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Earth Location User's Guide (ELUG)

Revision 2

July 2005

Prepared by:

U.S. Department of Commerce
National Oceanic and Atmospheric Administration (NOAA)
National Environmental Satellite, Data, and Information Service (NESDIS)

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Preface

This document comprises the initial National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) DCN 2 baseline publication of the Earth Location User's Guide (document number NOAA-GOES/OSD3-1998-015R2UD0; July 29, 2005 issue).

The purpose of this document is to provide GOES I-M and GOES-NOP users with the information describing the process of Earth locating imagery formatted into the GOES Variable (GVAR) data stream.

NOAA/NESDIS acknowledges the efforts of Space Systems/Loral (SS/L) and Integral Systems, Incorporated (ISI) for their preparation of the original version of this document, SS/L-TR00689, published January 13, 1994, and ISI-36-439 (Revision A) published September 26, 1994, under National Aeronautics and Space Administration (NASA) Contract NAS 5-29500. ISI is acknowledged for contributions to the NOAA/NESDIS DCN 0 baseline of the document, ISI-36-439R0UD0, published May 15, 1997. Also, Lockheed-Martin Space Mission Systems and Services (LMSMS&S), Swales Aerospace, and ISI are acknowledged for contributions in the content update of the Revision 1 document baseline.

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Section 1.0 Introduction

This document provides GOES I-M and GOES-NOP users with the information describing the process of Earth locating imagery formatted into the GOES Variable (GVAR) data stream. The information provided is a description of the Earth location algorithm used by the Sensor Processing Subsystem (SPS)[1] of the Operations Ground Equipment (OGE) and its software implementation. The descriptions provided assume knowledge of the Imager and Sounder instruments and the GVAR format. The Imager and Sounder instrument characteristics and the GVAR data format are, respectively, described in the *Imager/Sounder – OGE Interface Control Document* (Ford Aerospace Corporation (FAC) specification #SJ572022) and the *OGE Interface Specification* (DRL 504-02), which were developed for the GOES I-M satellite program.

The manual is organized to provide a GOES user with a complete description of the functional process and relevant OGE software implementation. The specific organization is as follows:

Section 1.	Overview of the process, which includes brief descriptions of the coordinate systems, Orbit and Attitude (O&A) determination process, and relevant GOES user Earth location coordinate transformations.
Section 2.	Description of the O&A coefficient set contents as transmitted in the GVAR format. This is the set used to determine spacecraft position and instrument attitude.
Section 3.	Mathematical description of the instrument-related coordinate systems and the transformation between these coordinate systems.
Section 4.	Mathematical description of the transformations between the instrument-related coordinate systems and geographic coordinates.
Section 5.	Module descriptions of applicable software as implemented in the OGE's Sensor Processing Subsystem (SPS).
Section 6.	Test cases for use in verifying user implementations of Earth location software.
Appendix A.	Example of Earth Location Software Module Usage (modules described in Section 5).
Appendix B.	Fortran listings of the software described in Section 5.
Appendix C.	Kamel to Keplerian Transformation.

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[1] The SPS has been replaced by the Modernized SPS (MSPS) which provides the same functionality, i.e., adheres to the same Earth location algorithm, as the SPS.

1.1 Overview

Earth location determination involves the computation of transformations between geographic and instrument coordinate systems. This allows the determination of the pixel location within a processed frame of imagery corresponding to a selected geographic location. A brief description of the instrument coordinate systems used is provided in the next section prior to continuing with the overview of the transformation process.

While modifying the O&A model for flipped spacecraft, the instrument misalignment terms were found to be incomplete. The misalignment terms were correct for the Imager (and the Sounder in inverted mode) but were incorrect for the Sounder (and the Imager in inverted mode). The modifications to the misalignment model have been included in this update of the Earth Location User's Guide (ELUG). The misalignment corrections now vary with instrument and spacecraft orientation.

The geographic to instrument and instrument to geographic coordinates transformation algorithms were updated for GOES-NOP to be consistent with the GOES-NOP ground system.

1.1.1 Instrument Coordinate Systems

There are two coordinate systems, attached to either instrument's field of view, which express the "east/west" and "north/south" angle position in different units. The first coordinate system is used when reporting the mirror position in cycles and increments to the SPS, which is responsible for processing Imager and Sounder raw data and outputting the resulting products in the GVAR Processed Data Relay (PDR). The second involves the transformation of the reported mirror position cycles/increments into line/pixel coordinates, providing a user-friendly method of expressing location within the instrument field of view. Both coordinate systems are described in the following paragraphs with their mathematical interrelationship described in Section 3.1.

Before the problems with GOES-10, these two coordinate systems were parallel and related linearly to geographic north, south, east, and west. For spacecraft flying "upside down," such as GOES-10, this relationship no longer holds. To minimize the impact to users for inverted operations, the line/pixel coordinate system will remain Earth-fixed with line 1 as the northernmost line and pixel 1 as the westernmost pixel. Since cycles and increments are inherently body fixed, they will remain so. Therefore, relative to the Earth, the cycles/increments coordinate system will be inverted.

A consequence of keeping line/pixel Earth related is that the transformation from line/pixel to cycles/increments changes with the spacecraft orientation. These changes will be detailed in Section 3.

1.1.1.1 Scan Mirror Position

The coordinate system used when reporting mirror position in the wideband data stream is derived from each instrument's two servo motors, which control scanning in the north/south direction and the east/west direction. Each mirror position coordinate is provided in units of cycles and increments, as determined by the instrument's inductosyn, which measures the mechanical shaft rotation angle of the servo motor.

The cycle/increment value received in each raw instrument downlink can be used to determine the corresponding angle within the field of view, since a cycle can be equated to 2.8125 degrees of mechanical shaft rotation. Increments are finer measures of shaft rotation angles and are different for each instrument. For the Imager, each cycle contains 6136 increments, each of which is approximately equal to 8 microradians of mechanical shaft rotation. For the Sounder, each cycle contains 2805 increments, each of which is equal to approximately 17.5 microradians of mechanical shaft rotation.

As a result of the manner in which the instrument scanning mirrors have been gimbaled, the relationship between a given shaft mechanical angle and the corresponding image optical angle is not the same in both axes. In the north/south direction, the mechanical shaft angle is equal to the mirror’s optical angle. In the east/west direction, a mechanical shaft angle change has a doubling effect upon the mirror’s optical angle.

Figures 1-1 and 1-2 illustrate the cycles/increments coordinate system as related to the Imager and Sounder fields of view for an upright spacecraft. The origin of the coordinate system is in the upper left corner for the Imager and in the lower left corner for the Sounder. At a nominal geosynchronous orbit, the Earth will be positioned within the frame as indicated. Under these conditions, instrument nadir corresponds to the subsatellite point and has the coordinates denoted in the figure. The actual nadir values will vary somewhat according to the results of the factory alignment. Figures 1-3 and 1-4 are the equivalent figures for an inverted spacecraft.

There are two inner boundaries within the coordinate system to consider. The first is the mechanical scanning limits of the instrument, which are enforced via physical stops. The second boundary is defined as the instrument’s operational field of view, or the planned scanning limits. Instrument scanning is performed within these bounds during normal operations. It is important to note that due to the variation of the instrument nadir point, which is expected to be slightly different for each instrument, the mechanical scanning limits will vary slightly with respect to the origin of the cycles/increments coordinate system.

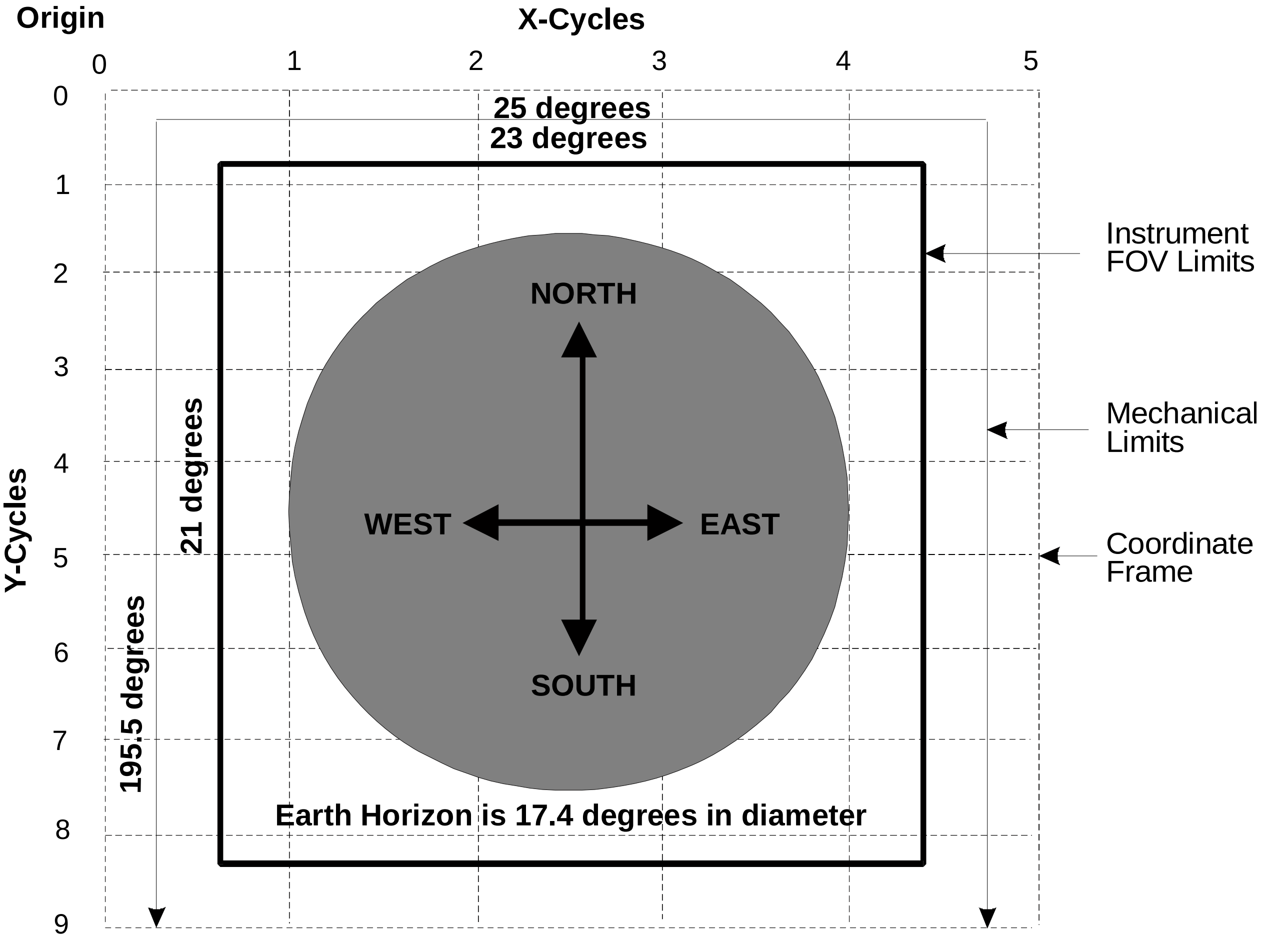
1.1.1.2 Line/Pixel Coordinate System

The line/pixel coordinate system was developed to provide GOES users with instrument scan position information in a traditional graphics form. In this coordinate system, the east/west scan position is described in pixels with the north/south scan position described in lines. The visible channel provides the basis for the line/pixel coordinate system for both instruments. Since a line and pixel unit corresponds to the north/south and east/west angle swept by one visible detector sample, line/pixel coordinates can be directly mapped to the received visible image arrays.

The line/pixel coordinate system is absolute: the calculation of these coordinates is performed without regard to the starting location of the frame. Different frame start locations are absolutely mapped to unique line/pixel coordinates, rather than mapping schemes in which coordinates are defined relative to the start of each frame.

The origin of the line/pixel coordinate system is defined relative to that of the instrument (i.e., scan mirror position) as a mapping of the northernmost visible detector in the visible detector array to the northwest corner of the instrument coordinate frame. The origin is not defined with respect to the operational instrument field of view limits due to the variation of the actual instrument nadir point from one instrument to another, which would cause the mapping to be instrument unique rather than general for all instruments.

For the Imager, line/pixel reference locations are provided in the GVAR format for the image frame corners, each image point, the current scan line number, and the easternmost and westernmost visible pixel in the current scan. All of this data is contained in the Imager documentation block (GVAR Block 0). For the Sounder, line/pixel coordinates are provided for each pixel sampled in addition to the frame and scan line references previously described for the Imager. Providing line/pixel coordinates for every Sounder sample is possible due to the far lower data rate of the Sounder as compared with the Imager.

