MOPITT

Measurement of Pollution in the Troposphere

Level 1-B
ALGORITHM THEORETICAL BASIS DOCUMENT

Conversion of MOPITT Digital Counts into Calibrated Radiances
in Carbon Monoxide and Methane Absorption Bands

MOP-01 Data Product

(Level 0 to Level 1)

University of Toronto and
NCAR MOPITT Team

ATBD Release 2

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DRAFT

Table of Contents

Production of MOP-01 (Located, Calibrated MOPITT Radiances) from Instrument Output Counts

1.0 Introduction

1.1 Purpose

This document briefly outlines the Measurement of Pollution in the Troposphere (MOPITT) investigation and describes the physics and mathematics of the algorithms that convert the instrument outputs from raw digital counts (Level-0 data) into geolocated, calibrated radiances which make up the Level-1 data product (MOP-01). The Level 0 inputs to these algorithms are:

- The telemetered instrument outputs, including those from the detectors, all temperature, pressure, time and angle sensors, and other monitors of instrument state and performance.
- Data on the spacecraft position and attitude as a function of time as made available through toolkits provided at the NASA Langley Distributed Active Archive Center (DAAC).
- Historical and pre-launch data in the form of calibration history and pre-launch conversion coefficients.

The Level 1 outputs from these algorithms will subsequently be used as inputs to the algorithms that retrieve vertical profiles of carbon monoxide, and total column amounts of carbon monoxide and methane (Level 2 data). The algorithms that create the Level 2 data from the Level 1 data are discussed in a separate ATBD.

The algorithms described herein are to be implemented in the Version 1 (Engineering Version) Science Data Product (SDP) Software to be delivered to the NASA Langley DAAC. Prototypes of most of these are being developed by the Instrument Team at the University of Toronto on their facilities, where they will be applied to data collected during calibration and testing of the MOPITT engineering and flight model instruments. This allows the team to explore different approaches to the most efficient recovery of the information from the MOPITT output data, including taking account of the instrument effects expected to be present in the flight data.

Subsequently, these algorithms will be incorporated into formally documented codes which will be written and tested on the NCAR Science Computing Facility (SCF). These codes will then be rehosted to the Langley DAAC, where their operation and outputs will be verified. Lessons learned during the development and testing of the Engineering Version SDP software will be incorporated into the Flight Version. The Flight Version SDP software will be used to process MOPITT data during the mission phase.

1.2 Applicable Documents and Publications

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Drummond, J. R., Measurements of Pollution in the Troposphere (MOPITT), in *The use of EOS for Studies of Atmospheric Physics,* edited by J. C. Gille and G. Visconti, pp. 77-101, North Holland, Amsterdam, 1992.

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General Instrument Interface Specification, EOS-AM Project, December 1, 1992, Rev. A

HDF-EOS Primer for Version 1 EOSDIS, Hughes Applied Information Systems, Landover, Maryland, Document # 175-WP-001-001.

HDF-EOS User’s Guide for the ECS Project, Hughes Information Technology Systems, Upper Marlboro, Maryland, Document # 170-TP-005-001.

Mand, G. MOPITT Test Plan, MOPITT document number MOPITT-TD-0005, University of Toronto, Department of Physics, 1995.

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Mand, G. MOPITT Environmental Test Program MOPITT document number MOPITT-TD-0007, University of Toronto, Department of Physics, 1995.

MOPITT Instrument Specification. COM DEV Atlantic, Cambridge, Ontario, Canada. Document # EQS/MOP/113360/01 Revision P3.

MOPITT Software Specification Interface Control Document. COM DEV Atlantic, Cambridge, Ontario, Canada. Document # ICD/MOP/113364/400 Revision P6.

MOPITT Validation Plan

MOPITT Quality Assurance Plan

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Reichle, Jr., H. G., V. S. Connors, J. A. Holland, R. T. Sherrill, H. A. Wallio, J. C. Casas, E. P. Condon, B B.Gormsen, and W. Seiler, The distribution of middle tropospheric carbon monoxide during early October 1984, *J. Geophys,. Res.*, *95*, 9845-9856, 1990.

SDP Toolkit Users Guide for the ECS Project, EOSDIS Core System Project Document 333-CD-003-004, Hughes Information Technology Corporation, Upper Marlboro, Maryland.

Taylor, F. W., Pressure modulator radiometry, in *Spectroscopic techniques. Vol.III*, pp.137-197, Academic Press Inc., 1983.

Theoretical Basis of the SDP Toolkit Geolocation Package for the ECS Project. Document 445-TP-002-002, Hughes Applied Information Systems, Landover, Maryland

2.0 Overview and Background Information

2.1 Experimental Objective

The MOPITT experiment has been described by Drummond (1992). The primary objective of the MOPITT investigation is to enhance our knowledge of the chemistry of the troposphere, and particularly how it interacts with the surface/ocean/biomass systems, atmospheric transports, and the carbon cycle. The particular focus is the time evolution of the distributions of CO and CH_4 in the troposphere. From these a better knowledge of their chemical interactions, transports, sources and sinks will be obtained. Understanding their biogeochemical cycles and their intimate interrelation with each other and with climate will lead to better predictions of possible effects of anthropogenic activities.

For CO the objective is to obtain profiles with a resolution of 22 km horizontally, 4 km vertically and with an accuracy of 10% throughout the troposphere. For CH_4 the objective is to measure the column in the troposphere to a precision of better than 1%, with a spatial resolution similar to that of the CO measurement. The column measurements will only be available on the sunlit side of the orbit.

The global distribution of these profiles and column amounts will be used in descriptive studies of these gases. MOPITT will thus provide the first detailed, long-term, global information on the CH_4 and CO horizontal, vertical and temporal variations, their relationships to other activities such as: biomass burning, industrial activity, thunderstorm venting of the boundary layer, etc. They will also be used in parallel modeling efforts to advance our understanding of global tropospheric chemistry and its relationship to sources, sinks, and atmospheric transports, which can be determined from other data.

2.2 Historical Perspective

There has been no previous use of these algorithms. However, they are typical of those used frequently to calibrate the outputs of radiometers, and to locate the observations made by space-based instruments on the earth’s surface.

2.3 Instrument Characteristics

2.3.1 Measurement Principle and Physics of the Problem

The measurement concept and ideas of correlation radiometry are briefly described here. Drummond (1992) has outlined the MOPITT instrument. The approach and viewing geometry are shown in Figure 2.3.1. MOPITT, on the AM-1 platform, measures upwelling thermal emission from the atmosphere and surface, and solar radiation that has passed through the atmosphere, been reflected at the surface, and transmitted back up through the atmosphere.

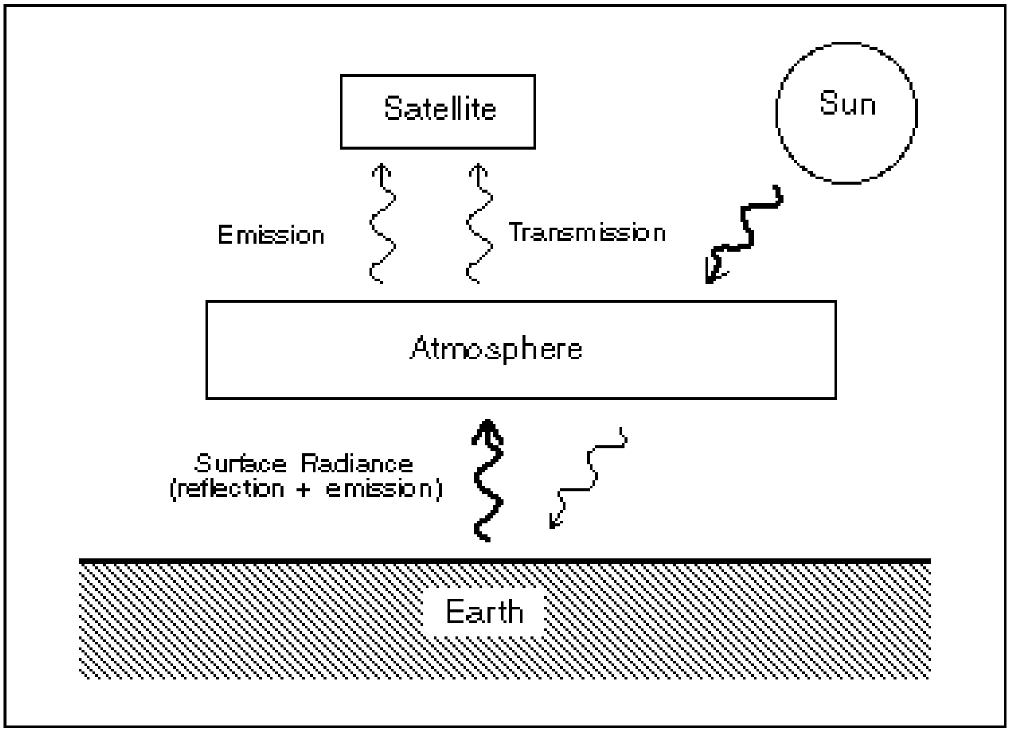

Fig. 2.3.1 Schematic of MOPITT measurement approach.

Measurement of the transmittance of reflected sunlight is a convenient way to determine the total column amount of a trace gas. This requires that the gas have an absorption band in a spectral region where there is significant solar radiance, and for which the total optical depth along such a path is not too large. Methane has a set of overtone and combination bands near 2.2 µm which provide a measurable, but not too large, total absorption for such a path. For carbon monoxide, the first overtone band, at 2.3 µm, is suitable for measurement of total atmospheric column.

For vertical profiling, the requirement is that significant and measurable portions of the signal must originate in different atmospheric layers, which means that there must be a few values of different but appreciable opacity in the atmosphere, and that there must also be a source of radiation in the atmosphere. Thermal emission is a radiation source, and the CO fundamental band at 4.7 µm has enough opacity to determine atmospheric amounts, as demonstrated by Reichle et al. (1986, 1990).

All three of these bands are in regions of the spectrum with other gas bands, and the lines of interest are mixed with those of interfering species. In principle it is possible to measure total emission or transmission in a spectral band, and then correct for the contributions of the interfering species to arrive at a measurement of the species of interest. However, the contributions of the other species are considerably larger than those of the gases of interest, and their amounts are often not known with sufficient accuracy. The uncertainties of the corrections may significantly degrade, or even mask, the detection of changes in the gas of interest.

The MOPITT approach to meeting this challenge is to enhance the sensitivity of the instrument to the gas of interest. Since all gases in the atmosphere are emitting/absorbing simultaneously it is essential that we be able to separate out the effect of the gas of interest from the general radiation field. Further, since we shall see that the information about the height distribution of the gases is contained within the shape of an individual absorption/emission line, it is necessary to be able to resolve the line shape in some manner.

There is, however, a fundamental problem, since the above implies high dispersion to separate the fine details of the spectrum. With high dispersion comes low sensitivity and high precision requirements that are difficult to implement in a space-based instrument. Correlation Radiometry (CR) offers the opportunity for high selectivity without the attendant low sensitivity and high precision requirements.

