBRC emissivity equation

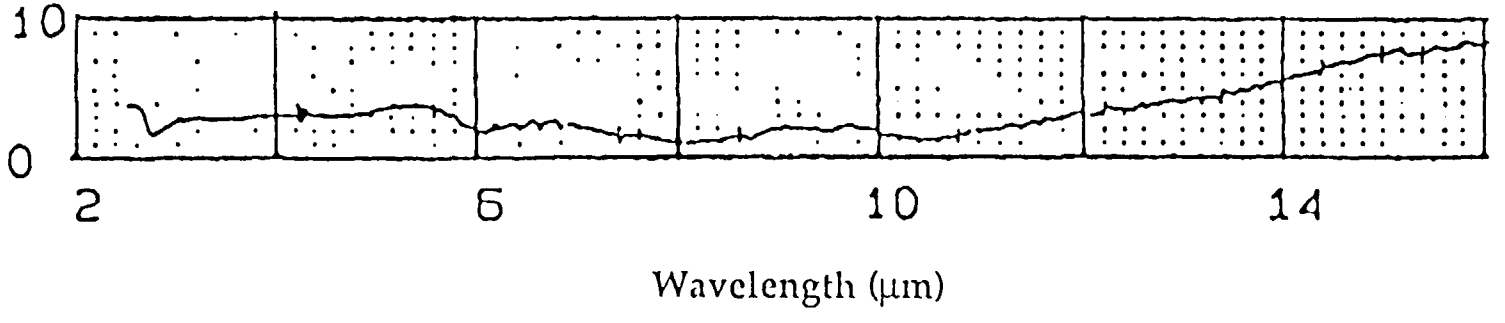


Reflectance of Black Anodized Aluminum

Candidate Anodized Aluminum Material for MODIS Blackbody:

- 6101-T6
- 1100-H18
- 1100-annealed

%Reflectance Plot of Type II Black Anodized Aluminum



Derivation of V-Groove Blackbody Emissivity Equation

$$\varepsilon(\lambda)=1-P(\lambda)$$

where; $P(\lambda)$ = reflectance of blackbody

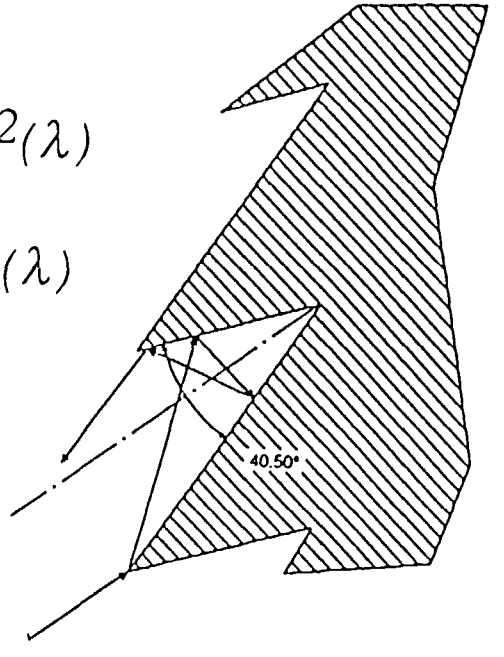
if light undergoes one specular reflection then $P_1(\lambda)=\rho(\lambda)$

if light undergoes two specular reflections then $P_2(\lambda)=\rho(\lambda)P_1(\lambda)=\rho^2(\lambda)$

if light undergoes n specular reflections then $P_n(\lambda)=\rho(\lambda)P_{n-1}(\lambda)=\rho^n(\lambda)$

if light undergoes a variety of reflections with k as its maximum then

$$\varepsilon(\lambda)=1-\sum_{n=1}^{k} w_n \rho^n(\lambda)$$



Calculated Emissivity of the MODIS Blackbody

$$\varepsilon(\lambda)=1-\sum_{n=1}^{k} w_n \rho^n(\lambda)$$

k = # of spectral reflections

$\rho(\lambda)$ = reflectance of black anodized aluminum

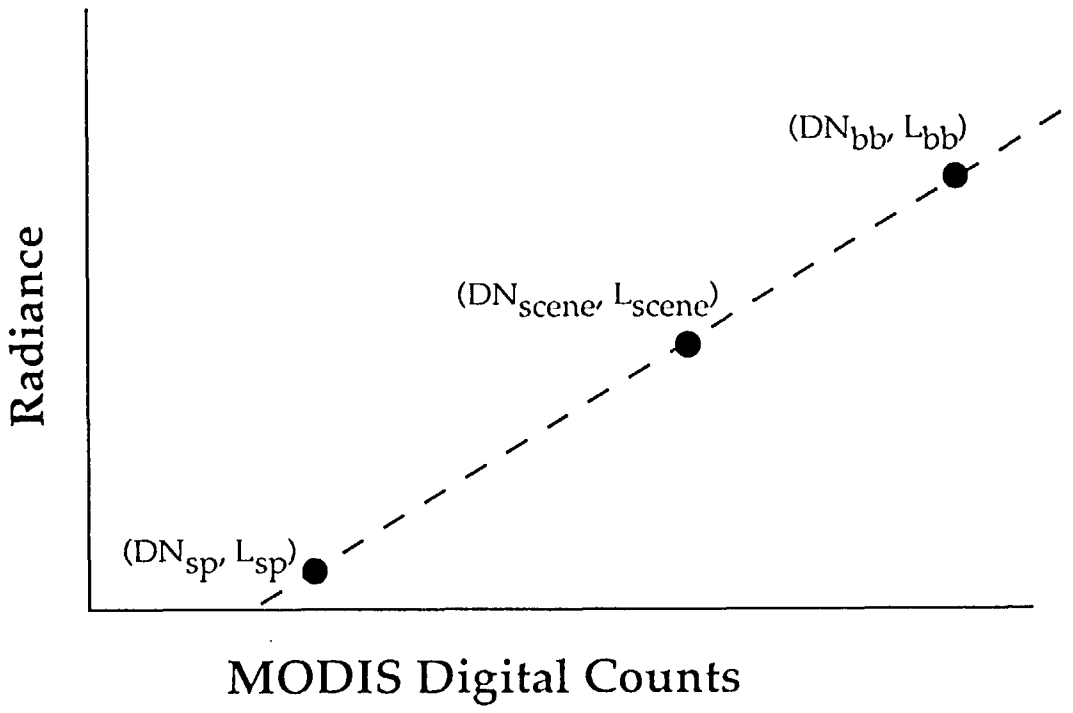
w_1 = 0.1 (10% weight for one specular reflection)

w_4 = 0.9 (90% weight for four specular reflections)

The MODIS V-groove blackbody is designed such that 90% of the reflected light undergoes at least four specular reflections. The remaining 10% undergoes at least one specular reflection. Therefore, emissivity can be calculated as follows:

$$\varepsilon(\lambda)\geq 1-(w_4\rho^4(\lambda)+w_1\rho(\lambda))$$

SBRC's Algorithm Assumes Linear Calibration



$$L_{scene} = L_{sp} + m(DN_{scene} - DN_{sp})$$

$$m = \frac{L_{bb} - L_{sp}}{DN_{bb} - DN_{sp}}$$

SBRC's Radiometric Calibration Algorithm

$$L\_scene(B\#,Ch\#,FD\#) = \frac{DN\_scene(B\#,Ch\#,FD\#) - DN\_sp\_avg(B\#,Ch\#,FD\#)}{R\_avg(B\#,Ch\#)}$$

$$R\_avg(B\#,Ch\#) = \frac{\Sigma R(B\#,Ch\#,FD\#)}{\Sigma FD\#}$$

$$R(B\#,Ch\#,FD\#) = \frac{DN\_bb(B\#,Ch\#,FD) - DN\_sp-avg(B\#,Ch\#)}{\Delta L}$$

$$DN\_sp\_avg(B\#,Ch\#) = \frac{\Sigma DN-sp(B\#,Ch\#,FD\#)}{\Sigma FD\#}$$

L_scene = Radiance of the scene
DN_scene = MODIS digital signal of the scene
DN_sp_avg = Average MODIS digital signal of the space view
R_avg = Average responsivity of the blackbody

$L_{Earth/eff}$ = Effective radiance of the Earth

$L_{Moon/eff}$ = Effective radiance of the Moon

$L_{bb/eff}$ = Effective radiance of the MODIS blackbody

T_{bb} = Temperature of a spatial area of the MODIS blackbody

T_{cav} = Temperature of the MODIS cavity

$\Omega_{cav(bb)}$ = solid angle segmented by the cavity and the blackbody

$\Omega_{Moon(sv)}$ = solid angle segmented by the Moon and the space view

$\Omega_{Earth(bb)}$ = solid angle segmented by the Earth and the blackbody

$\Omega_{Earth(ev)}$ = solid angle segmented by the Earth and the Earth view

ρ_{bb} = reflectance of the MODIS blackbody

ρ_{cav} = reflectance of the MODIS cavity

R = spectral responsivity of the MODIS band

fd# = spatially coincident frame of data

b# = MODIS band number

ch# = MODIS channel number

$\Delta\lambda$ = wavelength resolution

λ_{upper} = center wavelength minus twice the bandwidth

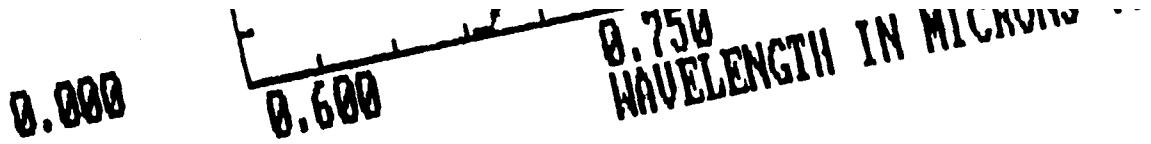
λ_{lower} = center wavelength plus twice the bandwidth

$$B_\lambda = \left[\frac{2hc^2}{\lambda^5 (e^{(ch/\lambda kT)} - 1)} \right]$$

MAT MEETING

Michael Weinreb
NOAA/NESDIS

(March 9, 1994)



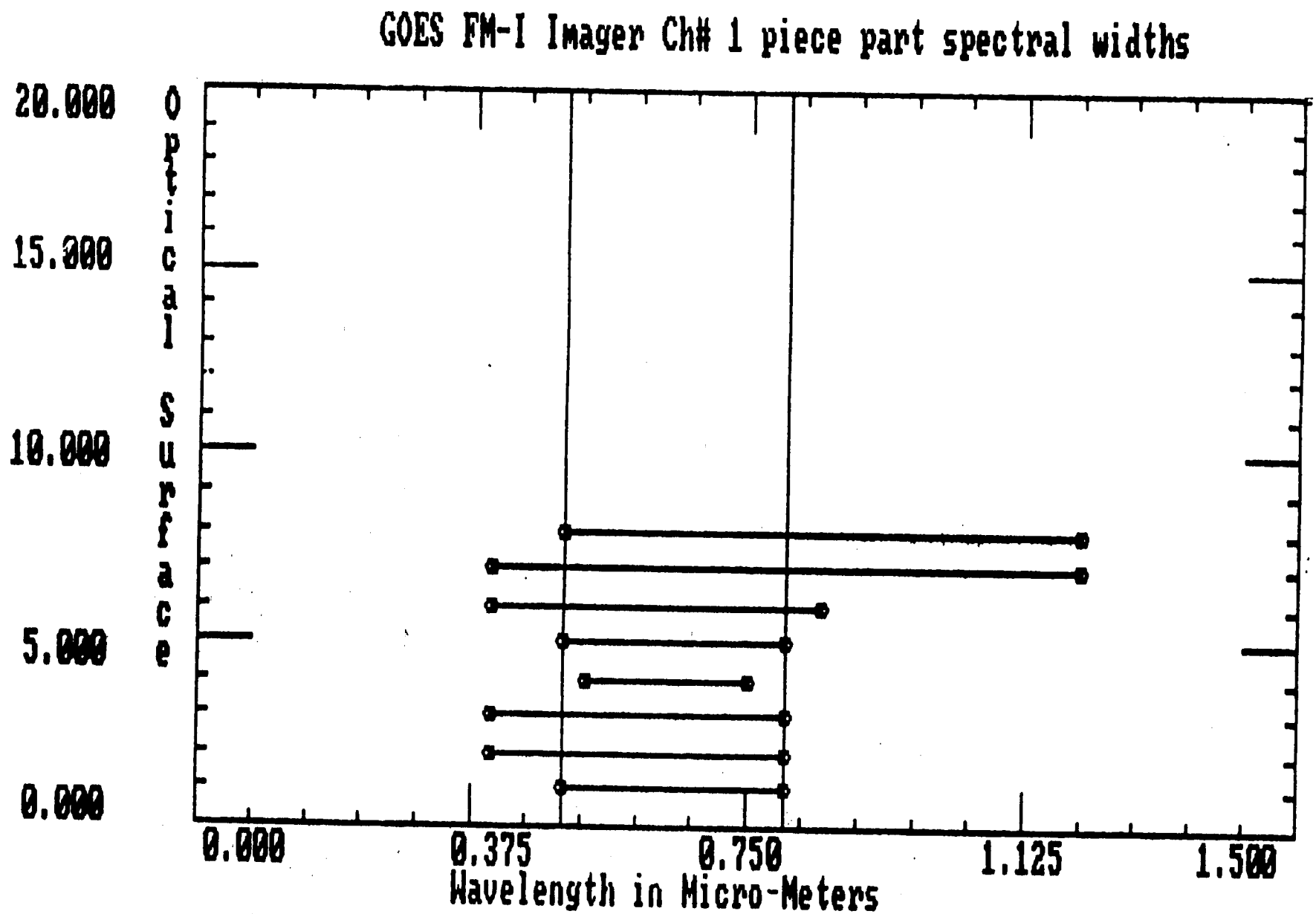
SPECTRAL RESPONSE MEASUREMENT
(IR & VIS)

1. Direct full-system measurement (AVHRR)

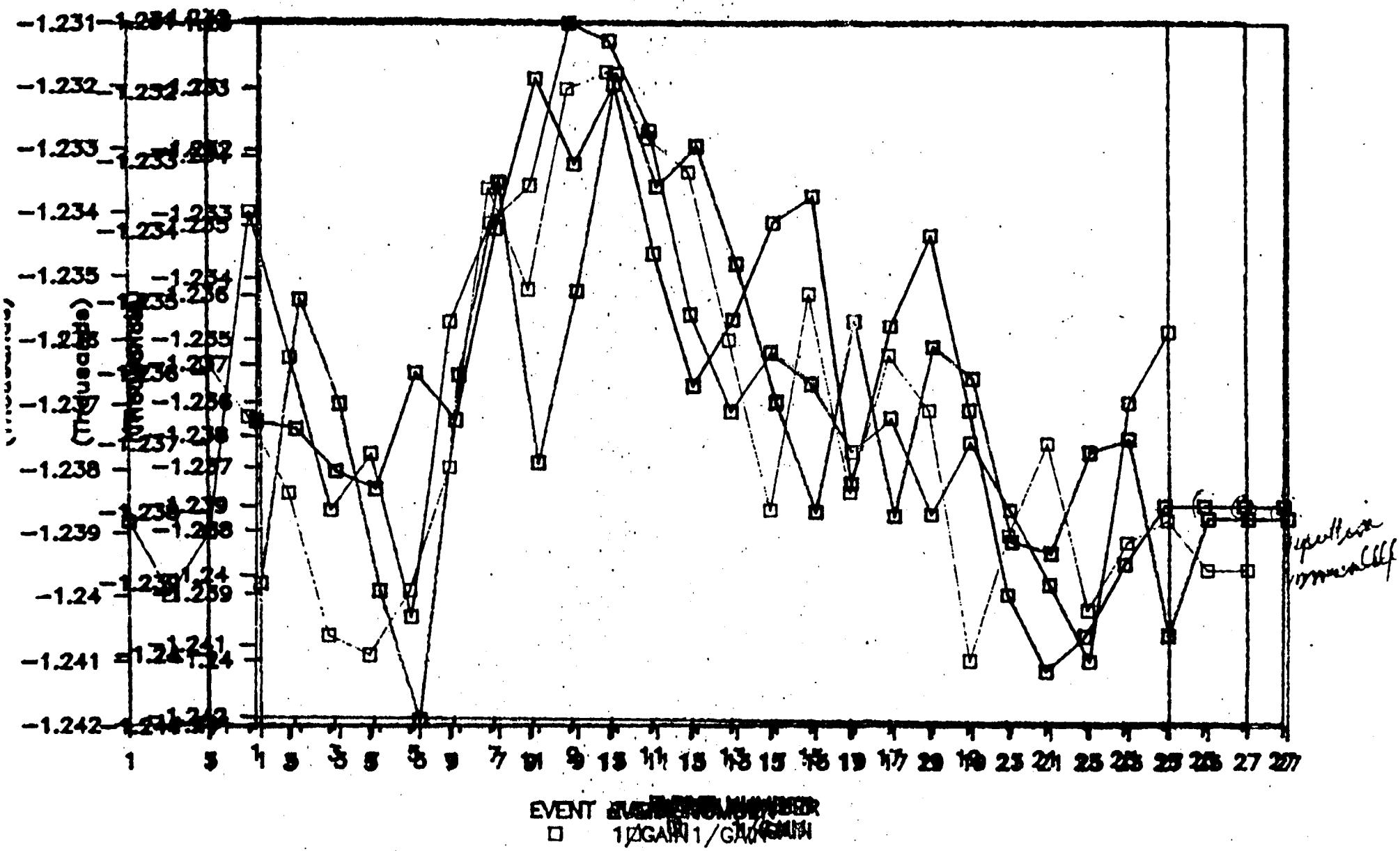
2. Multiplication of responses of individual components or "witness" samples (HIRS, GOES I-M)

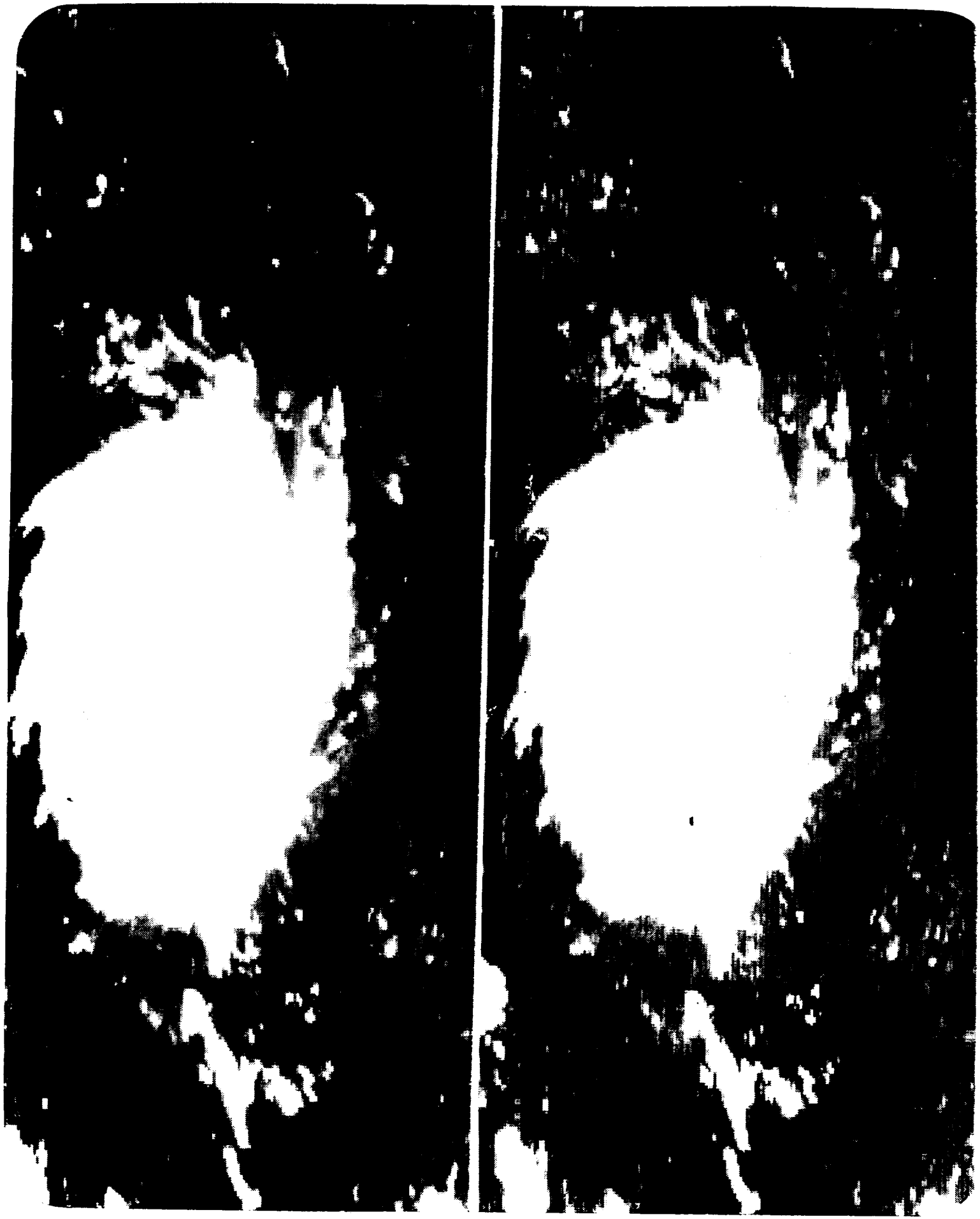
   - o Some components' responses are incomplete