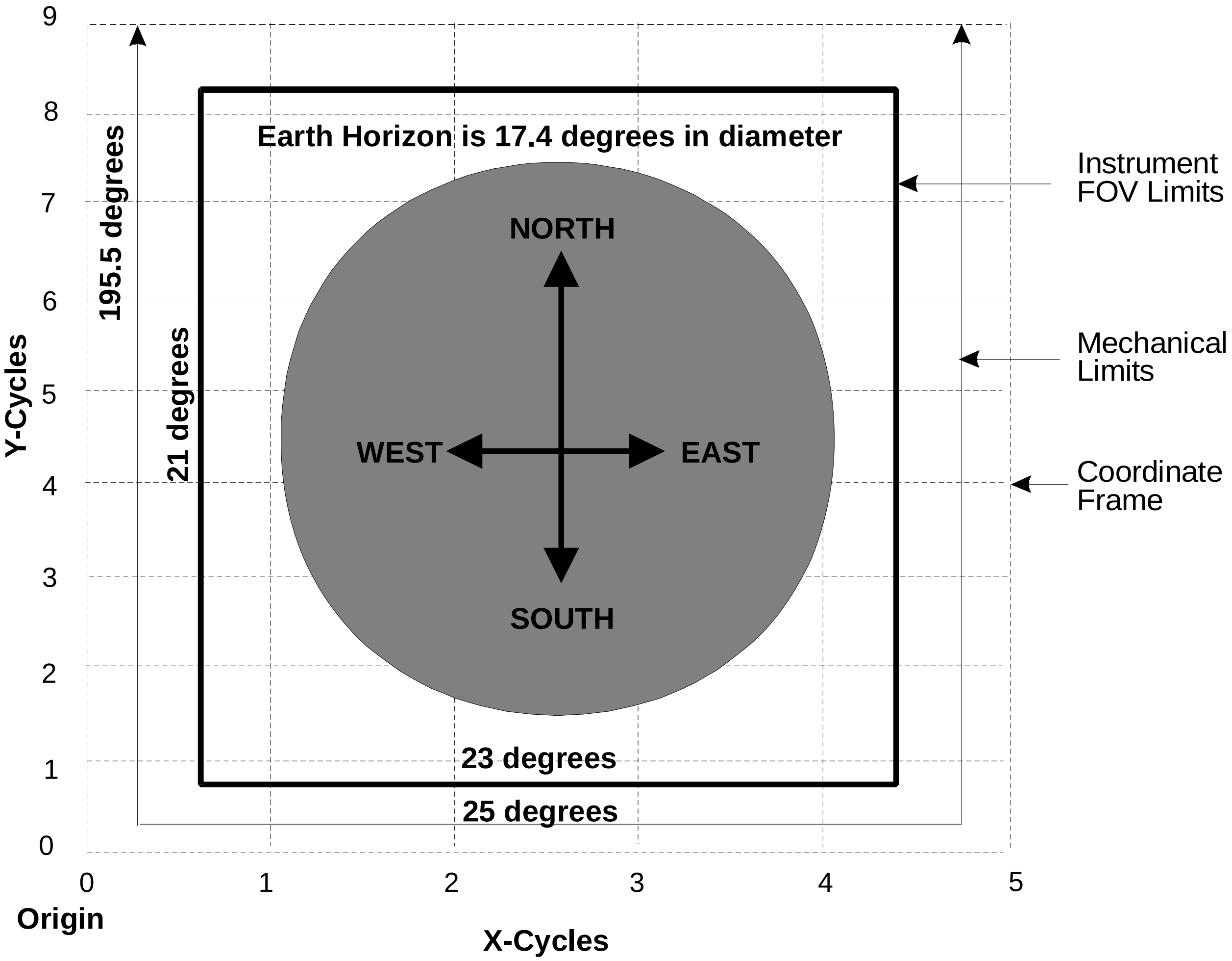


Imager Instrument Nadir

Offset from Origin	E/W	N/S
Mechanical Degrees	7.03125	12.65625
Cycles/Increments	2/3068	4/3068

Imager Increments/cycle: 0-6135

Figure 1-1. Imager Coordinates and Frames (Upright)

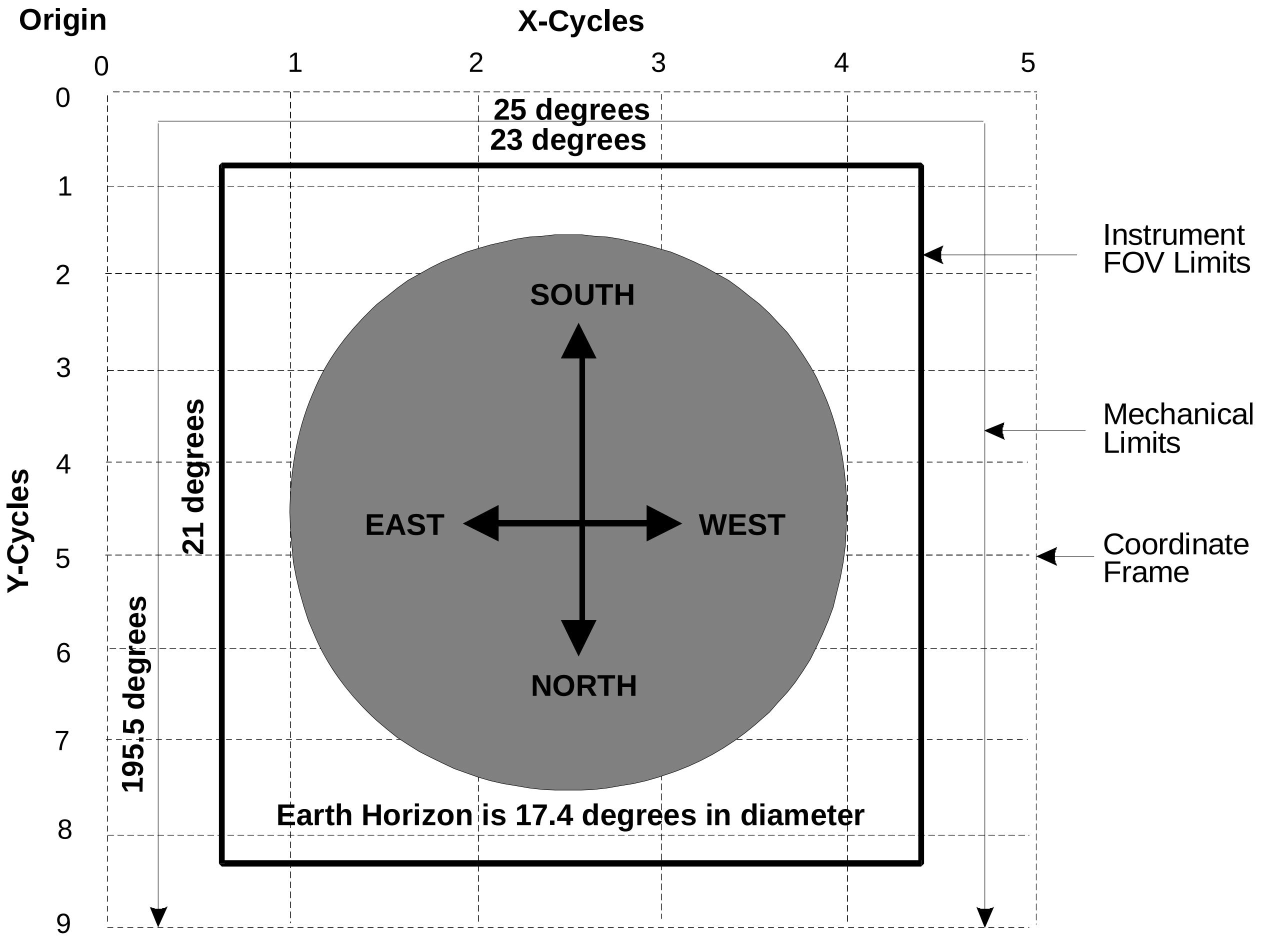


Sounder Instrument Nadir

Offset from Origin	E/W	N/S
Mechanical Degrees	7.03125	12.65625
Cycles/Increments	2/1402	4/1402

Sounder Increments/Cycle: 0-2804

Figure 1-2. Sounder Coordinates and Frames (Upright)

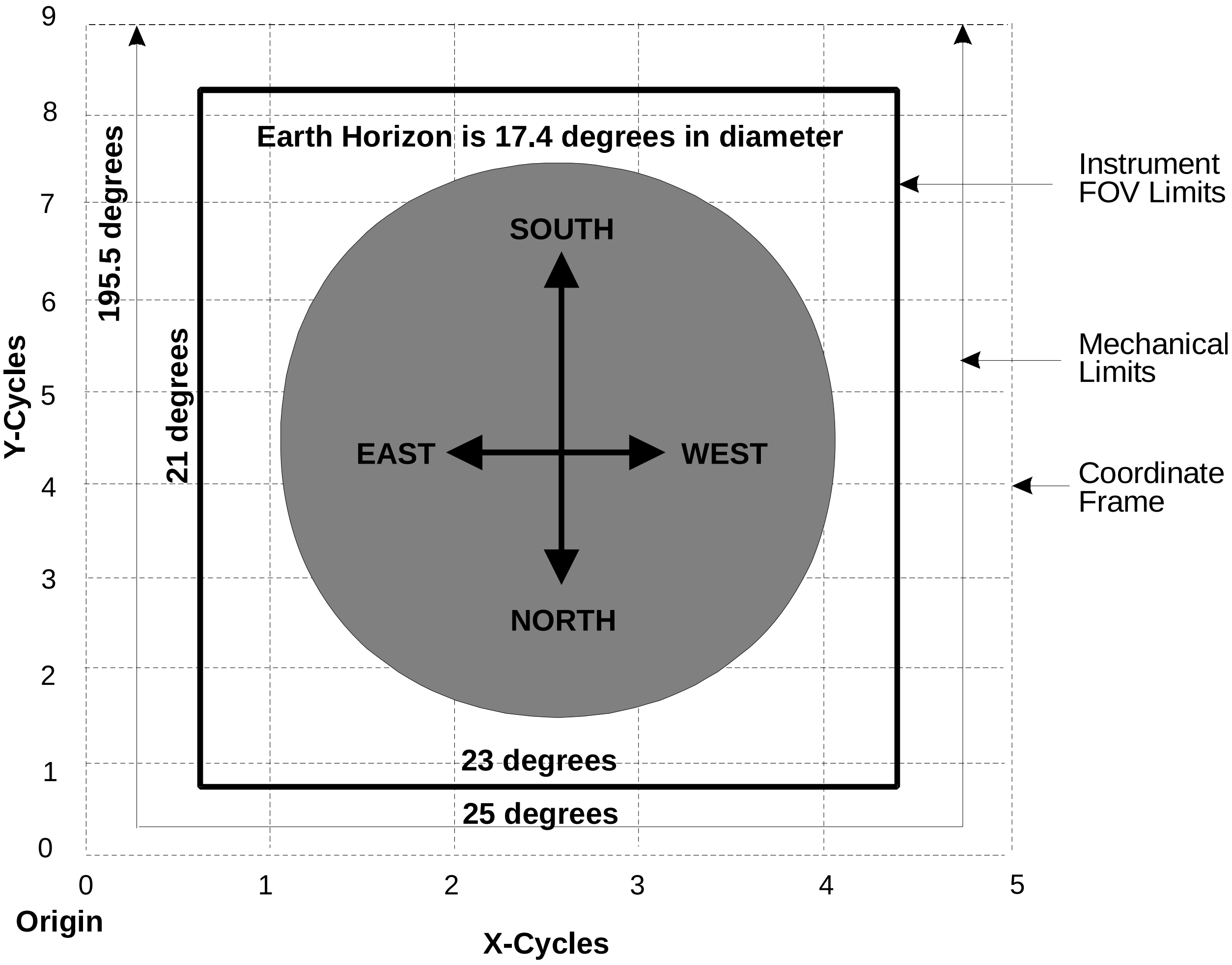


Imager Instrument Nadir

Offset from Origin	E/W	N/S
Mechanical Degrees	7.03125	12.65625
Cycles/Increments	2/3068	4/3068

Imager Increments/cycle: 0-6135

Figure 1-3. Imager Coordinates and Frames (Inverted)



Sounder Instrument Nadir

Offset from Origin	E/W	N/S
Mechanical Degrees	7.03125	12.65625
Cycles/Increments	2/1402	4/1402

Sounder Increments/Cycle: 0-2804

Figure 1-4. Sounder Coordinates and Frames (Inverted)

1.1.2 Earth Location Processing

The GVAR format provides Earth location references to varying degrees for each instrument. For the Imager, the user is provided with the Earth locations expressed in latitude/longitude coordinates for the northwest and southeast corners and the subsatellite point of the imaging frame. For the Sounder, the above references are provided along with the Earth locations of each detector sample (pixel) and the boresight (i.e., scan mirror position). In general, GOES users would employ Earth location processes that allow the extraction of image areas within an Imager frame which are bounded by predefined Earth locations. The process would not be necessary for the Sounder, since both the location in the instrument and Earth frames are, respectively, provided in line/pixel and latitude/longitude coordinates. The Earth location process described would involve the determination of a line/pixel location given a latitude/longitude coordinate or vice versa. These processes are the inverse of one another and involve the determination of the spacecraft position and instrument attitude using the O&A coefficient set, which is provided in the appropriate instrument's documentation block. Prior to continuing with the description of the transformation, an overview is provided in the following paragraphs of the Image Motion Compensation (IMC) process from an OGE operational point of view.

1.1.2.1 OGE Image Motion Compensation Processing

One of the most important features of the GOES I-M and GOES-NOP satellite system is the onboard coregistration of image frames received over a specified time interval. The time interval is referred to as the coregistration interval and is planned to be nominally 24 hours. Coregistration of successive image frames involves both the OGE and the instruments operating in a closed loop fashion as described in the following paragraphs.