The fundamental techniques of correlation radiometry are illustrated using the generic apparatus illustrated in Figure 2.3.1.2. The cell contains a sample of the gas under consideration. If monochromatic radiation enters from the left and is detected by the system on the right then the output as a function of spectral frequency is shown in Figure 2.3.1.3-a for two different amounts of gas in the absorption cell. By cycling the amount of gas in the absorption cell between the two states, the detector will be alternately looking through two different filters. If the difference of the two signals is taken, this signal will be identical to the output of a system in which the gas cell and it's modulator are replaced by an optical filter of profile shown by the Effective Difference Transmission (EDT) curve in Figure 2.3.1.3-b.

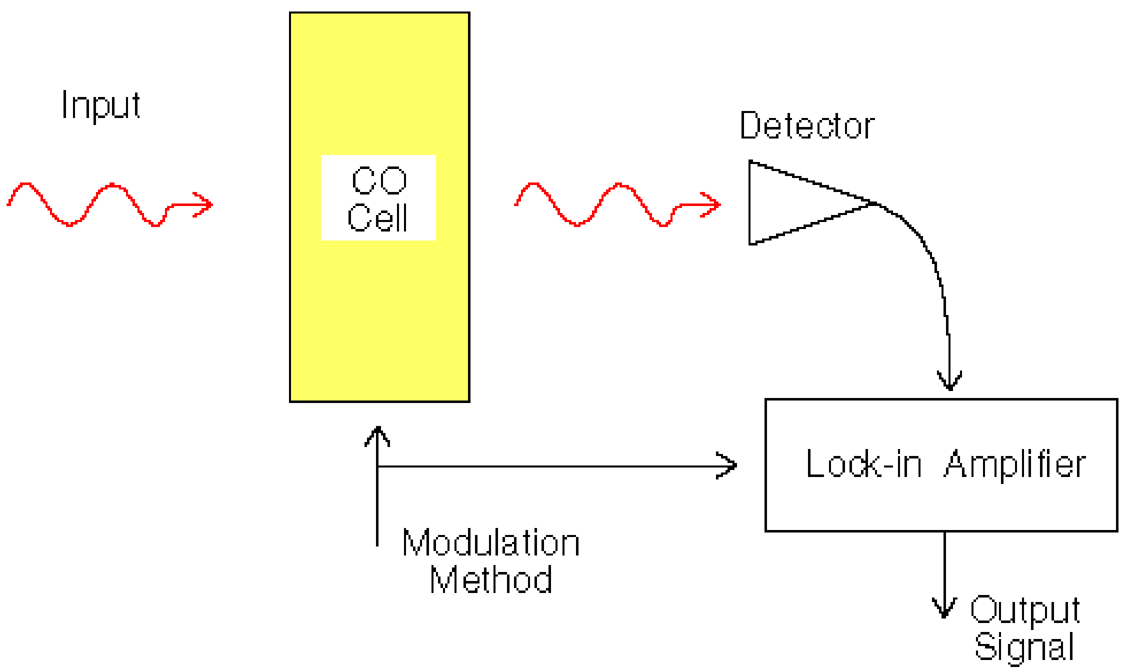

Fig. 2.3.1.2 A basic correlation radiometry system.

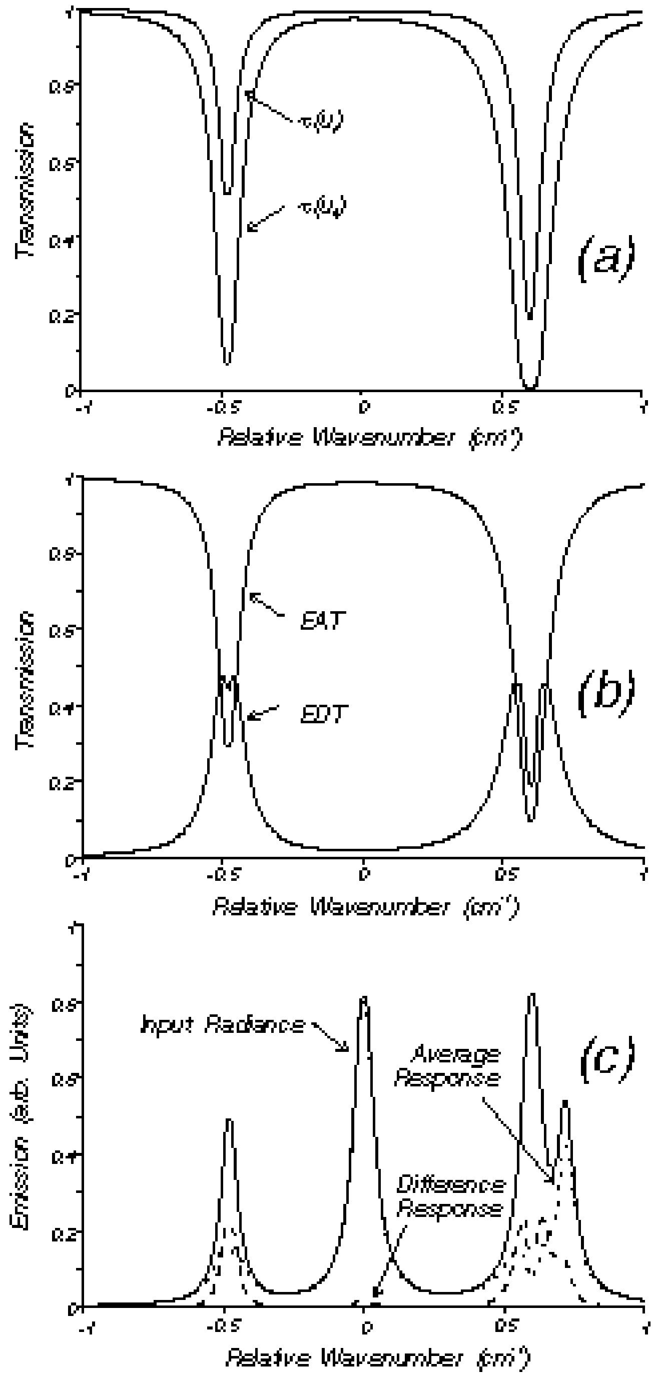

Fig. 2.3.1.3 Operation of a correlation spectrometer in spectral space. EAT is the Equivalent Average Transmission. EDT is the Equivalent Difference Transmission.

Note that this apparatus has the following properties:

- The "equivalent filter profile" approaches zero between the spectral lines of the gas in the cell, eliminating signals from most of the spectrum.

- The filter profile has a maximum at each spectral line and therefore the energy from each spectral line in a broadband emission is seen simultaneously. The system is therefore very sensitive to radiation with a spectrum identical or similar to that of the gas in the cell. Evidently the spectrum of the gas itself is the best correlated with the filter profile.
- The apparatus contains no high precision optical adjustments. Quantum mechanics keeps the spectra aligned. In fact the only phenomena which affects the alignment is Doppler shifting of the cell and the emission spectrum. The effect of the filter is shown in Figure 2.3.1.3-c where it can be seen that the spectral emission from lines coincident with spectral lines of the gas in the cell (even if they originate from another gas) is detected and other emission lines are suppressed.
- Although not shown explicitly here, if small amounts of gas are placed in the cell, the spectral lines will be narrow, with incomplete absorption at the centers of the lines. The EDT will be largest at the line centers, where absorption coefficients are largest. If larger amounts of gas are in the cell, the lines will be broader and completely absorbed in the centers. In this case, the differences will be larger in the line wings, where absorption coefficients are smaller.

The largest part of the upwelling signal emitted by the atmosphere comes from the altitude region in which the optical depth is near unity. Thus, a cell that is sensitive to the line center will respond to signals originating higher in the atmosphere, while a cell with larger amounts of gas will respond to signals originating in the wings of the pressure broadened lines, corresponding to lower altitudes.

The average of the signals obtained at the two states of the CR cell can also be obtained. The resulting Effective Average Transmittance (EAT) is also shown in Figure 2.3.1.3-b. It has the property that its transmittance is near unity away from the lines in the cell, but it reduces the signals at the centers of the lines. Thus, it is sensitive to other gases, and especially to the surface contribution to the upwelling radiation in the spectral regions considered here.

MOPITT makes use of two methods to modulate the gas transmittance. The first is by pressure modulation, through use of pressure modulated cells (PMC's), which have been described by Taylor (1983). The second is by modulating the length of the gas cell in the optical path, through length modulated cells (LMC's), which have been described by Drummond (1989).

Additional components are needed to convert the simple apparatus described above into a functional remote sensing instrument. These include a telescope system with scan mirror to direct the field of view to different earth scenes and to inflight calibration sources including an on-board blackbody and cold space viewports; an optical chopper to eliminate the effects of internal emissions and a data acquisition system to capture the detector outputs. A simplified diagram of a single channel correlation radiometer optical system is shown in Figure 2.3.1.4. A more complete system description of the MOPITT instrument will be presented in Section 2.3.2.

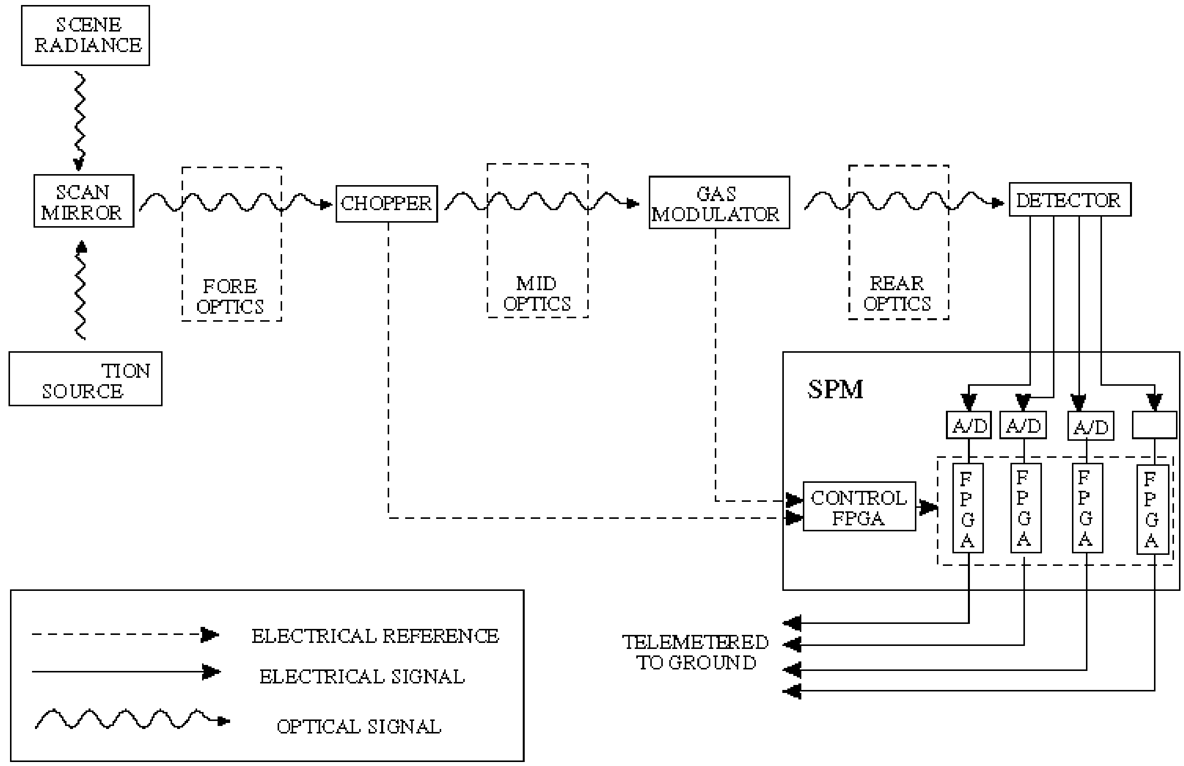

Fig. 2.3.1.4 Single channel optical functional diagram.

