Date: March 2, 1995

To: Harry Montgomery
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Subject: Effects of Low Emissivity Regions in using the On-Board Calibrator Blackbody

Ref: "Usable Size of OBC Blackbody" PL3095-Q04586 (#2130), by Eric Johnson, January 11, 1995.
"OBC Blackbody Usability", PL3095-N04653, by Jim Young, February 13, 1995.

Summary

Recently, we became aware of the fact that the rounded corners of the on-board calibrator blackbody will introduce variations in the blackbody radiance as a function of scan angle. To examine this problem, we have mapped out the blackbody spatial variations, determined the area of the blackbody contributing radiance to the focal planes, calculated the effect on the radiometric calibration from these non-uniformities, and identified the optimal data collection frames to minimize the resulting uncertainties.

Blackbody Geometry and Focal Plane Projections

The high total emissivity of the blackbody relies on having multiple bounces (four) within the v-grooves before the light is seen by the MODIS. "Insufficient" regions are those where the emissivity of the blackbody is lower than the derived requirements by at least 0.004 (SBRC tolerance). Figure 1 shows the blackbody geometry from a front and side view. As was pointed out by SBRC in the referenced memos, the rounded corners seen in the front view produce a lower emissivity in portions of the top v-grooves and bottom v-grooves. Figure 2 shows the blackbody as viewed by MODIS at an angle of 39 degrees from the blackbody normal with the shaded regions representing lower "insufficient" emissivity regions. For the top grooves, some regions are incomplete (missing portions of the inner walls), thus creating low emissivity regions. For the bottom v-grooves, the walls are shorter than normal in some regions, amplifying the contributions from the tips and valleys. Additionally, there are regions at the edge of the cavity where light can enter through the sides of a groove and reach the MODIS aperture with less than four bounces. The Appendix to this memo discusses how the dimensions of the shaded regions and focal plane contributions were determined. Note that the focal plane gets contributions from the shaded areas, indicating that some non-uniform radiance will be incident on the focal plane. Figure 2 also shows the region that contributes radiance to the LWIR focal plane for two scan angles, encompassing 16 FOV.

It should be noted that frequently we and SBRC talk about the "projection" of the focal planes onto the blackbody. What is meant by the word "projection" is the reverse ray trace from the detector and/or focal plane to the blackbody. Alternatively, this may be called the contributing area of the blackbody. Since the blackbody is not in focus, the projection may be non-intuitive. The relative projection sizes between the detector and the focal plane are not the same on the blackbody as they are on the Earth's surface. For example, while a single detector's projected area might be 0.3% of the focal plane's area when projected onto the Earth, it will be about 60% of the focal plane's area when projected onto the blackbody. This is depicted in Figure 3 for Detector 1 in Band 32 and Detector 5 in Band 34. This is an example of the worst and best cases pertaining to the fraction of low emissivity region viewed by the detector.

Radiometric Uncertainty due to Lower Emissivity Regions

To analyze the effect of the low emissivity regions, a sensitivity simulation was constructed. This model is discussed in the Appendix. The major effect of the low emissivity regions is to increase the susceptibility to reflected light from the earth and scan cavity. The sensitivity simulation allows one to calculate the radiometric uncertainty due to the non-uniformity (i.e., above and beyond the standard calibration uncertainty) as a function of earth temperature, blackbody temperature, scan cavity temperature, blackbody gradients, substrate emissivity, and the low emissivity fraction of the total contributing area. Figure 4 shows the sensitivity for Band 32 as a function of Earth scene and blackbody temperature. The geometric configuration is that shown in Figure 3. In this configuration, the low emissivity regions contribute 3.2% of the light incident on detector 1 of Band 32 (includes ghosting contributions). Table 1 depicts this, and gives the highest uncertainty for detector 1 in each infrared band. Note that due to symmetry, detector 10 for each band will have the same uncertainty as detector 1.

Data Collection Frame Selections

In processing the data, we select the data frames that correspond to a given focal plane collection area on the blackbody. By choosing these on a band by band basis, we can minimize the effects of the "insufficient" regions. These band based frames should be chosen such that the band does not directly view either the top or bottom v-grooves. Table 1 presents these recommended optical axis start angles to minimize the effects of the low emissivity regions of the blackbody. We recommend implementing this table.

Related Concerns

The original thermal analysis for the blackbody assumed square edges. George Daelemans estimates that there will be some increase in the thermal gradients, but this should be small.

Concerns have been raised about the effects of the Space View edges. The following measurements of the space view are required in order to conduct similar analysis: along scan length, cross scan width, wall thickness, and distance to scan mirror.

We have verified that the focal plane projection on the scan mirror is completely contained on the surface of the mirror for all scan angles and glint from the honeycomb edges will only be a factor if scattering off the fold mirror is significant. Furthermore, the footprint from the calibrator scan angles will be effectively identical in size, shape, and location, as the equivalent Earth view side angles.

It is possible to achieve considerably more than 15 frames of blackbody data (up to 67 frames) with a direct detector view of only "good" blackbody regions. There is a ghosting to noise trade off as the number of data frames increases.