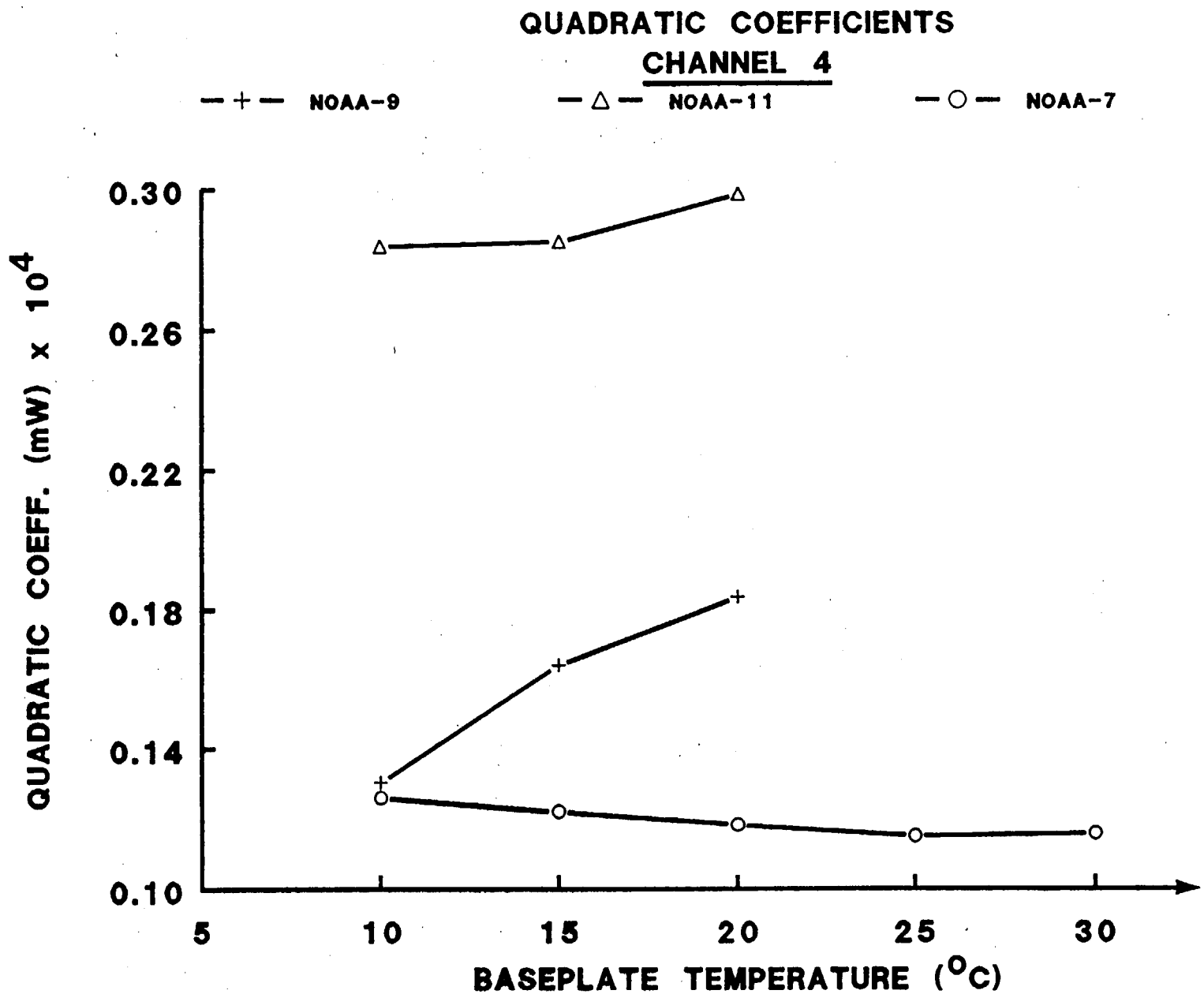
   - o How about polarization & angular effects?


GOES FM-I Imager Ch# 1 piece part spectral widths
20.000
15.000
10.000
5.000
0.000
Optical Surface
0.000
0.375
0.750
1.125
1.500
Wavelength in Micro-Meters

SLOPES: HIRS CH. 8 4 ORBITS OVERLAID






QUADRATIC COEFFICIENTS
CHANNEL 4
NOAA-9
NOAA-11
NOAA-7
QUADRATIC COEFF. (mW) x 10^4
0.30
0.26
0.22
0.18
0.14
0.10
5
10
15
20
25
30
BASEPLATE TEMPERATURE (°C)

QUADRATIC COEFF. (Wm) x 10^4
.130
.125
.120
.115
.110
5
10
15
20
25
30
BASEPLATE TEMPERATURE (°C)

FIGURE 4

$$R = a + bx + cx^2$$

$$\bar{c} = 0.1194 \times 10^{-4} \text{ mW}$$

$$\epsilon_c \leq 0.65 \times 10^{-6} \text{ mW}$$

$$\epsilon_R = \epsilon_c (x - x_{bb})(x - x_s)$$

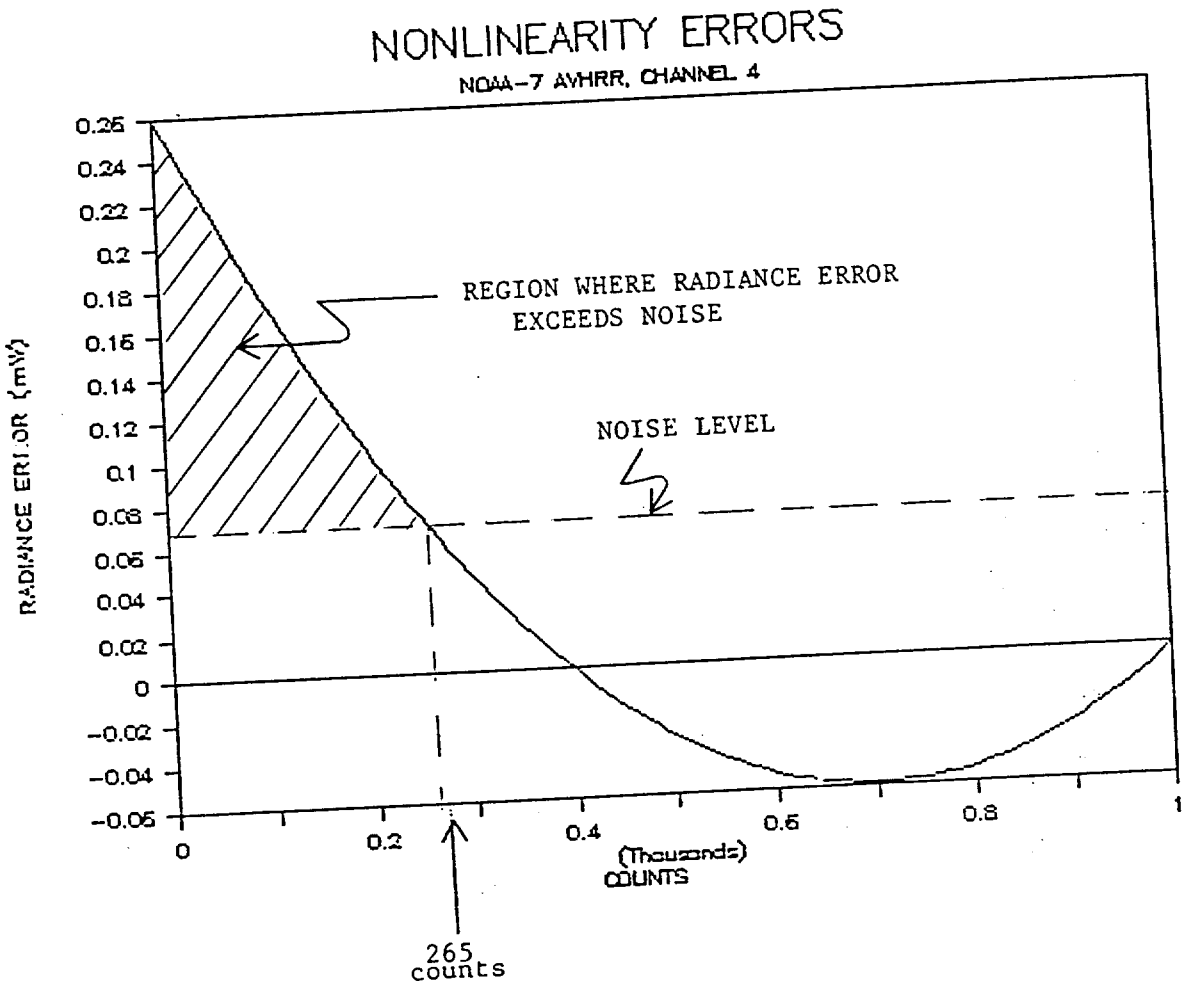
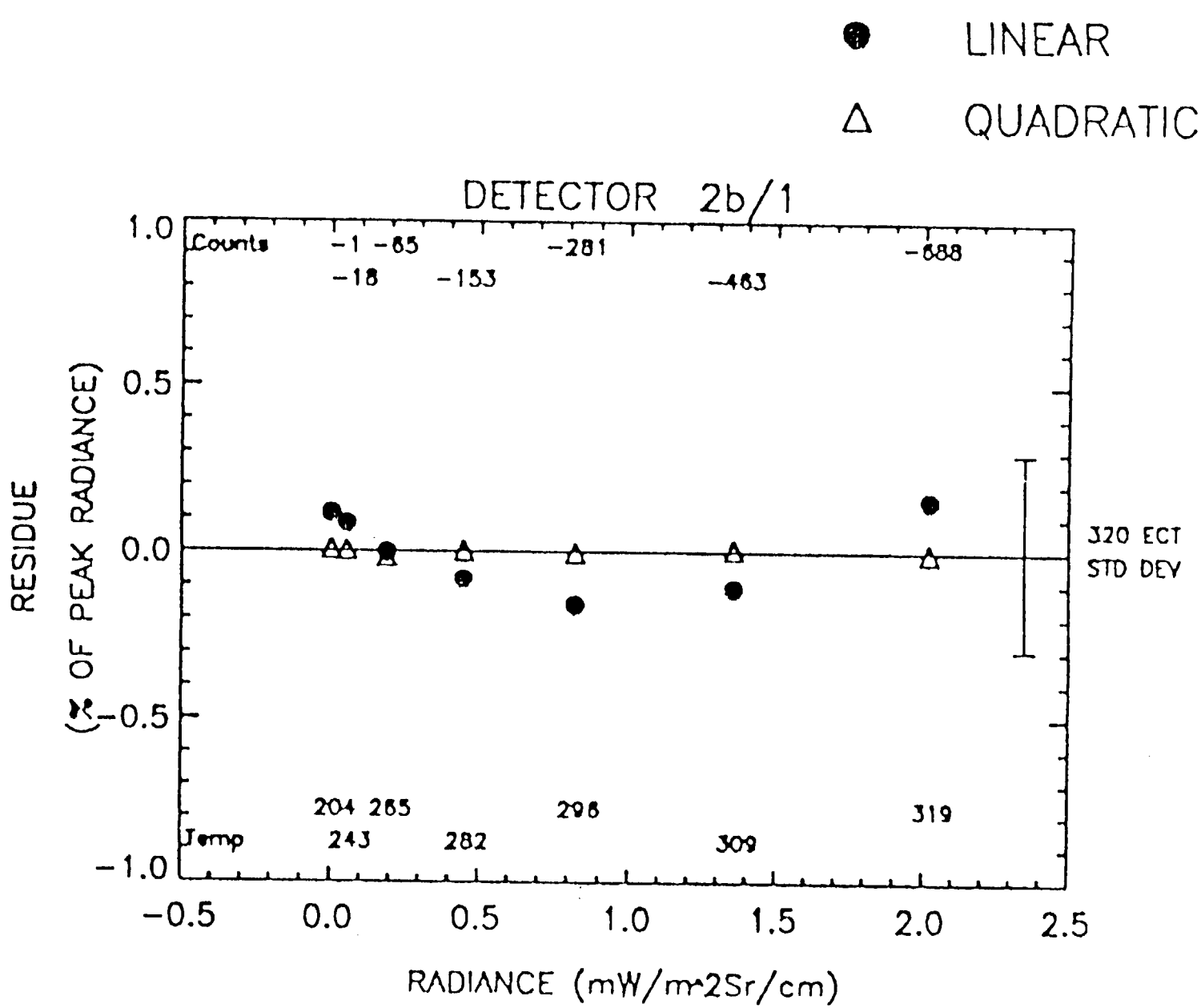
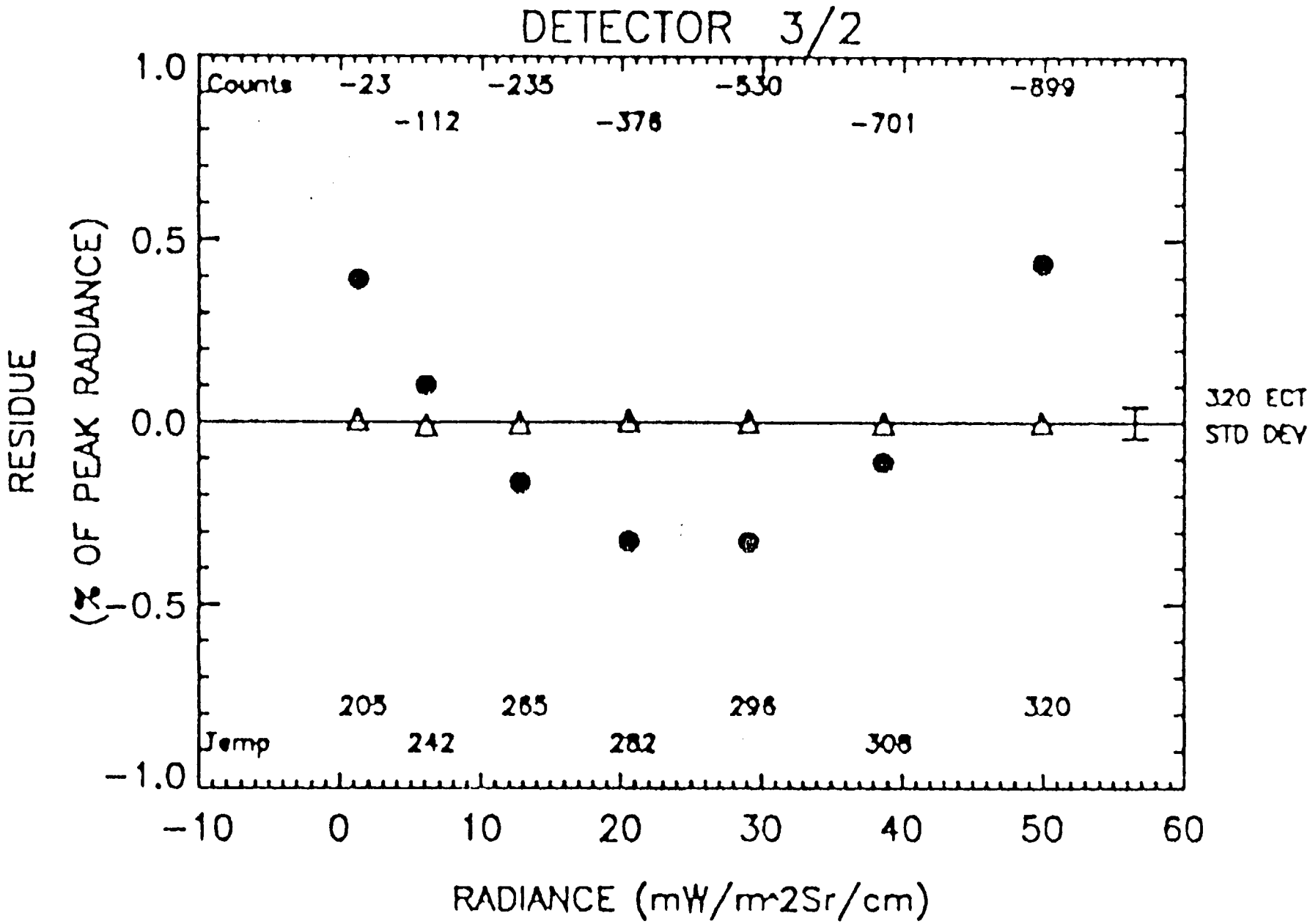

NONLINEARITY ERRORS
NOAA-7 AVHRR, CHANNEL 4
RADIANCE ERROR (mW)
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
REGION WHERE RADIANCE ERROR
EXCEEDS NOISE
NOISE LEVEL
0
0.2
0.4
0.6
0.8
1
(Thousands)
COUNTS
265
counts

