ATBD 1995
Thermal Calibration Algorithm

Draft Presentation and Technical Memorandum intended for review at Wallops Island

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THERMAL CALIBRATION

WITH THE ON-BOARD CALIBRATOR BLACKBODY

Thermal Calibration requires:

1. Radiance, Count pair [DN, L] at high radiance
   - use on-board blackbody (OBC BB)
   - traceability from ground Calibration source (BCS)

2. Radiance, Count pair [DN, L] at low radiance
   - use Space View (SV)

3. Check of Assumptions
   - effect of instrument and patch temperatures
   - stability of non-linear coefficients
   - scan angle dependence
   - detector drift (1/f noise and DC restore)
   - scatter/ghosting/crosstalk
   - polarization
   - no interference from other calibrations

4. Uncertainty Analysis

RADIANCE, COUNT PAIR AT HIGH RADIANCE

The OBC BB provides a radiance, count pair every scan
- --V-groove design relies on 4 bounces
- --surface is Type II anodize sealed with thin layer CTL-15 paint
- --reflectance on EM OBC BB measured at 3.39 um to be 0.0008.
- --OBC BB slightly oversized to get 15 "clear" frames out of 50.
  Knowles/Knight show rounded corners require frame selection on per-band basis (2/95).

Radiance determined from OBC BB model and thermistors.

NIST traceability through transfer from Blackbody Calibration Source (BCS).

OBC Blackbody Spectral Radiance Determination

$$L_{\lambda,bb} = \varepsilon_{bb} B_{\lambda,bb} + \frac{1-\varepsilon_{bb}}{\pi}\left(\Omega_{cav} B_{\lambda,cav} + \Omega_{ev} B_{\lambda,Earth}\right)$$

where

Ω_{cav} is the effective solid angle of the scan cavity subtended at the blackbody

Ω_{ev} is the effective solid angle of the Earth view porthole visible to the blackbody

ε_{bb} is the effective emissivity of the blackbody

12 thermistors averaged to obtain one effective temperature for the blackbody

Small gradient expected

Focal plane "footprint" covers about 90% of the blackbody for any single data sample

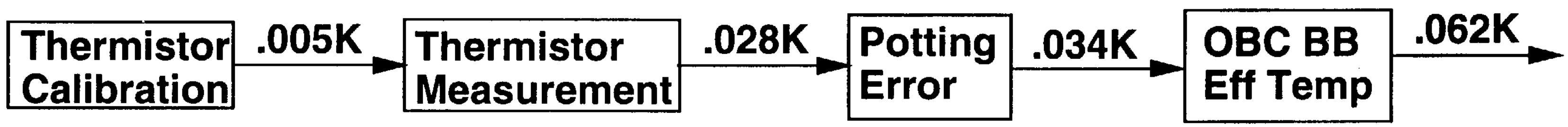
Thermistors which sufficiently deviate from the mean will not be used

Scan cavity temperature algorithm TBD

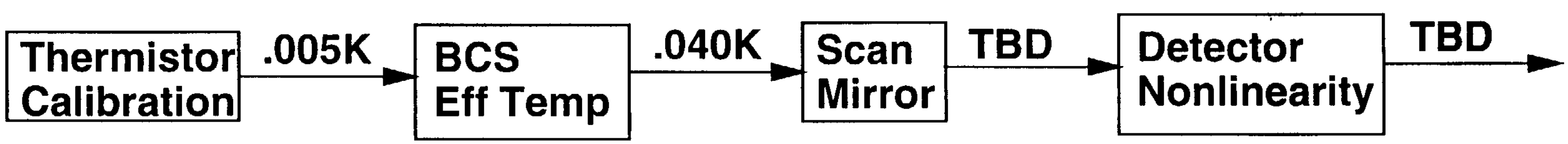
Effective Earth termperature algorithm TBD

NIST Traceability of the OBC Blackbody

Internal Traceability



External Traceability



RADIANCE, COUNT PAIR AT LOW RADIANCE

SpaceView is slightly oversized hole to space--15 'clear' frames/ 50 total.

Outliers rejected

~20 stars/planets visible to MODIS

not yet added to algorithm

Average over clear frames to get counts.

Radiance of space assumed to be zero.

CHECK OF ASSUMPTIONS

Effect of Instrument and Patch Temperatures

Two philosophies have been used in accounting for instrument and patch temperature differences:

A. 'Master Curve' approach: Carries instrument temperature as effective background radiance.

- --Advocated by SBRC
- --Algorithm included in ATBD '94
- --Verification from Engineering Model not shown yet

B. 'Traditional' approach: Carries instrument temperature as separate coefficient term.

- --Successfully used on previous programs.