Conclusion

We have analyzed the effects of the non-uniform blackbody surface on the radiometric uncertainty. These effects are minimal in the ambient mode, but are significant for Bands 31 and 32 in the heated mode. These effects can be effectively removed by careful selection of the data frames for each band.

cc:

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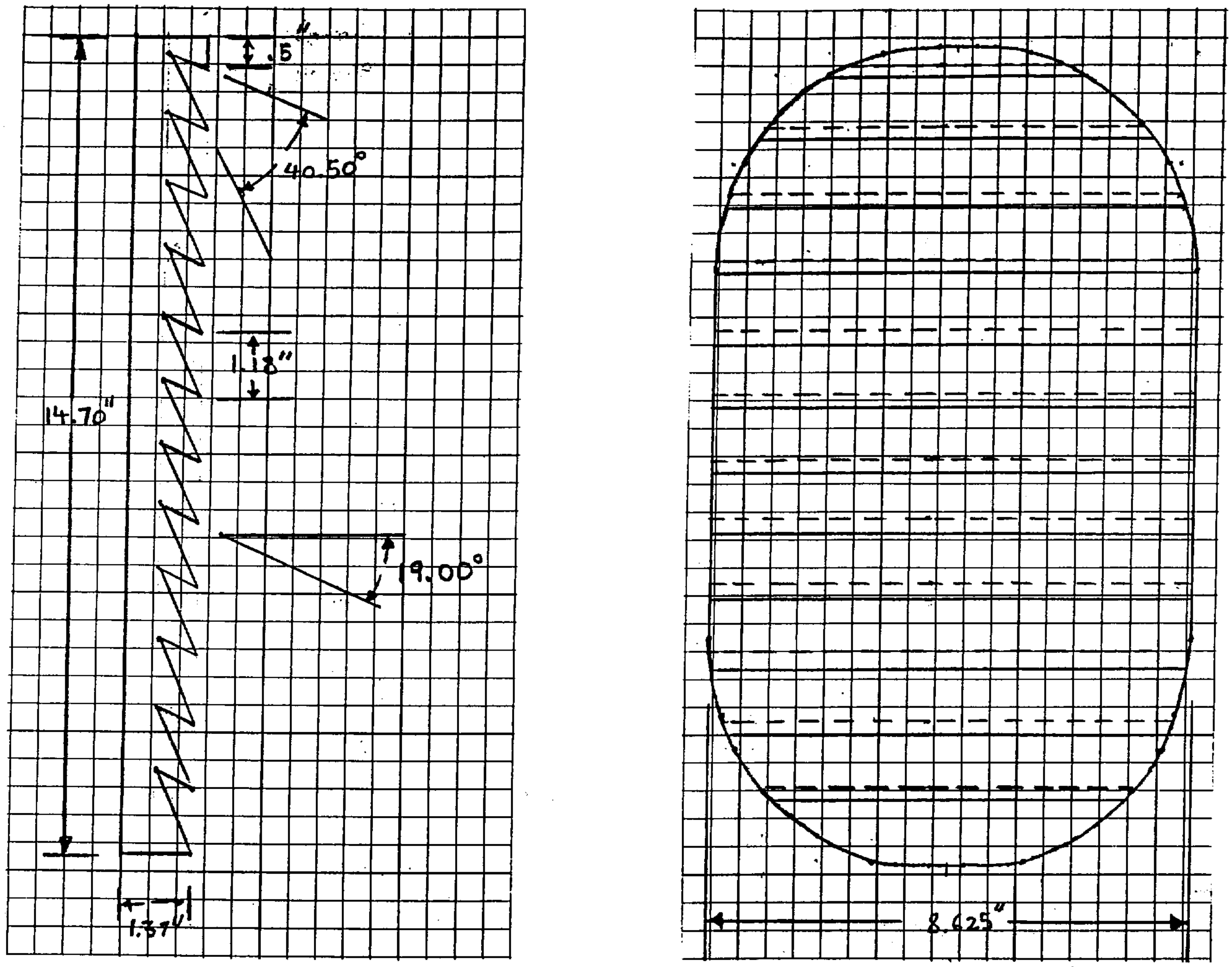


Figure 1. MODIS blackbody schematic (side and front view with the horizontal dashed lines depicting the hidden groove valleys).