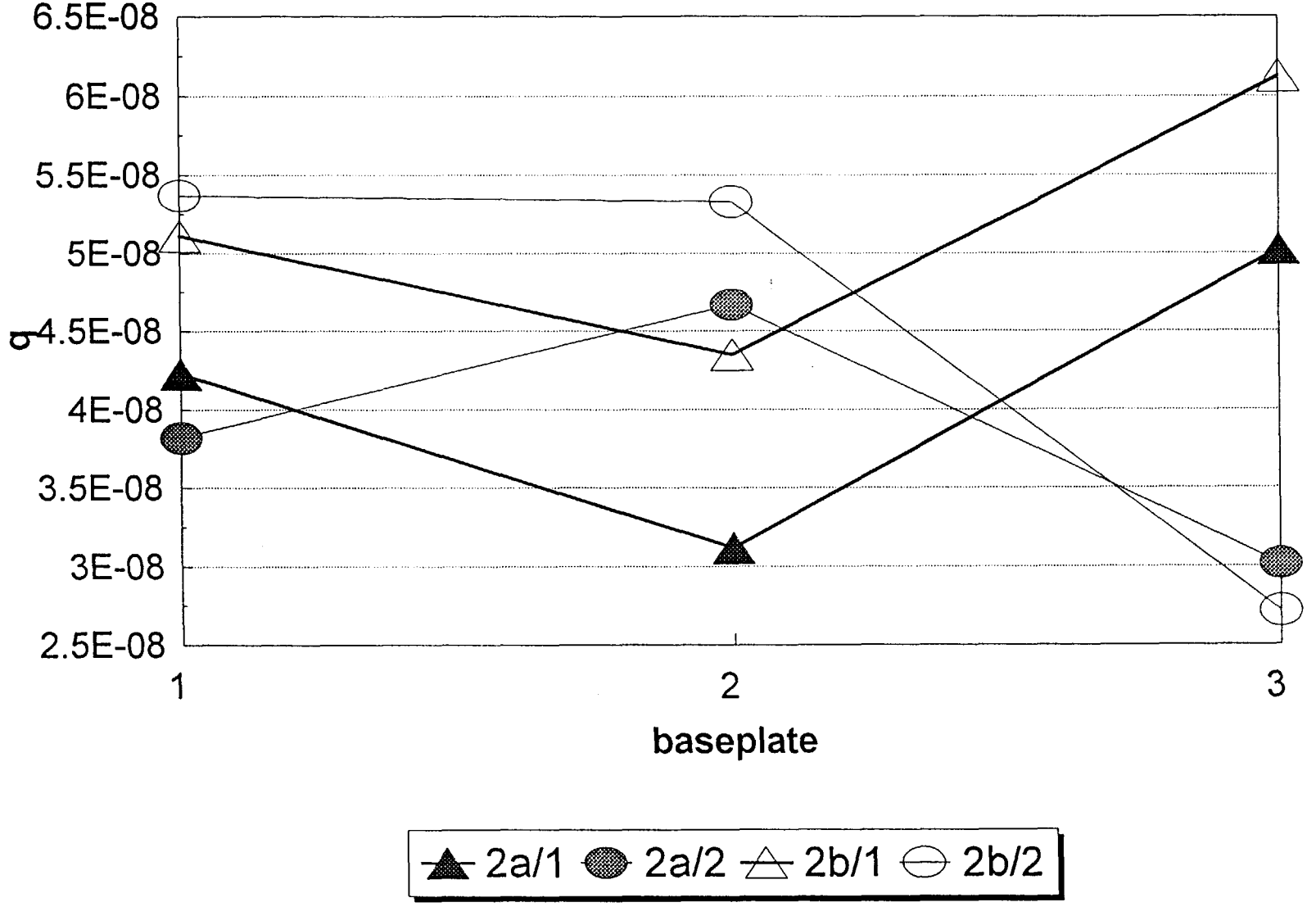
FIG. 5


LINEAR
QUADRATIC
DETECTOR 2b/1
Counts
-1 -65
-18
-153
-281
-463
-688
Temp
204 265
243
282
298
309
319
320 ECT
STD DEV
RESIDUE
(% OF PEAK RADIANCE)
1.0
0.5
0.0
-0.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
RADIANCE (mW/m^2Sr/cm)


DETECTOR 3/2
Counts
-23
-112
-235
-378
-530
-701
-899
Temp
205
242
265
282
296
308
320
320 ECT
STD DEV
RESIDUE
(% OF PEAK RADIANCE)
1.0
0.5
0.0
-0.5
-1.0
-10
0
10
20
30
40
50
60
RADIANCE (mW/m^2Sr/cm)

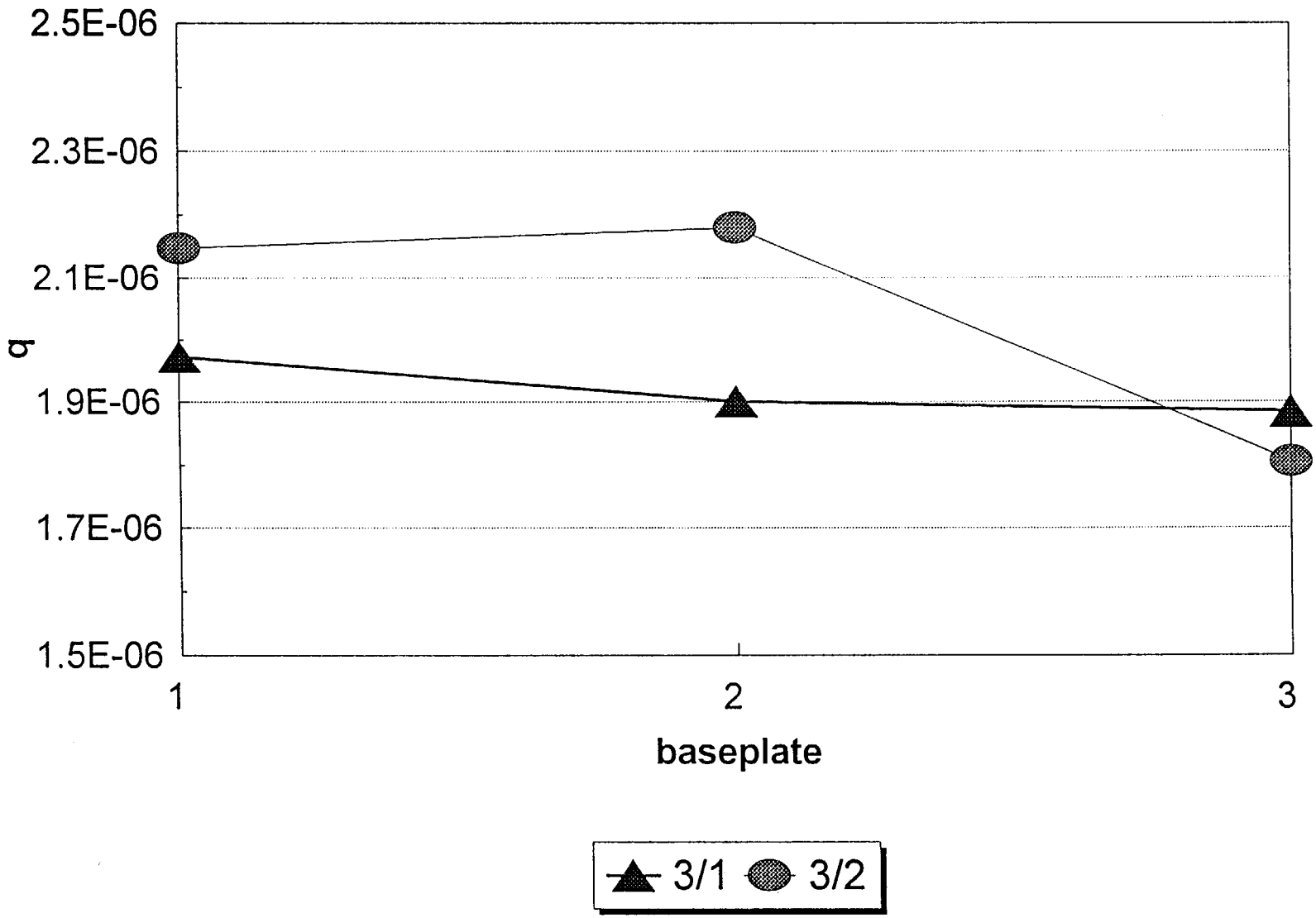
Q vs Baseplate

(ch 2; patch 1)



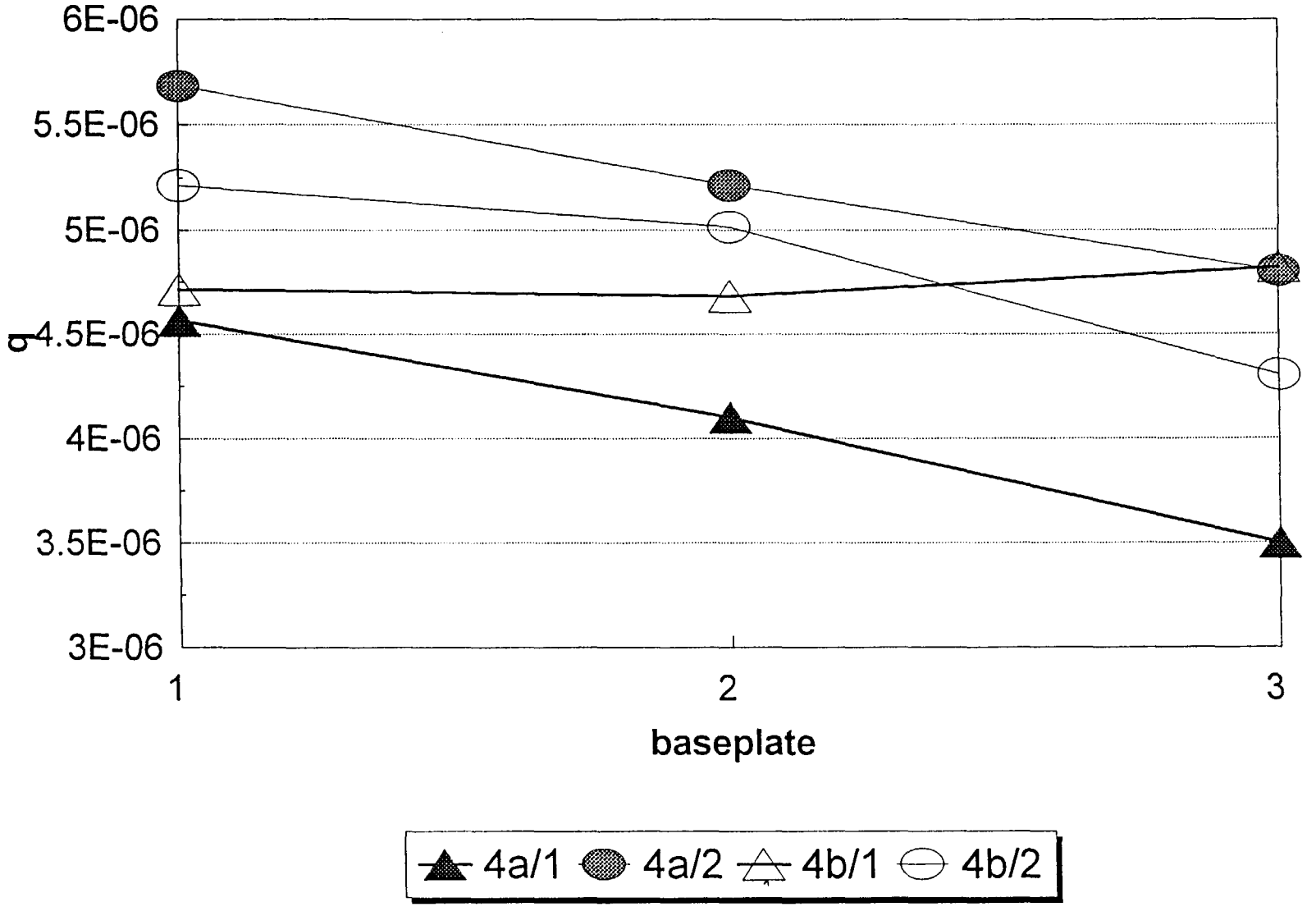
Q vs Baseplate

(ch 3; patch 1)



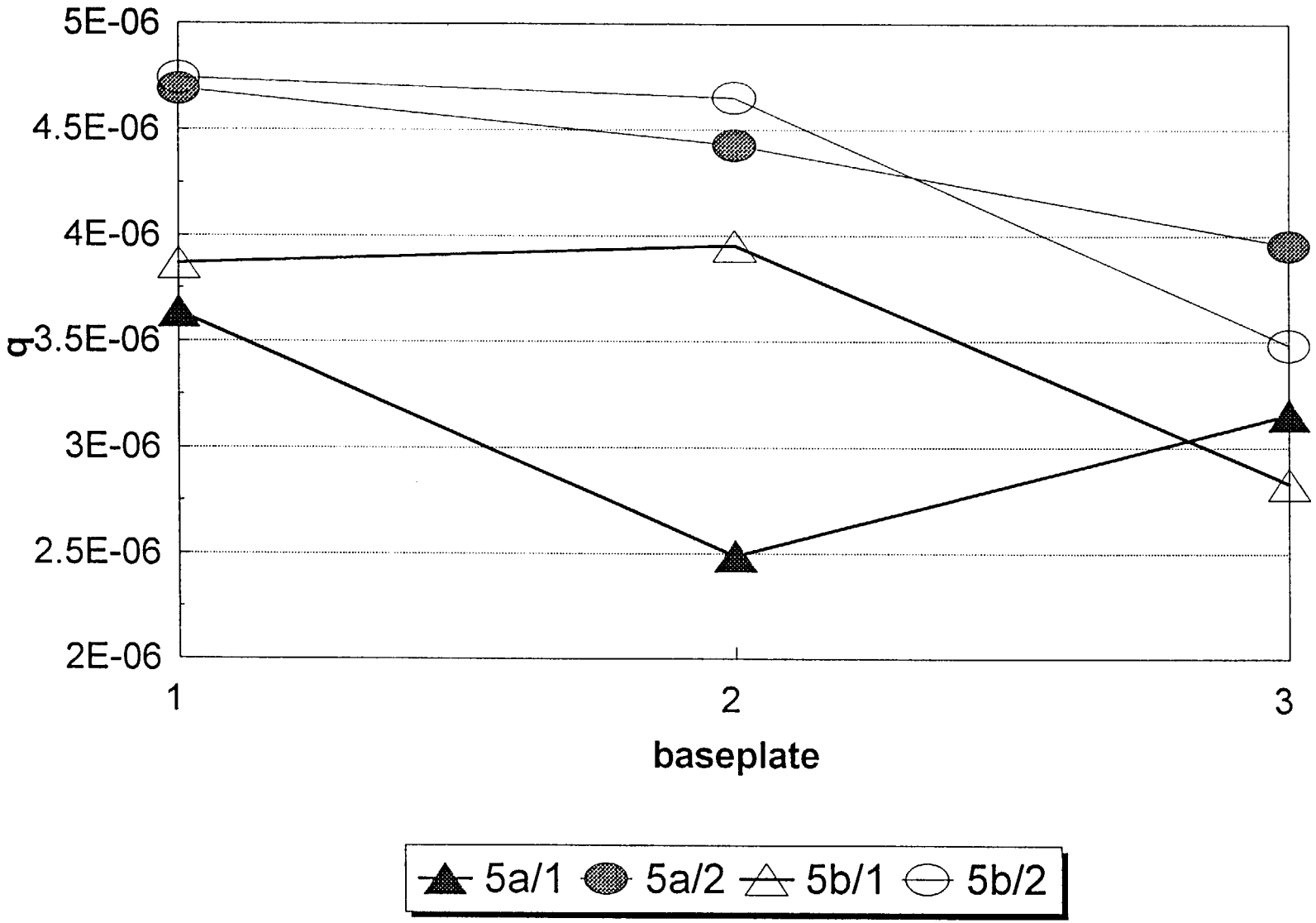
Q vs Baseplate

(ch 4; patch 1)



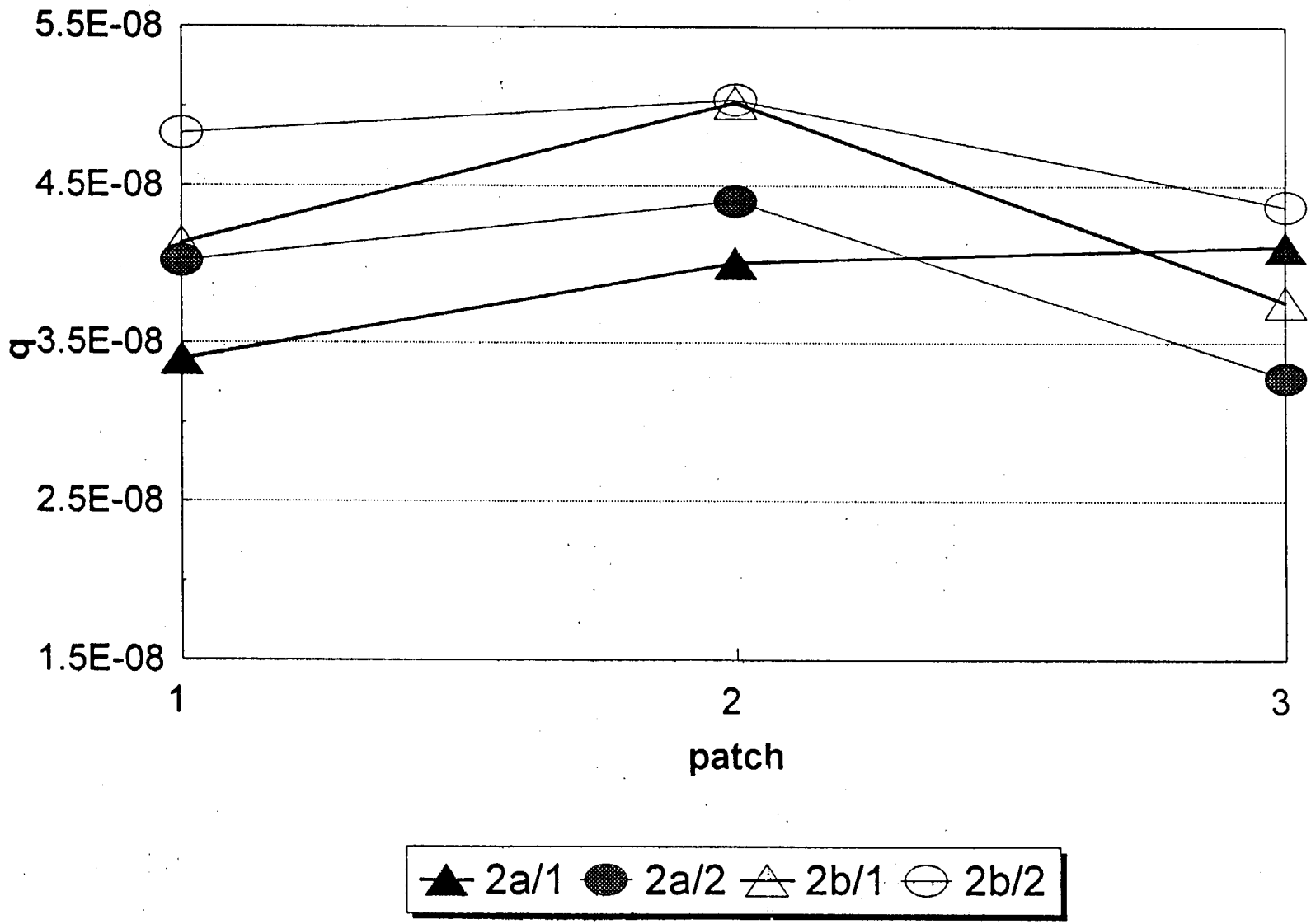
Q vs Baseplate

(ch 5; patch 1)