The process starts with the determination of the O&A over the specified coregistration interval. This is performed by the OGE's Orbit and Attitude Tracking System (OATS). It results in the upload of an IMC coefficient set to the spacecraft containing estimates of the orbital state and the instrument attitude, allowing the particular instrument's scan mirror drive to compensate for the satellite motion and instrument attitude variations. Each updated IMC set is determined from star measurements, known landmarks, and range data, previously provided by other OGE subsystems.

In conjunction with the upload of the IMC coefficient set to the spacecraft, the O&A set is sent to the appropriate SPS for Earth location and gridding processing functions and for incorporation into the GVAR format. The O&A coefficient set is a version of the IMC coefficient set which has been tailored for ground processing use. In general, the SPS implements the O&A set at the start of the next image frame; therefore, if the update occurs in the middle of a frame, the current set will continue to be used and reported in GVAR throughout the remainder of the frame. This prevents discontinuities in Earth location determination and gridding within a frame. It is important to note that if the O&A coefficient set is updated in the middle of a normal frame and the frame is later interrupted by a priority frame, the current set is used throughout the normal frame with the updated set used throughout the priority frame.

Since the image is coregistered when IMC is active, the supporting SPS only requires a time-independent expression of the O&A consisting of the orbital reference position and the instrument attitude reference angles. Therefore, when determining Earth locations with IMC active, the instrument position is fixed relative to the Earth frame of reference over the coregistration period. As previously explained, operating the instruments with IMC active is the normal mode of operation, but since IMC may be deactivated at any particular time, both the SPS and GOES users require a time-varying O&A expression. It is because of this that the O&A set contains both time series representations of O&A, for situations when IMC has been deactivated, and the aforementioned orbital reference and attitude reference angles when IMC is active.

1.1.2.2 Earth Location Determination

The typical GOES user requires the ability to determine the latitude/longitude of a particular line/pixel location and to determine the converse—the line/pixel location corresponding to a particular Earth location in latitude/longitude. Determination of the latitude/longitude corresponding to a given line/pixel location first involves the computation of the east/west and north/south angles within the instrument field of view. A mathematical description of this conversion is provided in Section 3. A transformation is then made between the position of the pixel, as expressed by the east/west and north/south angles within the instrument field of view, and Earth-fixed coordinates by using the O&A coefficient set to determine the spacecraft position and instrument attitude relative to the Earth frame of reference. As previously mentioned, the O&A coefficient set provided has two distinct parts: the first contains the orbital reference and attitude reference angles, which allow a relatively simplistic calculation when IMC is active; and the second contains time series O&A representations used when IMC has been deactivated. Therefore, when IMC is active, the position and attitude remain fixed in time to the reference position, and Earth location information is only calculated once for the entire time the particular O&A coefficient set is in effect (i.e., until reference O&A are no longer valid). Conversely, if IMC has been turned off, the position and attitude will change as a function of time as modeled by the time series O&A representations. Therefore, this would require periodic updating of Earth location information. Currently, the SPS updates the spacecraft position and instrument attitude every 14 input scans (note: the scan is defined by the large Infrared (IR) detector’s swath, which is equal in height to eight visible detectors) for the Imager and at each sounding for the Sounder. The mathematical description of the instrument-to-Earth coordinate transformation is provided in Section 4.

The reverse transformation of latitude/longitude to line/pixel coordinates is most useful when sectorizing images, since each pixel’s line/pixel coordinate is readily determined, but the sector boundaries are typically expressed in latitude/longitude coordinates. The process, which is also described in Section 4, involves the determination of the east/west and north/south angle within the instrument field of view as previously described. Once these angles have been determined, the conversion to line/pixel is relatively direct (as described in Section 3). The mathematical description of the Earth location software and the accompanying description of the software implementation also contains adequate information to allow the determination of Earth locations from the instrument cycle/increment mirror position coordinates. This is the transformation performed by the SPSs and is not expected to be undertaken by the majority of GOES users. Some additional explanation applies to this particular type of transformation. For the Imager, only the mirror position (i.e., scan addresses) of either end of each scan are reported. Determination of the mirror position within a scan is determined in the SPS by linear interpolation. The reported mirror position is provided in the Imager documentation block (Block 0) as part of the header and trailer block reports. In the case of the Sounder, the mirror position of each dwell is reported, but the servo error value must be added to the mirror position in cycles/increments prior to performing any transformations to determine the mirror's true position. Since there are several servo error values reported with each dwell, one value has been selected which best represents the true servo error contribution to the mirror position as seen in the image data. This value is E-W scan servo error #8 which is contained in word #181 of the Sounder raw data block. (Raw block contents included with each Sounder Sensor Block 11 are described in the GVAR format specification.) In addition, the description and corresponding software of the routine used to determine the Earth locations of the Sounder detectors is also provided. Earth locating these detectors requires an additional correction for detector rotation which is a function of the north/south angle. Rotation correction is not necessary for the Imager, since it is performed by the instrument.

1.2 Document Organization

Section 2 of this document discusses the auxiliary GVAR data, Section 3 presents a mathematical description of the instrument-related coordinate systems, and Section 4 describes the transformations between the instrument and geographic coordinates. Module descriptions and test cases are given in Sections 5 and 6, respectively (for GOES I-M only):

The following three appendices are also provided, for GOES I-M only:

Appendix A—Example of OGE Earth location software usage
Appendix B—OGE Earth location software listings
Appendix C—Kamel-to-Keplerian transformation

Section 2.0 Auxiliary GVAR Data

Besides the scan data, the GVAR stream contains additional information necessary for Earth location. This auxiliary data consists of the O&A coefficient set, the YAW FLIP flag, and the nadir offsets for each instrument. Each of these is discussed in this section.

2.1 Orbit and Attitude (O&A) Coefficient Set

This section provides a description of the form and content of the O&A coefficient set. Tables 2-1 and 2-2 define the format of the Imager and Sounder O&A coefficient sets as they are transmitted in the GVAR format. The Imager O&A set is contained in the Imager documentation block (Block 0) and the Sounder's is included within the Sounder documentation Block 11. Both tables have been extracted from the GVAR format description contained in the OGE Interface Specification (DRL 504-02). The word number references in the left column are the actual word numbers of the data portion of the block (i.e., numbering does not include the header portion). The functional content of both O&A coefficient sets is identical, so their content is described collectively in the following paragraphs in sequential order. Please note that the word references used in the description are the Imager's (see Table 2-1 given at the end of Section 2.1.1).

2.1.1 O&A Format Description

At the start of each O&A coefficient set, an IMC set identifier is provided. Each set has a unique ASCII identifier enabling users to discriminate changes in O&A coefficient sets. The format of the IMC set identifier is described in Section 4.3.1.1 of the OGE Interface Specification (DRL 504-02).

The next seven parameters (words 295 through 322) provide the O&A position references which are used when IMC is active. The first four parameters are orbital position references with the remaining three being the roll, pitch, and yaw reference angles. The roll and pitch misalignment angles are totally compensated when IMC is active and, therefore, references for these angles are not required. The reference O&A parameters are then followed by the epoch date and time of the O&A set, which is the set's reference time. In other words, the epoch time defines T = 0 for the O&A coefficient set and is used only when IMC is off to time reference the O&A time series equations. The recommended IMC set enable time from epoch (words 331–334) is the time when the IMC set is nominally activated on the spacecraft.

The spacecraft compensation parameters (words 335 to 346) provide the capability to apply the same correction bias to the Imager and Sounder due to spacecraft disturbance that may occur during the coregistration period.

Following the spacecraft compensation parameters are the coefficients for the orbital time series used for calculating the spacecraft position when IMC is off. The functional form of the time series is described in Section 4.1.

The remainder of the O&A coefficient set consists of the exponential start time from epoch which is followed by the time series expressions describing the instrument attitude variation of the five attitude angles—roll, pitch, yaw, roll misalignment, and pitch misalignment. The roll and pitch misalignment angles define the misalignment of the instrument optical axis and are incorporated as corrections to the instrument elevation and scan angles. Each angle's time series equation has the same functional form consisting of exponential, Fourier, and monomial sinusoid functional components. Since the exponential component is not normally in use, the exponential start time is provided to define when it should be activated as part of the time series computation. It is expressed as a delta time from epoch and should be positive. The Fourier and the monomial sinusoid components are expressed as a series containing a variable number of these functions. The format of the associated word fields allows for the maximum number of each of the functions expected. The number of Fourier and monomial sinusoid coefficients that are applicable in a particular O&A coefficient set is respectively defined in words 535 to 538 and words 659 to 662. The practical maximums are currently expected to be 15 Fourier and 4 monomial sinusoids.

Table 2-1 provides the O&A parameters in use for the Imager instrument. The format and engineering units of each variable are denoted in parentheses. The partition is sized to hold the largest expected O&A set. In general, the actual number of parameters in effect is less than the maximum and varies through time. The "numeric" parameters (words 535–538 and 659–662) are used to denote the number of active terms employed for the roll attitude angle. In a similar fashion, each of the remaining four angles modeled by the O&A set is provided with "numeric" parameters defining the number of active terms. Inactive terms are not compressed out of the O&A set; their places are occupied by zeroed data words.

Table 2-2 provides the O&A parameters in use for the Sounder instrument. The format and engineering units of each variable are denoted in parentheses. The partition is sized to hold the largest expected O&A set. In general, the actual number of parameters in effect is less than the maximum and varies through time. The "number" parameters (words 563–566 and 687–690) are used to denote the number of active terms employed for the roll attitude angle. In a similar fashion, each of the remaining four angles modeled by the O&A set is provided with "numeric" parameters defining the number of active terms. Inactive terms are not compressed out of the O&A set; their places are occupied by zeroed data words.

Table 2-1. Imager Documentation Block 0 Format Definition (1 of 2)

Words	Description (Format, Units)
279–282	IMC Set Identifier (I*16, 4 ASCII characters)
283–294	Spares – not used
295–298	Reference longitude (R*4, rad), positive east
299–302	Reference radial distance from nominal (R*4, km)
303–306	Reference latitude (R*4, rad)
307–310	Reference orbit yaw (R*4, rad)
311–314	Reference attitude: roll (R*4, rad)
315–318	Reference attitude: pitch (R*4, rad)
319–322	Reference attitude: yaw (R*4, rad)
323–330	Epoch date/time: standard BCD format
331–334	IMC set enable time from epoch (R*4, min)
335–338	Spacecraft compensation: roll (R*4, rad)
339–342	Spacecraft compensation: pitch (R*4, rad)
343–346	Spacecraft compensation: yaw (R*4, rad)
347–398	Change in longitude from ref. (13@R*4, rad), positive east
399–442	Change in radial distance from ref. (11 @ R*4, km)
443–478	Sine geocentric latitude, total (9 @ R*4, no units)
479–514	Sine orbit yaw, total (9 @ R*4, no units)
515–518	Daily solar rate (R*4, rad/min)
519–522	Exponential start time from epoch (R*4, min)
Words 523–742 apply to roll attitude angle	
523–526	Exponential magnitude (R*4, rad)
527–530	Exponential time constant (R*4, min)
531–534	Constant, mean attitude angle (R*4, rad)
535–538	Number of sinusiods/angles (I*4, no units)
539–542	Magnitude of first-order sinusoid(R*4, rad)
543–546	Phase angle of first-order sinusoid (R*4, rad)
⋮	⋮
651–654	Magnitude of fifteenth sinusoid (R*4, rad)
655–658	Phase angle of fifteenth sinusoid (R*4, rad)

Table 2-1. Imager Documentation Block 0 Format Definition (2 of 2)

Words	Description (Format, Units)
659–662	Number of monomial sinusiods (I*4, no units)
663-666	Order of applicable sinusoid (I*4, no units)
667–670	Order of first monomial sinusoid (I*4, no units)
671–674	Magnitude of monomial sinusoid (R*4, rad)
675–678	Phase angle of monomial sinusoid (R*4, rad)
679–682	Angle from epoch where monomial is zero (R*4, rad)
683–702	Repeat of 663–682 but for second monomial
703–722	Repeat of 663–682 but for third monomial
723–742	Repeat of 663–682 but for fourth monomial
743–962	Repeat of 523–742 for pitch attitude angle
963–1182	Repeat of 523–742 for yaw attitude angle
1183–1402	Repeat of 523–742 for roll misalignment angle
1403–1622	Repeat of 523–742 for pitch misalignment angle
1623–1689	Spares – unused
1690	Longitudinal parity (XOR) of words 279–1689

Table 2-2. Sounder Instrument Documentation Block (1 of 2)

Words	Description (Format, Units)
307–310	IMC set identifier (I*16, 4 ASCII characters)
311–322	Spares – not used
323–326	Reference longitude (R*4, rad), positive east
327–330	Reference radial distance from nominal (R*4, km)
331–334	Reference latitude (R*4, rad)
335–338	Reference orbit yaw (R*4, rad)
339–342	Reference attitude: roll (R*4, rad)
343–346	Reference attitude: pitch (R*4, rad)
347–350	Reference attitude: yaw (R*4, rad)
351–358	Epoch date/time: standard BCD format
359–362	IMC set enable time from epoch (R*4, min)
363–366	Spacecraft compensation: roll (R*4, rad)
367–370	Spacecraft compensation: pitch (R*4, rad)
371–374	Spacecraft compensation: yaw (R*4, rad)
375–426	Change in longitude from ref. (13 @ R*4, rad), positive east
427–470	Change in radial distance from ref. (11 @ R*4, km)
471–506	Sine geocentric latitude, total (9 @ R*4, no units)
507–542	Sine orbit yaw, total (9 @ R*4, no units)
543–546	Daily solar rate (R*4, rad/min)
547–550	Exponential start time from epoch (R*4, min)
Words 551–770 apply to roll attitude angle	
551–554	Exponential magnitude (R*4, rad)
555–558	Exponential time constant (R*4, min)
559–562	Constant, mean attitude angle (R*4, rad)
563–566	Number of sinusiods/angles (I*4, no units)
567–570	Magnitude of first-order sinusoid (R*4, rad)
571–574	Phase angle of first-order sinusoid (R*4, rad)
⋮	⋮
679–682	Magnitude of fifteenth sinusoid (R*4, rad)
683–686	Phase angle of fifteenth sinusoid (R*4, rad)

