

List of Figures

Figure 1.1	Components of the TOA radiation budget for the Earth and its atmosphere.	103
Figure 2.1	Components of a general radiometric system.	104
Figure 2.2	Off-axis optical system.	105
Figure 2.3	Cassegrain optical system.	106
Figure 2.4	Ideal behavior of thermal detectors and photon counters.	107
Figure 2.5.	Illustration of overlap in instantaneous footprints for an instrument	

which scans perpendicular to the orbital direction.	108
Figure 2.6 Illustration of aliasing error. On the left, the sampling frequency is seven times the original frequency; while on the right, the sampling frequency is 7/5 of the original frequency [39].	109
Figure 2.7 Illustration of zenith, θ , and azimuth, ϕ , angles used to define the instrument field-of-view.	110
Figure 3.1 CERES instrument package.	111
Figure 3.2 Elevation scan profiles for the CERES Proto-Flight Model (PFM) located on the Tropical Rainfall Measuring Mission (TRMM) spacecraft.	112
Figure 3.3 Cross-sectional view of a CERES instrument.	113
Figure 3.4 Illustration of footprint scan patterns for (a) normal cross-track scan mode, and (b) biaxial scan mode.	114
Figure 3.5 A CERES radiometric channel.	115
Figure 3.6 End-to-end spectral response for the CERES PFM radiometric channels.	116
Figure 3.7 Truncated diamond precision aperture for the CERES radiometric channels.	117

Figure 3.8	CERES Proto-Flight Model detector nominal specifications.	118
Figure 3.9	CERES Proto-Flight Model pre-amplifier electronic circuit.	119
Figure 3.10	CERES Four-pole Bessel filter.	120
Figure 3.11	Computed bode plot for the CERES 4-pole Bessel filter.	121
Figure 3.12	Computed phase angle plot for the CERES four-pole Bessel filter.	122
Figure 3.13	Filtering function for the CERES 4-pole Bessel filter.	123
Figure 3.14	TRW's Radiometric Calibration Facility (RCF) used in the CERES ground calibration [18].	124
Figure 3.15	Narrow Field Black Body (NFBB) used in the CERES Radiometric Calibration Facility (RCF) [18].	125
Figure 3.16	CERES Internal Calibration Source (ICS) module [18].	126
Figure 4.1	Schematic of the Detector Module Assembly (Not To Scale).	127
Figure 4.2	Illustration of the modeled boundary conditions.	128
Figure 5.1	Comparison of time response functions for a theoretical first-order response, for the baseline numerical model, and for the actual PFM total channel flight sensor.	129

Figure 5.2	Conceptual comparison of temperature profiles for (a) actual interface resistance, and (b) modeled interface resistance.	130
Figure 5.3	Predicted effect of varying the effective thermal conductivity of the Indium layer on the normalized time response function of the CERES detector module assembly.	131
Figure 5.4	Comparison between the CERES PFM total channel sensor response functions and the “best-fit” numerical model.	132
Figure 5.5	Qualitative comparison between a numerically simulated step input from the “best fit” numerical model and chopped data from the Short Wave Reference Source (SWRS) calibration for the PFM total channel.	133
Figure 5.6	Relationship between the longwave filtered and unfiltered radiances from the radiometric ground calibration for the PFM total channel.	134
Figure 5.7	Calculation of A_v^{-1} based on the radiometric ground calibration for the PFM total channel sensor.	135
Figure 5.8	Comparison of the ideal model normalized response function with the response function from the “best fit” model version.	136
Figure 5.9	Effective increase in responsivity due to varying the value of thermal conductivity, k ($\text{Wm}^{-1}\text{K}^{-1}$), for the Indium interface.	137
Figure 5.10	Curve fits to the ideal detector response, $u(t)$, and the predicted as-built detector response, $w(t)$.	138