MCST current approach (ATBD '95) based on Master Curve mathematics with additional instrument temperature dependencies included.

Both require characterization at the controlled focal plane temperatures (patch temperatures).

Test Conditions for Determining Nonlinear Coefficient

Instrument Temperature

Patch Temperature	Low	Nom	Hi
Low	✓	✓	
Nom	✓	✓	✓
Hi		✓	

Traditional vs Universal algorithm argument is based on this incomplete 3 X 3 grid

Historically a 4 X 4 grid has been used (AVHRR)

** Check marks denote possible higher priority tests

CHECK OF ASSUMPTIONS

Stability of non-linear coefficients

Non-linearities expected in HgCdTe detectors; particularly PC (up to 5%).

Algorithm includes non-linear term; measured pre-launch.

On-orbit verification of non-linear term accomplished through two methods:

A. Use of OBC BB at 315 K.
   --greater temperature uncertainty/gradients

B. Use of OBC BB as it cools from 315 K (several hours)
   --much more uniform

OBC BB was heated during EM tests
   --radiometric analysis not complete

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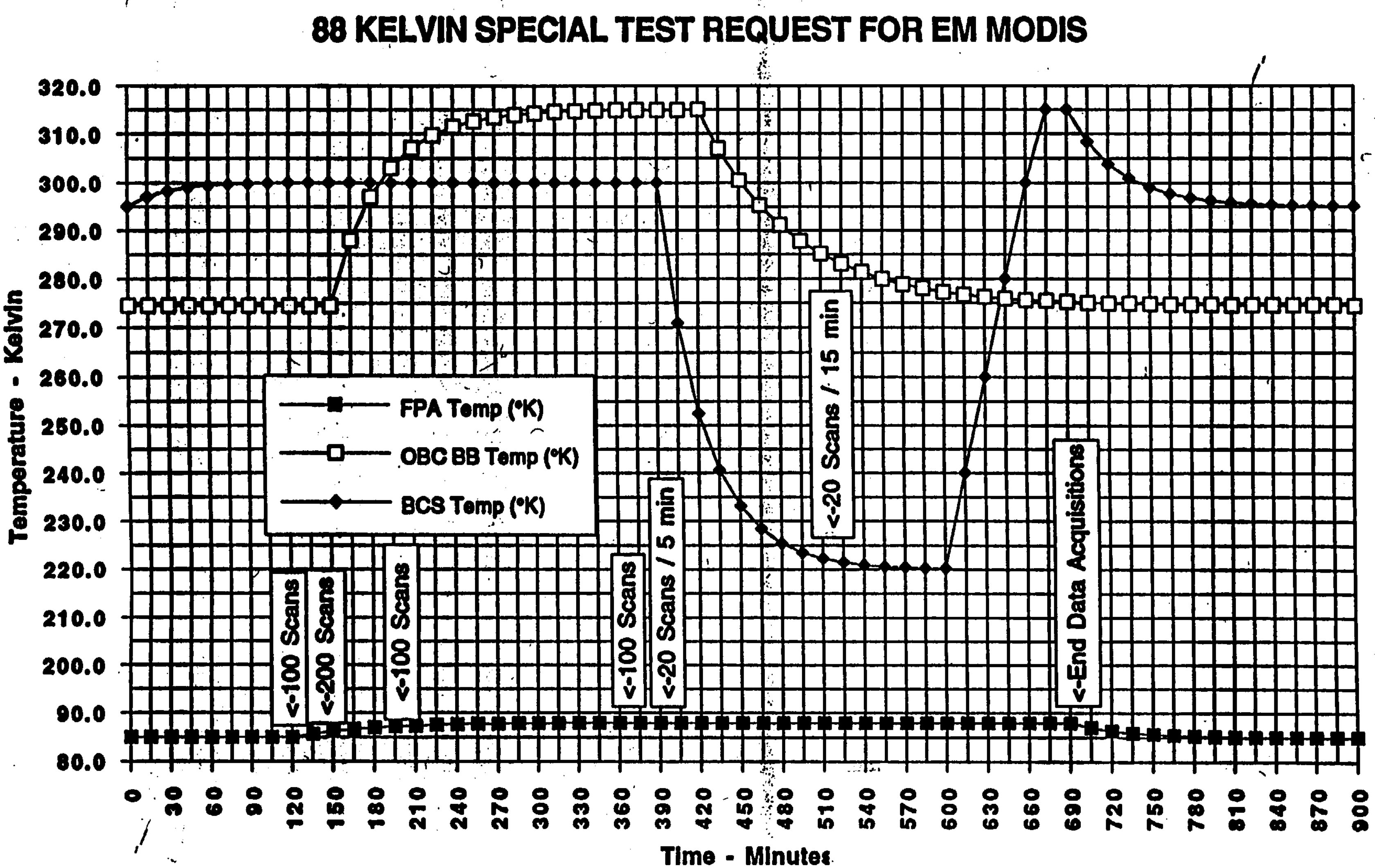
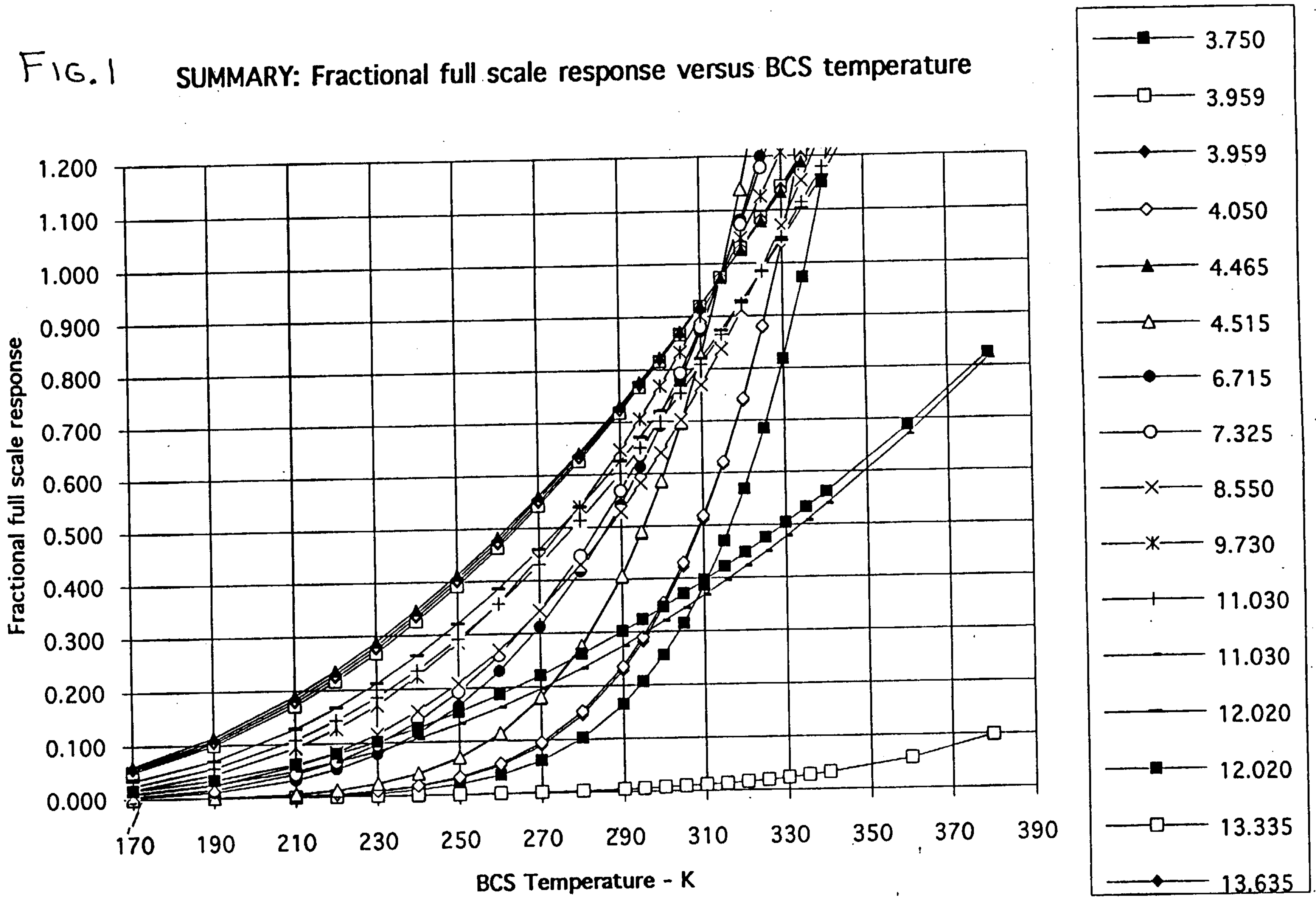

88 KELVIN SPECIAL TEST REQUEST FOR EM MODIS
Temperature - Kelvin
320.0
310.0
300.0
290.0
280.0
270.0
260.0
250.0
240.0
230.0
220.0
210.0
200.0
90.0
80.0
FPA Temp (°K)
OBC BB Temp (°K)
BCS Temp (°K)
<-100 Scans
<-200 Scans
<-100 Scans
<-100 Scans
<-20 Scans / 5 min
<-20 Scans / 15 min
<-End Data Acquisitions
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720 750 780 810 840 870 900
Time - Minutes

T/V CALIB AD Chart 9-1

FIG. 1



CHECK OF ASSUMPTIONS

Scan Angle Dependence

Lincoln Lab data indicates up to 10% change in mirror reflectance as a function of scan angle for some bands.