Table 2-2. Sounder Instrument Documentation Block (2 of 2)

Words	Description (Format, Units)
687–690	Number of monomial sinusoids (I*4, no units)
691–694	Order of applicable sinusoid (I*4, no units)
695–698	Order of first monomial sinusoid (I*4, not units)
699–702	Magnitude of monomial sinusoid (R*4, rad)
703–706	Phase angle of monomial sinusoid (R*4, rad)
707–710	Angle from epoch where monomial is zero (R*4, rad)
711–730	Repeat of 691–710 but for second monomial
731–750	Repeat of 691–710 but for third monomial
751–770	Repeat of 691–710 but for fourth monomial
771–990	Repeat of 551–770 for pitch attitude angle
991–1210	Repeat of 551–770 for yaw attitude angle
1211–1430	Repeat of 551–770 for roll misalignment angle
1431–1650	Repeat of 551–770 for pitch misalignment angle
1651–1717	Spares – unused
1718	Longitudinal parity (XOR) of words 307–1717

2.1.2 Notation Conversion

The notation used in Section 4 when describing the functional form of the equations associated with the O&A coefficients can be directly mapped to the word location using the following equations:

a. $a(i) = X + (i - 1) * 4$
   where X is the starting word location of the O&A coefficient set,
   X = 279 (Imager) or 307 (Sounder)
   a(i) maps to the value located at word position $x + (I - 1) * 4$

b. $C(j) = a(k + j - 1)$
   where a(k) corresponds to the word location of the C(1) coefficient.
   Definition of C(1) varies with respect to the particular attitude angle as described in Section 4.3.

2.2 Yaw Flip Flag

As discussed earlier, the misalignment model takes different forms for normal and flipped spacecraft, as well as for different instruments. Therefore, it is necessary to transmit in the GVAR data stream a flag denoting the spacecraft configuration. Block 0 contains the yaw-flip flag in bit 16 of ISCAN; it is equal to 0 for normal operations or 1 for flipped operations. All Block 11 messages contain the yaw-flip flag in the SAD ID word 20. It has the value x ‘00’ for normal operations or the value x ‘3F’ for flipped operations. The Sounder Scan Documentation Block 11 has the yaw-flip flag in bit 0 of word 57, with 0 for normal operations or 1 for flipped operations.

It is the responsibility of the user's software to store this flag in such a way that the ELUG routines can use it.

2.3 Nadir Offset

Ideally each instrument points at the subsatellite point (nadir) when the mirror is centered in the instrument field of view. In general, this is not the case. To accommodate hardware limitations, nadir offset parameters were introduced. All O&A sets use these values, which are transmitted in GVAR, as a reference. Earth location requires knowledge of these parameters. The values are a combination of the measured instrument deviation from ideal, Earth sensor pitch biases, and other biases that may have been introduced into the system. All of these are reflected in the numbers reported by the SPS in GVAR. Although not often, these numbers change if the controlling Earth sensor is changed or if other biases are introduced into the system. The ELUG routine SETCONS uses these values to calculate ELVMAX and SCNMAX for each instrument. (Section 3.3 gives a more detailed discussion of ELVMAX and SCNMAX.) SETCONS (or its equivalent) should be called anytime the instrument nadir values change.

Section 3.0 Mathematical Description of Instrument-Related Coordinate Systems

This section describes instrument-related coordinate systems used in the Earth location process and the algorithms used to perform the necessary coordinate conversions.

3.1 Parameters for the Coordinate Transformations

The following parameters are used in conversions between the (cycles, increments), (elevation, scan angle) and (line, pixel) coordinates of the instruments:

INCMAX (inst)	Number of increments per cycle (Imager, 6136; Sounder, 2805)
SCNINCR (inst)	Change in scan angle per increment (Approximate values: Imager, 16 μrad; Sounder, 35 μrad)
ELVINCR (inst)	Change in elevation angle per increment (Approximate values: Imager, 8 μrad; Sounder, 17.5 μrad)
SCNPX (inst)	Change in scan angle per pixel (Approximate values: Imager, 16 μrad; Sounder, 280 μrad)
ELVLN (inst)	Change in elevation angle per detector line (Approximate values: Imager, 28 μrad; Sounder, 280 μrad)
SCNMAX (inst)	Bias in scan angle; defined in Section 3.4
ELVMAX (inst)	Bias in elevation; defined in Section 3.4

Here, inst = 1 for the Imager and = 2 for the Sounder.

3.2 Cycles and Increments

As explained in Section 1.1.1.1, the instrument scanning mirror position is controlled by two servo motors, one for the north/south elevation angle, and one for the east/west scan angle. Each servo motor has an associated inductosyn to measure the mechanical shaft rotation angle. The position of the scanning mirror, and hence the coordinate system employed for the instruments (refer to Figures 1-1 and 1-2), is measured in terms of the inductosyn outputs, which are expressed in terms of "cycles" and "increments." Cycles (denoted CX for east/west and CY for north/south) are coarse measures of shaft rotation angles. Increments (denoted INCX for east/west and INCY for north/south) are finer measures. Each Imager cycle contains 6136 increments; each Sounder cycle contains 2805 increments. It is also important to note that a shaft angle change in the east/west direction has a doubling effect upon the mirror's optical angle.

The origin of the coordinate system (zero cycles, zero increments) corresponds to the northwest corner of the Imager's field of view for normal operations and the southeast corner for inverted operations. For the Sounder, the origin is in the southwest corner in the Sounder's field of view for normal operations and the northeast corner for inverted operations. The instruments' mechanical limits are enforced by the presence of physical stops

3.3 Lines and Pixels

As previously described in Section 1.1.1.2, the mapping scheme which translates instrument cycles/increments coordinates to line/pixel coordinates was designed to cover the entire instrument coordinate frame. Therefore, the area covered by the line/pixel coordinate system can be directly superimposed over the instrument coordinate frame which covers 9 cycles in the north/south dimension and 5 cycles in the east/west dimension. This scheme was chosen to provide a mapping that is instrument independent. The mapping would not be instrument independent if the line/pixel coordinate system only covered the area defined by the operational limits (instrument field of view, refer to Figures 1-1 and 1-2). The instrument dependence would be caused by the variation of the actual nadir location between versions of the Imager or Sounder instruments.

A line and pixel unit, respectively, corresponds to the north/south and east/west angles swept by one visible pixel. Therefore, the mapping can be visualized as the division of the Imager and Sounder coordinate frame into visible detector lines in the north/south direction and pixel units in the east/west direction. The origin of the line and pixel coordinate system is at the northwest corner of the instrument coordinate system for both the Imager and the Sounder and is defined as line #1, pixel #1, where

- Line #1 corresponds to the northernmost visible detector line possible, which is located at the extreme northernmost elevation angle in the instrument coordinate frame. Line numbers increase in the southerly direction.

- Pixel #1 corresponds to the extreme western position of the instrument's coordinate system. Pixel numbers increase in the easterly direction.

Table 3-1 gives the correspondence between line 1, pixel 1 and cycles/increments for both upright and flipped spacecraft.

Table 3-1. Line 1 Pixel 1 Cycles and Increments

Mode	Imager	Sounder
Normal	0 cycles 0 increments north/south 0 cycles 0 increments east/west	9 cycles 0 increments north/south 0 cycles 0 increments east/west
Inverted	9 cycles 0 increments north/south 5 cycles 0 increments east/west	0 cycles 0 increments north/south 5 cycles 0 increments east/west

3.4 Elevation and Scan Angles

Zero elevation and zero scan angles correspond to the instrument pointing at the subsatellite point (nadir). Therefore, the origin of the elevation-and-scan-angle coordinate system is biased relative to the origin of the cycles/increments coordinate system. The east/west bias is denoted as SCNMAX, and the north/south bias is denoted as ELVMAX. Their values are supposed to correspond to 4 cycles, 3068 increments north/south and 2 cycles, 3068 increments east/west for the Imager; and to 4 cycles, 1402 increments north/south and 2 cycles, 1402 increments east/west for the Sounder. The actual values are derived from the factory-measured nadir location of the instrument, expressed in north/south and east/west cycles and increments and are provided, respectively, in the Imager documentation Block 0 (words 6305–6310) and the Sounder documentation Block 11 (words 3005–3010).

For all spacecraft, normal and flipped, the elevation angle decreases from north to south and the scan angle increases from west to east. This means that the transformation from cycles/increments coordinates to elevation-and-scan-angle coordinates depends upon the spacecraft orientation.

For a normal spacecraft, ELVMAX and SCNMAX are defined as the offset from the northwest corner of the instrument as shown in Figure 3-1. Because the elevation/scan angle coordinates are an Earth-based system, ELVMAX and SCNMAX are kept as the offsets from the northwest corner of the instrument for flipped spacecraft as shown in Figure 3-2. Using the nadir locations distributed in GVAR of NSCYC1/NSINC1 and EWCYC1/EWINC1 for the Imager and NSCYC2/NSINC2 and EWCYC2/EWINC2 for the Sounder, the following equations give the value of ELVMAX and SCNMAX:

$$\mathrm{ELVMAX}(1) = \mathrm{ELVINCR}(1) * [\mathrm{NSCYC1}*\mathrm{INCMAX}(1) + \mathrm{NSINC1}]$$

$$\mathrm{SCNMAX}(1) = \mathrm{SCNINCR}(1) * [\mathrm{EWCYC1}*\mathrm{INCMAX}(1) + \mathrm{EWINC1}]$$

$$\mathrm{ELVMAX}(2) = \mathrm{ELVINCR}(2) * [(9 - \mathrm{NSCYC2})*\mathrm{INCMAX}(2) - \mathrm{NSINC2}]$$

$$\mathrm{SCNMAX}(2) = \mathrm{SNCINCR}(2) * [\mathrm{EWCYC2}*\mathrm{INCMAX}(2) + \mathrm{EWINC2}]$$

For a flipped spacecraft, the SPS will distribute nadir values in GVAR such that the above definitions will compute the correct values for ELVMAX and SCNMAX.

Users must, however, recalculate ELVMAX and SCNMAX if the nadir locations change.