Figure 5.11	Validation of the slow-mode numerical filtering algorithm for a step input at time, $t=0$.	139
Figure 5.12	Validation of the slow mode filtering algorithm for a nominal Earth scene.	140
Figure 5.13	Effectiveness of slow-mode numerical filter in forcing the “best fit” model to respond in the same fashion as the ideal model for the radiative input displayed in Figure 5.12.	141
Figure 5.14	Definition of various angles used in the discretization of the field-of-view into discrete solid angles.	142
Figure 5.15	Predicted and measured attenuation at the edge of the optical field for the PFM total channel.	143
Figure 5.16	Comparison of attenuation for a theoretical effective blur circle and the predicted attenuation in the scan direction from the ray-trace module.	144
Figure 5.17	The predicted Optical Point Spread Function (OPSF) for the CERES PFM total channel in (a) topographical, and (b) three-dimensional representations.	145
Figure 5.18	Illustration of trace lines used by TRW to measure the PFM total channel instrument point spread function.	146

Figure 5.19	Topographical representation of a point spread function for a generic scanning instrument.	147
Figure 5.20	Discretization of the instrument point spread function with an equi-angular 16-by-16 grid.	148
Figure 5.21	Predicted dynamic instrument point spread function of the CERES PFMtotal channel for a nominal scan rate of 63.5 deg/s in (a) topographical, and (b) three-dimensional representations.	149
Figure 5.22	Comparison between an experimentally measured and numerically predicted point spread function trace line taken along the 0-deg cross-scan plane.	150
Figure 5.23	Predicted dynamic instrument point spread function of the CERES PFM total channel for a nominal scan rate of 254 deg/s in (a) topographical, and (b) three-dimensional representations.	151
Figure 5.24	Comparison of trace lines from the rapid retrace, 254 deg/s, and normal, 63.5 deg/s, point spread functions. The trace lines correspond to a cross-scan angle of 0 deg.	152
Figure 5.25	Topographical comparison of the instrument point spread function for the (a) normal scan rate of 63.5 deg/s and the (b) rapid retrace rate of 254 deg/s.	153

Figure 5.26	Predicted (a) Bode (b) phase angle diagram for the CERES PFM total channel sensor based on the numerical end-to-end model.	154
Figure 5.27	(a) Normalized input used to assess the effectiveness of the low-pass filtering, and (b) end-to-end model output corresponding to the input seen in (a).	155
Figure 5.28	Comparison of the predicted output of the end-to-end model for a 10-Hz input and a superimposed 10- and 30-Hz input.	156
Figure 5.29	50-by-50 km Earth scene modules used in Villeneuve's Atmospheric Radiation Transfer model [32].	157
Figure 5.30	500-km mosaic TOA strip constructed from ten 50-by-50 km modules [32].	158
Figure 5.31	Virtual satellite scanning a 500-km TOA strip from three different orbital positions [32].	159
Figure 5.32	Ratios of average radiance arriving at the aperture to the power arriving at the active flake for three effective fields-of-view for the CERES sensors.	160
Figure 5.33	Determination of the optimal instantaneous field-of-view for the CERES flight sensors.	161
Figure 5.34	Illustration of two extreme weightings of the dynamic instrument point spread function used to assess the sensitivity of recovered TOA flux to point spread function weighting. In (a) all 16-by-16	

bins are assigned a weighting of $1/256$, in (b) the four central bins are assigned a weighting of $1/4$. 162

Figure 5.35 ERBE shortwave TOA fluxes (Wm^{-2}) determined using ERBE Pathfinder CERES-like data processing algorithms and an equally weighted 16-by-16 PSF array. 163

Figure 5.36 Difference in calculated ERBE SW TOA flux (Wm^{-2}) for the two weightings of the PSF displayed in Fig. 5.34. 164

Figure 5.37 Results of using an autoregressive model to recover a 20-Hz scene. The model was formulated with $n=4$, $N=12$, and the A_i coefficients determined with a 10-Hz source. 165