2.3.2 Instrument Configuration and Operation

2.3.2.1 Optical System Description

The complete MOPITT instrument has 4 optical trains each with an independent scan mirror, chopper, internal blackbody calibrator and 4 element linear detector arrays. The scan mirrors and optical trains are coaligned such that each channel views the same points on the earth. During scan sequences, the mirrors operate in lock-step to maintain field-of-view alignment. The detector arrays are arranged as a line of 4 adjacent 22X22 km pixels in the direction of the sub-satellite track at the nadir position. Cross track scanning directs the pixel array to 14 angular locations on either side of nadir for a swath coverage of ~640km.

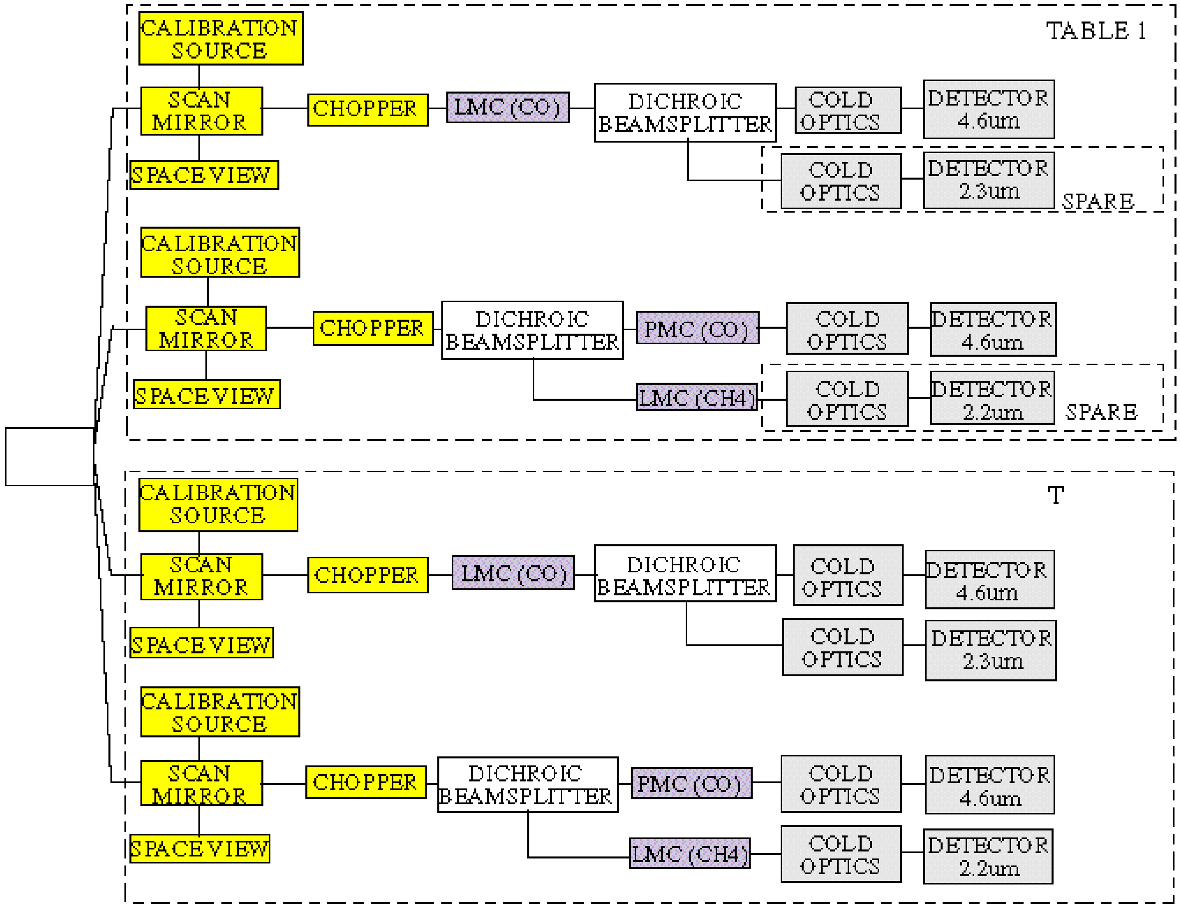

Fig. 2.3.2.1 MOPITT block diagram.

2.3.2.2 System Chopping and Correlation Cell Modulation

The MOPITT optical arrangement, shown in Figure 2.3.2.1, employs 2 pressure modulated radiometers (PMR's) with different mean pressures, and 4 length modulated radiometers (LMR's) containing different amounts of gas. Dichroic filters are used to separate the 2.2 µm and 2.3 µm channels from the 4.7 µm channels, thus producing a total of 8 separate channels. The characteristics of the channels are given in Table 2.3.2.1. Each channel produces an Average (A) and Difference (D) signal on each of the 4 adjacent pixels representing the co-aligned fields-of-view. It is the outputs of these radiometer channels that must be calibrated and earth-located.

The correlation cell is a cell containing an atmospheric target gas whose physical state (either pressure, for a pressure modulator cell (PMC) or length (LMC)) is modulated at a known rate in a known manner. The purpose of this cell is to produce a signal which is indicative of radiance around the absorption lines of the cell gas alone. In this analysis the correlation cell is considered as a device with two states, generically referred to as the UP and DOWN states. This description is adequate for the LMC, but in practice a more detailed model of the PMC will be required. Modulation rates are approximately 20 Hz for LMCs and 50 Hz for PMCs.

The chopper is used to partially eliminate the instrument emission signals from the problem. It consists of a blade which blocks the input beam and substitutes a known radiance (the back of the chopper blade) for the input radiance. The measurement of a known radiance at frequent intervals enables the changes in the instrument emission signals to be monitored.

The chopper in MOPITT is a rotating chopper, and this fact is used advantageously to make the chopping asymmetric (the OPEN time is longer than the CLOSED time). This is done to equalize the noise contributions from the two states. For some channels the noise in the OPEN state is higher due to the increased photon flux and for nearly all channels the smoothing of the CLOSED states (see below) effectively decreases the noise.

The total (OPEN + CLOSED) chopping interval is about 1.6 ms per cycle. This fast interval is also linked to the data acquisition system and to the correlation cell rates, thus all rates are synchronized for optimum data collection.

Channel Characteristics	1	2	3	4	5	6	7	8
Gas Species	CO	CO	CO	CH_4	CO	CO	CO	CH_4
Nominal Gas Pressure (kPa)	20	20	7.5	80	80	80	3.8	80
Mid-Wavenumber (cm^{-1})	2166	4285	2166	4430	2166	4285	2166	4430
Wavenumber Range (cm^{-1})	52	40	52	139	52	40	52	139
Mid-Wavelength (mm)	4.617	2.334	4.617	2.258	4.617	2.334	4.617	2.258
Wavelength Range (mm)	0.111	0.022	0.111	0.071	0.111	0.022	0.111	0.071
Modulator Type & Number	LMC1	LMC1	PMC1	LMC2	LMC3	LMC3	PMC2	LMC4
Nominal Modulator Freq (HZ)	11.78	11.78	51.85	11.78	11.54	11.54	42.85	11.54
Nominal Chopper Freq (Hz)	518.5	518.5	518.5	518.5	600	600	600	600
Scan Mirror/Chopper Number	#1	#1	#2	#2	#3	#3	#4	#4
Calibration Source Number	#1	#1	#2	#2	#3	#3	#4	#4
Optical Table	#1	#1	#1	#1	#2	#2	#2	#2

Table 2.3.2.1 Nominal MOPITT channel characteristics. Channels 1,3,5, and 7 are CO thermal channels. Channels 2 and 6 are CO solar channels. Channels 4 and 8 are CH_4 solar channels.

2.3.2.3 Instrument Operations

A drawing of the MOPITT instrument is shown in Figure 2.3.2.2. The space calibration view ports are located on the anti-sun side of the space craft along with a radiator to dump heat from the power supplies. During ground handling and launch, the earth and space view ports are sealed by contamination covers which are opened on-orbit after an appropriate spacecraft outgassing period is completed. The radiator supplements general instrument heat dissipation provided by the AM-1 spacecraft cooling loop.

Also shown is the Stirling-cycle refrigerator system required to cool and maintain the detectors at operating temperature. Two detectors “nests” each containing 4 linear arrays are connected by cold fingers to the refrigerator system.

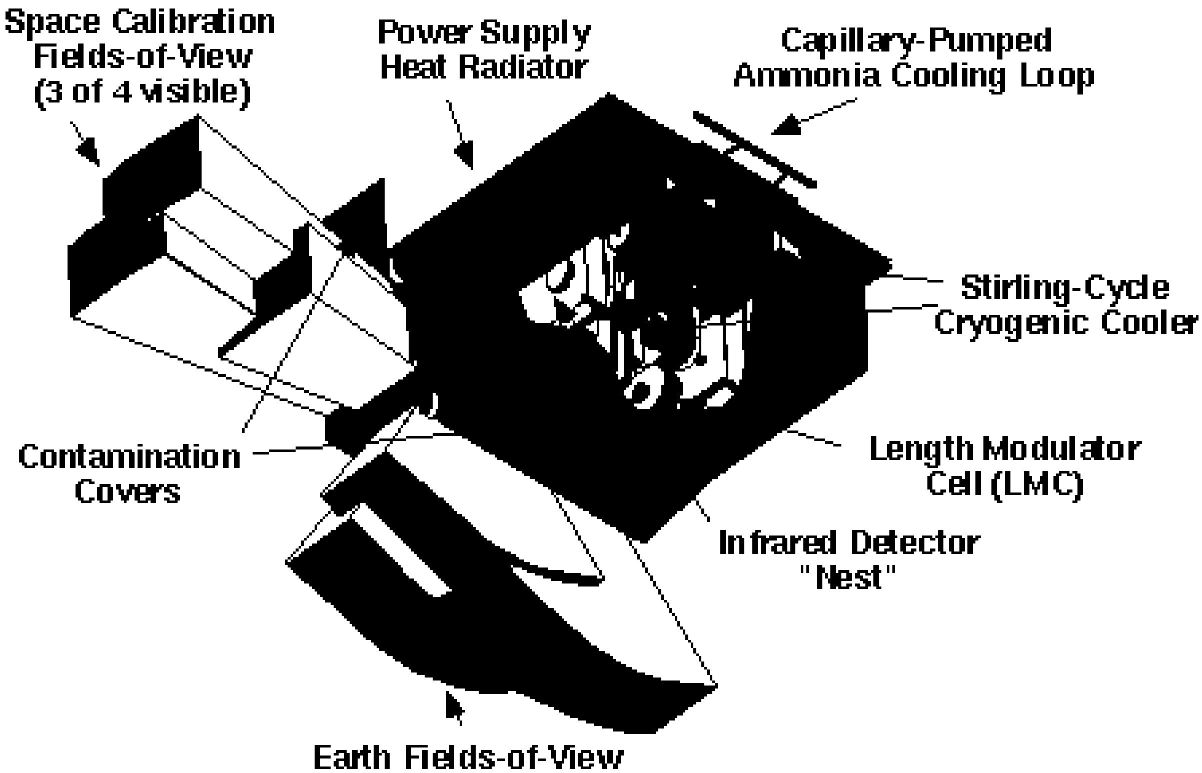

Figure 2.3.2.2 MOPITT Instrument Configuration

The operation of the instrument can be described as follows. A series of earth views or “stares” is taken each with a set integration time at fixed scan mirror positions relative to nadir. Each stare contains 4 adjacent pixels. The scanning system combined with the spacecraft forward motion moves this view across the planet such that stares on successive scans are close to adjacent in a “heel-to-toe” arrangement. This provides nearly contiguous coverage over a swath about 640km wide as shown in Figure 2.3.2.3. These views are denoted as EARTH views.