Effect currently included in algorithm

Concerns on ability to accurately measure this pre-launch

Will require deep space scan to account for changes with contamination

Pursuing use of cavity corner as second thermal source.

CHECK OF ASSUMPTIONS

Scatter/Ghosting/Crosstalk

Currently not included in algorithm; not accurately quantized for uncertainty analysis

Breault report indicates low scatter for MWIR/LWIR.

Ghosting expected to be low.

Engineering Model had significant crosstalk

- Band 36 to 32.
- Band 27 to 33.

CHECKS ON ASSUMPTIONS

Polarization

Algorithm currently does not include effects of infrared polarization.

Knowles/Knight indicate OBC BB may have 1% residual polarization (6/95).
--SBRC rolls into emissivity term.

Knight indicates radiometric uncertainty ~0.01% at OBC BB angle (7/95).

Uncertainty at high scan angles (55 degrees) and some targets may be significant (est. ~0.5% for oceans, higher for man-made objects).

Knight pursuing infrared polarization contributions to uncertainty in greater depth (formal derivation, desert scenes, BCS, MODIS residual polarization).

Blackbody Estimated Emissivity due to Polarization Effects

Band	OBC Blackbody Emissivity
20	.9920
21	.9919
22	.9919
23	.9918
24	.9916
25	.9916
27	.9949
28	.9961
29	.9968
30	.9960
31	.9951
32	.9938
33	.9913
34	.9903
35	.9893
36	.9884

Scan Mirror Polarization Factor

Wavelength	26 deg	65 deg
um	PF Mirror	PF Mirror
3.75	0.00246522	0.01781625
3.959	0.00257608	0.01644125
4.05	0.00183071	0.01566043
4.465	0.0026929	0.01633859
4.515	0.00298998	0.01715603
6.715	0.00440368	0.01966586
7.325	0.00334134	0.02215427
8.55	0.01120478	0.10054851
9.73	0.01043451	0.09084717
11.03	0.00638524	0.05523017
12.02	0.00583872	0.05286712
13.335	0.01149319	0.09408547
13.635	0.01075171	0.10256485
13.935	0.01146021	0.10506176
14.235	0.01246831	0.11085346

OBC Blackbody Polarization Factor

Wavelength	26 deg
μm	PF OBC Blackbody
4	0.0034
5	0.0032
6	0.0029
7	0.0023
8	0.0014
9	0.0025
10	0.0029
11	0.0031
12	0.0037
13	0.0042
14	0.0057

CHECKS ON ASSUMPTIONS

No interference from other calibrations

Algorithm does not yet account for stray light/thermal effects from SRCA or SD/SDSM use.

Algorithm needs to account for moon in SV (not yet included).

Uncertainty Analysis

MODIS Band	Sensitivity Budget*	MODIS Specification*	Key Uncertainty Parameters
20	1.23%	0.75%	Wavelength, Digitization/Noise, BB Temp, Cavity Temp
21	8.40%	10.00%	Digitization/Noise
22	1.25%	1.00%	Wavelength, Digitization/Noise, BB Temp
23	1.22%	1.00%	Wavelength, Digitization/Noise, BB Temp
24	1.29%	1.00%	Wavelength, Scan Mirror Reflectivity, BB Temp
25	1.17%	1.00%	Wavelength, Digitization/Noise, BB Temp
27	1.25%	1.00%	Nonlinearity, Scan Mirror Reflectivity
28	1.05%	1.00%	Nonlinearity, Digitization/Noise
29	0.75%	1.00%	
30	1.22%	1.00%	Nonlinearity, Digitization/Noise
31	0.50%	0.50%	Digitization/Noise, BB Temp
32	0.49%	0.50%	Digitization/Noise, BB Temp
33	0.80%	1.00%	Digitization/Noise
34	0.80%	1.00%	Digitization/Noise
35	0.81%	1.00%	Digitization/Noise
36	0.91%	1.00%	Digitization/Noise
31hi	9.83%	10.00%	Nonlinearity, Digitization/Noise
32hi	4.77%	10.00%	Nonlinearity, Digitization/Noise

* Radiometric uncertainty in percent of Ltyp