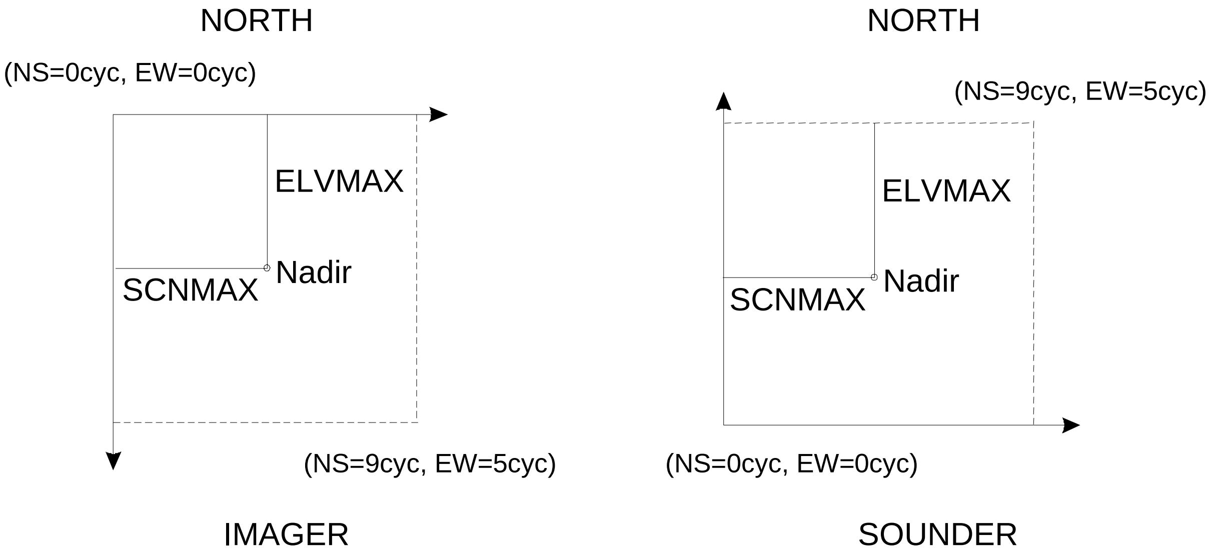


Figure 3-1. ELVMAX and SCNMAX for a Normal Spacecraft

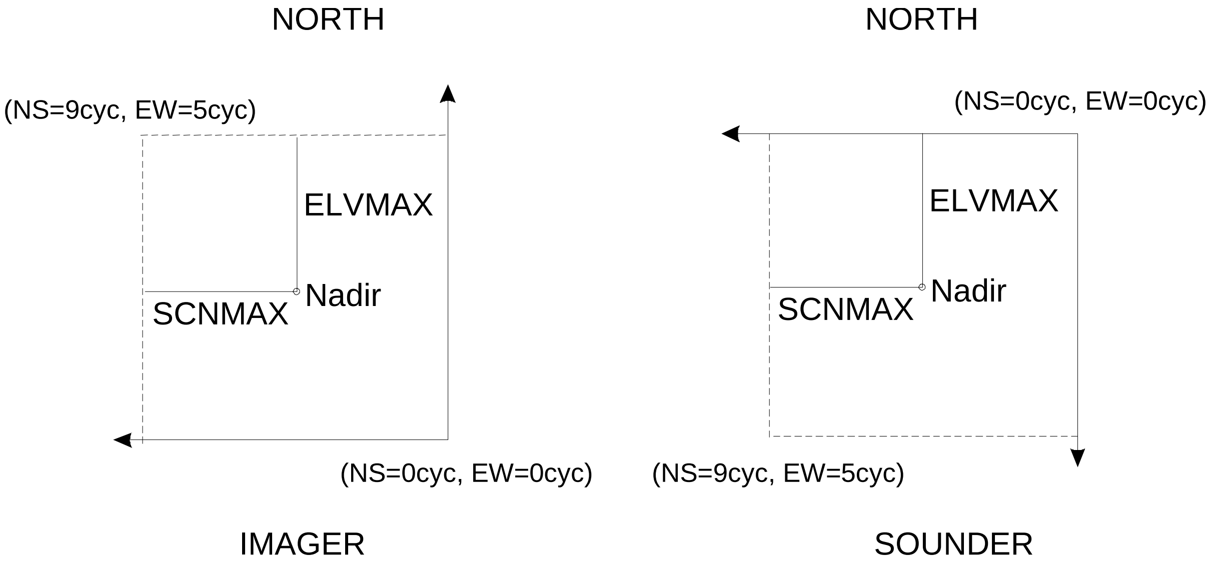


Figure 3-2. ELVMAX and SCNMAX for a Flipped Spacecraft

3.5 Notes on the Instrument-Related Coordinate Systems

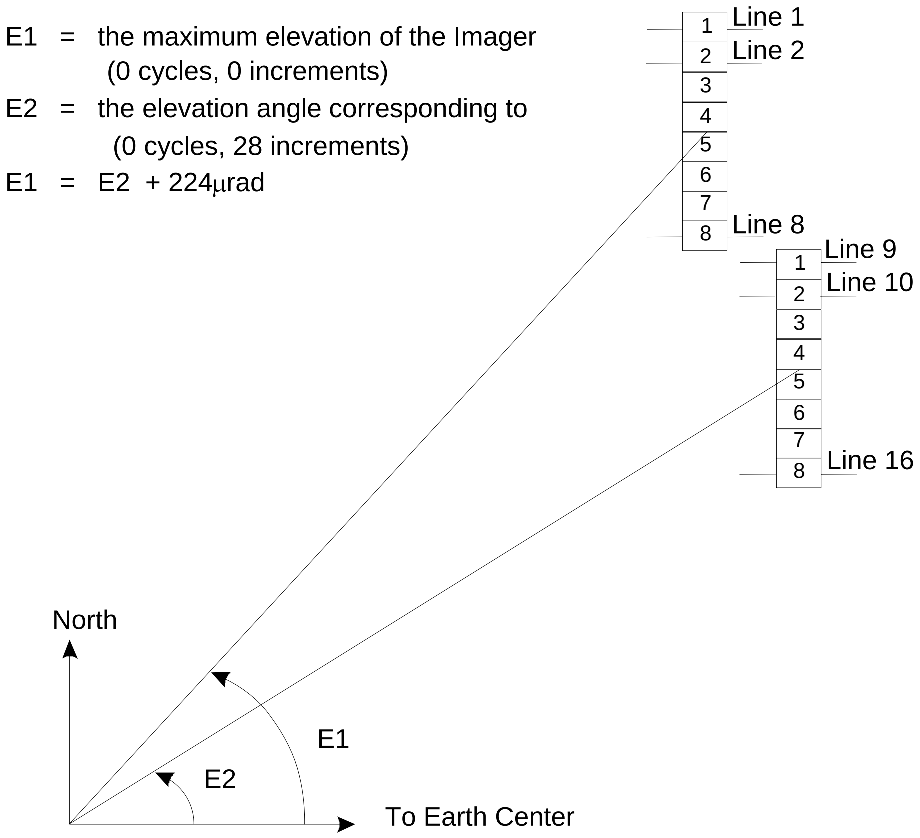
Cycles/increments coordinates define the north/south and east/west positions of the instrument scanning mirror, that is, the direction of its optical axis. Cycles/increments coordinates are inconvenient for describing the pointing of the instruments' individual detectors which are always biased relative to the optical axis.

Lines and pixels are defined as coordinates of the uniformly spaced grid covering the instrument's field of view. The northernmost line of the grid, line #1, corresponds to the line drawn by the uppermost detector when the optical axis of the instrument has the maximum possible elevation. The relation between the line and elevation coordinates for the Imager VIS channel is shown in Figure 3-3 for a normal spacecraft and in Figure 3-4 for a flipped spacecraft.

For the Imager VIS channel, the elevation angle related to line #1 is a sum of ELVMAX (instrument pointing) and 3.5 detector heights [uppermost detector pointing with respect to the optical axis of the instrument (see Figure 3-5 for the Imager VIS channel of a normal spacecraft)]. The corresponding formula is given in Section 3.7. The above also implies that, for the Imager VIS channel, the elevation angles related to the first four visible lines are always greater than ELVMAX.

Similarly, pixel #1 (westernmost pixel) corresponds to the extreme western position of the instrument's optical axis. The magnitude of the related scan angle is denoted as SCNMAX.

The relationship between lines/pixels and elevation/scan angles depends on the nadir offset of each instrument. Like the elevation/scan angle coordinates, the line/pixel coordinates are absolute—they are independent of a particular image frame, which is defined by the cycle/increment coordinates of the frame corners. Correspondingly, the lines and pixels should not be confused with the images of individual detectors. Due to the instrument's mechanical limits, an actual image frame never contains points with line = 1 or pixel = 1 coordinates.



E1 = the maximum elevation of the Imager (0 cycles, 0 increments)

E2 = the elevation angle corresponding to (0 cycles, 28 increments)

E1 = E2 + 224μrad

Figure 3-3. Elevation and Line Coordinates of the Imager for a Normal Spacecraft

E1 = the maximum elevation of the Imager (9 cycles, 0 increments)

E2 = the elevation angle corresponding to (8 cycles, 6108 increments)

E1 = E2 + 224 μrad

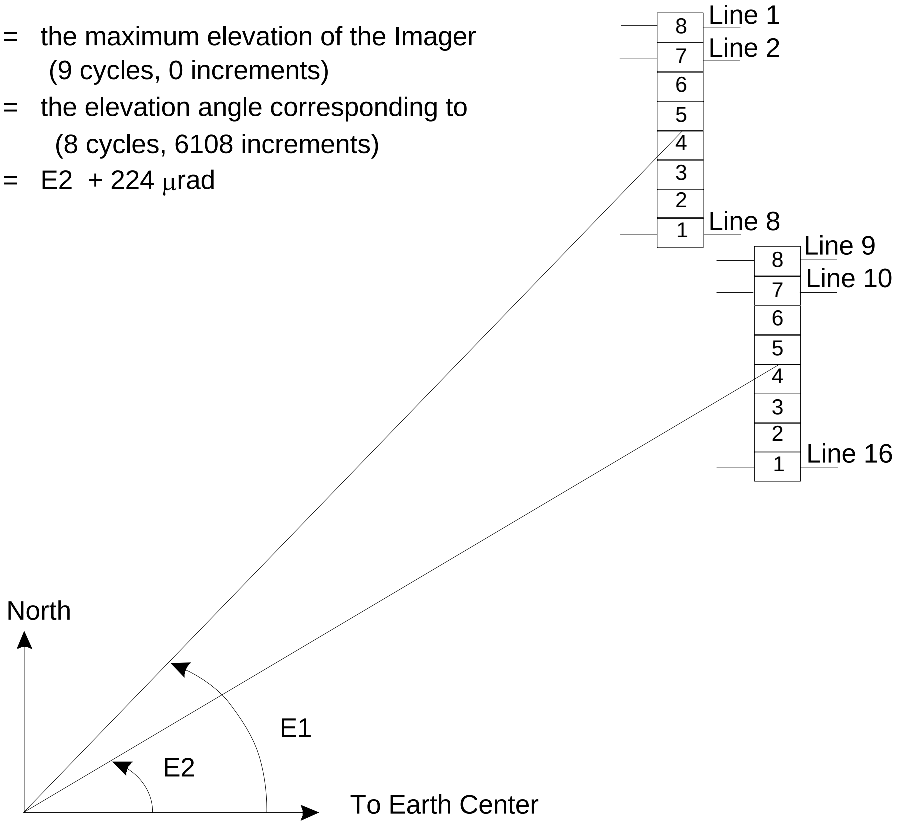
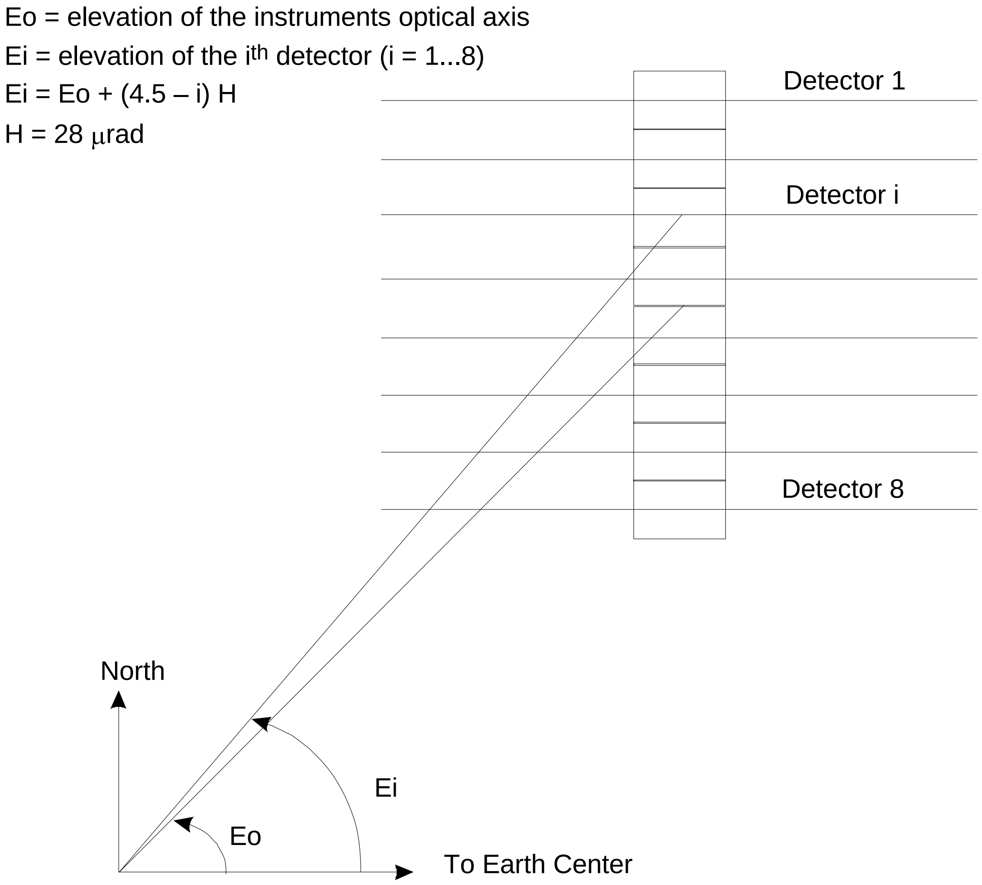


Figure 3-4. Elevation and Line Coordinates of the Imager for a Flipped Spacecraft



Eo = elevation of the instruments optical axis

Ei = elevation of the i^{th} detector ($i = 1...8$)

$Ei = Eo + (4.5 - i)\ H$

$H = 28\ \mu\text{rad}$

Figure 3-5. Instrument Optical Axis and Detector Pointings

3.6 Cycles/Increments to Elevation and Scan Angles Conversion

With the elevation/scan angle coordinate system being Earth-fixed, the transformations for cycles/increments differs for normal and flipped spacecraft.

For a normal spacecraft, the transformation from the north/south cycles and increments (CY,INCY) to the instrument scanning mirror elevation angle, EV, is defined as

$$EV = ELVMAX(1) - ELVINCR(1)*[CY*INCMAX(1) + INCY]$$

$$EV = ELVMAX(2) - ELVINCR(2)*[(9-CY)*INCMAX(2) - INCY]$$

and the transformation from east/west cycles and increments (CX, INCX) to the mirror scan angle, SC, is

$$SC = SCNINCR(inst)*[CX*INCMAX(inst) + INCX] - SCNMAX(inst)$$

For a flipped spacecraft, the transformation from the north/south cycles and increments (CY,INCY) to the instrument scanning mirror elevation angle, EV, is defined as

$$EV = ELVMAX(1) - ELVINCR(1)*[(9-CY)*INCMAX(1) - INCY]$$

$$EV = ELVMAX(2) - ELVINCR(2)*[CY*INCMAX(2) + INCY]$$

and the transformation from east/west cycles and increments (CX, INCX) to the mirror scan angle, SC, is

$$SC = SCNINCR(inst)*[(5-CX)*INCMAX(inst) - INCX] - SCNMAX(inst)$$

where inst = 1 for the Imager and = 2 for the Sounder.