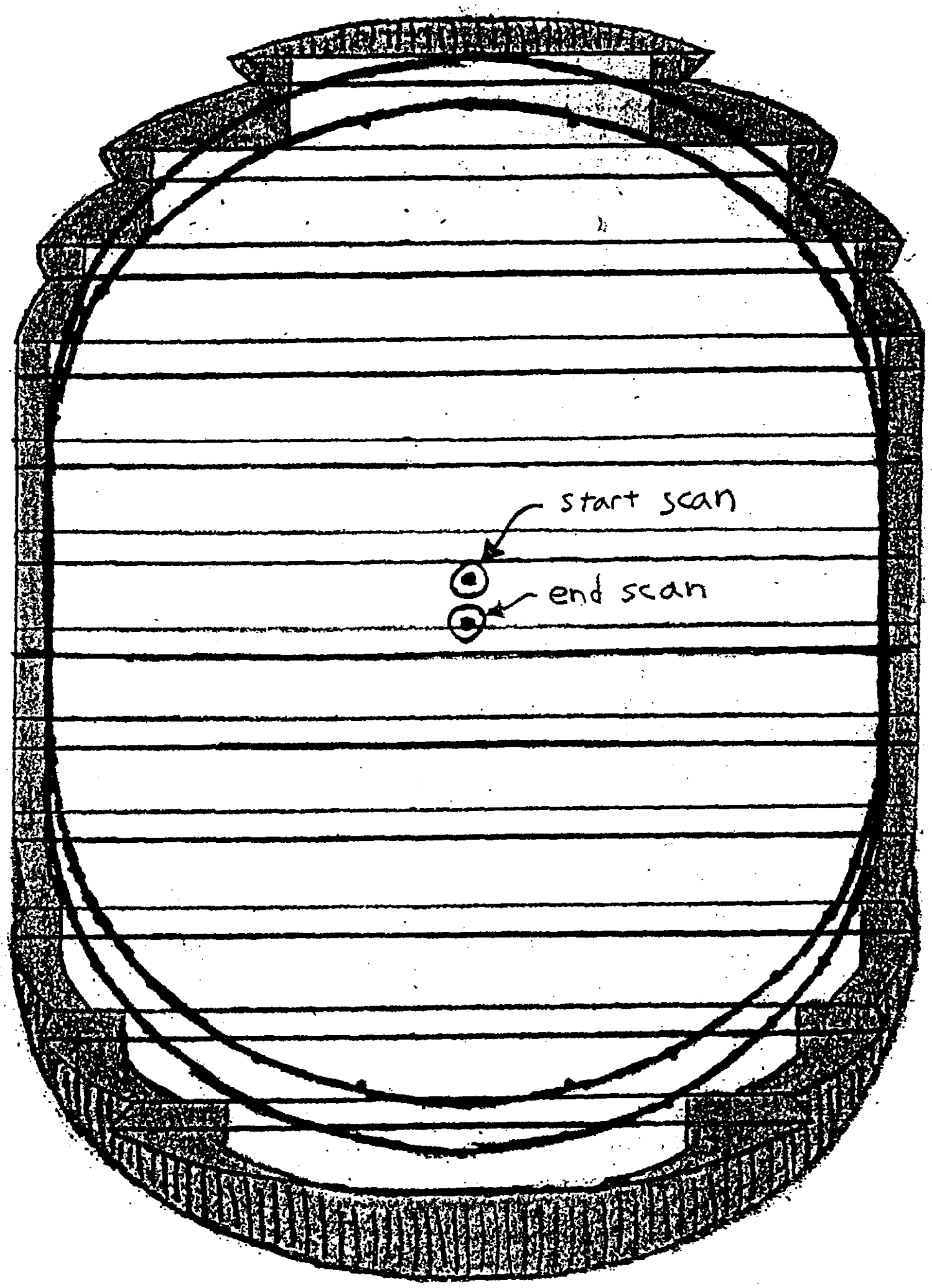


Figure 2. Footprint of the LWIR focal plane onto the MODIS blackbody for start and end of 16 FOV scan (as viewed through the optical port at an angle of 39 degrees from blackbody normal). Shaded regions represent low emissivity regions of the blackbody.