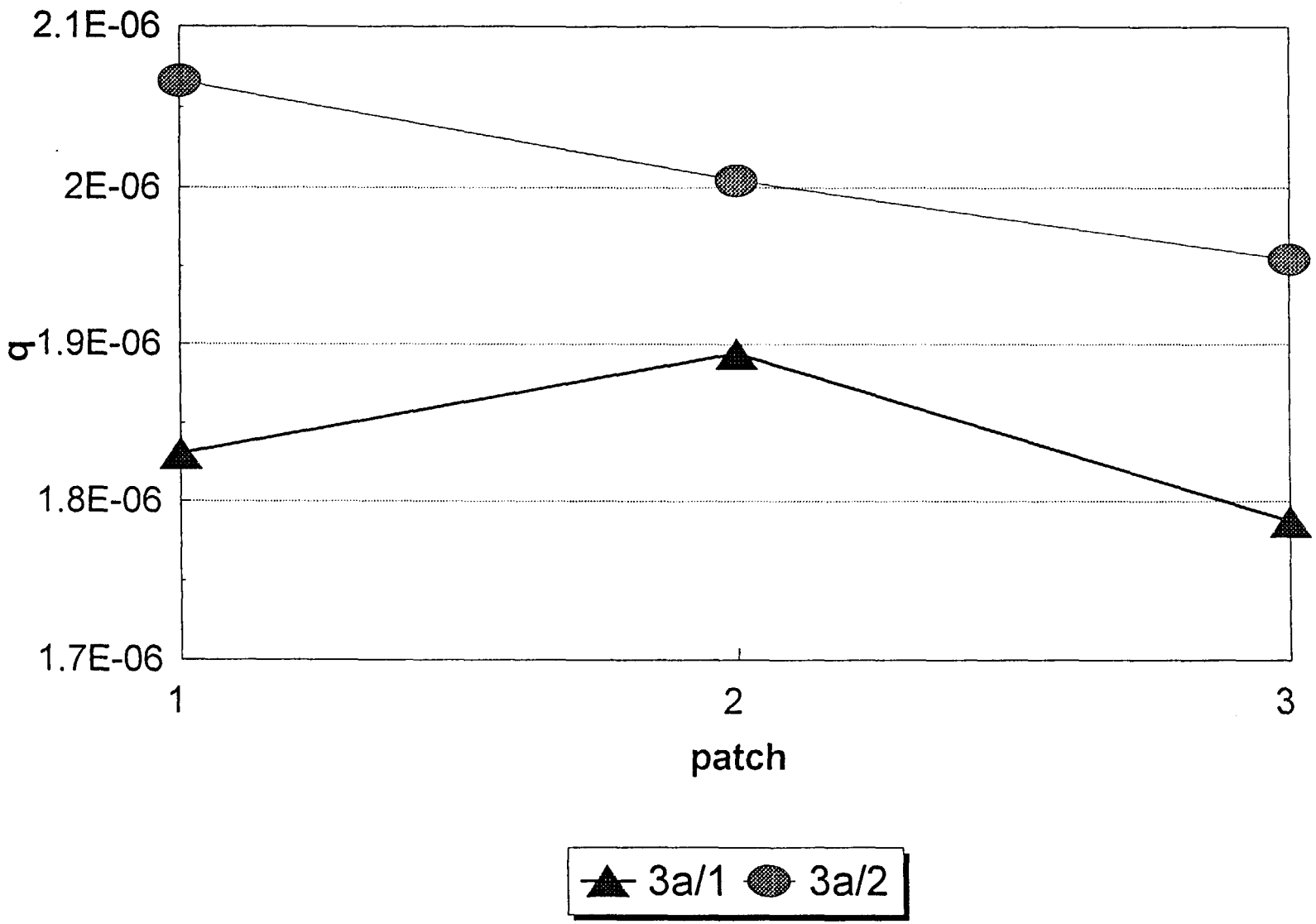
Q vs Patch (MIT)

(ch 2; average baseplate)



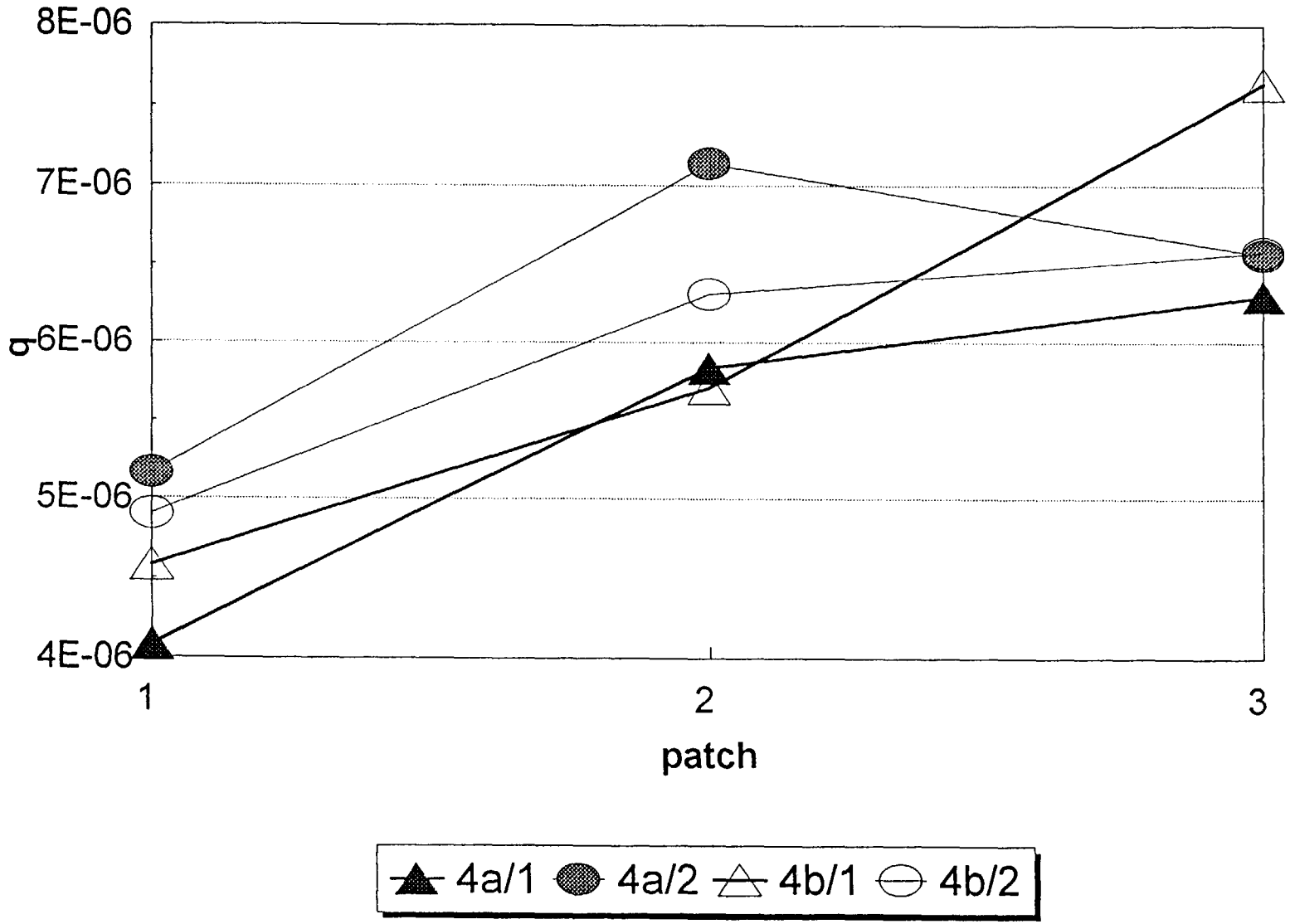
Q vs Patch (MIT)

(ch 3; average baseplate)



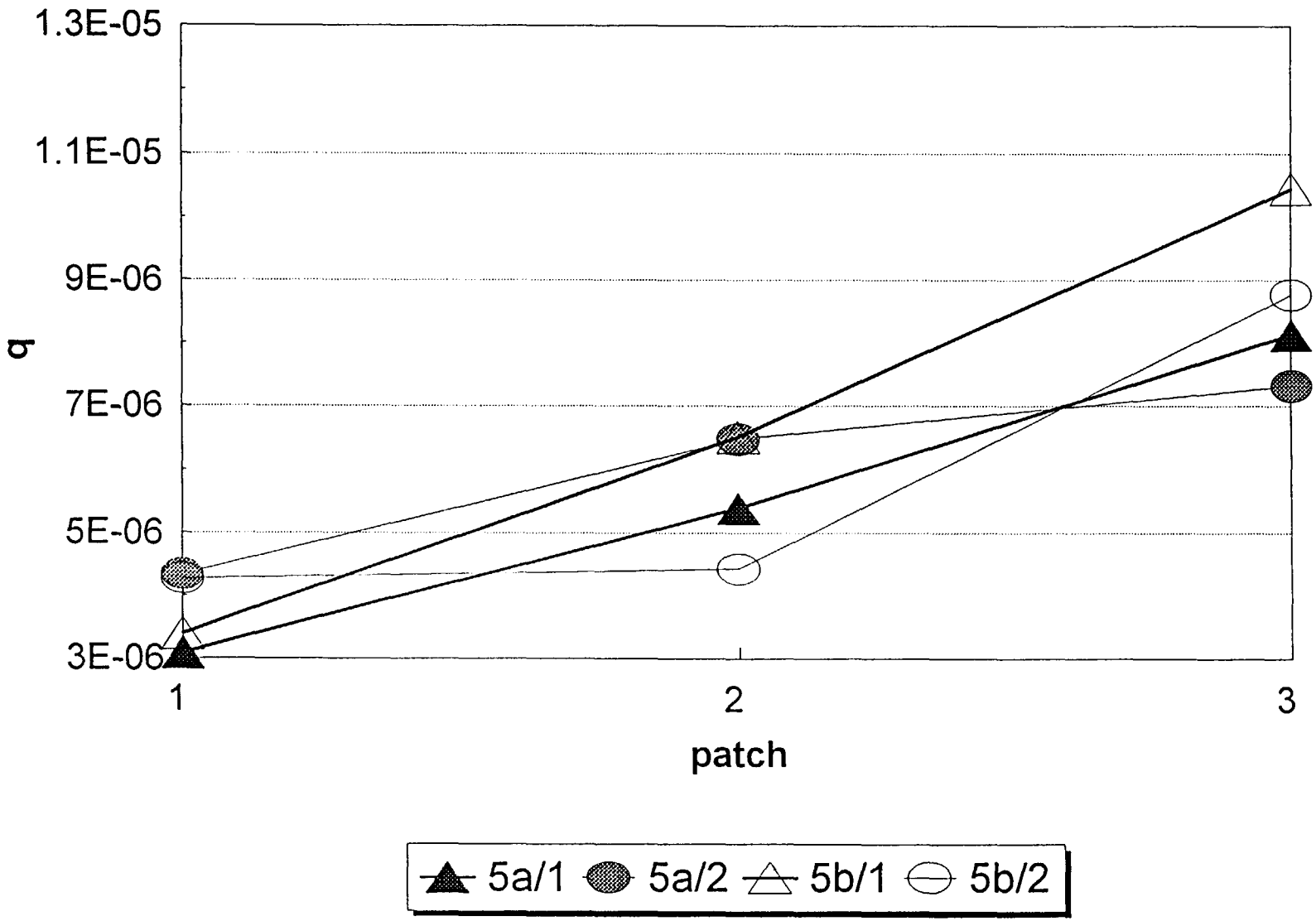
Q vs Patch (MIT)

(ch 4; average baseplate)

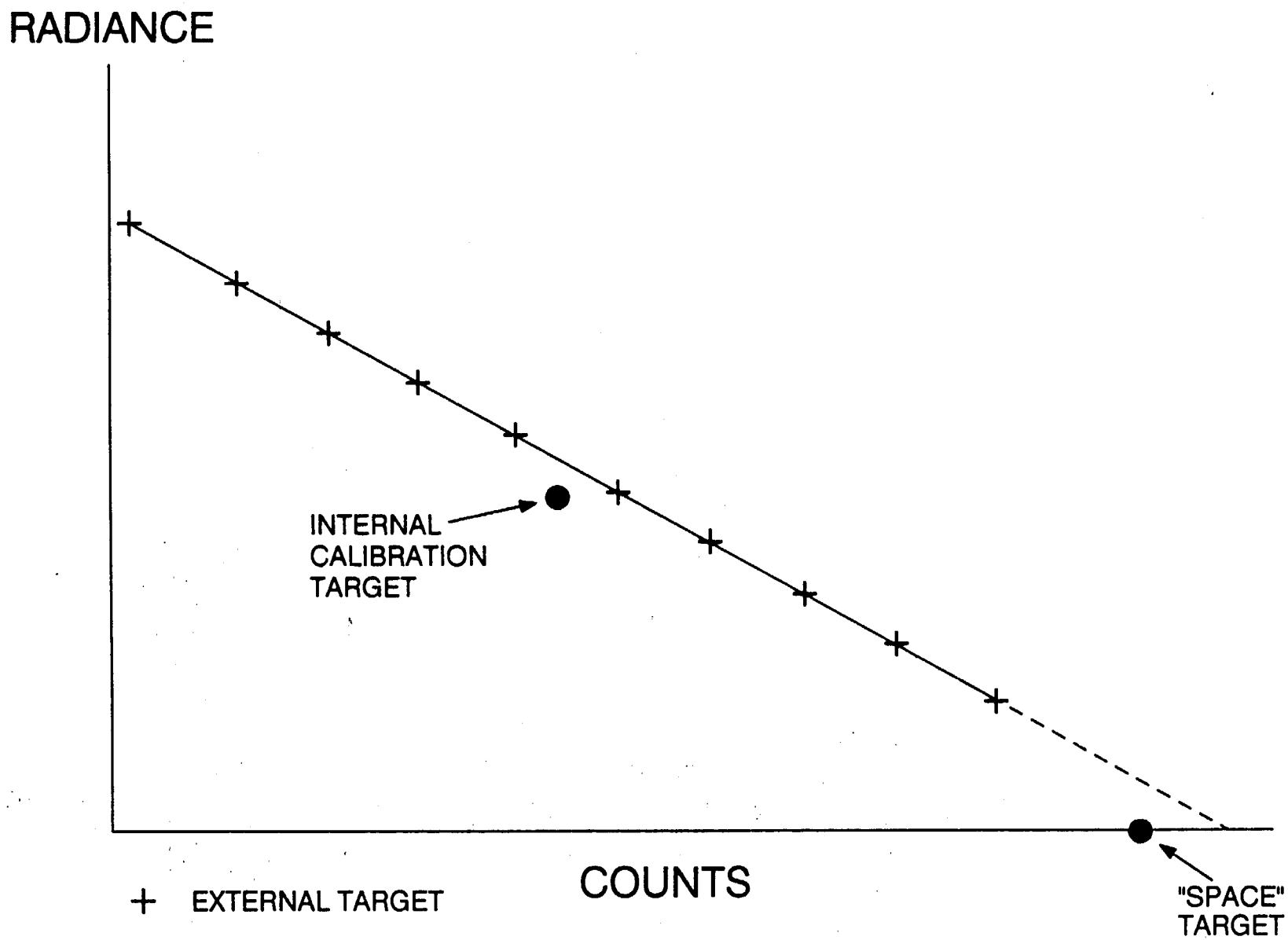


Q vs Patch (MIT)

(ch 5; average baseplate)

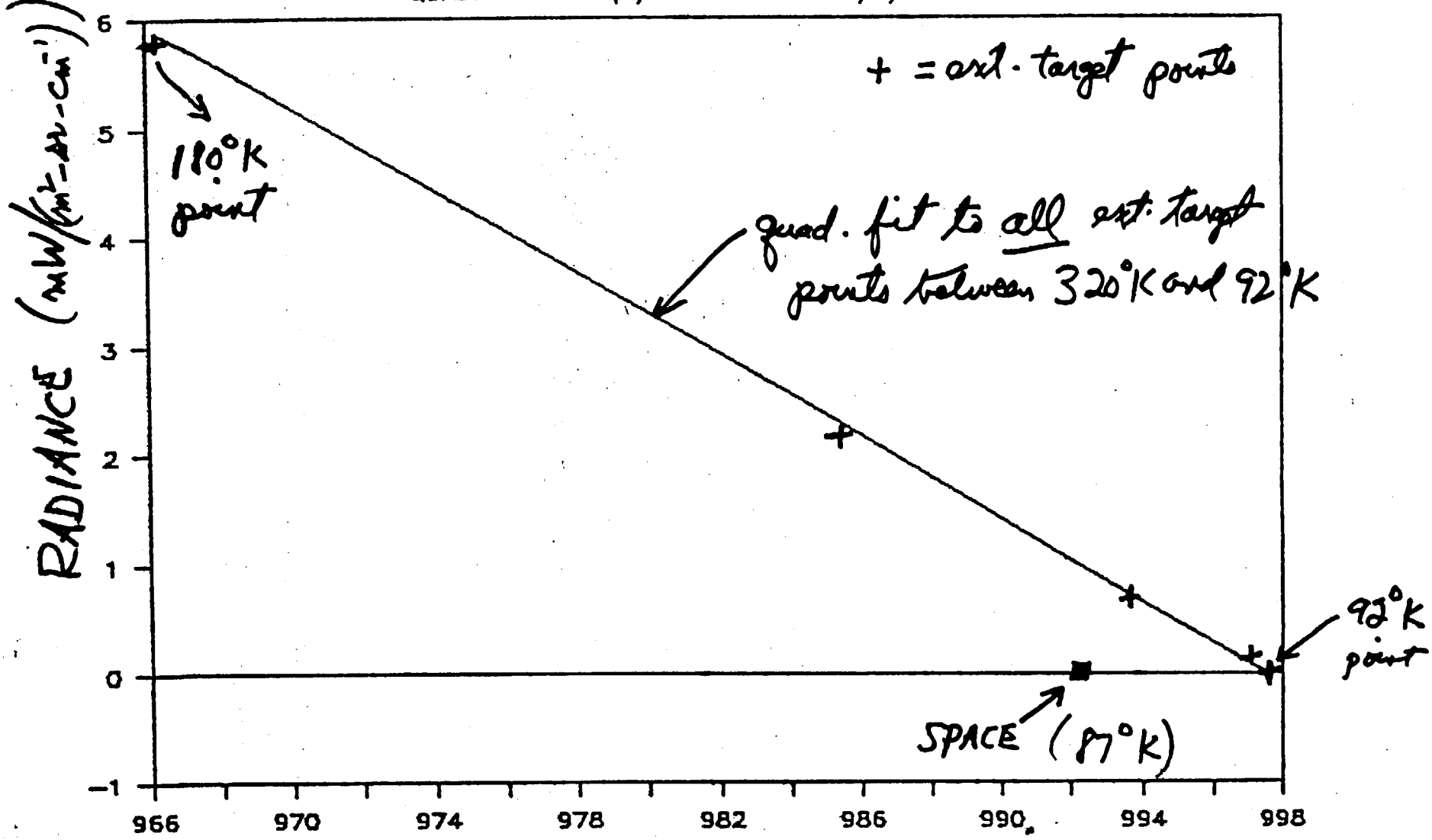


CALIBRATION OFFSETS



AVHHR/3 CH--4 PRE-LAUNCH CAL.