3.7 Line/Pixel to Elevation/Scan Angle Conversion

For a given instrument, the elevation angle, EV, is computed from the line number, LINE, as

$$EV = ELVMAX(inst) + (D - LINE) * ELVLN(inst)$$

where D is the elevation of the northernmost detector relative to the optical axis of the instrument, expressed in detector lines. For the Imager, D = 4.5; for the Sounder, D = 2.5. The scan angle, SC, is computed from the pixel number, PIXEL, as

$$SC = (PIXEL - 1) * SCNPX(inst) - SCNMAX(inst)$$

Correspondingly, the transformations from elevation and scan angles to line and pixel coordinates are written as

LINE = [ELVMAX(inst) – EV]/ELVLN(inst) + D
PIXEL = [SCNMAX(inst) + SC]/SCNPX(inst) + 1

3.8 Optical Axis Correction

When transforming cycles and increments or lines and pixels to/from elevation and scan angles, OATS includes an additional optical axis correction term that was not included in the ELUG equations. This correction is applied as the final step in converting to elevation and scan angles and is applied as the first step in converting from elevation and scan angles. When converting cycles and increments to/from lines and pixels via the elevation and scan angles, these terms cancel. They are only relevant for cycles and increments or line and pixel conversions to/from latitude and longitude. To minimize the changes in the ELUG software, this correction has been added to the routines LPOINT and GPOINT. When converting from latitude and longitude, the angles EV' and SC' need to be corrected by the following equations:

EV = EV' + EV'*SC' * (SCNMAX(INSTR) – 2.5*INCMAX(INSTR) * SCNINCR(INSTR))
SC = SC' – EV'^{2} * (SCNMAX(INSTR) – 2.5*INCMAX(INSTR) * SCNINCR(INSTR))/2

When converting from angles EV' and SC' to latitude and longitude, the following corrections need to be applied:

EV = EV' – EV' * SC' * (SCNMAX(INSTR) – 2.5*INCMAX(INSTR) * SCNINCR(INSTR))
SC = SC' + EV'^{2} * (SCNMAX(INSTR) – 2.5*INCMAX(INSTR) * SCNINCR(INSTR))/2

Section 4.0 Transformations Between the Instrument and Geographic Coordinates

4.1 Orbit Model

The satellite position is described by four states (see Appendix C for definition and relationship to Keplerian elements): the longitude (LAM), the radial distance (R), the geocentric latitude (PHI), and the orbit yaw (PSI). Their values are computed from a set of 336 O&A coefficients in GVAR Block 0. These O&A coefficients are denoted as a1, a2, a3, … , a335, a336.

If IMC is enabled, LAM = a5, R = 42164.17478 + a6, PHI = a7, and PSI = a8. Nominally, a5 = station longitude (positive east) and a6 = a7 = a8 = 0.

If IMC is disabled, the orbit is described by 42 coefficients that are used to determine four time-dependent values that give the current orbit state. The four quantities are the sine of the orbit yaw (DYAW), the change in the radial distance from the reference orbit radius (DR), the sine of the geocentric latitude (DLAT), and the change in the longitude (DLON). The corresponding formulas are as follows:

$$
\begin{aligned}
\mathrm{DLON} = {} & a18 + a19*A + a20*A^2 + 2 * [a21*\sin(A) + a22*\cos(A) \\
& + a23*\sin(2*A) + a24*\cos(2*A) + a25*\sin(1.9268*A) \\
& + a26*\cos(1.9268*A) + a27*\sin(0.927*A) \\
& + a28*\cos(0.927*A)] + 2*A*[a29*\sin(A) + a30*\cos(A)]
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{DR} = {} & a31 + a32*\cos(A) + a33*\sin(A) + a34*\cos(2*A) \\
& + a35*\sin(2*A) + a36*\cos(1.9268*A) + a37*\sin(1.9268*A) \\
& + a38*\cos(0.927*A) + a39*\sin(0.927*A) \\
& + A * [a40*\cos(A) + a41*\sin(A)]
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{DLAT} = {} & a42 + a43*\cos(A) + a44*\sin(A) + a45*\cos(2*A) \\
& + a46*\sin(2*A) + A * [a47*\cos(A) + a48*\sin(A)] \\
& + a49*\cos(0.927*A) + a50*\sin(0.927*A)
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{DYAW} = {} & a51 + a52*\sin(A) + a53*\cos(A) + a54*\sin(2*A) \\
& + a55*\cos(2*A) + A*[a56*\sin(A) + a57*\cos(A)] \\
& + a58*\sin(0.927*A) + a59*\cos(0.927*A)
\end{aligned}
$$

Here $A = 0.7292115E\text{–}4 * T$ and T = time in seconds since epoch. If IMC is disabled,

$$LAM = a5 + DLON$$
$$R = 42164.17478 + DR$$
$$PHI = \arcsin(DLAT)$$
$$PSI = \arcsin(DYAW)$$

In the next step, the IMC longitude, the geocentric latitude, and the orbit yaw are converted to the orbit inclination (i), the argument of latitude (u), and the longitude of the ascending node (ASC):

$$i = \arcsin\{[\sin^2 (PHI) + \sin^2 (PSI)]^{1/2}\}$$
$$u = \arctan[\sin(PHI)/\sin(PSI)]$$
$$ASC = LAM - u$$

The related subsatellite longitude and geodetic latitude are given by

$$RLON = ASC + \arctan[\cos(i)*\sin(u)/\cos(u)]$$
$$RLAT = \arctan[\tan(PHI)/(1 - F)^{2}]$$

where F is the Earth flattening factor.

All these computations are performed by the LMODEL subroutine.

4.2 Spacecraft to Earth-Fixed Coordinates Transformation

The spacecraft orbital coordinate system (Y_1,Y_2,Y_3) has the axis Y_3 pointed towards the Earth's center, the axis Y_2 pointed in the negative orbital angular momentum direction (approximately to the south), and the axis Y_1 pointed roughly in the orbit velocity direction (see Figure 4-1).
The Earth-centered fixed coordinate system (X_1,X_2,X_3) rotates with the Earth. It has its center at the center of mass of the Earth, with the X_1 axis lying in the equatorial plane and directed along the meridian of Greenwich. The X_2 axis lies in the equatorial plane and 90 degrees in advance of the X_1 axis. The X_3 axis coincides with the spin axis of the Earth. Matrix **B** = ($B_{k,j}$) defines the spacecraft to Earth-fixed coordinates transformation, **X = B * Y**, where

$B_{1,1} = -\cos(ASC) * \sin(u) - \sin(ASC) * \cos(u) * \cos(i)$

$B_{2,1} = -\sin(ASC) * \sin(u) + \cos(ASC) * \cos(u) * \cos(i)$

$B_{3,1} = \quad \cos(u) * \sin(i)$

$B_{1,2} = -\sin(ASC) * \sin(i)$

$B_{2,2} = \quad \cos(ASC) * \sin(i)$

$B_{3,2} = -\cos(i)$

$B_{1,3} = -\cos(ASC) * \cos(u) + \sin(ASC) * \sin(u) * \cos(i)$

$B_{2,3} = -\sin(ASC) * \cos(u) - \cos(ASC) * \sin(u) * \cos(i)$

$B_{3,3} = -\sin(u) * \sin(i)$

where ASC, u, and i are defined in the previous section.

Matrix **B** is computed by the LMODEL subroutine.

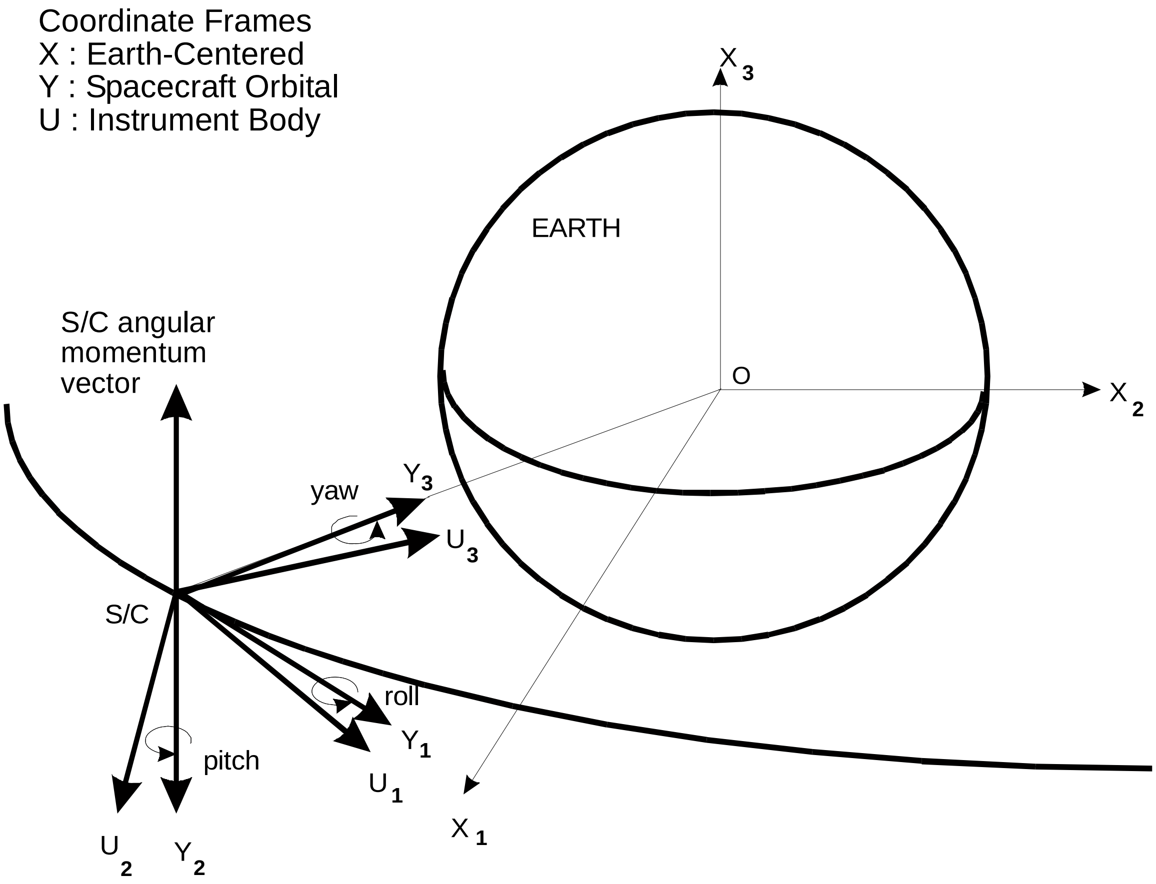


Figure 4-1. Spacecraft Coordinate System Geometry

4.3 Attitude Angles and Attitude Misalignments

The instrument pointing is described by the roll, pitch, and yaw attitude angles (ROLL, PITCH, YAW) and the roll and pitch attitude misalignment angles (R_{ma}, P_{ma}).

If IMC is enabled, these five quantities are the following:

$$ROLL = a9,\ PITCH = a10, = YAW = a11,\ R_{ma} = P_{ma} = 0$$

If IMC is disabled, the attitude angles and misalignments include the time-dependent terms ATT1,

ATT2, ... , ATT5, as follows:

$$ROLL = a9 + ATT1 + a15$$
$$PITCH = a10 + ATT2 + a16$$
$$YAW = a11 + ATT3 + a17$$
$$R_{ma} = ATT4$$
$$P_{ma} = ATT5$$

The quantities ATT1, ... , ATT5 have the generic form:

$$\begin{aligned} ATT = {} & C(1) * \exp[-(T - a61)/C(2)] + C(3) \\ & + \textstyle\sum_{k=1}^{C(4)} \{C(3+2k) * \cos[WA*k + C(4+2k)]\} \\ & + \textstyle\sum_{j=1}^{C(35)} \{C(33+5j) * [WA - C(35+5j)]^{C(32+5j)} \\ & \qquad * \cos[WA*C(31+5j) + C(34+5j)]\} \end{aligned}$$

where

$WA = a60 * T$

$\sum_{n1}^{n2}$ denotes summation from n1 to n2 (n1 >0)

and C(1), … ,C(55) are a subset of the O&A parameters:

C(1) = a62 for ATT1, C(2) = a63 for ATT1, …
C(1) = a117 for ATT2, C(2) = a118 for ATT2, …
C(1) = a172 for ATT3, C(2) = a173 for ATT3, …
C(1) = a227 for ATT4, C(2) = a228 for ATT4, …
C(1) = a282 for ATT5, C(2) = a283 for ATT5, …

Note that the exponential term must be zero if $T < a61$. All the above values are computed by the LMODEL routine. LMODEL calls the GATT function to compute the quantities ATT1, ... , ATT5.

4.4 Instrument to Earth-Fixed Coordinates Transformation

If the roll, pitch, and yaw angles are zero, the instrument frame (U_1,U_2,U_3) coincides with the spacecraft orbital coordinate system (Y_1,Y_2,Y_3).