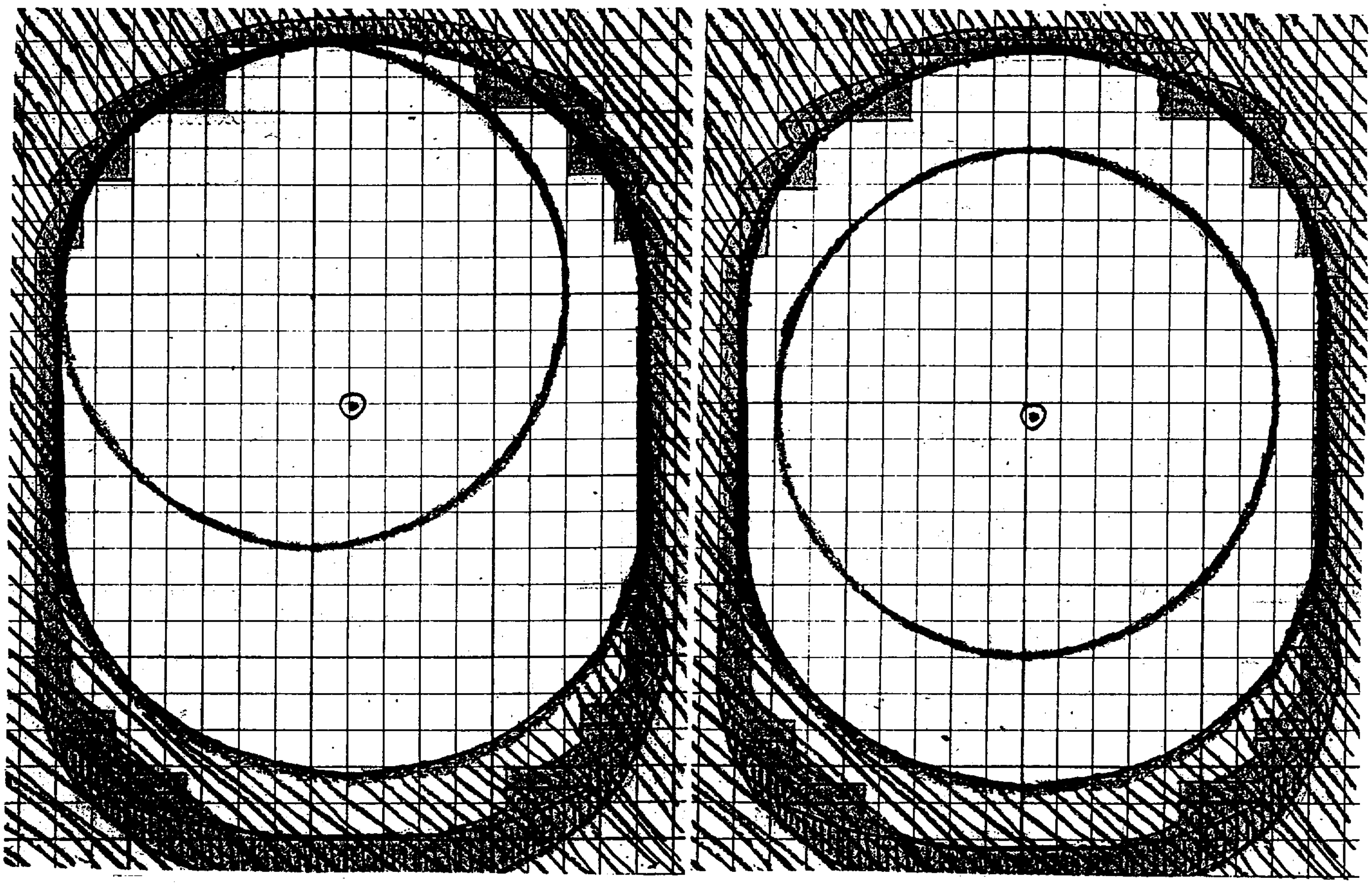
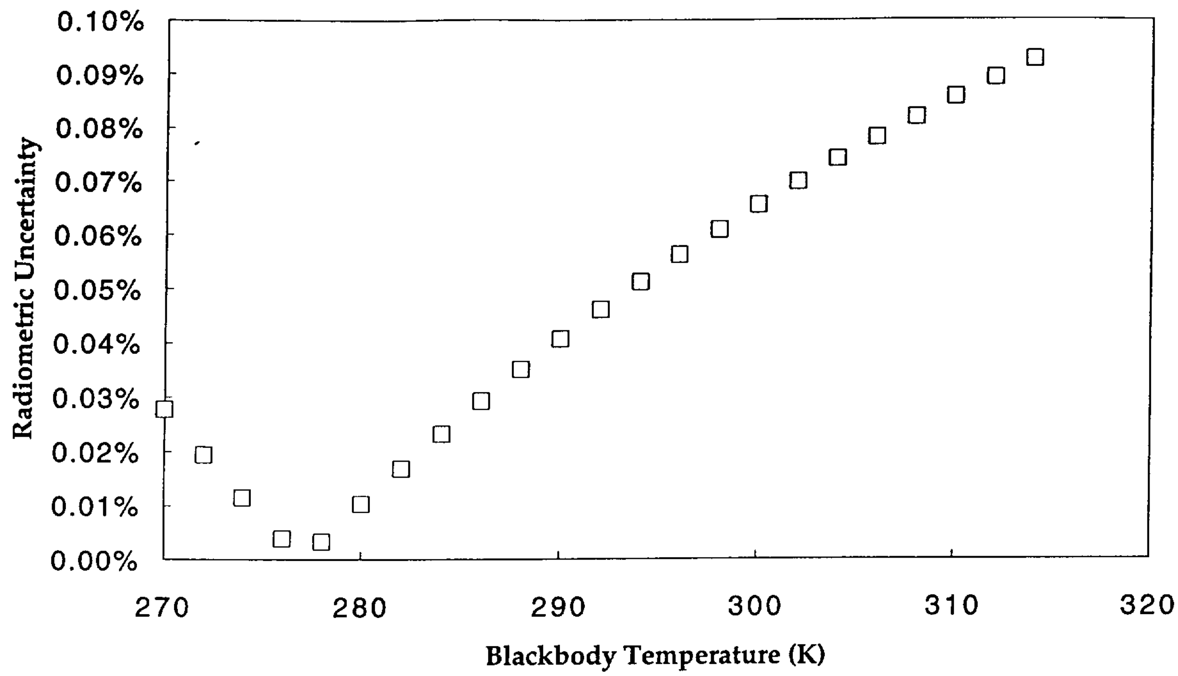


Figure 3. Cutout of blackbody at scan start as viewed by Band 32, Detector 1 (left) and Band 34, Detector 5 (right). The circular region is the detector view, the oval region is the remainder of the focal plane, the shaded region is the low emissivity portion of the blackbody, and the striped region is not visible to the focal plane.