QUAD.FIT & real pt/SN301 ITTDATA 8/2/92

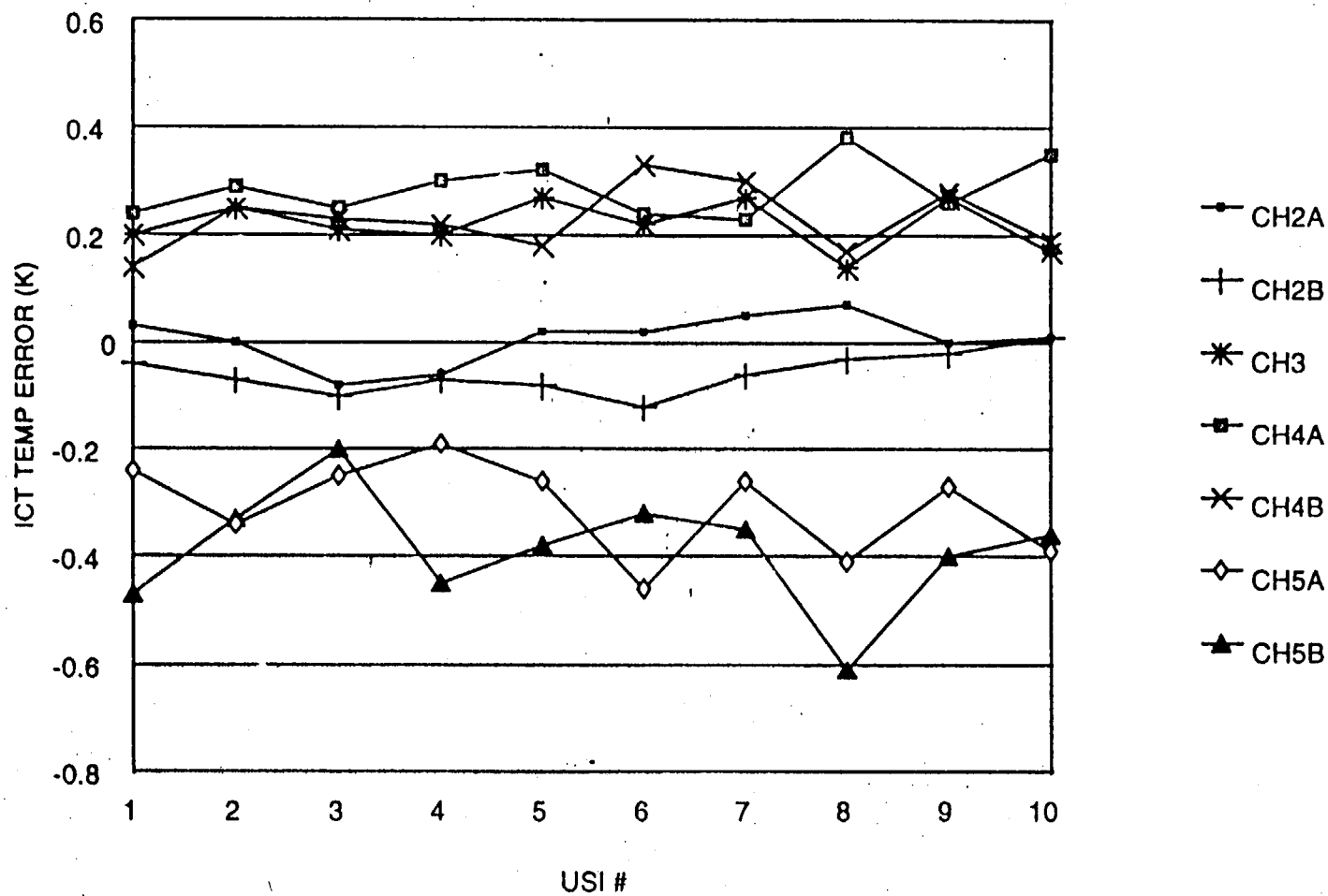


C.B.10/1/92 NESDIS

M. Weinreb
10/1/92

BB/ECAL TEMP ERROR

MISSION LOW PATCH MED SIDE 2

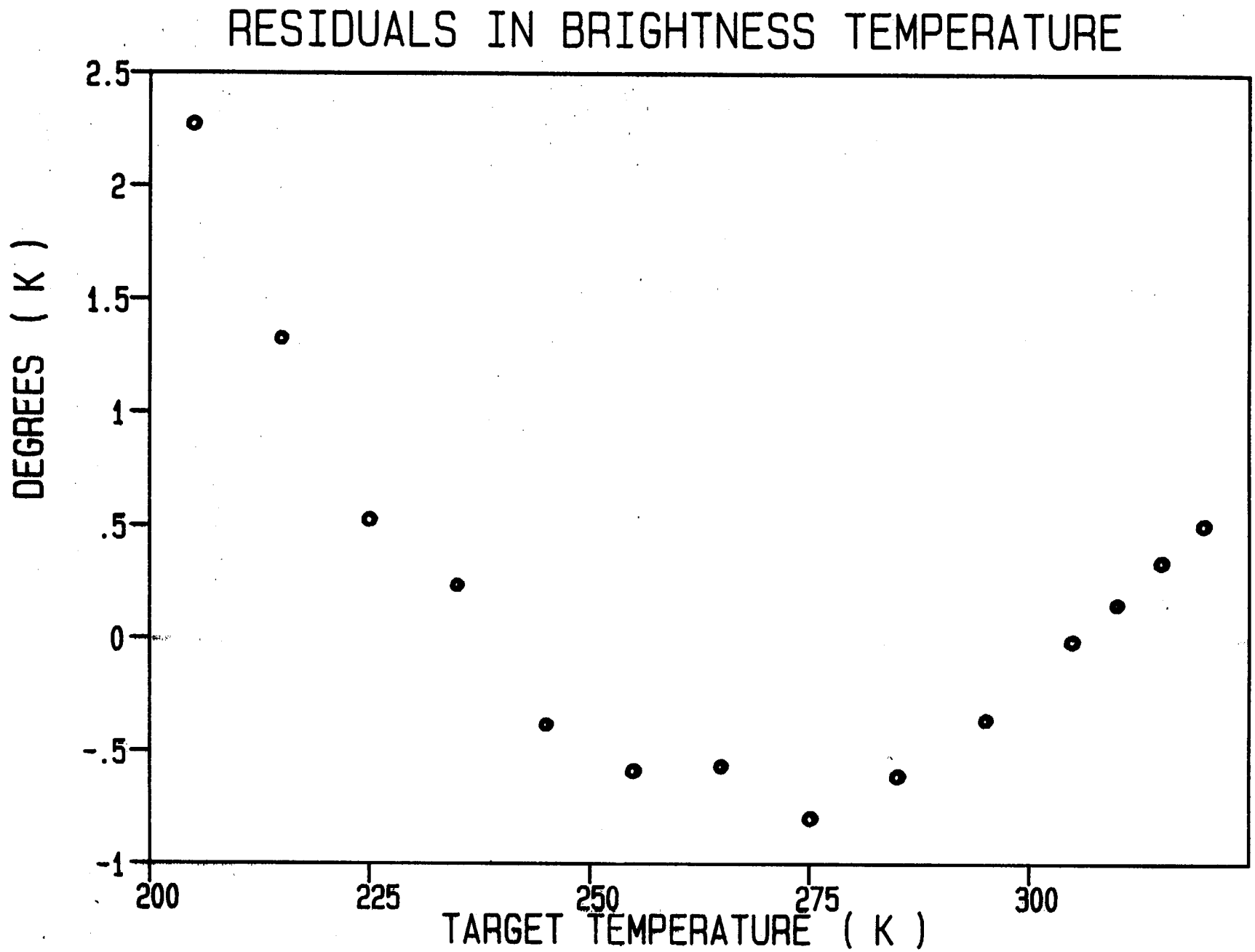


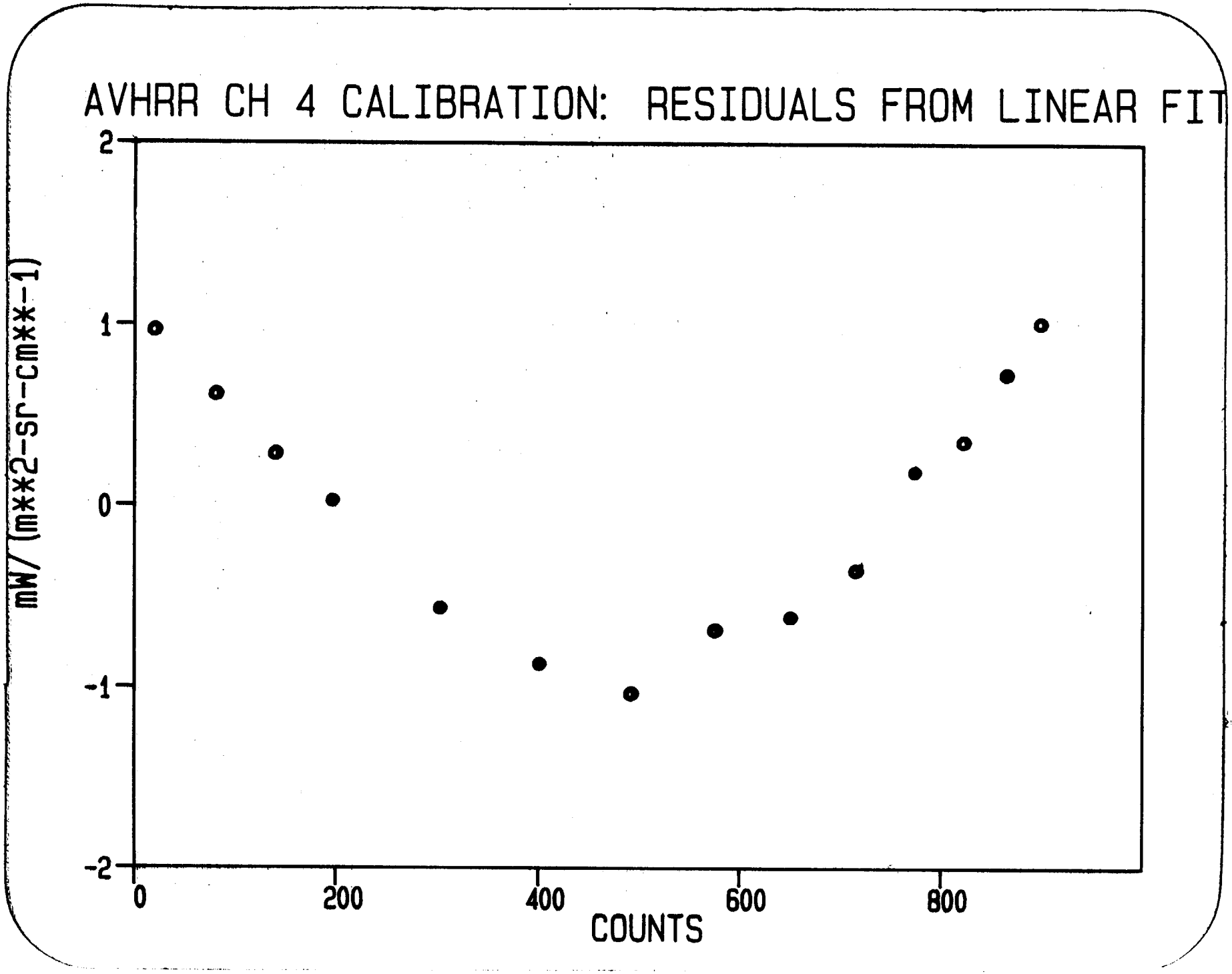
IN-ORBIT CALIBRATION EQUATION

$R = qx^2 + mx + b$

q determined before launch

m, b determined from in-orbit views of space & cal target


RESIDUALS IN BRIGHTNESS TEMPERATURE
DEGREES (K)
2.5
2
1.5
1
.5
0
-.5
-1
200
225
250
275
300
TARGET TEMPERATURE (K)


AVHRR CH 4 CALIBRATION: RESIDUALS FROM LINEAR FIT
mW/(m**2-sr-cm**-1)
2
1
0
-1
-2
0
200
400
600
800
COUNTS

MAT MEETING

Paul Anuta

(March 9, 1994)

March 9, 1994

Weinreb-1 — cont'd

1. Nonlinearity

2. Don't get same gain in lab and space

3. Uncertainties in lab calibration
   Channel to chan .5°

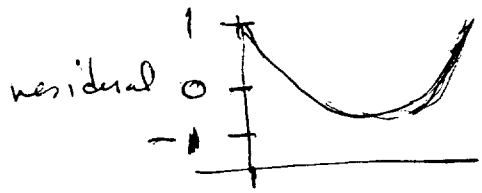
1. Nonlinearity

HIRS 66 — they have 2 AVHRR similar

ATSR — has 2

AVHRR Data → space view is 66 at K

0 — 900 count ≡ 150 MW/m²-sr-cm⁻¹



.7% nonlinearity → 2.25, -.75, even in temperature can't tolerate

so decided to use quadratic

GOES, HIRS, AVHRR } IT

Quadratic coefficient ≡
Change with baseplate temperature
(patch — 104K held constant)

Ft. Way

.28 — .3 range

use average over all baseplate temp — .1199 x 10⁻⁵

Radiance error — ~~[illegible]~~ ~~[illegible]~~ .26 at hottest in W

300 x .007
= 2.1 K

Currently table lookup correction for nonlinearity

Indium antimonide — less nonlinear — should be

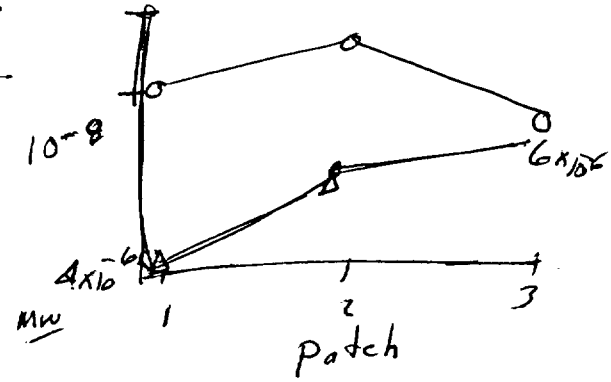
HgTeTe — big nonlinearity

Weinreb 2

GOES-I

Baseplate

	Lo	Mid	Hi
Mission Lo	94	101	104
Mission Nom			
Mission Hi			



.3° ~~AVHRR~~ GOES

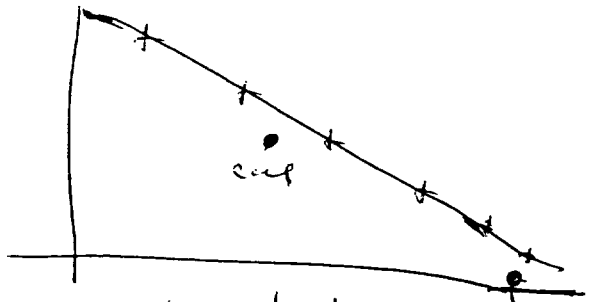
2° AVHRR

Get charts

Calibration offsets — seen in lab. — will it be in space? Don't know

Don't know why

Swales, MIT, IIT, Local



Bruce → scan angle dependent background?? —

polarization — ± 2.5° variation across scan

Scan mirror temp

Harry Fenthing ESSC to SWALES

[No MODIS IR polarization tests in program]

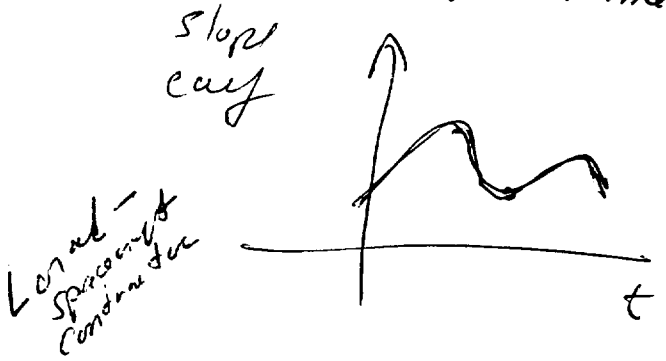
Spacepoint problem

Cal — scatter corrupts measurement

• 1/f noise changes — causing error

Weirrob3

- Goes-I striping 1/4 of dynamic range
  2 detectors — cal at same time but noise in 66 cal — cannot be different.
  matched mean & std. to destripe



can't average
pick specific time to average

MODIS SRCA SPATIAL CALIBRATIONS: ALGORITHM DEVELOPMENT

T. Zukowski

SRCA OPTICAL DESIGN COMPLETE

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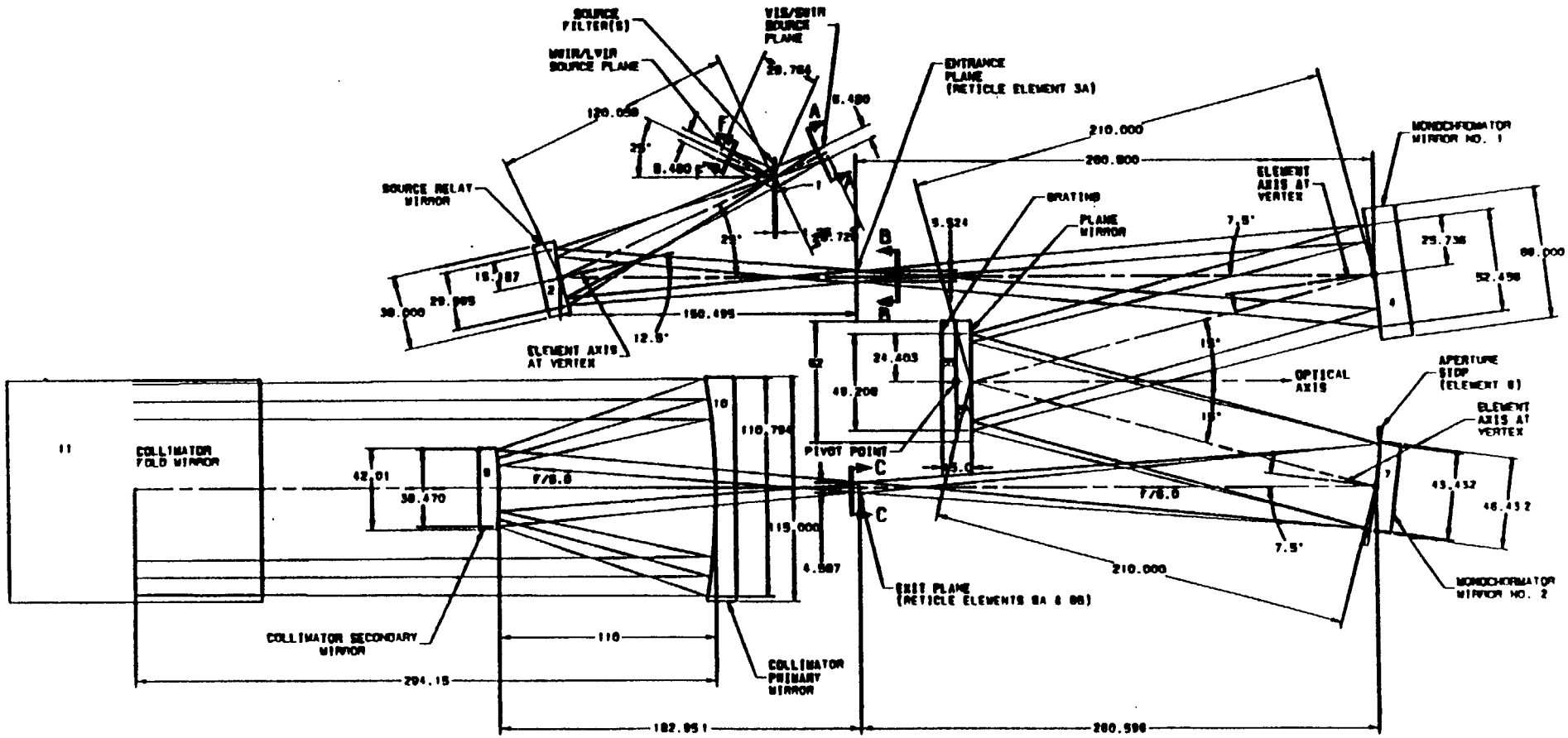
SRCA OPTICAL SYSTEM (DRAWING #405410)