The transformation between these two coordinate systems, based upon the instrument pointing errors ROLL, PITCH, and YAW, is defined by the rotation matrix M as follows:

$$\mathbf{Y = M * U}$$

Using the small angle approximation of trigonometric functions, the matrix **M** = $(M_{j,k})$ is written as

$M_{1,1} = 1 - 0.5 * (\mathrm{YAW}^2 + \mathrm{PITCH}^2)$

$M_{1,2} = -\mathrm{YAW}$

$M_{1,3} = \mathrm{PITCH}$

$M_{2,1} = \mathrm{YAW} + \mathrm{ROLL}*\mathrm{PITCH}$

$M_{2,2} = 1 - 0.5 * (\mathrm{ROLL}^2 + \mathrm{YAW}^2)$

$M_{2,3} = -\mathrm{ROLL}$

$M_{3,1} = -\mathrm{PITCH} + \mathrm{ROLL}*\mathrm{YAW}$

$M_{3,2} = \mathrm{ROLL} + \mathrm{PITCH}*\mathrm{YAW}$

$M_{3,3} = 1 - 0.5 * (\mathrm{ROLL}^2 + \mathrm{PITCH}^2)$

Correspondingly, the instrument to Earth-fixed coordinate transformation is given by

$$\mathbf{X = BT * U}$$

where matrix **BT = B * M**. All these computations are done in the INST2ER subroutine.

4.5 Pointing Vectors in the Instrument Frame

A unit vector **U** = (U_1,U_2,U_3) in Cartesian instrument coordinates is a function of the elevation and scan angles (EV, SC) and the two misalignments, R_{ma} and P_{ma}. The scan angle increases from west to east. The elevation decreases from north to south (instrument angle geometry, refer to Figure 4-2). The instrument pointing vector is computed as

$U_1 = \sin(S_0)$

$U_2 = -\sin(E_0)*\cos(S_0)$

$U_3 = \cos(E_0)*\cos(S_0)$

where E_0 and S_0 are the elevation and scan angles corrected for the roll and pitch misalignments.

For the Imager in normal operations and the Sounder in flipped operations, the corrections are

$$E_0 = EV - P_{ma} * \sin(EV) * [1/\cos(SC) + \tan(SC)] - R_{ma} * [1 - \cos(EV)/\cos(SC)]$$

$$S_0 = SC + R_{ma} * \sin(EV)$$

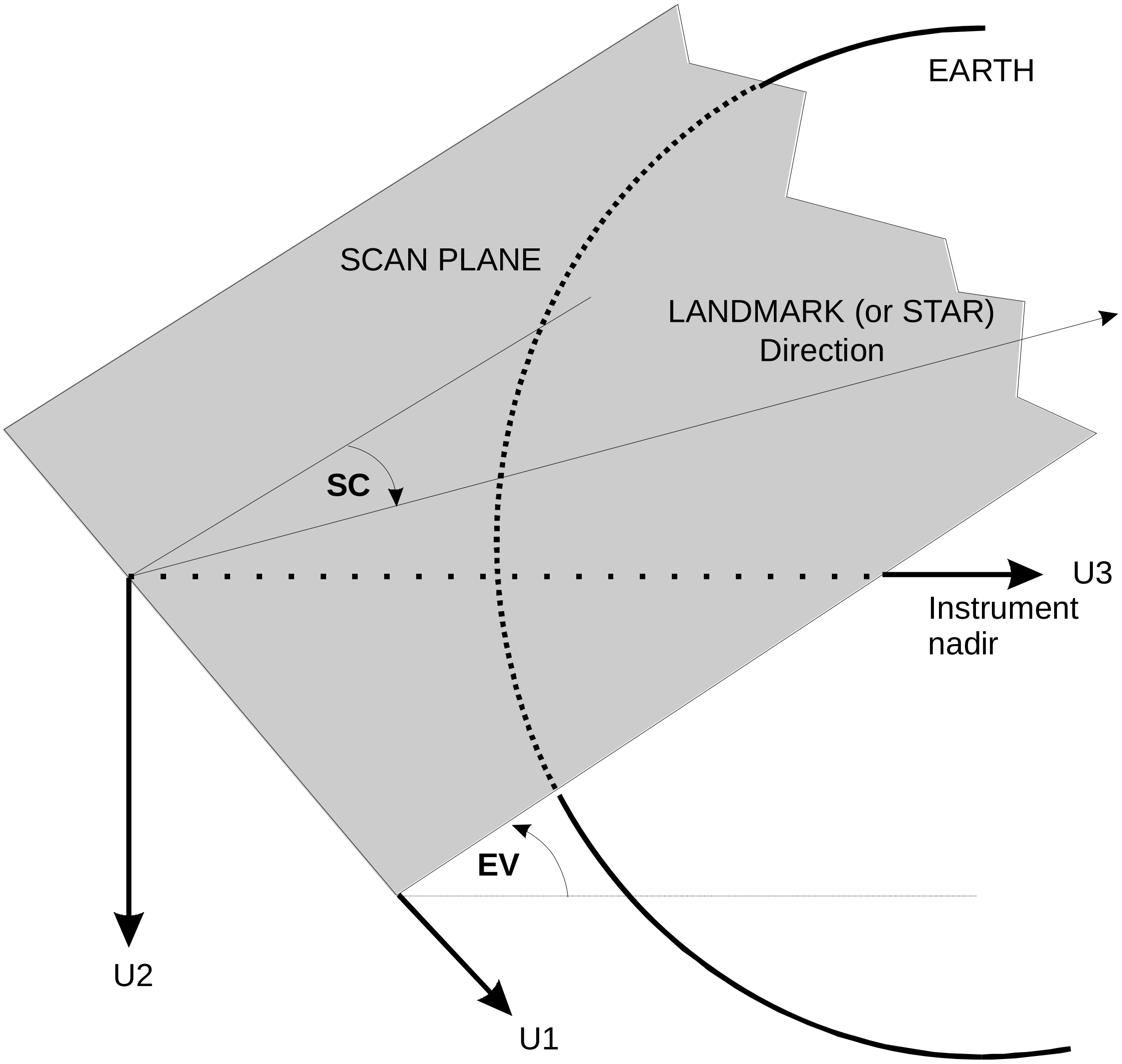


Figure 4-2. Instrument Angle Geometry

For the Imager in flipped operations and the Sounder in normal operations, the corrections are the following:

$$E_0 = EV + P_{ma}*\sin(EV)*[1/\cos(SC) - \tan(SC)] - R_{ma}*[1 - \cos(EV)/\cos(SC)]$$

$$S_0 = SC - R_{ma}*\sin(EV)$$

In the above, the angles EV and SC correspond to the optical axis of the instrument. To find the pointing angles of a particular detector, EV and SC must be corrected for the detector biases from the center of the instrument mirror. Namely, in the above equations, the angles EV and SC are replaced, correspondingly, with (EV + dE) and (SC + dS). The corrections dE and dS are

$$dE = d1 * \cos(EV) - d2 * \sin(EV)$$

$$dS = d1 * \sin(EV) + d2 * \cos(EV)$$

where d1 and d2 are, respectively, the vertical (north/south) and horizontal (east/west) biases of the detector relative to the optical axis of the instrument.

4.6 Geographic to Instrument Coordinates Transformation (for GOES I-M)

Transformation of geographic coordinates, LAT/LON, to the instrument elevation and scan angles, EV/SC, proceeds in the following order:

- Compute the geographic (geodetic) latitude, LAT, to geocentric latitude PHI:

  $$PHI = \arctan[(1 - F)^2 * \tan(LAT)]$$

  where F = 1 – BE/AE is the Earth flattening factor and AE and BE are, respectively, the Earth equatorial and polar radii.

- Compute the normalized coordinates of the point in the Cartesian Earth-centered fixed coordinate system:

  $$X_1 = r * \cos(PHI)*\cos(LON)$$

  $$X_2 = r * \cos(PHI)*\sin(LON)$$

  $$X_3 = r * \sin(PHI)$$

  where r is the local Earth radius, expressed in units of AE,

  $$r = [1 + p * \sin^2(PHI)]^{-1/2}$$

  and

  $$p = (1 - F)^{-2} - 1 = (AE/BE)^2 - 1$$

- Compute the pointing vector **W** = (W_1,W_2,W_3):

  $$\mathbf{W} = \mathbf{X} - \mathbf{R}$$

  where **R** is the spacecraft position vector in units of Earth radii and in the Earth-fixed coordinate system.

  If the angle between the pointing vector and the normal to the Earth's surface at a given point is less than 90 degrees, the point is invisible to the instrument. Since the vector X_1, X_2, $[(AE/BE)^2*X_3]$ is directed along the normal, the condition of invisibility is as follows:

  $$W_1*X_1 + W_2*X_2 + W_3*X_3/(1 - F)^2 > 0$$

- Compute the vector **W** = (W_1,W_2,W_3) transformation to the instrument frame, obtaining the vector **U** = (U_1,U_2,U_3):

  $$\mathbf{U} = \mathbf{BT}^T * \mathbf{W}$$

  where $\mathbf{BT}^T$ is the transpose of **BT**.

- Compute the elevation and scan angles related to the vector **W**:

  $$E_0 = -\arctan(U_2/U_3)$$
  $$S_0 = \arctan[U_1/\mathrm{sqrt}(U_2*U_2 + U_3*U_3)]$$

- The elevation and scan angle correction for the attitude misalignments depends upon the instrument and spacecraft orientation. For the Imager in a normal configuration and the Sounder in the flipped configuration, the corrections are the following:

  $$EV = E_0 + P_{ma}*\sin(E_0)*[1/\cos(S_0) + \tan(S_0)] + R_{ma}*[1 - \cos(E_0)/\cos(S_0)]$$
  $$SC = S_0 - R_{ma}*\sin(E_0)$$

  For the Imager in the flipped configuration and the Sounder in a normal configuration, the corrections are the following:

  $$EV = E_0 - P_{ma}*\sin(E_0)*[1/\cos(S_0) - \tan(S_0)] + R_{ma}*[1 - \cos(E_0)/\cos(S_0)]$$
  $$SC = S_0 + R_{ma}*\sin(E_0)$$

All the above computations are performed by the subroutine GPOINT.

4.7 Geographic to Instrument Coordinates Transformation (for GOES-NOP)

Transformation of geographic coordinates, LAT/LON, to the instrument elevation and scan angles, EV/SC, proceeds in the following order:

- Compute the geographic (geodetic) latitude, LAT, to geocentric latitude PHI:

  $$\mathrm{PHI} = \arctan\,[(1 - F)^2 * \tan(\mathrm{LAT})]$$

  where F = 1 – BE/AE is the Earth flattening factor and AE and BE are, respectively, the Earth equatorial and polar radii.

- Compute the normalized coordinates of the point in the Cartesian Earth-centered fixed coordinate system:

  $$X_1 = r * \cos(\mathrm{PHI})*\cos(\mathrm{LON}-\mathrm{omega}*\mathrm{tau})$$

  $$X_2 = r * \cos(\mathrm{PHI})*\sin(\mathrm{LON}-\mathrm{omega}*\mathrm{tau})$$

  $$X_3 = r * \sin(\mathrm{PHI})$$

  where r is the local Earth radius, expressed in units of AE,

  $$r = [1 + p * \sin^2(\mathrm{PHI})]^{-1/2}$$

  and

  $$p = (1 - F)^{-2} - 1 = (AE/BE)^2 - 1$$

  and omega is the sidereal rate and tau is the light-travel time from the Earth to the satellite. Take tau = 0.125 sec. as a first guess.

- Compute the pointing vector **W** = (W_1,W_2,W_3):

  $$\mathbf{W} = \mathbf{X} - \mathbf{R}$$

  where **R** is the spacecraft position vector in units of Earth radii and in the Earth-fixed coordinate system.

  If the angle between the pointing vector and the normal to the Earth's surface at a given point is less than 90 degrees, the point is invisible to the instrument. Since the vector X_1, X_2, [$(AE/BE)^2*X_3$] is directed along the normal, the condition of invisibility is as follows:

  $$W_1*X_1 + W_2*X_2 + W_3*X_3/(1 - F)^2 > 0$$

- Compute tau = |**W**|/c

- Repeat the last three steps until tau changes by less than 1 picosecond.

- Adjust the pointing vector **W** to compensate for the aberration due to orbital velocity **V**:

  $\mathbf{W} = \mathbf{W} + \mathbf{V}*\mathrm{tau}$

  with $\mathbf{V} = \mathbf{OMEGA} \times \mathbf{R}$,
  $\mathbf{OMEGA} = [0, 0, \mathrm{omega}]$

- Compute the vector $\mathbf{W} = (W_1,W_2,W_3)$ transformation to the instrument frame, obtaining the vector $\mathbf{U} = (U_1,U_2,U_3)$:

  $$\mathbf{U} = \mathbf{BT}^T * \mathbf{W}$$

  where $\mathbf{BT}^T$ is the transpose of **BT**.