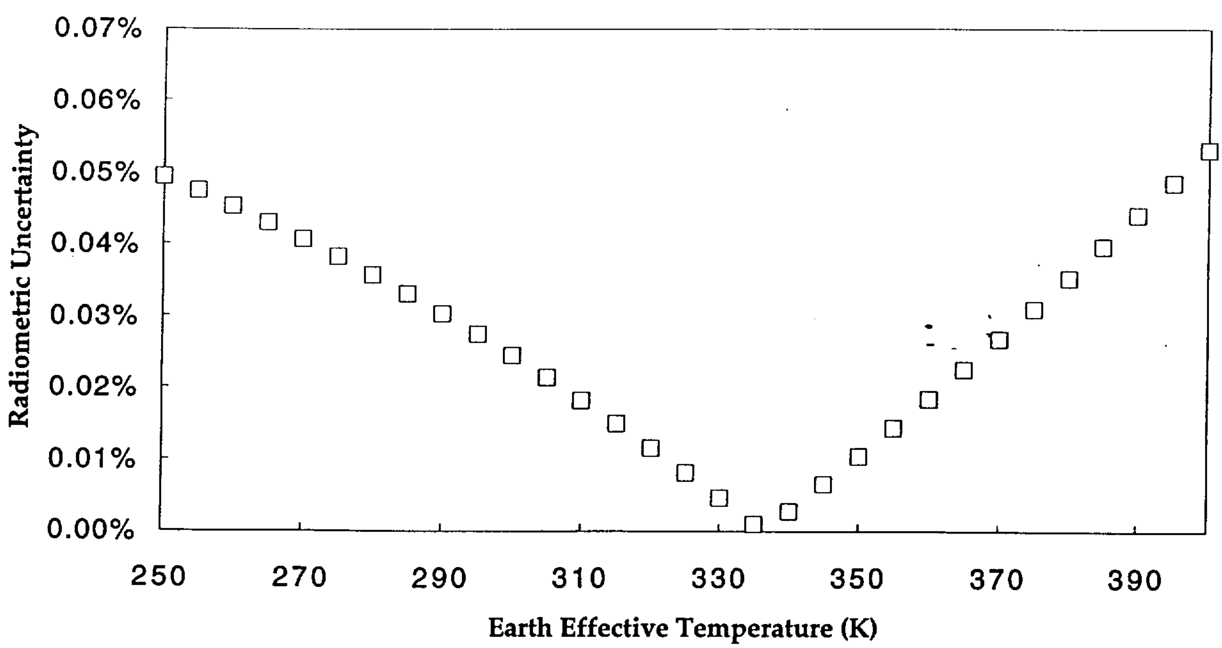


Figure 4. Radiometric uncertainty of Band 32, Detector 1, due to low emissivity regions of the blackbody with respect to blackbody temperature (top chart) and effective Earth temperature (bottom chart)

Band	Effective Emissivity of current blackbody**	Low Emissivity Area in Focal Plane	Low Emissivity Area Directly Viewed By Detector	Effective Low Emissivity Area Viewed By Detector	Effective Blackbody Radiance Uncertainty Due to Low Emissivity Regions (Ambient Mode)	Effective Blackbody Radiance Uncertainty Due to Low Emissivity Regions (Heated Mode)	Suggested Start Angle to Minimize Low Emissivity Effects *
20	0.9917	3.72%	0.00%	0.37%	0.02%	0.02%	230.75
21	0.9917	3.72%	0.00%	0.37%	0.02%	0.02%	230.75
22	0.9917	3.72%	0.00%	0.37%	0.02%	0.02%	230.75
23	0.9917	3.72%	0.00%	0.37%	0.02%	0.02%	231.29
24	0.9914	3.72%	0.31%	0.65%	0.02%	0.04%	230.75
25	0.9917	3.72%	0.00%	0.37%	0.01%	0.02%	230.21
27	0.9914	3.72%	0.31%	0.65%	0.02%	0.03%	230.75
28	0.9917	3.72%	0.00%	0.37%	0.01%	0.02%	230.75
29	0.9914	3.72%	0.31%	0.65%	0.01%	0.03%	229.94
30	0.9914	3.72%	0.31%	0.65%	0.01%	0.02%	229.13
31	0.9909	3.72%	1.05%	1.32%	0.02%	0.04%	231.56
32	0.9894	3.72%	3.13%	3.18%	0.04%	0.09%	232.37
33	0.9917	3.72%	0.00%	0.37%	0.01%	0.01%	230.75
34	0.9917	3.72%	0.00%	0.37%	0.01%	0.01%	230.75
35	0.9917	3.72%	0.00%	0.37%	0.01%	0.01%	230.75
36	0.9917	3.72%	0.00%	0.37%	0.01%	0.01%	230.75

*** Suggested start blackbody view angles (with respect to nadir) of the optical axis to minimize the effects of the low emissivity regions of the blackbody. The determination of these angles is a systems engineering issue, however, our objective is to not use frames where the detector directly views either the top or bottom v-grooves of the blackbody.**

**** As compared with a rectangular blackbody with an emissivity of .9920 for all bands**

Table 1. Effects of blackbody rounded corners with compensation scan angles.