SRCA WITH PLANE MIRROR SELECTED

IN-FLIGHT REGISTRATION MEASUREMENT CAN DETERMINE LAUNCH INDUCED ERRORS

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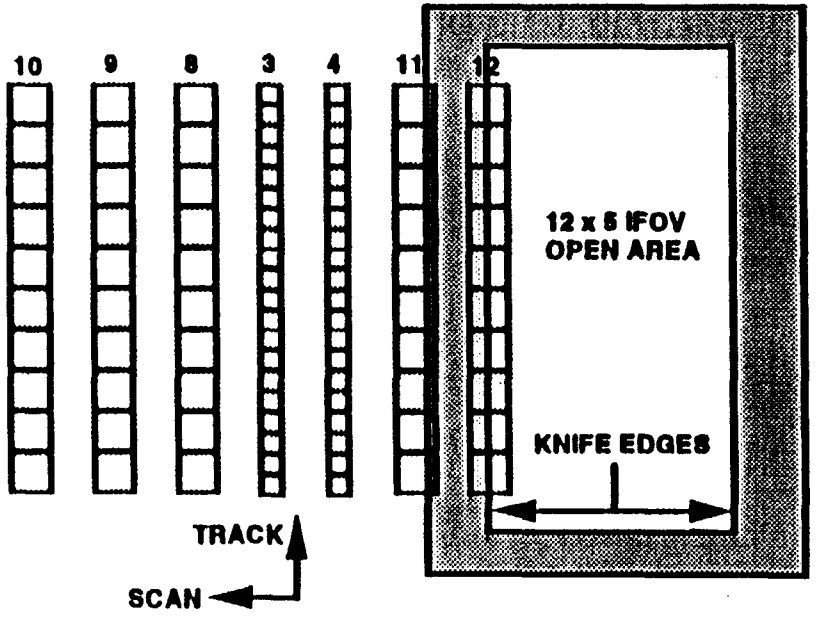
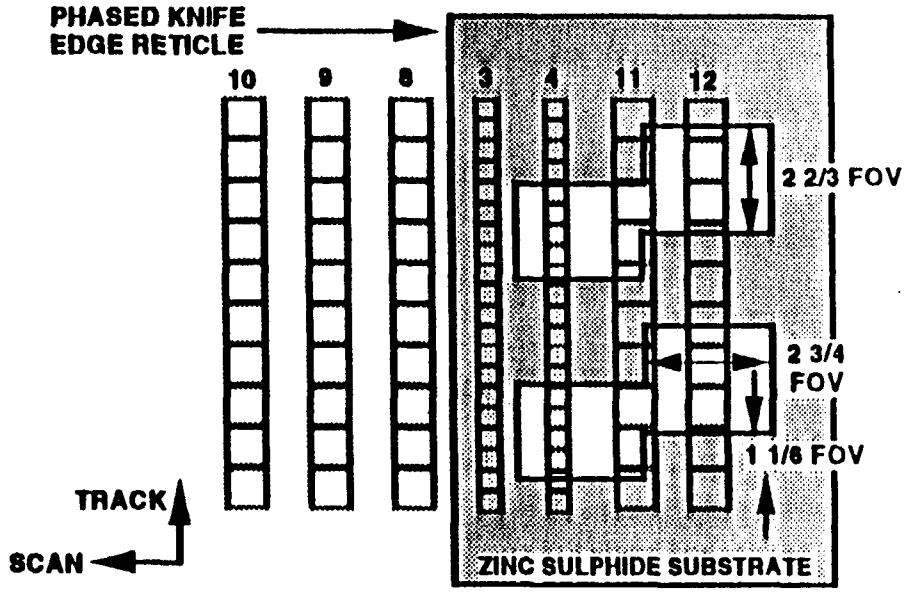
- MONOCHROMATOR EXIT WHEEL CONTAINS TWO SELECTABLE RETICLES

SCAN MEASUREMENT

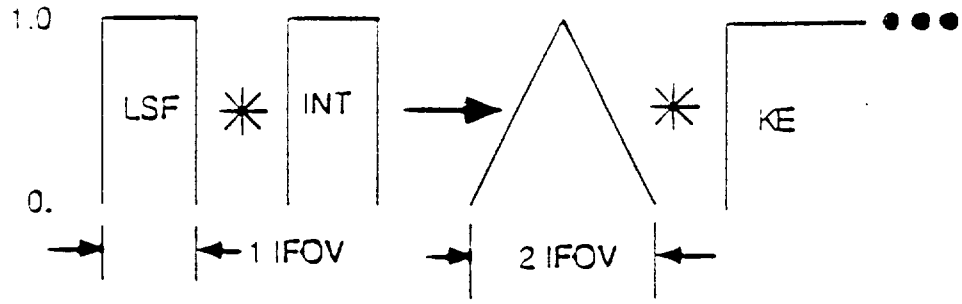


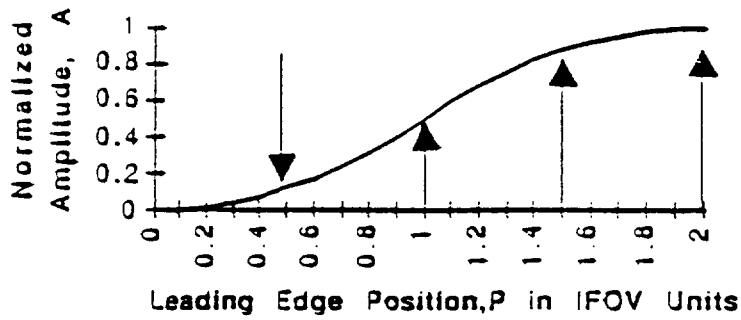
- ELECTRONIC PHASE DELAY STEPS ARRAY ACROSS KNIFE EDGES IN SCAN DIRECTION
  - Delay Step Range: ± 0.5 Pixel
  - No. of Positions: 5 - 10 per Radiance Level
- MEASURMENT REPEATABILITY: ~ 0.05 Pixel

TRACK MEASUREMENT



- ELECTRONIC DELAY POSITIONS ARRAY IN RETICLE
- 8 DIFFERENT DETECTORS SAMPLED PER BAND
- PREDICTED PARTIAL APERTURE ALONG-TRACK KERs REQUIRED TO DETERMINE SHIFT
- MEASUREMENT REPEATABILITY: ~ 0.1 Pixel





Analytical Form for Ideal Functions with 5 IFOV Target:

Leading Edge:

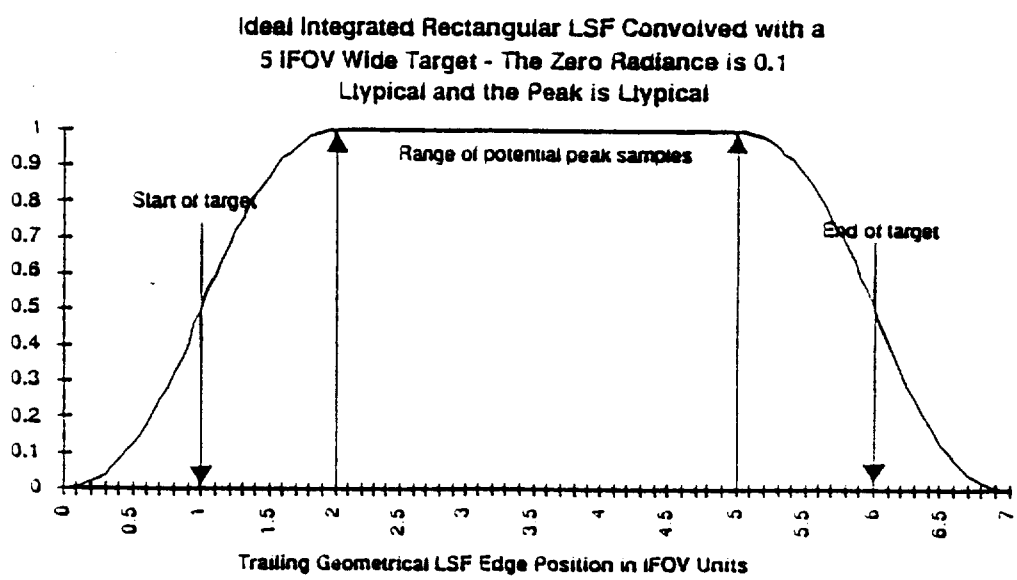
$A(P) = P^2/2$ for $P < 1$

$= -P^2/2 + 2P - 1$ for $1 < P < 2$

Trailing Edge:

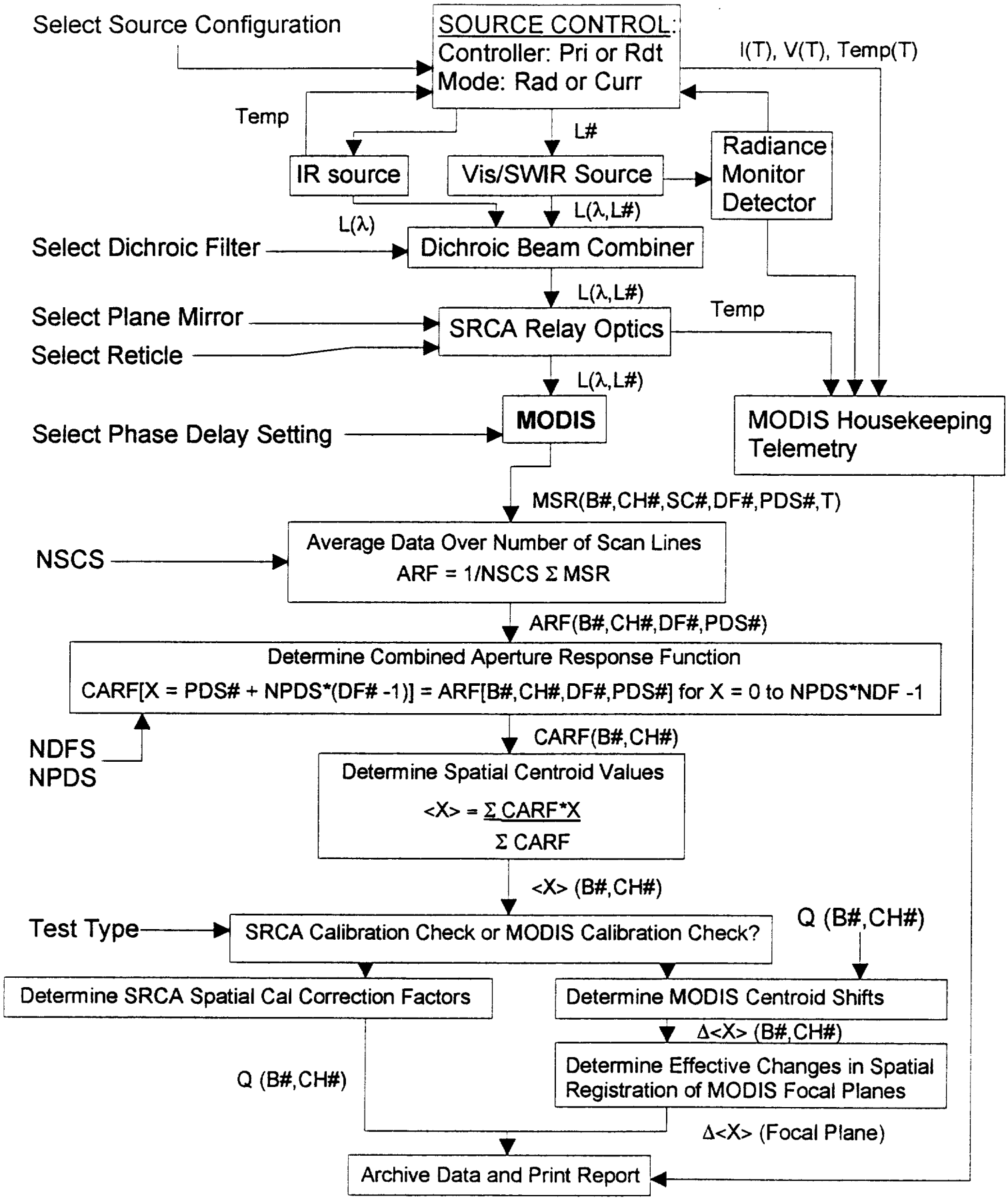
$A(P) = -(P-5)^2/2 + 1$ for $5 < P < 6$

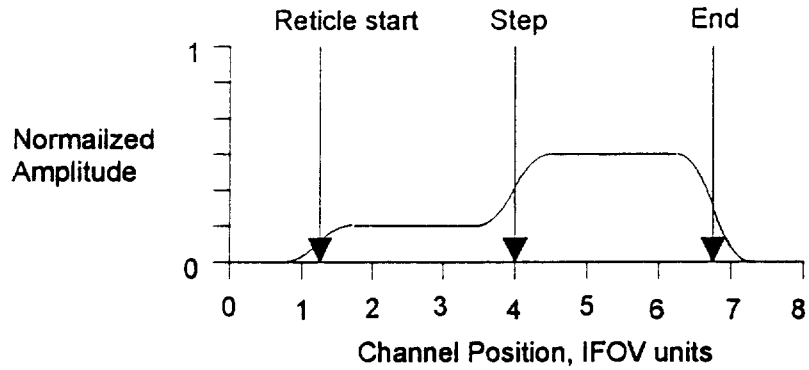
$= (P-7)^2/2$ for $6 < P < 7$



Figures from SBRC 151868

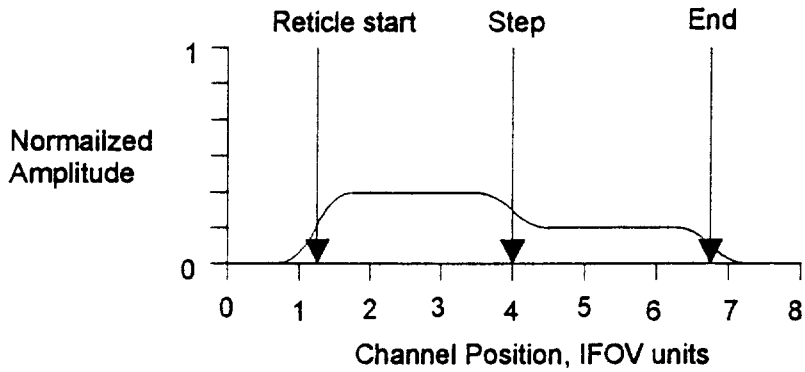
SRCA Spatial Calibration: Scan Direction (from SBRC CDRL #404, Fig. 6.9)





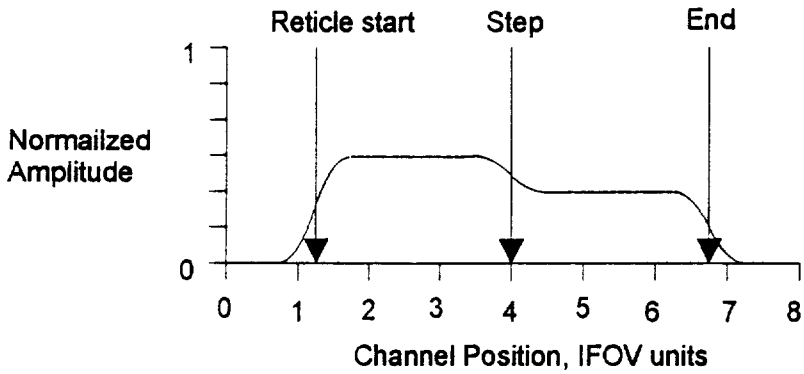
Channel X

+



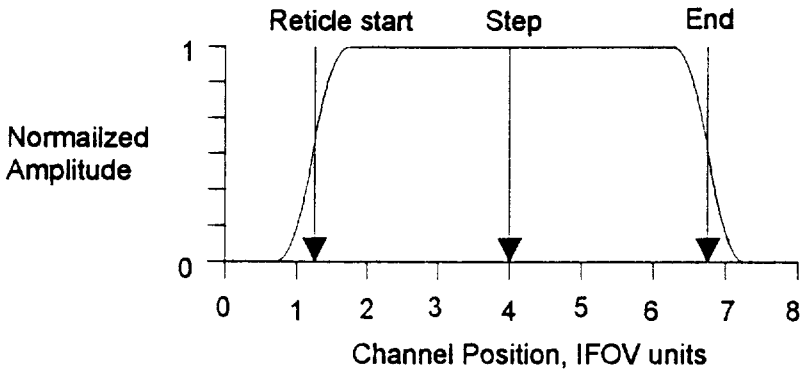
Channel Y

+



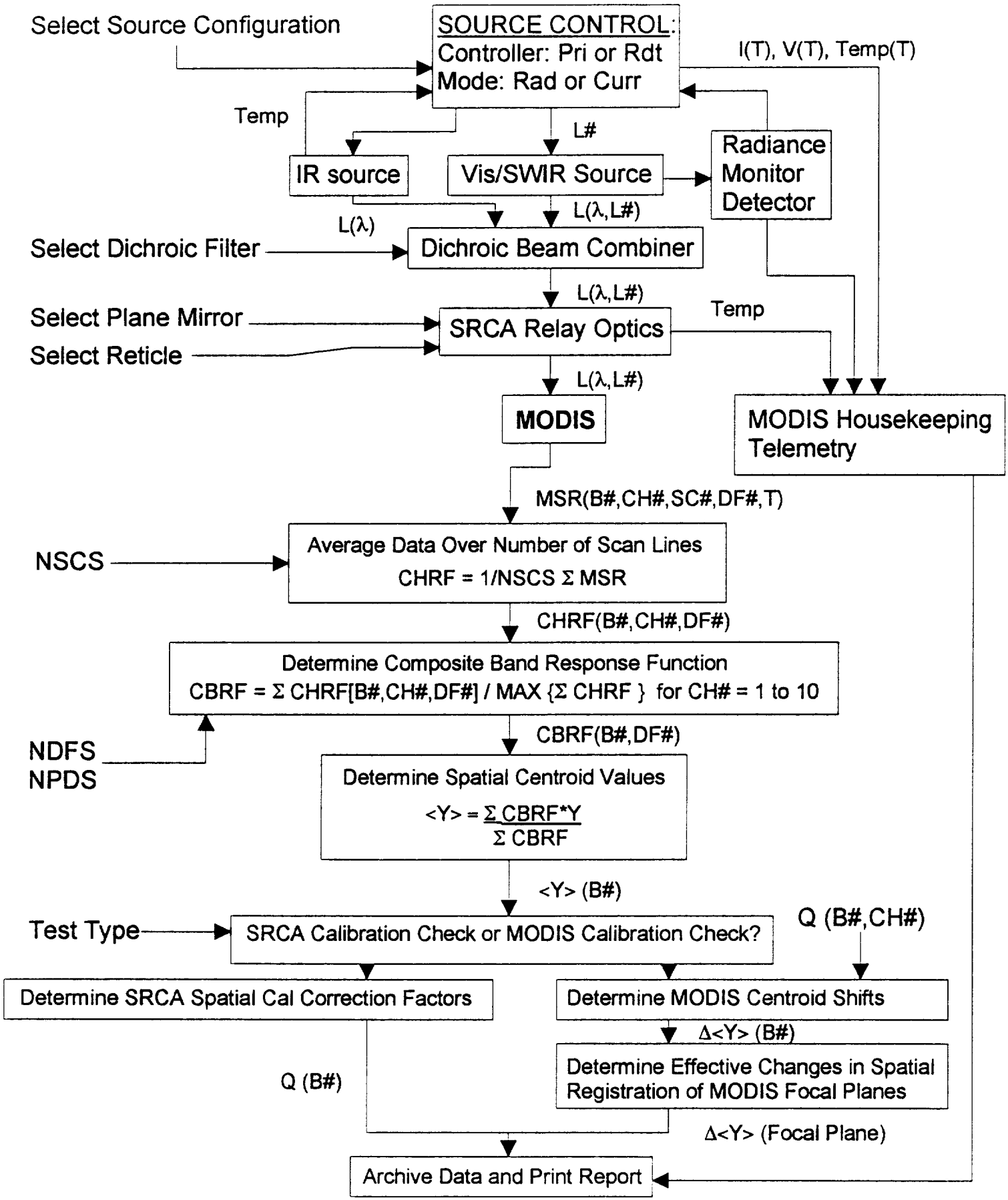
Channel Z

=



Composite Band Response Function

SRCA Spatial Calibration: Track Direction



Some SRCA Spatial Calibration Issues:

Error sources in centroid determination

- Low SNR
- MTF degradation - SRCA image quality v.s. MODIS changes
- Distortion, relative rotations of FPAs and SRCA
- Along track- detector-to-detector variations
- Non-uniform SRCA illumination
- Scan dependencies due to SRCA optical configuration (MTF variation, illumination angle)
- Reticle repeatability - mechanical tolerances of SRCA/environmental influences
- integrator reset time

Additional analyses of SRCA Spatial Calibration data

- MTF/LSF - separation of MODIS effects
- IFOVs - input to geometrical correction of images?
- statistics - can enough data be gathered, and can measurement drifts be accounted for?