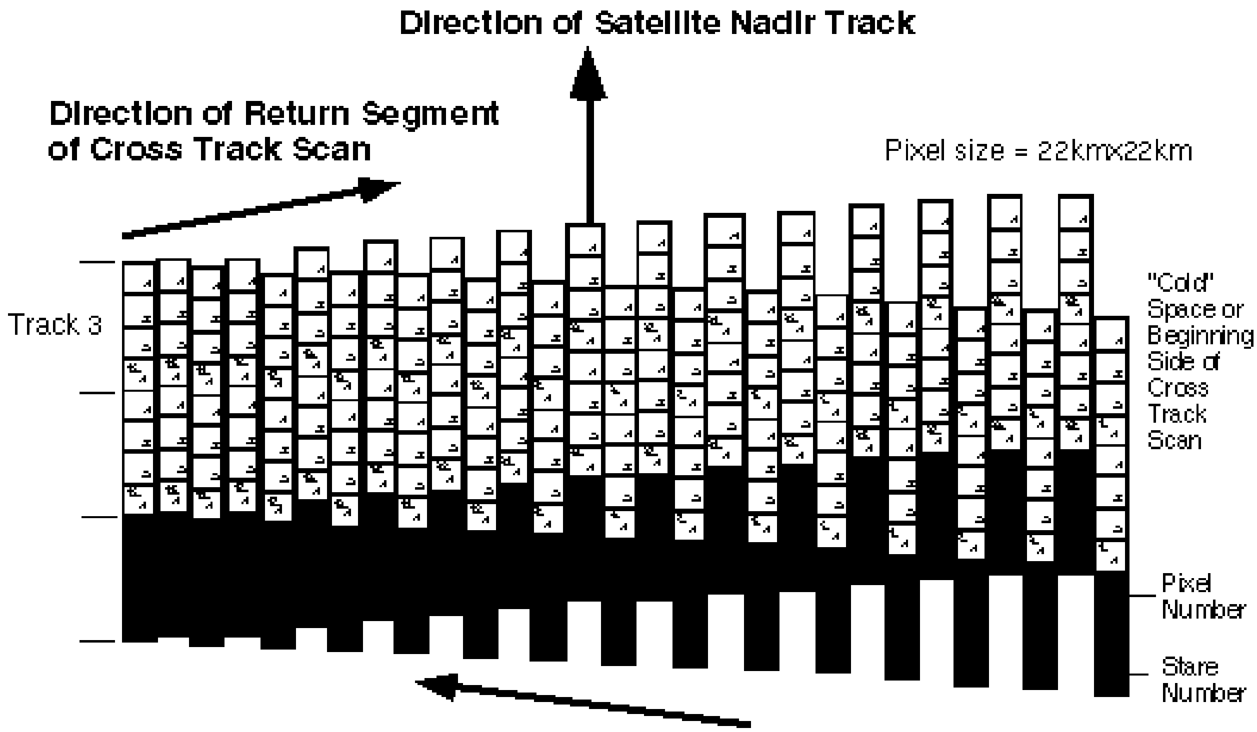

Fig 2.3.2.3 MOPITT Scan Pattern Showing Earth Views

Periodically the scanning is interrupted and a SPACE view is taken using the side port of the instrument. At longer intervals a SPACE view and an INTERNAL view are taken in succession before the scanning sequence is resumed. The calibration blackbodies are maintained close to the baseplate temperature for the majority of the time (short calibration events) as this is the appropriate radiance to calibrate the thermal infrared channels. However, periodically the blackbodies are elevated to about 450 K for short-wave calibration (long calibration event). A typical scanning sequence is illustrated in Figure 2.3.2.4.

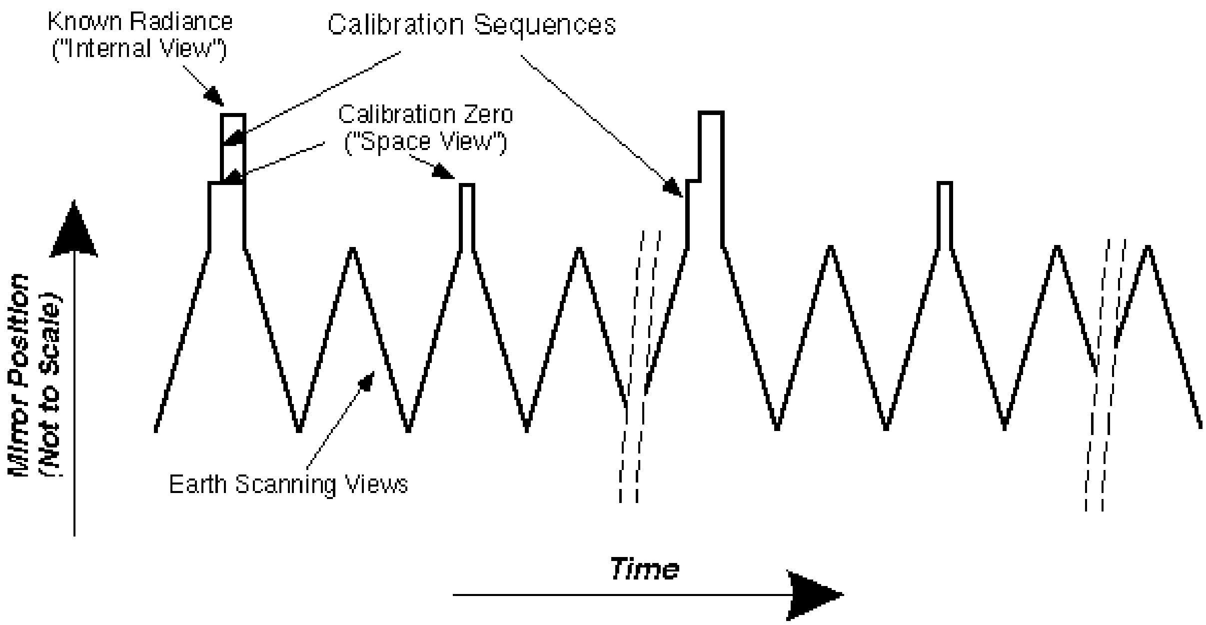

Fig. 2.3.2.4 Typical MOPITT scanning sequence.

2.3.2.4 Data Acquisition

All data acquisition is done in intervals of stares. A stare view time is 0.4 s in length with 0.054 s between stares. The inter-stare time exists to permit the data-processing system time to read out the signals and the mirror time to step and settle. However, all data is considered on a stare interval basis even if the mirror does not move.   Thus a view of a calibration target may be described as "32 stares" implying that there will be 32 data units 0.4 s in length to be averaged for that radiance input.

The data acquisition system in MOPITT is designed to be as stable as possible which implies a high digital content. The signals are amplified and minimally filtered before being digitized and averaged over the chopper OPEN and chopper CLOSED situations. The averages are taken during the period of OPEN and CLOSED only, specific gating being applied to eliminate transitional data. This restricts the data taken, but ensures that they are stable and valid at all times.

The analog-to-digital converter actually samples at an extremely high rate (about 320 kHz) but this rate is reduced to one sample per sector internally to the Signal Processing Module (SPM) in MOPITT by summing a large number of samples. This total, along with the knowledge of how many samples are being summed, becomes the signal for the chopper state. The signals transmitted to the ground system are:

- For a PMC the sum of the chopper OPEN and chopper CLOSED states for each of the PMC UP and DOWN states for one stare (4 signals/stare).

- For an LMC the sums of the chopper OPEN and chopper CLOSED states for each of the LMC sectors in the stare (16 signals/stare). The interpolation to 4 signals/stare is discussed below.

The two sums just listed are converted to average values as part of the processing after the signals are received on the ground. Because the detector output is sampled only when the chopper is fully open, or fully closed, there is no chopping factor that enters into the L0 to L1 processing. The processing software does require knowledge of the times of summation for each of the OPEN and CLOSED regimes, represented as the number of A/D samples summed, and any other scaling operation performed on the output to maintain the precision.

3.0 Algorithm Description

As stated in Section 1.1, the main purpose of the Level 0 process is to convert raw digital counts (Level-0 data) into geolocated, calibrated radiances which make up the Level-1 data product (MOP-01). The MOPITT Level-0 data will be received at the DAAC as two separate data streams, the level-0 science stream and the level-0 engineering stream. These two level-0 streams will be decommutated, reconstructed and used in conjunction with the SPD toolkit data and routines to produce the Level-1 data products. This is illustrated in Figure 3.0.0.

In the sections 3.1 and the 3.2 the algorithms used in the conversion of the engineering streams and science streams, respectively, will be discussed in detail. Following these sections will be a discussion on the practical considerations of implementing the algorithms.