Appendix

Determination of the effective emissivity of the blackbody

For the current "square" blackbody emissivity model, it is assumed that 10% of the light rays which leave the substrate come from either the tips or the groove valleys thus achieving only one specular bounce. The remaining 90% of the light exits from the groove surfaces with 4 bounces. Although this is not exactly the case, it is a good model and appears in Volume 3 of the 1994 MODIS CDR. For this experiment we will assume that each band just meets specification (i.e. each band has an effective emissivity of .992) Therefore, the effective blackbody emissivity equation is:

$$\varepsilon_{bb} = 1 - (w_{good}\rho_{sub}^{4} + w_{bad}\rho_{sub})$$

where:

w_{good} is the weighting factor for the "good" four bounce light ($w_{good} = .9$)
w_{bad} is the weighting factor for the "bad" one bounce light ($w_{bad} = .1$)
ρ_{sub} is the reflectivity of the anodized aluminum substrate

From this equation it can be determined that if the effective emissivity of the blackbody is .9920 then the reflectivity of the substrate is .920

Since the blackbody has rounded corners, there are additional regions within some of the v-grooves which also permits light to take only a single bounce. After taking ghosting into account, the contribution of these regions is listed in column 5 of Table 1. The value from this column is then added to w_{bad} and subtracted from w_{good}. Therefore, for the worst case, Band 32, detector 1, w_{good} becomes .8681 and w_{bad} become .1319. Applying the values of column 5 of Table 1 to the effective blackbody emissivity equation yields column 2 of Table 1.

Determination of the low emissivity regions of the tilted blackbody

To determine these low emissivity regions, it is necessary to view the blackbody from the same angle as the MODIS optical axis (i.e. 39 degrees from blackbody normal) This was done on grid paper and appears in Figure 2 and 3. All footprints in this analysis are done onto this tilted view of the blackbody and do not need a cosine factor applied to them. The shaded areas are the low emissivity regions.

The top and bottom are shaded since this portion is the flat edge of the blackbody.

For the top grooves, all of the surface which juts out from the valleys must be shaded since the groove is incomplete for these surfaces.

For the bottom v-grooves, although the v-groove is complete, the groove region is small at the ends. Since the tips and valleys occupy 10% of the region for normal sized grooves, it can be determined from the blackbody emissivity equation that this tip/valley to groove surface ratio can be at most 15% to achieve a blackbody emissivity of .988 (minimum specification). The minimum size region for a "sufficient" groove region is 66% of the normal sized groove (.1/.15 = .66). Therefore, all bottom grooves with region less than 66% are shaded.

For the sides, light comes at an angle, and will not achieve four bounces if it is too close to the edge. We have establish an edge criteria that requires light coming in from the edge to travel at least 2" through the grooves before exiting toward the optics. Figure A1 shows the calculations for the blackbody edge region (bb-edge). Therefore .22" of the edge region must be shaded with the value decreasing as the width decreases at the top and bottom of the blackbody. Note that this edge factor affects the top and bottom grooves in addition to the afore mentioned effects.

Determination of the focal plane and detector projection and 16 FOV scan of the tilted blackbody.

Figure A2 shows a ray trace cartoon which portrays the focal plane footprint onto the blackbody. The focal plane footprint on the tilted blackbody is 10.08" along scan and 8.03" cross scan. The detector footprint on the tilted blackbody is 7.10" along scan and 7.10" cross scan. The along scan distance that a 16 FOV scan covers on the tilted blackbody is .49" (Figure A3).

Determination of the focal plane and detector areas and percent "bad" areas

Refer to Figure A4
FPA total area = 67.2 in^2
Detector total area = 39.9 in^2

The effective low emissivity area was determined as a weighting function between the percent focal plane "bad" area (ghosting) and the percent detector "bad" area. Since the ghosting light contains a higher percentage of "bad" area for all bands than the direct detector light, a heavier weight on the ghosting factor will yield a greater percentage of "bad" areas. Current estimates indicate that near field response will be 1% or less. This model will weight the ghosting at 10%. Column 5 of Table 1 shows the results of this calculation. Comparing column 4 with column 5 it can be noted that the ghosting contributions are minimal for the selected scan angles

Determination of the suggested scan angles to minimize the effects of the low emissivity regions of the blackbody

See Figure A5
Note that adjustment only need to be made to Bands, 23, 25, 29, 30, 31, and 32.

Determination of the effective blackbody radiometric uncertainty due to the low emissivity regions

This was performed using a simple simulation. The simulation was done on an EXCEL spreadsheet and the nominal parameters are easily changed. The spreadsheet determines the radiance exiting the blackbody with a weighting factor between the "good" and "bad" emissivity regions. This result is then compared with the radiance that a "square" blackbody of emissivity .992 would have emitted. The following are the nominal parameters:

- Blackbody nominal temperature = 290K (315K in heated mode).