SYNTHESIS OF MODIS CALIBRATION

Presented by Nianzeng Che

Swales & Associates, Inc.

(March 9, 1994)

Data available from pre-launch calibration

1. Initial calibration algorithms provided by SBRC
2. Laboratory measurement characteristics and data
3. Ambient and T/V measurement data for on-board calibrators

MODIS on-board & vicarious calibration sources

on-board calibrators

- Solar diffuser and SDSM
- SRCA (spectral, radiometric, and spatial)
- Space view (zero radiance)
- Blackbody at 285K or/and 315K

Vicarious calibartion methods

- Aircraft radiance measurement
- Ground reflectance-based calibration
- Radiance-based measurement by lunar observation
- Solar-radiation-based calibration
- Oceanic ship and buoy measurement
- Cross calibration with other on-board sensors

Image-derived calibration

- Distriping in-band image by histogram equalization
- Curve-fit to solar spectral curve for between-band normalization
- Long-term radiometric stability monitoring by 10–100 sites on the earth
- Earth night-viewing for space count bias check
- Automated calibration-site-based radiometric rectification
- MTF inversion
- Correct radiometric errors introduced by stray- & ghost-light

Radiometric calibration accuracy

A multiple calibration approach assures high radiometric accuracy to the MODIS

1. VS/NIR/SWIR (claimed)

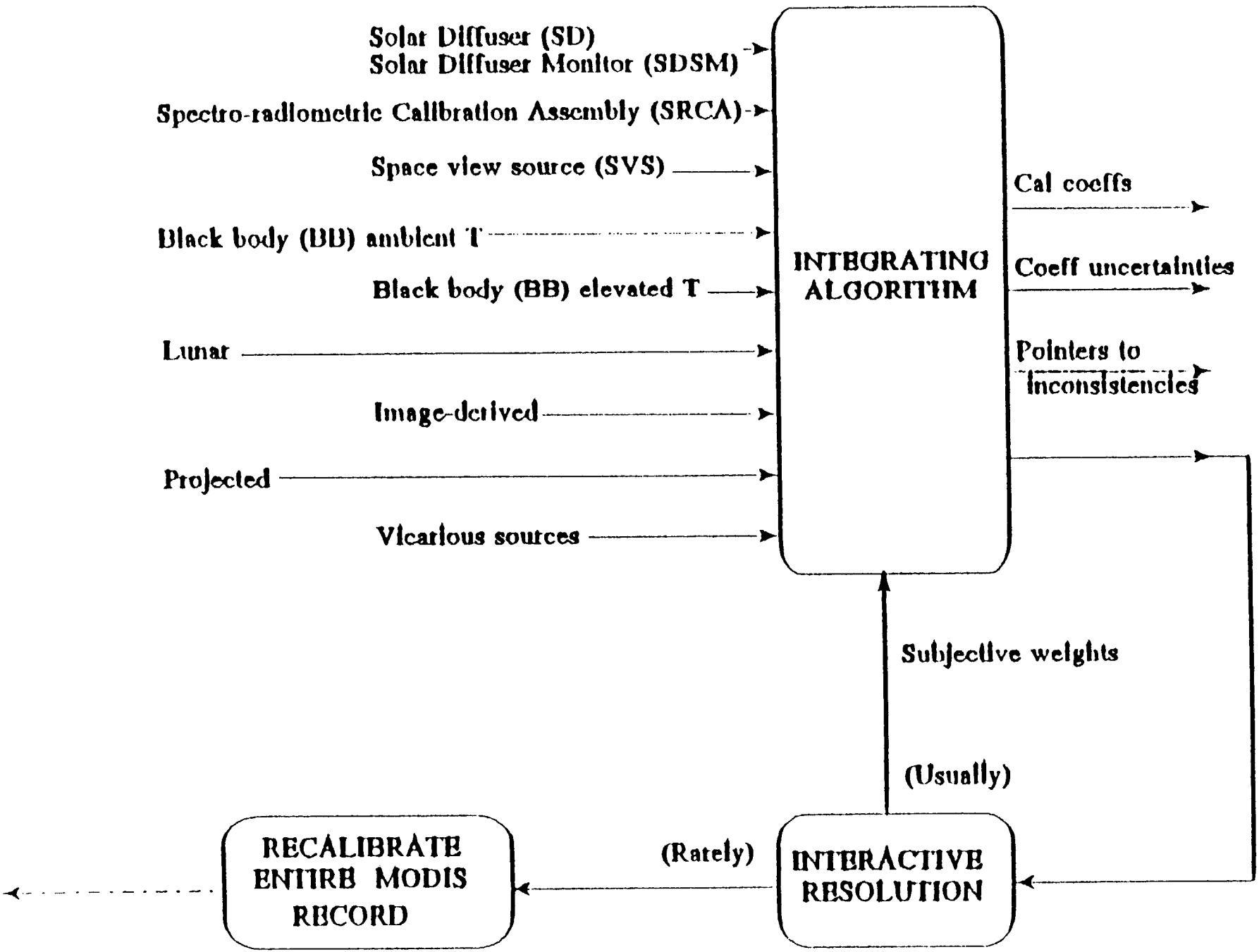
(1) Solar diffuser, SDSM, SRCA	±4.0%
(2) Aircraft radiance measurement	±4.0%
(3) Ground-based reflectance calibration	±3.5%
(4) Ground radiance-based calibration	±3.0%
(5) Solar-radiation-based calibration	±3.0%
(6) Radiance-based measurement by lunar observation	±3.0%
(7) Cross calibration with other satellite sensors (assume ±3.0%)	±3.5%
(8) Oceanic ship and buoy measurement	

2. MWIR/LWIR

(1) On-board blackbody, space view	±1.0%

Calibration activation during MODIS in orbit

1. Evaluate the instrument stability in space environment.
2. The instrument output is compared to the pre-launch characteristics.
3. Data collected from on-board calibrators and vicarious calibration sources.
4. Produce calibration coefficients after giving weighted coefficient to each calibration source.
5. Calibration committee coordinates MODIS calibration.
6. Validation, diagnosis, and improvement of calibration performance.

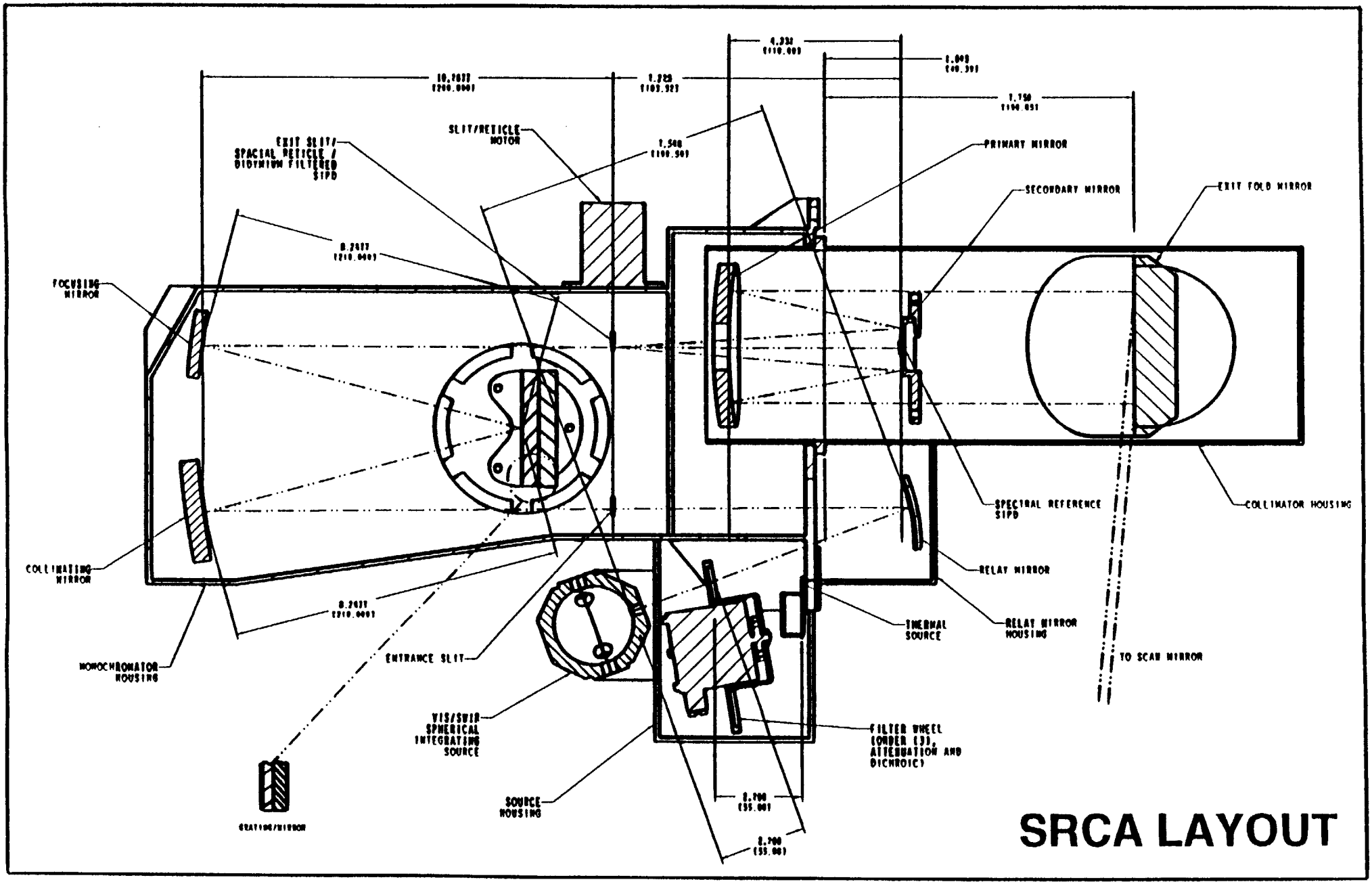

Solar Diffuser (SD)
Solar Diffuser Monitor (SDSM)
Spectro-radiometric Calibration Assembly (SRCA)
Space view source (SVS)
Black body (BB) ambient T
Black body (BB) elevated T
Lunar
Image-derived
Projected
Vicarious sources
INTEGRATING ALGORITHM
Cal coeffs
Coeff uncertainties
Pointers to inconsistencies
Subjective weights
(Usually)
INTERACTIVE RESOLUTION
(Rarely)
RECALIBRATE ENTIRE MODIS RECORD

Spectral and radiometric calibration with spectroradiometric calibration assembly (SRCA)

Presented by Nianzeng Che

Swales & Associates, Inc.

(March 9, 1994)


EXIT SLIT/
SPACIAL RETICLE /
DIDYMIUM FILTERED
SIPD
SLIT/RETICLE
MOTOR
PRIMARY MIRROR
SECONDARY MIRROR
EXIT FOLD MIRROR
FOCUSING
MIRROR
COLLIMATING
MIRROR
MONOCHROMATOR
HOUSING
ENTRANCE SLIT
VIS/SWIR
SPHERICAL
INTEGRATING
SOURCE
SOURCE
HOUSING
GRATING/MIRROR
SPECTRAL REFERENCE
SIPD
COLLIMATOR HOUSING
RELAY MIRROR
THERMAL
SOURCE
RELAY MIRROR
HOUSING
TO SCAN MIRROR
FILTER WHEEL
(ORDER (3),
ATTENUATION AND
DICHROIC)

SRCA LAYOUT

DIDYMIUM FILTER PASS BANDS USED TO CALIBRATE SPECTRAL OUTPUT

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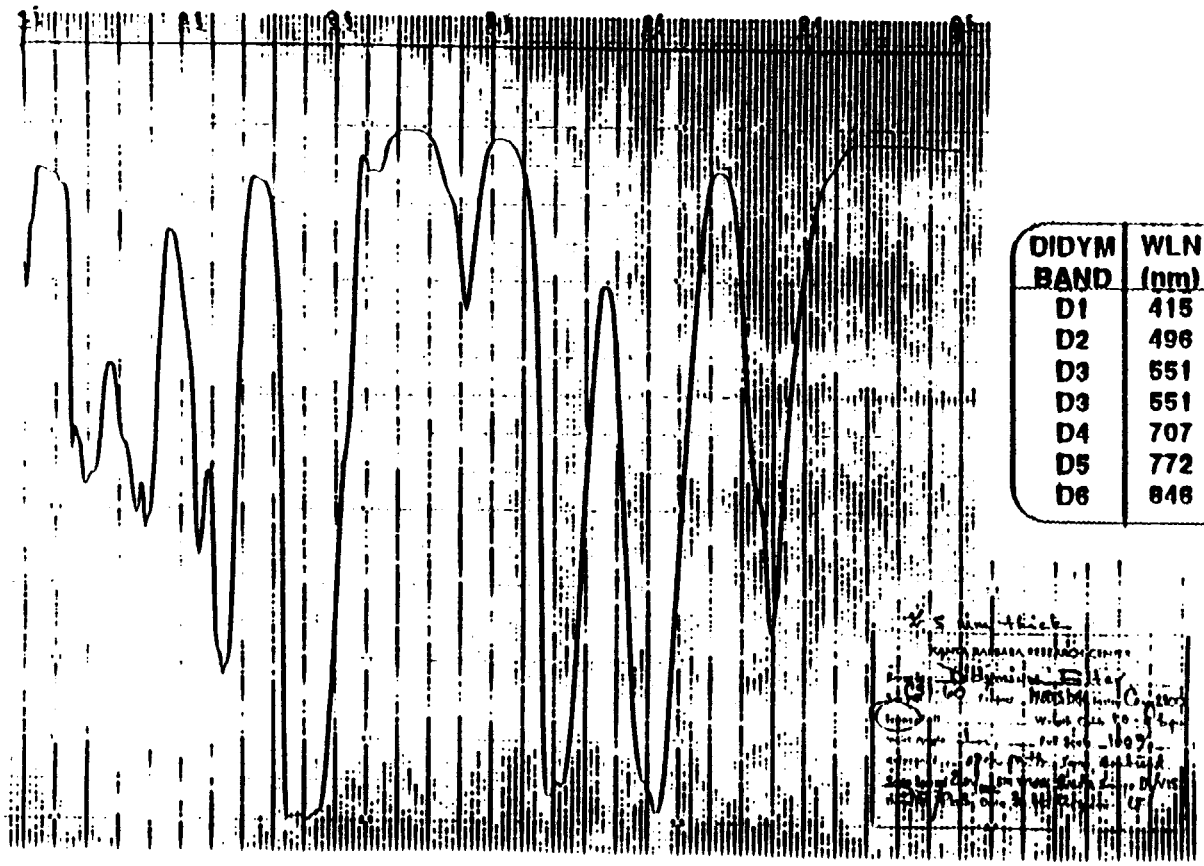

DIDYM BAND	WLN (nm)	BW (nm)	Diff Order	Lower Øg (deg)	Center Øg (deg)	Upper Øg (deg)
D1	415	25	3	7.84467	8.111	8.377
D2	496	25	3	9.5729	9.84	10.11
D3	551	30	2	6.88446	7.097	7.309
D3	551	30	3	10.698	11.02	11.34
D4	707	40	2	9.02789	9.313	9.598
D5	772	25	2	10.0617	10.24	10.42
D6	846	35	2	11.0489	11.3	11.55

3/93
93-0218-43

MONOCHROMATOR OPTICAL PERFORMANCE MINIMIZES SPECTRAL BROADENING

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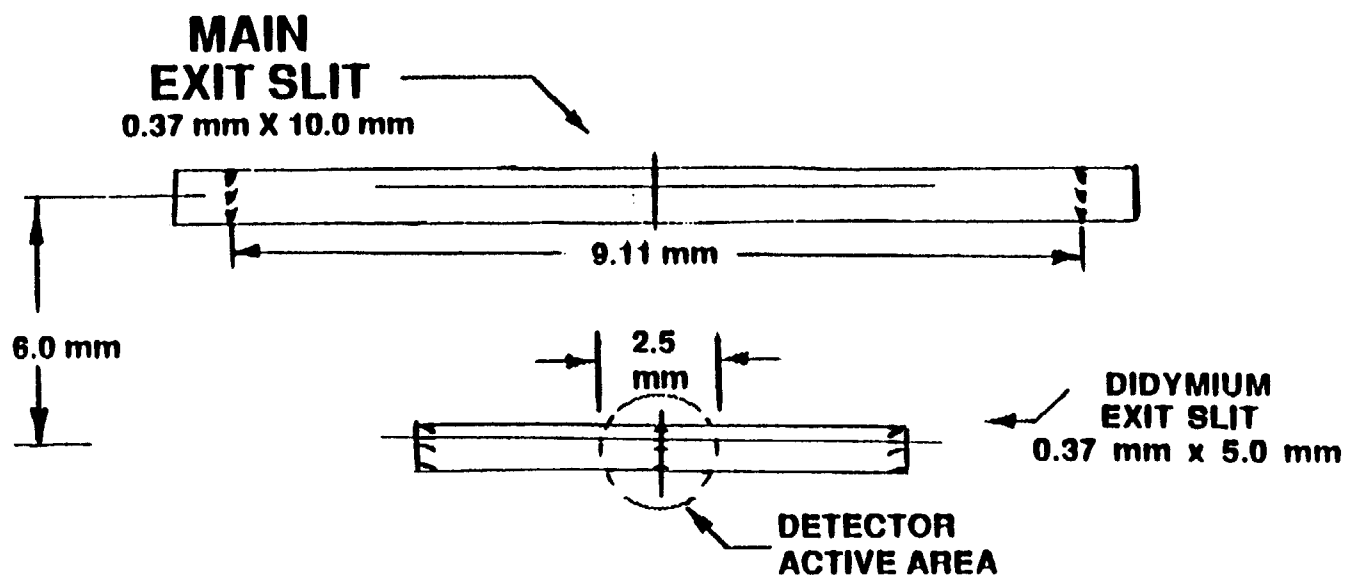
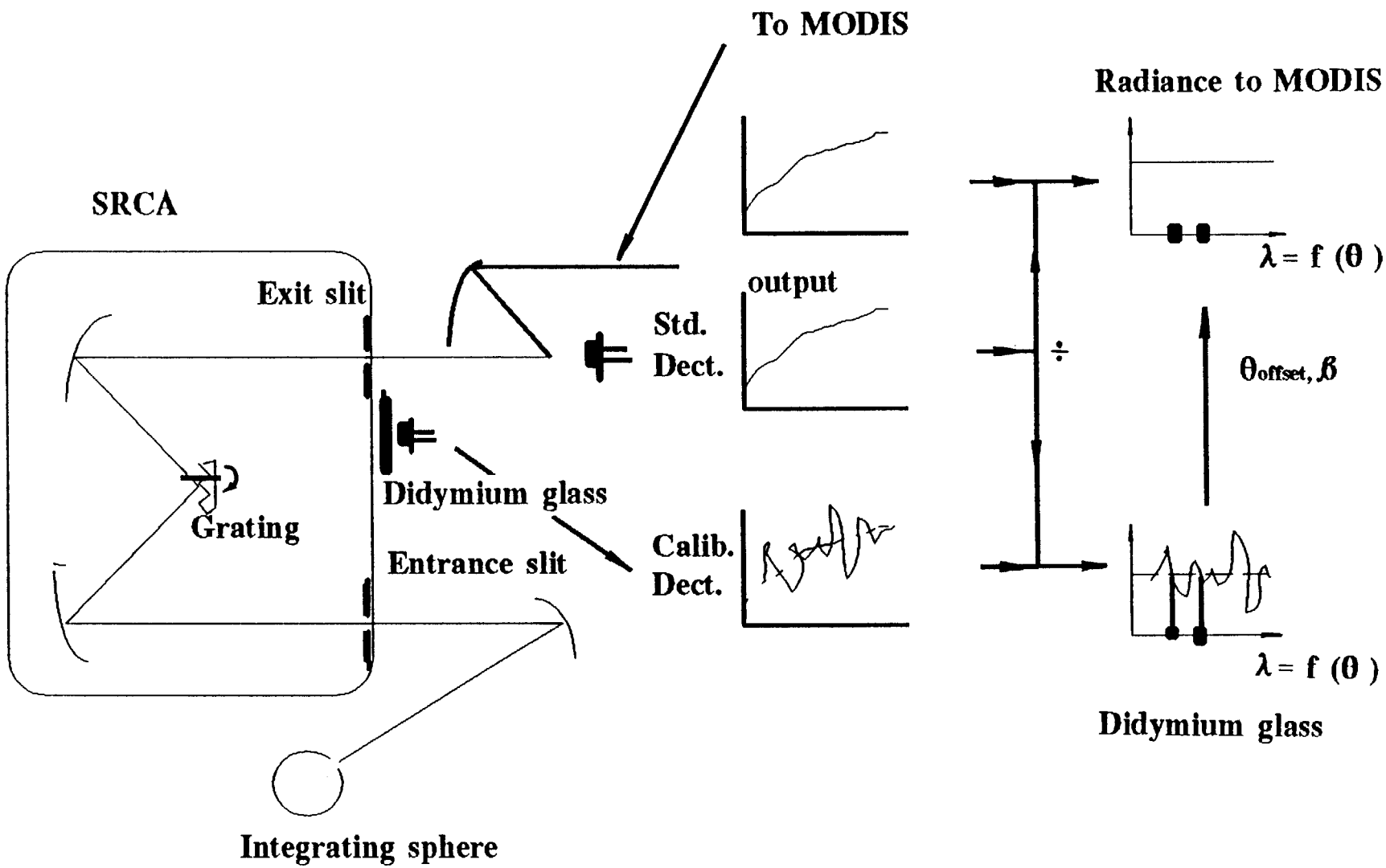
- GEOMETRIC BLUR SPOTS SHOWN FOR 9 FIELD ANGLES



MAIN SLIT WORST CASE : $\Theta g = 13.21^0$, $\lambda = 0.936\ \mu m$ (BAND 18)
DIDYMIUM SLIT WORST CASE : $\Theta g = 11.02^0$, $\lambda = 0.551 \mu m$ (BAND D3)

Data base for spectral calibration of SRCA

1. MODIS response to SRCA output for each grating position.
2. Normalized spectral response of standard detector of SRCA.
3. SRCA monochromator parameters:
   - Grating line width
   - SRCA monochromator focal length
   - Distance between exit slit and didymium exit slit
4. Centroid wavelength for didymium pass bands.
5. Grating motor steps related to grating rotating angle.
6. Central wavelength of detectors for MODIS channel 1 - 19 & 26.
7. Central wavelength difference for MODIS with ground supporting equipments (GSE) and SRCA.