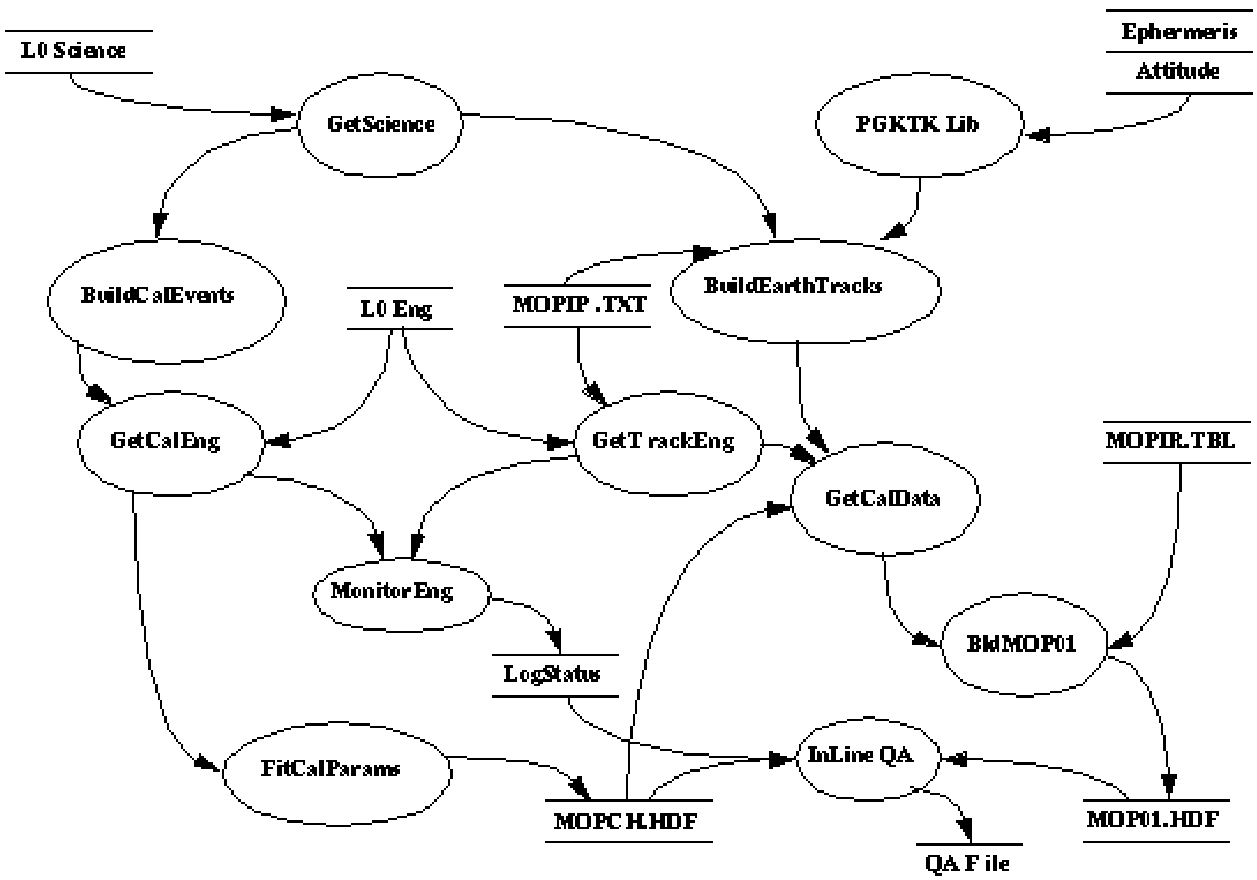

Fig. 3.0.0 Top Level Data Flow for the MOPITT Level 0-1 Processor

3.1 Engineering Stream Conversion

The Level-0 Engineering Stream consists of three basic parts or blocks, the housekeeping data, the engineering data and the ancillary data. The housekeeping data block consists of normal housekeeping data such as temperatures, voltages, currents, and other critical status bits. The engineering data block of the engineering stream consists of the important temperatures and pressures required in the interpretation and processing of the science stream. The formatting and detailed descriptions of housekeeping and engineering data are detailed in the MOPITT Software Specification Interface Control Document. Only the algorithms and equations use to convert the raw digital ADC to voltages, currents, and temperatures will be discussed in this section.

The spacecraft ancillary data block contains information about the spacecraft state vector and orientation. This particular spacecraft data is not used in the MOPITT data processing scheme. Therefore the formatting and conversion of this data which are detailed in the General Instrument Interface Specification, EOS-AM Project and will not be discussed here.

3.1.1 Engineering Stream Temperature Conversion Equations

All of the engineering stream temperature conversions are two step conversion processes. The first step is to deduce the resistance *R* of the particular thermistor type or in the case of diode thermistor the voltage V. The final step is to use this deduced resistance (or voltage) value in the appropriate thermistor conversion equation.

In the following thermistor sections, the conversion is broken down into the two equations:

1. Determining *R*
2. Converting *R* into temperature.

All constants used in the following equations will be established during sub-system testing and in some cases as part of the pre-flight calibration of the MOPITT flight instrument.

3.1.1.1 Platinum Resistance Thermometer (PRT) Thermistor Conversion Equations

Platinum resistance thermometers are used for temperature monitors in systems which require high accuracy and precision. In MOPITT these include the inflight calibration black bodies and the correlation cell molecular sieves. Each of the blackbodies contains two PRTs. Each of the sieves contains a PRT.

PRT resistance equation:

$$R_t = \frac{(T_1 - T_3)}{(T_2 - T_3)} R_2 + R_3$$

PRT temperature equation:

$$Temp(C) = \frac{1}{2}\left(\frac{10000}{\delta} + 100\right) - \frac{1}{2}\sqrt{\left(\frac{10000}{\delta} + 100\right)^2 + 4\left(\frac{10000}{\alpha\delta}\right)\left(1 - \frac{R_t}{R_o}\right)}$$

where

T_1 = Sensor Reading
T_2 = High Reference Reading
T_3 = Low Reference Reading
$R_2, R_3, R_O, \alpha, \delta$ are defined in Appendix C for each PRT thermistor.

3.1.1.2 Nonlinear Thermistors Sensors Conversations Equations

Nonlinear response thermistors are used as temperature monitors for most other applications except for the low temperature components in the detectors dewars.

Nonlinear thermistor resistance equation:

$$R_t = \frac{(T - T_l)R_b}{(T_h - T_l)/\alpha} - (T - T_l)$$

Nonlinear thermistor sensor temperature equation:

$$Temp(C) = \frac{1}{\sum_{n=0}^{N} a_n \left[\ln(R_t)\right]^n}$$

where

T = Sensor Reading
T_h = High Reference Reading
T_l = Low Reference Reading
R_b, a_n, N, α, are defined in Appendix C for each nonlinear thermistor sensor.

3.1.1.3 Detector Diode Thermistor Conversion Equations

Diode thermistors are used in the cold detector dewars to monitor the temperatures of the detector arrays.

Detector diode voltage equation:

$$V_d = \frac{(N - N_l)}{(N_h - N_l)}(V_h - V_l) + V_l$$

Detector diode thermistor sensor temperature equation:

$$Temp(C) = \sum_{n=0}^{M} a_n V_d^n$$

where

N = Sensor Reading
N_h = High Reference Reading
N_l = Low Reference Reading
V_h, V_l, a_n, M, α, are defined in Appendix C for each linear thermistor sensor.

3.1.1.4 Cold Filter Diode Thermistor Conversion Equations

Detector diode thermistor equation:

$$V_d = \frac{(N - N_l)}{(N_h - N_l)}(V_h - V_l) + V_l$$

Detector diode thermistor sensor temperature equation:

$$Temp(C) = \sum_{j=0}^{N} c_j T_j(V_d)$$

where

N = Sensor Reading
N_H = High Reference Reading
N_L = Low Reference Reading
$T_j(V_d)$ = the jth Chebyshev polynomial.
V_H, V_l, a_n, M, α, are defined in Appendix C for each linear thermistor sensor.

3.1.2 Engineering Stream Pressure Conversion Equation

3.1.2.1 Pressure Modulator Cell (PMC) Pressure Derivation

The Pressure Modulator Cell has a constant cell length and gas amount but the pressure is varied continuously by means of an oscillatory piston. Cell temperatures also vary due to compression and expansion of the gas. The strategy for determining the form of the time cycles of temperature and pressure involves both pre-flight and in-flight measurements. The pressure and temperature cycles of the PMCs aboard MOPITT will be determined pre-launch using spectrometric techniques developed at the University of Toronto (Berman et al., 1993). These cycles will be measured as a function of average cell pressure. In-flight, it is then necessary to determine average cell pressure in order to derive the temperature and pressure cycle. Average cell pressure can be derived in either of two ways.

1. By means of the resonant frequency - defined as the frequency of minimum power requirement. This relationship is constant for a given PMC and is characterized before launch. This minimum power point is determined periodically during flight by taking the PMC off-line and changing the PMC frequency while monitoring the drive current required. From a polynomial fit to these data, the minimum power point can be located. A polynomial fit to the pre-launch data is then used to deduce the pressure, *p*, from the measured in-flight resonant frequency, *F*:

$$p = \sum_{i=0}^{n} f_i F^i$$

2. By means of the sieve temperature. This is not as precise as method 1, and is subject to a number of errors (e.g. gas contamination will not show up). However, this method can be used on a continuous basis. The sieve pressure versus temperature relationship is characterized before launch. The sieve temperatures will be monitored by means of PRT's in-flight. A polynomial fit to the pre-launch data is again used to deduce the pressure, *p*, from the measured in-flight sieve temperature, *T*.

$$p = \sum_{i=0}^{n} t_i T^i$$

3.1.2.2 Length Modulator Cell (LMC) Pressure Derivation

A length modulator cell is isothermal and has two length states: "long" and "short". The amount of gas in the "long" path can be controlled by a molecular sieve. The pressure can be monitored by an accurate pressure transducer on the cell and also (less precisely) by the temperature of the sieve system (CO cells only). The sieve temperature technique is as described above. The pressure sensor mounted on the LMC is strain gauge based. It has its own electronic processing, and produces a voltage which is (almost) proportional to the pressure. Thus the calculation proceeds in two stages:

1. Deduce the voltage *V* from measurements of the voltage, a reference voltage V_r measured in terms of converter counts (T, T_h, T_l):

$$V = \frac{(T - T_l)V_r}{(T_h - T_l)/\alpha} - (T - T_l)$$

2. Using pre-flight calibration data, relate the measured voltage to the pressure using a polynomial fit:

$$pressure = \sum_{n=0}^{N} a_n V^n$$

where

T = Sensor Reading

T_h= High Reference Reading

T_l = Low Reference Reading

V_r, a_n, N, α, are defined in Appendix C for each LMC pressure sensor.

The balance error of the cell also needs to be measured. This can be done by a pre-launch measurement supplemented by in-flight calibrations using the MOPITT blackbodies. Corrections for the spectral distribution of the blackbodies and known pressure dependent effects (reflection losses at the interfaces) in the system are also required.

3.1.3 Housekeeping Stream

3.1.3.1 Temperature Conversion Equation

All housekeeping temperature thermistors use the same equation for converting the ADC counts to degrees. This conversion is also a two step process where the first step is to deduce the thermistor resistance and then to convert the deduced resistance to degrees.

Resistance R equation:

$$R_t = \frac{R_2 V_{cal} T}{R_2 I_{bais} - V_{cal} T}$$

Housekeeping thermistor sensor temperature equation:

$$Temp(C) = \frac{1}{\sum_{n=0}^{N} a_n \left[\ln\left(R_t\right)\right]^n}$$

where

T = Sensor Reading

R_2, a_n, N, are defined in Appendix C for each nonlinear thermistor sensor.

3.1.3.2 Voltage Conversion Equation

Voltage monitor points within the housekeeping stream will be converted with gains and offsets set during sub-system and system level testing. These coefficients are given in tables in Appendix C.