- Blackbody edge temperature = 289.9K (314.9K in heated mode) models temperature gradient which may occur in the edge "bad" regions.

- Emissivity of cavity walls = .92 models the effects of indirect Earthshine reflected from the cavity walls onto the blackbody.

- Solid angle of the Earth subtended by the blackbody = $.1\pi$ models effects of direct Earth shine on blackbody.

- Solid angle of the cavity subtended by the blackbody = $.9\pi$ models effects of indirect Earth shine and direct cavity radiance on blackbody.

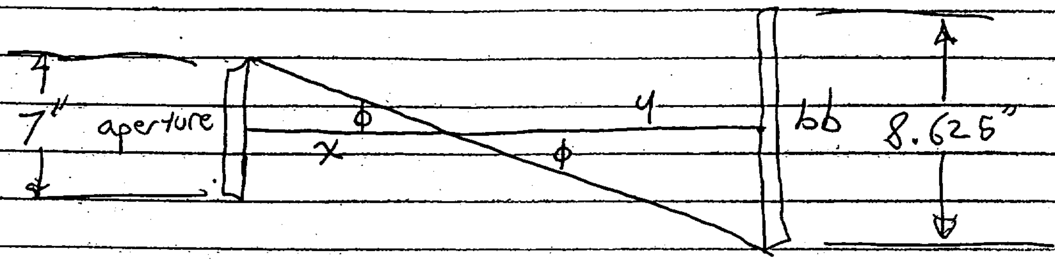
- Cavity temperature = 280K models effects of cavity radiance on the blackbody (note we used a 10K temperature difference between the cavity and blackbody to insure blackbody emissivity effects.)

- Earth temperature = 270K models cold scene (the choice of this value was made such that it differed from the cavity and blackbody temperature to insure cavity and blackbody emissivity effects.)

- Low emissivity region weighting factor = (value of Table 1 column 5 + .1 due to tips and valleys).

- Emissivity of the blackbody substrate material = .92 models a blackbody of .992 emissivity without rounded corner and edge effects.

Figure A1



Distance from bb to aperture is 72.5"

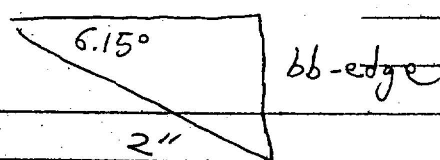
$$x + y = 72.5$$

$$\tan\phi = \frac{\frac{7}{2}}{x} \quad \text{and} \quad \tan\phi = \frac{\frac{8.625}{2}}{y}$$

$$\therefore \left(\frac{7}{2} + \frac{8.625}{2}\right)\frac{1}{\tan\phi} = 72.5$$

$$\phi = 6.15^\circ$$

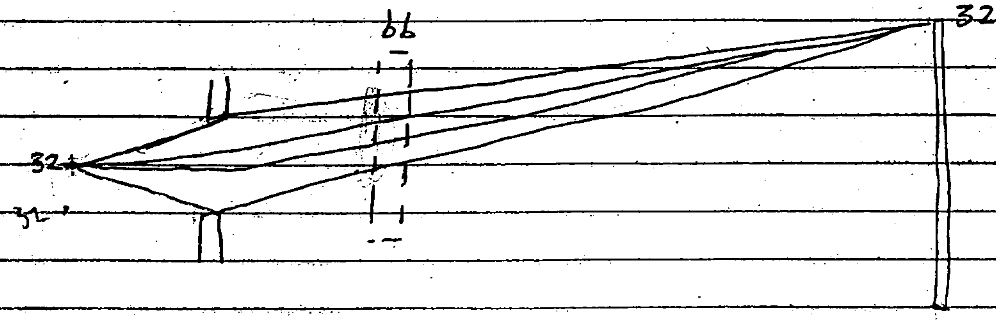
Distance light must travel is 2"