To MODIS
Radiance to MODIS
SRCA
Exit slit
output
Std.
Dect.
λ = f (θ)
÷
θoffset, β
Didymium glass
Grating
Entrance slit
Calib.
Dect.
λ = f (θ)
Didymium glass
Integrating sphere

SRCA CALIBRATION MODELS VALIDATED BY MEASUREMENTS

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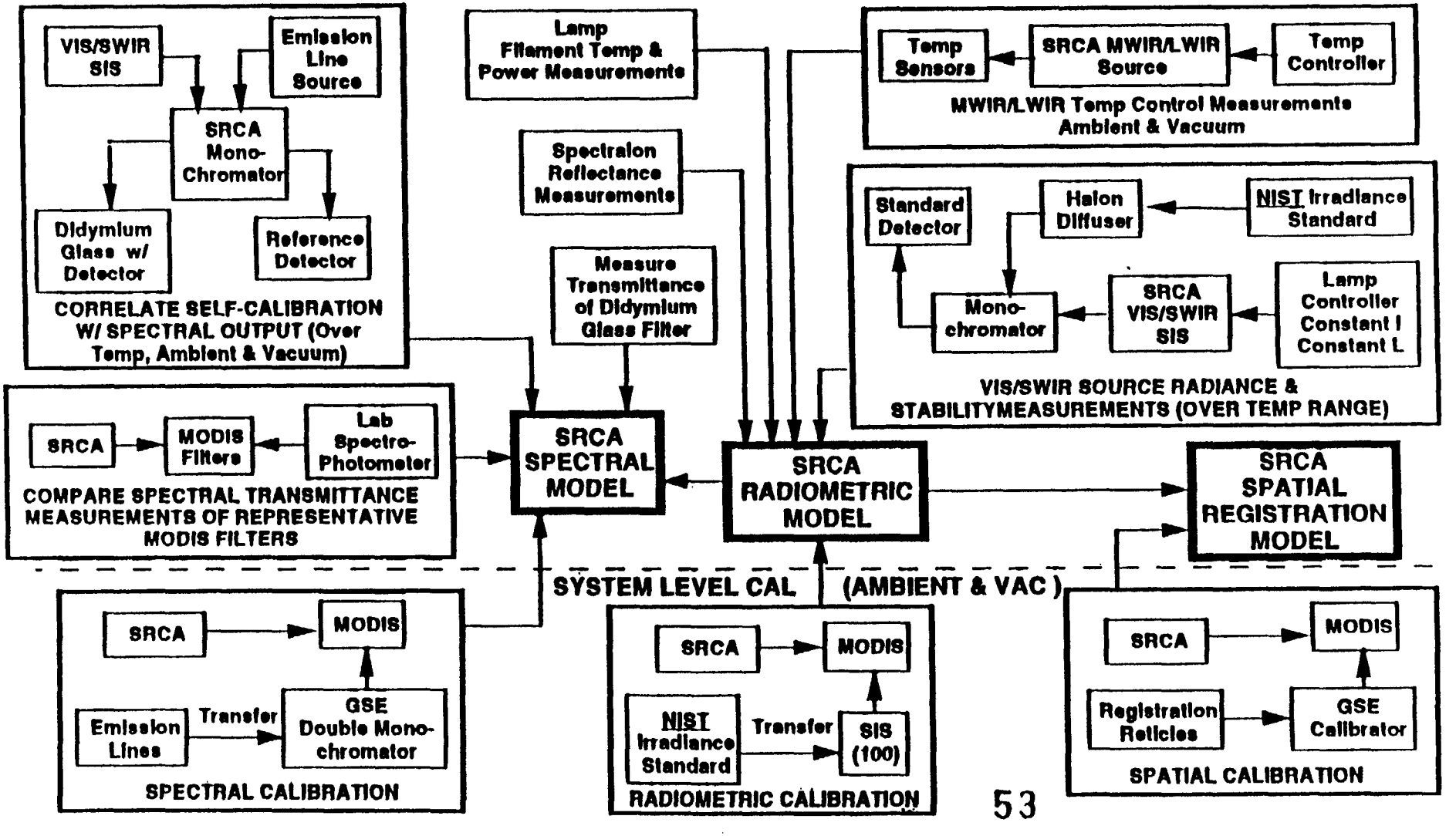


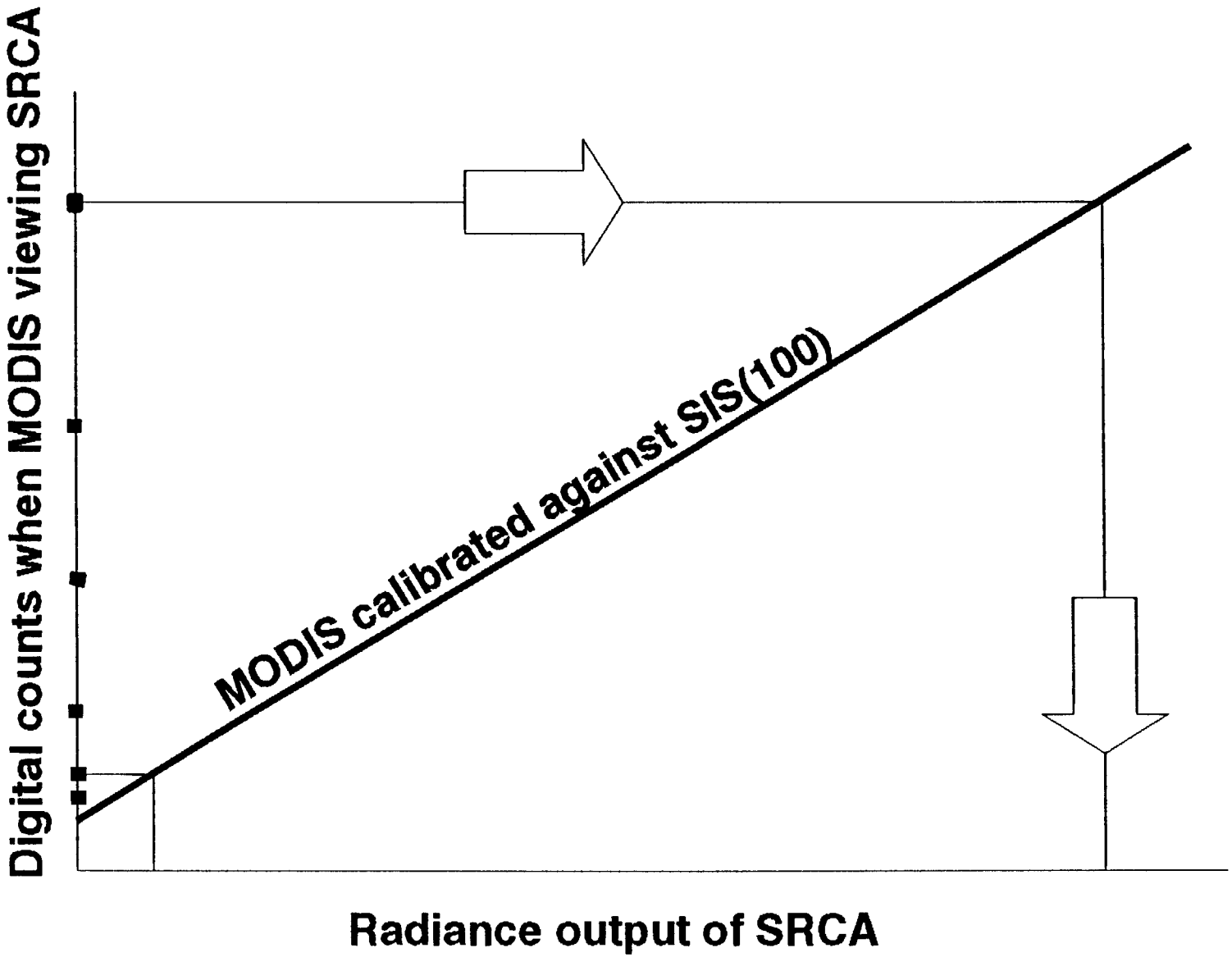
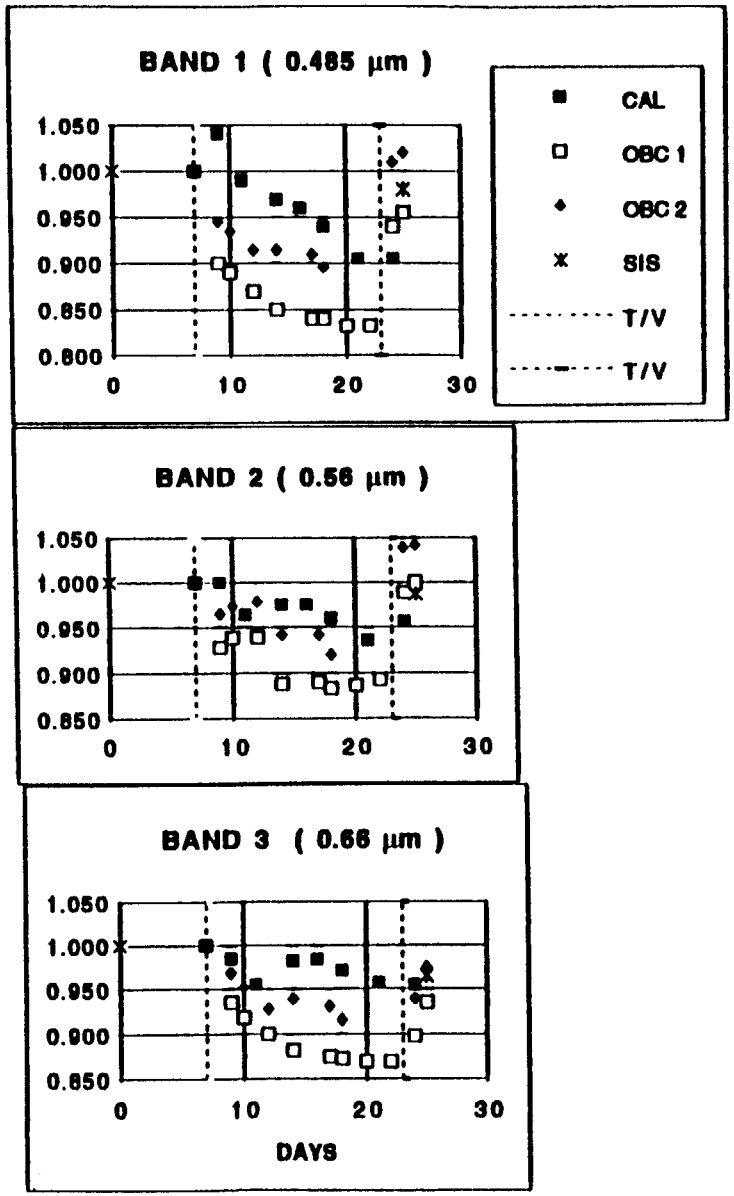

Digital counts when MODIS viewing SRCA
MODIS calibrated against SIS(100)
Radiance output of SRCA

TABLE 6.1. SRCA SOURCE CONFIGURATIONS

Lamp Configuration						Attenuation Filter	Electronic Controller	Control Mode
10 Watt				1 Watt				
#3	#2	#1	S	#1	S			
X	X	X				CLEAR	PRI	RAD
	X	X				CLEAR	PRI	RAD
		X				CLEAR	PRI	RAD
		X				ND	PRI	RAD
				X		CLEAR	PRI	RAD
				X		ND	PRI	RAD
X	X		X			CLEAR	RDT	RAD
	X		X			CLEAR	RDT	RAD
			X			CLEAR	RDT	RAD
			X			ND	RDT	RAD
					X	CLEAR	RDT	RAD
					X	ND	RDT	RAD
X	X	X				CLEAR	PRI	CUR
	X	X				CLEAR	PRI	CUR
		X				CLEAR	PRI	CUR
				X		CLEAR	PRI	CUR
X	X		X			CLEAR	RDT	CUR
	X		X			CLEAR	RDT	CUR
			X			CLEAR	RDT	CUR
					X	CLEAR	RDT	CUR

Factors unstablizing the radiometric calibration by SRCA

1. Output radiance of SRCA bulbs is suffering from environmental shifting. (Ambient ------> Vacuum chamber ------> Space)
2. Degradation in filament emissivity
3. Reflectance change in the integrating sphere coating (1% reduction in 1200 hours burning ------> 16% down in radiance)
4. Filament current/voltage uncertainty
5. Centrally obscured partial aperature calibration and MODIS spectral response has a dependency upon aperature illumination, calibartion error can be introduced due to partial change in MODIS performance.
6. Radiance constant mode ------> brightness temperature change



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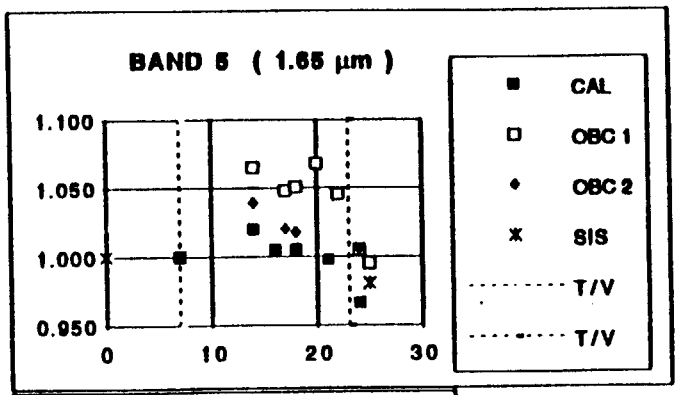
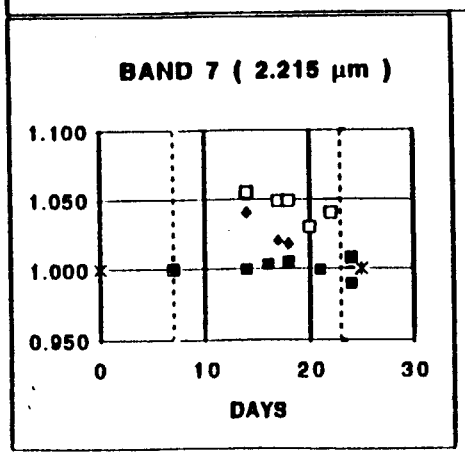
ETM ANOMALOUS AMBIENT TO VACUUM EFFECTS DRIVE MODIS TESTING CONFIGURATION

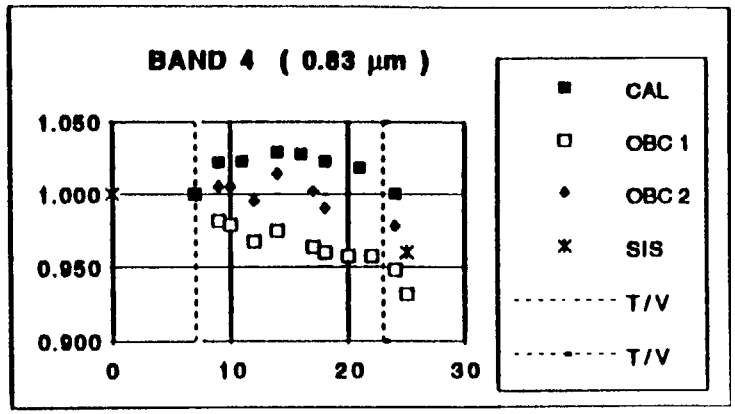
9/92
92-0620-156

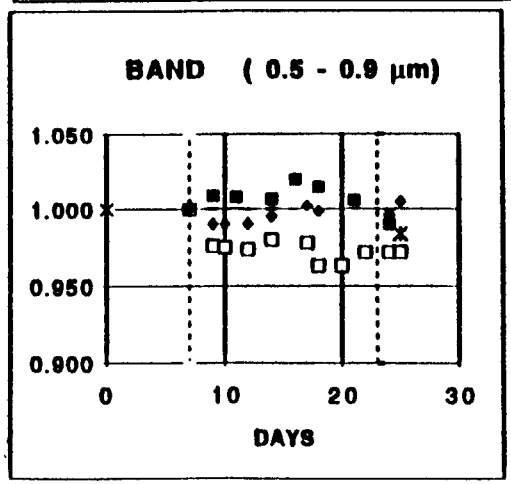
- PREFLIGHT TO ON-ORBIT LINKAGE REQUIRED
- AMBIENT TO VACUUM SHIFTS, IF PRESENT, NEED TO BE UNDERSTOOD
- TEST METHODOLOGY SUPPORTS THIS





- SENSOR SIGNALS VARIED +5% TO -17%
- VARIATION WAS DEPENDENT UPON – SPECTRAL BAND AND CALIBRATION SOURCE USED





- SRCA has a capability of spectral self-calibration.
- SRCA is not capable of providing primary absolute radiometric calibration for MODIS.

  (Partial aperture illumination results in differences in spectral and spatial responses of MODIS)

- Functions:

  To update MODIS radiometric calibration values obtained from primary, full-aperture calibration sources. To measure and track changes in MODIS performance over its life.