3.1.3.3 Current Conversion Equation

Current monitor points within the housekeeping stream will be converted with gains and offsets set during sub-system and system level testing. These coefficients are given in tables in Appendix C.

3.2 Science Stream Conversions (Radiance Calibration)

3.2.1 Theoretical Description

The next step in the data processing of the MOPITT instrument is the conversion of the science data stream values, which contain the detector outputs and scan mirror positions, into calibrated gelocated radiances. The fundamental assumptions of this processing procedure are:

1. All emissions within the instrument obey Planck's Radiation Law.
2. The optical system obeys Scharzchild's equation.
3. The optics, detector and electronic systems are linear.
4. Temperatures drift slowly and are monitored.

The two required radiances resulting from this process are:

1. The average signal over the two states of the correlation cell.
2. The difference signal between the two states of the correlation cell.

The optical system is monitored in twelve states (see Table 3.2.1), which are required to counteract two significant causes of systematic error in the instrument:

1. Temperature drifts in all optical components. This is particularly a problem for the 4.7 μm channels. These are short-term variations and tend to be cyclic or random in nature.
2. Long-term drifts in the system transfer function (gain) and in the electronic offsets. These are due to changes in the optical system, the detector system and the electronic system. These tend to be systematic over long (month-years) periods of time.

State	Chopper Condition	Correlation Cell Condition	Scan Condition
1	OPEN	UP	EARTH
2	CLOSED	UP	EARTH
3	OPEN	DOWN	EARTH
4	CLOSED	DOWN	EARTH
5	OPEN	UP	SPACE
6	CLOSED	UP	SPACE
7	OPEN	DOWN	SPACE
8	CLOSED	DOWN	SPACE
9	OPEN	UP	INTERNAL
10	CLOSED	UP	INTERNAL
11	OPEN	DOWN	INTERNAL
12	CLOSED	DOWN	INTERNAL

Table 3.2.1 Channel States

The definitions for the various mechanism states are:

- Chopper [OPEN]. Chopper is fully clear of the optical system
- Chopper [CLOSED]. Chopper fully blocks incoming radiation
- Correlation Cell [UP (DOWN)]. For a length modulator cell (LMC), this refers to the short (long) path condition. For a pressure modulator cell it refers to the condition with the piston above (below) the average time point. The average time point in turn is the point which the piston spends 50% of the time above and 50% of the time below.
- Scan Condition [EARTH]. Scan system is disposed so that the input radiance comes from some part of the planet; these data are the ones required.
- Scan Condition [SPACE]. The instrument scanning system uses the side ports to direct the view to space. The input radiance is effectively zero under these conditions.
- Scan Condition [INTERNAL]. The instrument scanning system directs the view into the appropriate on-board calibration blackbody.

3.2.2 Physics of the Problem

3.2.2.1 Input Radiance

The discussion in the following sections is deliberately presented in terms of radiances, since the radiances are the relevant quantities. A highly simplified optical diagram is shown in Figure 2.3.1.4. The corresponding equation (Eq. 3.2.2.1) for the signal *S* at any time with the chopper OPEN is:

$$S = \frac{G}{T_o}\int_{\nu_1}^{\nu_2}\{([L_{input}\tau_1 + L_1]\tau_2 + L_2)\tau_g\tau_3 + L_3\}\tau_4\tau_f\,dv + F \qquad \text{Eq. 3.2.2.1}$$

where T_o is the time interval the chopper is open, L_{input} represents the input radiance, L_1, L_2, L_3 represent the system emissions from before and after the chopper and correlation cell, τ_1, τ_2, τ_3, τ_4 the broadband optical transmissions, τ_g the gas transmission of the correlation cell, τ_f the normalized filter transmission, *G* the system gain and *F* the system offset. With the chopper CLOSED the equation becomes:

$$S = \frac{G}{T_c}\int_{\nu_1}^{\nu_2}\{([L_{chopper}]\tau_2 + L_2)\tau_g\tau_3 + L_3)\}\tau_4\tau_f\,dv + F \qquad \text{Eq. 3.2.2.2}$$

where Tc is the time interval the chopper is closed.

Therefore the signal observed at any instant in time can be considered to be a combination of emission from the instrument and the input signal to the optics with appropriate weighting of the two terms. This weighting varies with the state of the optics, scanning and time. By measuring the variation of the signal with optical state and understanding the mechanisms which cause the variation, the input signal alone can be deduced.

As an example of the process of elimination of the instrument terms consider the case where the emission signals L_2 and L_3 are stable on the time scale of the chopper. The above equations (Eq. 3.2.2.1 and Eq. 3.2.2.2) can be differenced to get:

$$\Delta S = G\int_{\nu_1}^{\nu_2}[L_{input}\tau_1 + L_1 - L_{chopper}]\tau_2\tau_g\tau_3\tau_4\tau_f\,dv \qquad \text{Eq. 3.2.2.3}$$

The terms L_1 and $L_{chopper}$ will be eliminated in the next step of the calibration process using the calibration sources. The signal Δ*S* will be referred to as the "chopper difference signal" (CDS).

3.2.2.2 Chopper Difference Signals (CDS)

The individual signals are first differenced to form the six CDSs shown in the following table.

State	Signal	Correlation Cell Condition	Scan Condition
1,2	$S_{1,2}$	UP	EARTH
3,4	$S_{3,4}$	DOWN	EARTH
5,6	$S_{5,6}$	UP	SPACE
7,8	$S_{7,8}$	DOWN	SPACE
9,10	$S_{9,10}$	UP	INTERNAL
11,12	$S_{11,12}$	DOWN	INTERNAL

These differences are taken to eliminate instrument emission terms due to temperature drifts in the optical components. They only eliminate emission terms on the detector side of the chopper and only then if the rate of change of the emission signal is insignificant over the interval of single chopper cycle. Since the chopper cycle is about 1.6 ms and the emission change with temperature is on a scale where 1 mK is small, temperature drifts of a fairly large magnitude can be suppressed.

The chopper closed signals have a number of properties which make a more sophisticated analysis appropriate:

- When the chopper is closed the instrument has no radiance input from outside and therefore can be expected to show the same signals for the same outputs from the internal temperature monitors within some fairly close limits.
- The chopper closed system input radiance is approximately the chopper blade temperature which is closely monitored. Although the $L_{chopper}$ term varies, the variations may be tracked through knowledge of the chopper temperature and the Planck function.

Thus the chopper closed signals can be smoothed through a period greater than one stare, potentially reducing the noise level on the signal and changes in the chopper closed signal can be explained by changes in the chopper temperature. These properties permit the thermal offsets of the instrument (the fast changing terms) to be better monitored since they are seen on the chopper time scale.

The variations in the stray radiance from the input optics L_1 may be tracked by monitoring of the temperature of the front optical system and the surrounding baffles. Changes in the emission over the short-term can be compensated for, but longer term changes will require a full calibration sequence. Frequency of inflight calibration events will be established by analysis of instrument performance during the first month of operations.

3.2.3 Mathematical Description of Algorithm

3.2.3.1 Derivation of Average and Difference Signals

The average signal may derived by taking the CDSs and then averaging over the states of the correlation cell during the stare period. e.g. $(S_{1,2}+S_{3,4})/2$.

The difference signal can be derived by taking the average of the difference of the CDSs for the two states of the correlation cell. e.g. $S_{1,2}$-$S_{3,4}$.

Attention must be paid to the fact that the correlation cells also differ slightly in operation and in input signal characteristics.

The Pressure Modulator cells are treated on a "stare" basis as in the above description. All state signals are averaged over the stare time before being processed. The Length Modulator cells are treated differently for two reasons:

- The cell consists of four sectors, two "up" and two "down" which are used in sequence. Four complete rotations make up one stare time. The sectors are telemetered separately to permit individual interpretation.
- The input signal may vary significantly over a "stare" time and care is required in the averaging. This is primarily because the sectors correspond to slightly different sampling times. Using the separately telemetered sectors, a fit is performed through the four points of each sector permitting a better estimate of the time-weighted mean of the stare than a simple average would provide. The two center-time "up" states are then averaged as are the two center-time "down" states to produce similar signals to the PMC channels.

A correction is applied at this point for the LMC channels to account for the fact that the cell rotors have slightly different transmissions in the two states and this causes an offset signal to appear in addition to the gas effect. This offset is calibrated before launch and also monitored during a long calibration sequences by analysis of the individual sector signals. The six signals are now:

Signal	Scan Condition
Average	EARTH
	SPACE
	INTERNAL
Difference	EARTH
	SPACE
	INTERNAL

3.2.3.2 Calibration of the Difference and Average Channels

The calibration of the MOPITT instrument output is split into two parts: the derivation of the offset terms, L_1 and $L_{chopper}$ and the determination of the transmission terms.

We begin with the derivation of the offset terms. These are determined by looking through the SPACE port at which time L_{input} is zero and Eq. 3.2.2.3 becomes:

$$\Delta S_{space} = G\int_{\nu_1}^{\nu_2}[L_1 - L_{chopper}]\tau_2\tau_g\tau_3\tau_4\tau_f d\nu \qquad \text{Eq. 3.2.3.1}$$

and the expression for the CDS becomes:

$$\Delta S = G\int_{\nu_1}^{\nu_2}[L_{input}\tau_1]\tau_2\tau_g\tau_3\tau_4\tau_f d\nu + \Delta S_{space} \qquad \text{Eq. 3.2.3.2}$$

Since the radiance terms, which are temperature dependent, can change rapidly, this part of the calibration will be performed more frequently than the part of the calibration that is used to determine the gain and transmission terms.

The term ΔS_{space} is a function of the chopper and front optics radiances. Since these are carefully monitored, it will be possible to interpolate space signals between the actual measurement times by using these temperatures to determine the variations. In fact the calibration interval will be determined by the ability of the monitoring to track these changes reliably. Depending upon the actual values encountered, the interval will be in the range of 3 minutes (shorter times prejudice the earth data view coverage) to 30 minutes (nominal interval for GAIN measurement).

The next computation is essentially the determination the channel GAIN using the INTERNAL signal as a known radiance, followed by the application of these values to the EARTH signals. This leads to the general equation:

$$L_{earth} = L_{internal}\left(\frac{\Delta S_{earth} - \Delta S_{space}}{\Delta S_{internal} - \Delta S_{space}}\right) \qquad \text{Eq 3.2.3.3}$$

This formula is applied to both the average and difference channels to produce the required radiances. The internal radiance $L_{internal}$ is derived from knowledge of the temperature and emissivity of the calibration source. This uses PRT sensors which are discussed in section 3.1.1.1.

$L_{internal}$, when divided by the denominator in Eq. 3.2.3.3, provides a useful measure of the system gain that can be monitored during mission operations. A more sophisticated analysis can obviously be applied based on the fact that the long-term drifts are exactly that “long term” and the emission changes in the instrument are correlated with temperature changes. Thus we assume that all gain and offset factors change slowly compared with the calibration period and that the emission signals correlate with measured temperatures. Under these assumptions it is possible to build two additional inputs for the calibration system: an instrument characteristic emission model and a gain/offset history. Thus in determining the current radiometric calibration, the overall radiometric calibration uses: (1) current calibration values, (2) historic calibration values, and (3) instrument temperatures.