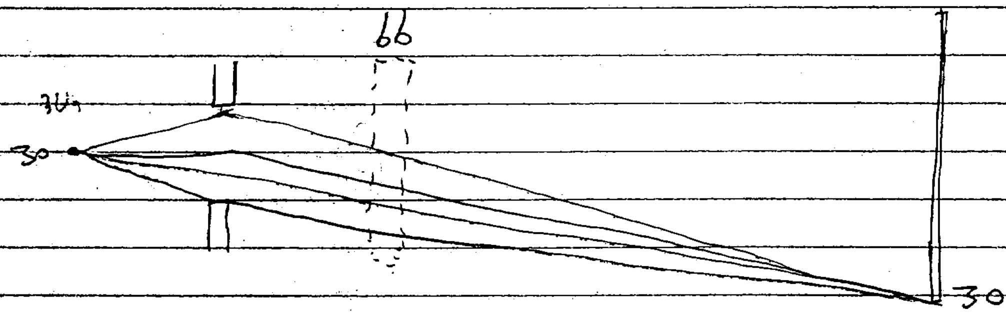


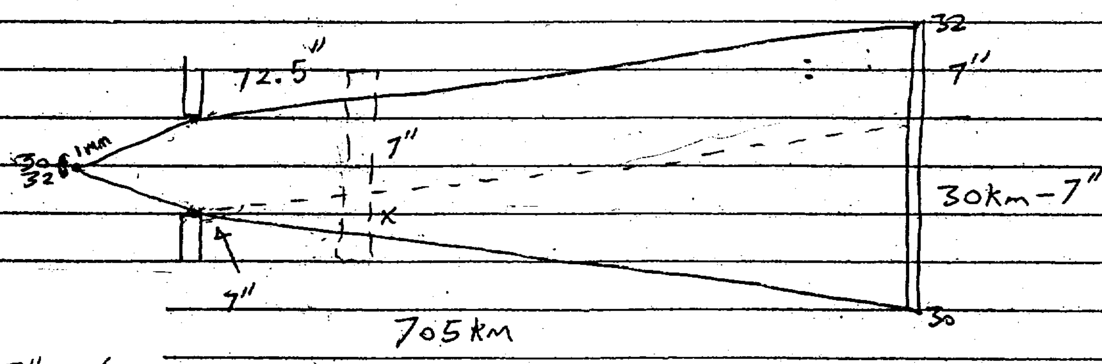
$$bb\text{-}edge = 2'' \tan 6.15^\circ$$

$$bb\text{-}edge = .22''$$

Figure A2





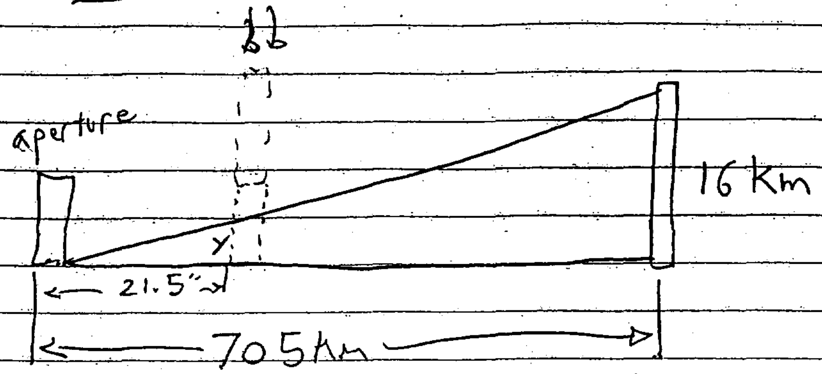


$fpa = 7'' + x$

$$\frac{x}{72.5''} = \frac{30km - 7''}{705km} = 3.08''$$

$fpa = 10.08''$

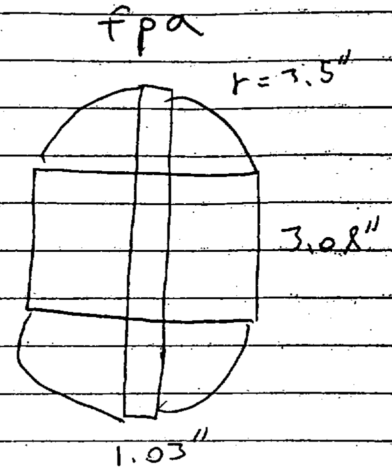
Figure A3



$$\frac{y}{21.5''} = \frac{16}{705}$$

$y = .49''$

Figure A4



$$\frac{x}{72.5''} = \frac{10km - 7''}{705km} = 1.03''$$

$$\frac{x}{72.5''} = \frac{30km - 7''}{705km} = 3.08''$$

$$\text{FPA area} = 2(1.03 \times 3.5) + 2(3.08 \times 3.5) + \pi 3.5^2$$

$$= 67.2\ in^2$$

$$\text{Det area} = 4(.1 \times 3.5) + \pi 3.5^2$$

$$= 39.9\ in^2$$

Band 32 "bad" area = $1\ in^2$

Band 32 percent "bad" area = $\frac{1}{39.9} = 2.5\%$

Add 25% measurement error to "bad" area due to grid measurement technique

Band 32 "bad" area = $2.5 \times 1.25 = 3.13\%$

FPA "bad" area = $2\ in^2$

FPA percent "bad" area = $\frac{1.25 \times 2}{67.2}$ 3.72%

Figure A5

Want 23, 31, 32 to start where 22 starts to make sure they do not view top groove

Want 29, 30, 25 to end where 24 ends to make sure they do not view bottom groove

Band	Reference to Band 22
23	2
31	3
32	6

Band	Ref to Band 24
29	-3
30	-6
25	-2

FPA length = 10.08″ Detector length = 7.10″

∴ 10.08 − 7.10 = 2.98″

Ref dist between detectors = $\frac{2.98}{29}$ = .10″

From Figure A2

$\frac{.1}{21.5''} = \frac{z}{705}$ z = 3.28 FD / det

3.28 (.081236) .27° / det

Normal 66 start = 230.75°

Band 22 Adjust 66 start = 230.75° + (ref to Band 22)(.27)

∴ Band 23 = 231.29°
31 = 231.56°
32 = 232.37°

Band 24 Adjust 66 start = 230.75° + (ref to Band 24)(.27)

∴ Band 29 = 229.94
30 = 229.13
25 = 230.21