3.2.3.3 Derivation of Pixel Location

The locations of observation points (pixels) on the surface of the earth are computed by combining knowledge of the MOPITT scan mirror position with spacecraft orbit and attitude information. Scan mirror positions are measured relative to a "reference" bore-sight axis by means of digital shaft encoders. Calibration of the encoders and mapping of the four pixel positions relative to the bore-sight are part of the pre-flight instrument characterization. The position of the MOPITT "reference" bore-sight axis relative to the spacecraft coordinate system is measured during integration of the instrument onto the spacecraft.

During flight, the mirror angles as measured by the shaft encoders are part of the Level-0 data stream at the time of each observation. The view directions of the pixels in the spacecraft coordinate frame are computed by combining the encoder outputs with the fixed "offset" of the reference bore-sight to the spacecraft axes. Geolocation is then accomplished by use of standard subroutines available in the Science Data Product (SDP) tool kit (NASA EOS Document 194-809-SD4-001). These routines include; coordinate transformation utilities which provide conversion from the spacecraft reference frame to the Earth Centered Inertial (ECI) frame and transformation from ECI to geodetic coordinates, SDP toolkit routines PGS_CSC_GetFOV_Pixel and PGS_CSC_ECItoECR.

Other auxiliary information necessary for interpretation of the measurements at the pixel locations is likewise obtained from standard utilities in the SDP tool kit. This includes the solar and spacecraft zenith angles, , SDP toolkit routine PGS_CSC_ZenithAzimuth.

3.2.3.4 Variance and Uncertainty Estimates

The accuracy of the calibrated radiances is related to the measurement of the input radiance in terms of the calibration sources, followed by their traceability to international standards. The calibration will initially be established in the Instrument Calibration Facility (ICF). The current specifications are:

long wave (4.7 μm) channels	±0.5 K
short-wave (2.3, 2.4 μm) channels	±1 K

Measured values for the variance and uncertainty will be available after calibration tests are performed on the engineering model of MOPITT. These will be far more valuable than any calculated values for the purpose of assessing instrument performance.

A note of caution, the radiances are computed in the same manner as for a broad-band radiometer. The nature of the spectral response of a correlation instrument, however, is very different and caution should be exercised when comparing these radiances to radiances from a true broad-band radiometer. Further information is contained in the MOPITT Calibration Plan.

The resolution or repeatability of the MOPITT calibration is governed by a number of factors, some of which have a short characteristic time scale and some of which have a longer characteristic time. The objective of MOPITT is to measure gas concentrations in the atmosphere, not necessarily radiance. A detailed analysis of this objective shows that the repeatability of MOPITT measurements are, over the long term, more important than the accuracy of the initial calibration.

The short-term resolution of the MOPITT calibration is governed by a number of factors, the first of which is the noise level associated with the calibration itself. This can be adjusted by adjusting the length of time each target is viewed. Longer times permit better averaging of the radiance and temperature data.

Secondary factors which contribute to the calibration resolution are the applicability of the current calibration values to the radiance transformation. Temperature drifts are the primary cause of inaccuracy here and govern the time between calibration sequences. The primary elements in this operation are the chopper emissivity and temperature, which are both carefully controlled and, in the case of the temperature, carefully monitored. The governing time is that time in the middle of which the uncertainty in the corrections grows to a level which prejudices the consistency of the calibration. A target for calibration is 30 minutes for a room temperature source and monthly calibration with a hot source.

In practical terms, the variance of the radiances can be found by using the fact that there are many calibration sequences that are measurements of known radiances and that the major features of the calibration (optical transmission, etc.) change slowly with time. Thus daily, weekly, monthly and annual estimates of the changes in calibration parameters from the calibration history give valuable information on the variance of the calibration parameters and their drift with time.

3.3 Practical Considerations

This section describes areas which may require special consideration in the design and implementation of the Level 0-1 SDP processor or in oversight of the creation of the MOP-01 data product.

3.3.1 Numerical Computation Considerations

Computation required in the generation are standard hardware arithmetic or standard intrinsic functions supplied by run-time libraries. No special numerical algorithms are required.

3.3.2 Programming/Procedural Considerations

The design of the Level 0-1 SDP processor should provide for the capability to interpolate instrument calibration parameters from the times of calibration events to the times of earth stares. The frequency and duration of each type of calibration event will need to be established on-orbit. It will also be necessary to analyze the calibration events for evidence of long term drifts perhaps due to changes in optical components. Should such drifts be detected it will be necessary to provide a means to correct for them during reprocessing, based on off-line analysis by the MOPITT Instrument Team. These requirements point to the need to maintain a Calibration History File which collects and holds information from each of three types of in-flight calibration events. This implies certain procedural considerations in the structure of the Level 0-1 processor for handling the telemetry ingest and radiance calibration phases of processing.

Efficient use of some SDP Toolkit facilities should be should be considered as well. One example is the use of geolocation services. Due to processing overhead in various look vector and coordinate transform routines, it is more efficient to call these services for a collection of pixels rather than one pixel at a time.

3.3.3 Calibration and Validation

As described in preceding sections, the integrity and consistency of the MOPITT radiances are greatly dependent on the proper pre-flight and in-flight calibration of the instrument and the correct application of the calibration information to the earth stares. The flow of calibration information from pre-flight and in-flight calibration into the processing and ultimately the data product is illustrated schematically in Figure 3.3.3.1. In various test plans, Mand (1995) describes pre-flight test procedures to be carried out which will characterize the MOPITT instrument. Where appropriate, the various characterization parameters resulting from these tests will be provided to the Level 0-1 processor through the Instrument Parameter File described in earlier discussion.

After launch, the resulting MOP-01 data product and the derived Level-2 data product will be assessed in an extensive validation effort. Details of these activities are given in the MOPITT Validation Plan.

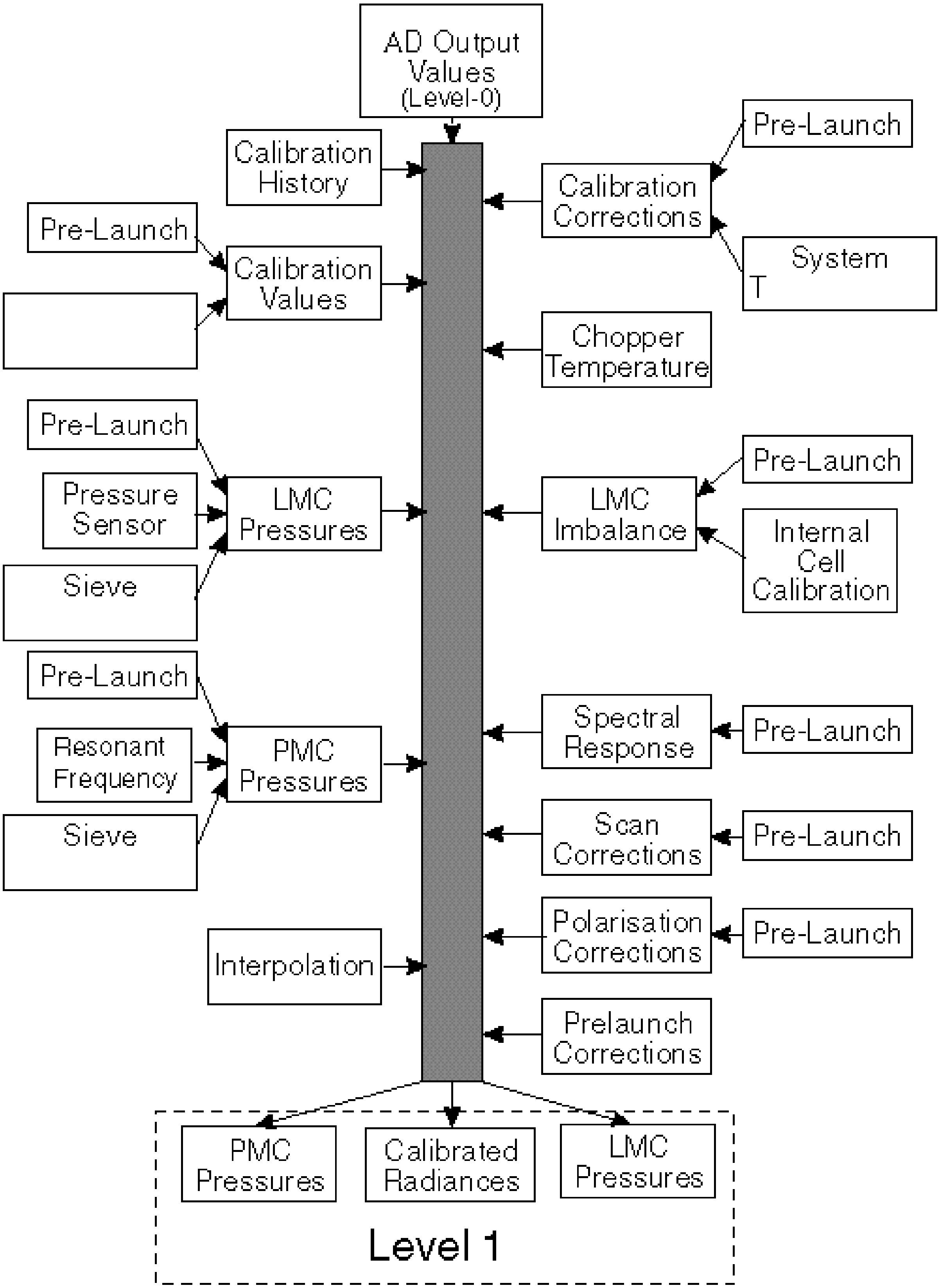

Fig. 3.3.3.1 Calibration and Instrument Characterization Information Flow

3.3.4 Quality Control and Diagnostics

In-line quality control procedures will be implemented as part of the Level 0-1 processor to provide an assessment of data quality to users. In addition, the screening process will also provide supplementary information on long term instrument performance to the MOPITT Instrument Team and to the data product validation activities mentioned above. Summary information, collected during the processing of each Level-1 data granule, will be reviewed by staff at the MOPITT Science Computing Facility (SCF). They will assess whether the overall quality of the granule is acceptable to allow its use by researchers. In cases where granules are found to be of unacceptable quality for subsequent use, corrective action will be undertaken to determine the source of the problem prior to any reprocessing. Data flow for quality assurance, instrument performance assessment and validation support is illustrated in Fig. 3.3.4.1. Details of the quality assurance procedures are presented in the MOPITT Quality Assurance Plan.

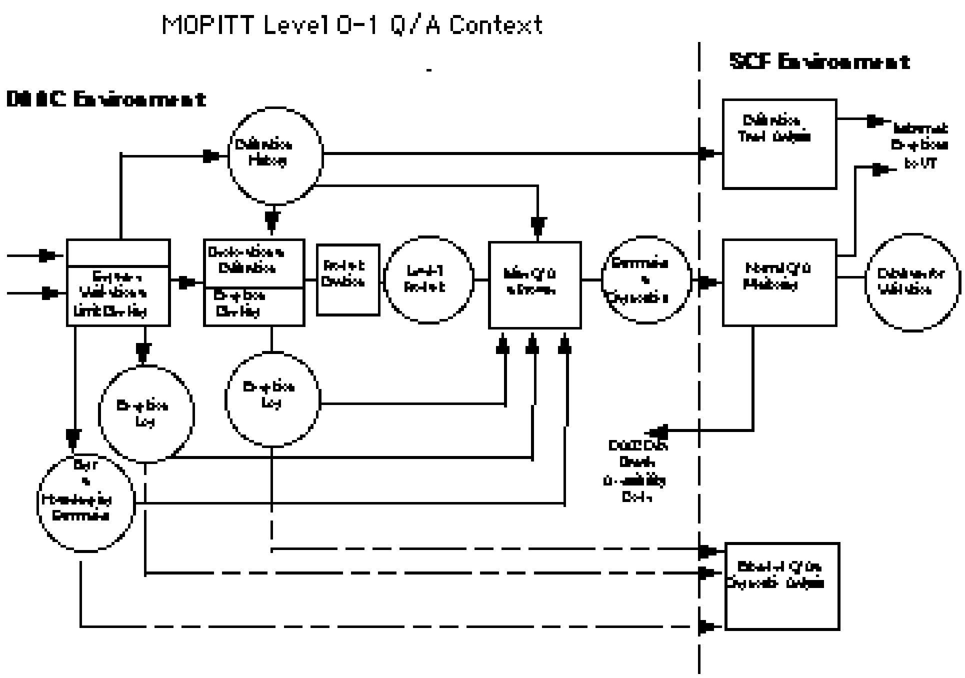

Fig. 3.3.4.1 Quality Assurance Data Flow for the MOPITT Level 0-1 Processor

Certain diagnostic information is collected and provided as part of the MOP-01 data product. This includes information on calibration, radiometric gain and offset, noise equivalent radiance and a summary of a subset of the most important engineering and housekeeping parameters. These data elements are described in the Level-1 Data Product Content presented in APPENDIX-D.

3.3.5 Exception Handling

Exception handling is performed as part of the quality assurance procedures described in the preceding section. All critical engineering and housekeeping telemetry elements will be monitored for out of limit conditions. Checking will be performed on telemetry elements important to computation of calibration parameters or instrument state parameters passed on to Level-2 processing. Provision for flagging incomplete or corrupted earth scenes is provided in the MOP-01 data structure described in APPENDIX-D.

APPENDIX A.

Peer Review Board Acceptance Report

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APPENDIX B.

Acronym List

ATBD	Algorithm Theoretical Basis Document
CDS	Chopper Difference Signal
CR	Correlation Radiometry
DAAC	Distributed Active Archive Center
ECI	Earth Centered Inertial
FOV	Field of View
HDF	Hierarchical Data Format
ICF	Instrument Calibration Facility
ISAMS	Improved Stratospheric and Mesospheric Sounder
LMC	Length Modulated Radiometer
MOPITT	Measurement of Pollution in the Troposphere
NCAR	National Center for Atmospheric Research
PMC	Pressure Modulated Radiometer
PMIRR	Pressure Modulated Infrared Radiometer
PRT	Platinum Resistance Thermometer
SAMS	Stratospheric and Mesospheric Sounder
SCF	Science Computing Facility
SDP	Science Data Product
SPM	Signal Processing Module
UT	University of Toronto

APPENDIX C.

Engineering Stream Telemetry Elements and Conversion Coefficients

(Contents in preparation)

APPENDIX D.

Level 1-B Data Product Content

EOSDIS Product Code: MOP-01

Data Product Overview

The MOPITT Level-1 data product consists of the geolocated, calibrated earth scene radiances, associated instrument engineering data summaries and inflight calibration information. Data granules are one day in duration and limited to the earth scenes observed within the midnight to midnight period. Data from special calibration sequences and instrument diagnostic modes have been excluded.

The MOPITT instrument is an eight-channel cross-track scanning correlation radiometer. Radiances representing the two states of the correlation cells are reported for each channel. These two states are:

- The “average” radiance which is a measure of the wide band signal seen by the detectors.
- The “difference” radiance which is a measure of the signal passed by the complex filter formed by the target gas in the correlation cell.

A complete description of these signals is given in the MOPITT Algorithm Theoretical Basis Documents referenced in Section 2.0. The characteristics of the eight channels are summarized in Table-D1.

Each of the eight channels is imaged on optically co-aligned linear arrays of four pixels. Each pixel is approximately 22 X 22 km square. Thus for every measurement time, 16 radiances are reported at each of four adjacent geographical locations. The footprint of the MOPITT observations is shown in Figure 2.3.2.3 for three cross-track scan sequences. Alternate scan sequences have been shaded for clarity. Periodically these scan sequences are interrupted for a short time while the instrument views internal calibration sources.

In the normal science data collection mode, the cross-track scan begins on the cold space calibrate side of the orbit track. There are 14 possible mirror positions on each side of the nadir position. During the scan, the mirror positions are interlaced on the forward and return parts of the cross-track to maximize coverage. Each observation is termed a “stare” with the time between “stares” equal to 450 msec. Twenty-nine stares are collected for each cross track scan. The stare and pixel positions are identified in Figure-2.3.2.3.

Selected instrument engineering data and the calibration factors, used to convert detector counts into radiances, are collected and summarized over the time interval of each cross-track sequence. Some of these data are needed for subsequent Level-2 processing. Other engineering information is provided for convenience to the MOPITT team in support of data validation and quality control activities.

Chan. No.	Target Gas	Cell Type	Center Wave length (μm)	Filter Band Width (μm)	Cell Pressure (kPa)	Use
1	CO	LMC	4.617	0.111	20	Thermal Radiation CO Profile
2	CO	LMC	2.334	0.022	20	Reflected Solar Radiation CO Column
3	CO	PMC	4.617	0.111	7.5	Thermal Radiation CO Profile
4	CH4	LMC	2.258	0.071	80	Reflected Solar Radiation CH4 Column
5	CO	LMC	4.617	0.111	80	Thermal Radiation CO Profile
6	CO	LMC	2.334	0.022	80	Reflected Solar Radiation CO Column
7	CO	PMC	4.617	0.111	3.8	Thermal Radiation CO Profile
8	CH4	LMC	2.258	0.071	80	Reflected Solar Radiation CH4 Column

Table-D1 MOPITT Correlation Radiometer Channel Characteristics

Data Format

The MOPITT Level-1B product is archived using the HDF-EOS Swath structure which is described along with Application Program Interfaces (APIs) in references listed in Section 2.0. This structure has been defined to represent time ordered, multi-channel instrument data such as MOPITT. HDF-EOS is an extension to the Hierarchical Data Format (HDF) standard developed at the University of Illinois National Center for Supercomputer Applications. Readers should familiarize themselves with HDF and HDF-EOS in advance of using the data.

Data Content

* NOTE -- DIMENSIONALITIES OF ARRAYS ARE DEFINED IN FORTRAN ORDER, C ORDER IS REVERSED *

DIMENSIONS

ntrack = unlimited	(number of cross-tracks = Number of swaths)
nstare = 29	(29 stares per cross track swath = Number in Crosstrack)
npixels = 4	(4 pixels per stare)
nchan = 8	(8 channels of radiance measurement)
nstate = 2	(Average and difference state of correlation cell)
nengpoints = 102	(102 engineering data elements per swath)
neng = 2	(Engineering data elements are represented as an average value over a swath and a standard deviation)
ncalib = 8	(Calibration parameters for each radiance element: swath average gain, offset, noise and internal black body radiance and associated standard deviations)
nsunparms = 2	(Number of solar location elements: zenith and azimuth angles)

GEOLOCATION FIELDS

The following are HDF VDATA variable names:

Track Count float: Number of tracks in this data set

Time : double (ntrack) (Holds time of day and date in Tai93 format for first stare in swath. Subsequent stares occur 450 milliseconds apart.See SDP Toolkit for description of Tai93 time format)

Swath Quality : int32 (ntrack) (TBD values to flag if entire swath has valid values)

The following are HDF Scientific Data Set (SDS) variable names

Latitude : float (npixels,nstare,ntrack) (Latitude in degrees -90 to 90)

Longitude : float (npixels,nstare,ntrack) (Longitude in degrees -180 to 180)

Solar Parms : float (nsunparms,npixels,nstare,ntrack) (Solar direction angles at pixel locations in degrees)

(in nsunparms dimension)

1=solar zenith angle

2=solar azimuth

Satellite Parms: float (nsunparms,npixels,nstare,ntrack) (Satellite direction angles at pixel locations in degrees)

(in nsunparms dimension)

1=satellite zenith angle

2=satellite azimuth

DATA FIELDS

The following are HDF Scientific Data Set (SDS) variable names

MOPITT Radiances: float (nstate,nchan,npixels,nstare,ntrack)
(MOPITT radiances in *Watts meter*$^{-2}$ *Sr*$^{-1}$ - swath format)

(in nstate dimension)

1=average state radiance

2=difference state radiance

Engineering Data: float (neng,nengpoints,ntrack) (Engineering data, one set per swath)

(in neng dimension)

1=Average over time of swath of engineering element

2=Standard deviation of engineering element

(in nengpoints dimension)

1 = cell pressure channel 1 CO LMC 4.7mic in mb (20 mb nominal)

2 = cell pressure channel 2 CO LMC 2.3mic in mb (20 mb nominal)

3 = cell pressure channel 3 CO PMC(Low state 50mb) 4.7mic

4 = cell pressure channel 3 CO PMC(High state 100mb) 4.7mic

5 = cell pressure channel 4 CH4 LMC 2.4mic in mb (80 mb nominal)

6 = cell pressure channel 5 CO LMC 4.7mic in mb (80 mb nominal)

7 = cell pressure channel 6 CO LMC 2.3mic in mb (80 mb nominal)

8 = cell pressure channel 7 CO PMC(Low state 25mb) 4.7mic

9 = cell pressure channel 7 CO PMC(High State 50mb) 4.7mic

10 =cell pressure channel 8 CH4 LMC 2.4mic in mb (80 mb nominal)

11 - 18 = Cell temperature for channels 1 to 8 (1&2 and 5&6 are the same) in Deg K

19 - 22 = Black Body temperature for 4 optical benches in Deg K

23 - 26 = Chopper temperature for 4 optical benches in Deg K

27 - 30 = Optics temperature for 4 optical benches in Deg K

31 - 102 (Unassigned Engineering data elements in Beta Delivery)

Calibration Data : float (ncalib,nstate,nchan,npixels,ntrack) (Calibration data for each state, channel and pixel) (AVERAGED OVER SWATH)

(in ncalib dimension)

1=gain

2=offset

3=noise equivalent radiance in *Watts* $meter^{-2}$ Sr^{-1}

4=Internal Black Body Radiance in *Watts* $meter^{-2}$ Sr^{-1}

5=standard deviation of gain

6=standard deviation of offset

7=standard deviation of noise in *Watts* $meter^{-2}$ Sr^{-1}

8=standard deviation of Internal Black Body Radiance in *Watts* $meter^{-2}$ Sr^{-1}