- Compute the elevation and scan angles related to the vector **W**:

  $$E_0 = -\arctan (U_2/U_3)$$
  $$S_0 = \arctan [U_1/\mathrm{sqrt}(U_2*U_2 + U_3*U_3)]$$

- The elevation and scan angle correction for the attitude misalignments depends upon the instrument and spacecraft orientation. For the Imager in a normal configuration and the Sounder in the flipped configuration, the corrections are the following:

  $$EV = E_0 + P_{ma}*\sin(E_0)*[1/\cos(S_0) + \tan(S_0)] + R_{ma}*[1 - \cos(E_0)/\cos(S_0)]$$
  $$SC = S_0 - R_{ma}*\sin(E_0)$$

  For the Imager in the flipped configuration and the Sounder in a normal configuration, the corrections are the following:

  $$EV = E_0 - P_{ma}*\sin(E_0)*[1/\cos(S_0) - \tan(S_0)] + R_{ma}*[1 - \cos(E_0)/\cos(S_0)]$$
  $$SC = S_0 + R_{ma}*\sin(E_0)$$

The above computations are not performed in any subroutines illustrated in Appendix A or B.

4.8 Instrument to Geographic Coordinates Transformation (for GOES I-M)

Transformation from elevation/scan angle to latitude/longitude coordinates is performed in the following order:

- Correct the given elevation and scan angles (EV, SC) for the roll and pitch misalignments. Again, this transformation is instrument and spacecraft orientation dependent. For the

Imager in normal operations and the Sounder in flipped operations, the corrections are the following:

$$E_0 = EV - P_{ma} * \sin(EV) * [1/\cos(SC) + \tan(SC)] - R_{ma} * [1 - \cos(EV)/\cos(SC)]$$

$$S_0 = SC + R_{ma} * \sin(EV)$$

- For the Imager in flipped operations and the Sounder in normal operations, the corrections are the following:

$$E_0 = EV + P_{ma} * \sin(EV) * [1/\cos(SC) - \tan(SC)] - R_{ma} * [1 - \cos(EV)/\cos(SC)]$$

$$S_0 = SC - R_{ma} * \sin(EV)$$

- Compute the instrument point vector as follows:

$$U_1 = \sin(S_0)$$

$$U_2 = -\sin(E_0) * \cos(S_0)$$

$$U_3 = \cos(E_0) * \cos(S_0)$$

- Transform the vector **U** to Earth-fixed coordinates

$$\mathbf{W} = \mathbf{BT} * \mathbf{U}$$

- Solve a system of four equations to find the intersection of the vector **W** with the Earth's surface as follows:

$$X_1 = R_1 + h * W_1$$

$$X_2 = R_2 + h * W_2$$

$$X_3 = R_3 + h * W_3$$

$$X_1 * X_1 + X_2 * X_2 + [X_3/(1 - F)]^2 = 1$$

where **R** is the spacecraft position vector in units of Earth radii and h is the unknown slant distance from the spacecraft to the intersect.

- Compute h as a solution of the quadratic equation

$$h^2 * Q_1 + 2 * h * Q_2 + Q_3 = 0$$

where

$$Q_1 = W_1 * W_1 + W_2 * W_2 + [W_3/(1 - F)]^2$$

$$Q_2 = W_1 * R_1 + W_2 * R_2 + W_3 * R_3/(1 - F)^2$$

$$Q_3 = R_1 * R_1 + R_2 * R_2 + [R_3/(1 - F)]^2 - 1$$

If $D = Q_2 * Q_2 - Q_1 * Q_3 < 0$, there is no solution; i.e., the instrument looks off the Earth.

Otherwise,

$$h = -[Q_2 + sqrt(D)]/Q_1$$

and the Cartesian coordinates of the intersect are obtained from the first three system equations.

- Convert the vector **X** to geographic latitude and longitude using the following:

$$LAT = \arctan[(1 - F)^{-2} * X_3/sqrt[X_1 * X_1 + X_2 * X_2)]$$

$$LON = \arctan(X_2/X_1)$$

All these computations are performed by the routine LPOINT.

4.9 Instrument to Geographic Coordinates Transformation (for GOES-NOP)

Transformation from elevation/scan angle to latitude/longitude coordinates is performed in the following order:

- Correct the given elevation and scan angles (EV, SC) for the roll and pitch misalignments. Again, this transformation is instrument and spacecraft orientation dependent. For the Imager in normal operations and the Sounder in flipped operations, the corrections are the following:

$$E_0 = EV - P_{ma} * \sin(EV) * [1/\cos(SC) + \tan(SC)] - R_{ma} * [1 - \cos(EV)/\cos(SC)]$$

$$S_0 = SC + R_{ma} * \sin(EV)$$

- For the Imager in flipped operations and the Sounder in normal operations, the corrections are the following:

$$E_0 = EV + P_{ma} * \sin(EV) * [1/\cos(SC) - \tan(SC)] - R_{ma} * [1 - \cos(EV)/\cos(SC)]$$

$$S_0 = SC - R_{ma} * \sin(EV)$$

- Compute the instrument point vector as follows:

$$U_1 = \sin(S_0)$$

$$U_2 = -\sin(E_0) * \cos(S_0)$$

$$U_3 = \cos(E_0) * \cos(S_0)$$

- Transform the vector **U** to Earth-fixed coordinates

$$\mathbf{W} = \mathbf{BT} * \mathbf{U}$$

- Adjust the pointing vector **W** to compensate for the aberration due to orbital velocity **V**:

  $$\mathbf{W} = \mathbf{W} - \mathbf{V}/c$$

  with $\mathbf{V} = \mathbf{OMEGA} \times \mathbf{R}$,
  $\mathbf{OMEGA} = [0,0,\text{omega}]$

- Solve a system of four equations to find the intersection of the vector **W** with the Earth's surface as follows:

  $$X_1 = R_1 + h * W_1$$
  $$X_2 = R_2 + h * W_2$$
  $$X_3 = R_3 + h * W_3$$
  $$X_1*X_1 + X_2*X_2 + [X_3/(1 - F)]^2 = 1$$

  where **R** is the spacecraft position vector in units of Earth radii and h is the unknown slant distance from the spacecraft to the intersect.

- Compute h as a solution of the quadratic equation

  $$h^2*Q_1 + 2*h*Q_2 + Q_3 = 0$$

  where

  $$Q_1 = W_1*W_1 + W_2*W_2 + [W_3/(1 - F)]^2$$
  $$Q_2 = W_1*R_1 + W_2*R_2 + W_3*R_3/(1 - F)^2$$
  $$Q_3 = R_1*R_1 + R_2*R_2 + [R_3/(1 - F)]^2 - 1$$

  If $D = Q_2*Q_2 - Q_1*Q_3 < 0$, there is no solution; i.e., the instrument looks off the Earth. Otherwise,

  $$h = -[Q_2 + \mathrm{sqrt}(D)]/Q_1$$

  and the Cartesian coordinates of the intersect are obtained from the first three system equations.

- Compute the light-travel time tau = h/c.

- Convert the vector **X** to geographic latitude and longitude using the following:

  $$\mathrm{LAT} = \arctan\,[(1 - F)^{-2}*X_3/\mathrm{sqrt}[X_1*X_1 + X_2*X_2)]$$
  $$\mathrm{LON} = \arctan\,(X_2/X_1)$$

- Adjust the LON for the Earth rotation during the light-travel time tau:

LON = LON + omega*tau

The above computations are not performed in any subroutines illustrated in Appendix A or B.

4.10 Year and Day of Year to Julian Day Transformation

Transformation from integer year, YEAR, and day of year, DAY, to number of days from 0 hours UT, 1950, January 1 (denoted as JD) is based on an algorithm by Fliegal and Van Flandern (*Communications of the ACM*, vol. 11, no. 10, October 1968):

JD = DAY + 1461*(YEAR+4799)/4 – 3*[(YEAR + 4899)/100]/4 – 2465022

Section 5.0 Module Descriptions (for GOES I-M Only)

5.1 Subroutine LMODEL

Subroutine LMODEL uses the O&A parameter set in the GVAR Block 0 format to compute the following, at a given time:

- Instrument attitude angles and attitude angle misalignments
- Subsatellite latitude and longitude
- Spacecraft to Earth-centered fixed coordinates transformation matrix, B
- Instrument to Earth-fixed coordinates transformation matrix, BT
- Spacecraft position vector in the units of the Earth equatorial radius

Usage:

```
CALL LMODEL (time, epoch_time, O&A_set, IMC, LAT, LON)
```

Input arguments:

- Time in minutes from 1950, January 1.0 (R*8)
- Epoch time of the O&A parameter set in minutes from 1950, January 1.0 (R*8)
- O&A parameter set in the GVAR Block 0 format, (R*4) 336 word array
- IMC status (I*4)

Output arguments:

- Subsatellite geographic latitude in radians (R*4)
- Subsatellite geographic longitude in radians (R*4)

Output variables in common ELCOMM:

- Roll, pitch, and yaw angles and the roll and pitch angle misalignments (R*4)
- Normalized satellite position vector (R*8)
- Matrices B and BT (R*8)
- LMODEL calls two subroutines—INST2ER and GATT.

5.2 Subroutine INST2ER

INST2ER accepts the roll, pitch, and yaw angles and the spacecraft to Earth-fixed coordinates transformation matrix and computes the instrument to Earth-fixed coordinates matrix.

Usage:

CALL INST2ER (ROLL, PITCH, YAW, B, BT)

Input arguments:

- ROLL, PITCH, YAW — roll, pitch, and yaw in radians (R*4)
- B — spacecraft to Earth-fixed coordinates transformation matrix, 3-by-3 array (R*8)

Output argument:

- BT — instrument to Earth-fixed coordinates transformation matrix, 3-by-3 array (R*8)

5.3 Function GATT

GATT uses a subset of the O&A parameter set in the GVAR Block 0 format to compute the attitude or attitude misalignment angle specified by its starting position in the O&A set. This function is used internally by LMODEL.

Usage:

ATT = GATT (k, a1, WA, time_delay)

Input arguments:

- k — starting position of the O&A parameter subset (I*4)
- a1 — O&A parameter set, 336-word array (R*4)
- WA — solar orbit angle in radians (R*4)
- time_delay — exponential time delay from epoch in minutes (R*4)

Output:

- Output is in radians (R*4).

5.4 Subroutine LPOINT

LPOINT transforms the instrument elevation (north/south) and scan (east/west) angles to the related geographic (geodetic) latitude and longitude. The instrument is defined by the content of common ELCOMM. This routine has been modified to reflect the spacecraft orientation changes. A new origin offset correction has also been added. This correction is a part of OATS but had not been added to the ELUG routines.

Usage:

CALL LPOINT (INSTR, FLIP_FLG, EV, SC, LAT, LON, IER)

Input arguments:

- INSTR — instrument code (1 for Imager, 2 for Sounder)
- FLIP_FLG — orientation flag (1 for normal, –1 for inverted)
- EV, SC — elevation and scan angles in radians (R*4)

Output arguments:

- LAT, LON — geographic latitude and longitude (R*4)
- IER — output status (I*4); = 1 if the instrument is pointed off the Earth, = 0 otherwise

5.5 Subroutine GPOINT

GPOINT transforms the geographic (geodetic) latitude and longitude to the corresponding elevation (north/south) and scan (east/west) angles of the instrument. The instrument is defined by the content of common ELCOMM. This routine has been modified to reflect the spacecraft orientation changes. A new origin offset correction has also been added. This correction is a part of OATS but had not been added to the ELUG routines.

Usage:

CALL GPOINT (INSTR, FLIP_FLG, LAT, LON, EV, SC, IER)

Input arguments:

- INSTR — instrument code (1 for Imager, 2 for Sounder)
- FLIP_FLG — orientation flag (1 for normal, –1 for inverted)
- LAT, LON — geographic latitude and longitude (R*4)

Output arguments:

- EV, SC — elevation and scan angles in radians (R*4)
- IER — output status (I*4); = 1 if a given point on Earth is invisible for the instrument, = 0 otherwise

5.6 Subroutine SNDELOC

SNDELOC accepts the instrument mirror position (expressed in cycles and increments), the servo error values, and the positional offsets for four detectors of a selected Sounder channel and computes the detector Earth locations in geographic latitude and longitude coordinates. This routine has been modified to reflect the spacecraft orientation changes.

Usage:

CALL SNDELOC (FLIP_FLG, CX, INCX, CY, INCY, SVX, SVY, OFF, GEO)

Input arguments:

- FLIP_FLG — Orientation flag (1 for normal, –1 for inverted)
- CX, INCX — east/west cycles and increments (I*4).
- CY, INCY — north/south cycles and increments (I*4).
- SVX — east/west servo error in radians (R*4).
- SVY — north/south servo error in radians (R*4).
- OFF — 4-by-2 array of offsets, expressed in radians (R*4). OFF(j,l) and OFF(j,2) correspond, respectively, to the east/west and north/south offsets of the j^{th} detector (j = 1, ..., 4). The offsets are defined with respect to the nominal positions of the detectors.

Output argument:

- GEO — 4-by-2 array of Earth locations, expressed in radians (R*4). GEO(j,l) is the geodetic latitude and GEO(j,2) is the geodetic longitude related to the j^{th} detector. If a detector looks off the Earth, the corresponding latitude and longitude are set to 999999.

SNDELOC calls the LPOINT subroutine.

5.7 Function TIME50

TME50 converts date and time given in BCD format to R*8 minutes from 1950, January 1.0.

Usage:

T = TIME50 (DW)

Input arguments:

- DW — two words containing date and time information, as follows:

  DW(1) = YYYYDDDH
  DW(2) = HMMSSLLL

where Y,D,H,M,S,L are BCD digits of year, day of year, hours, minutes, seconds, and milliseconds, respectively.

5.8 Subroutine SETCONS

SETCONS generates constants in common INSTCOMM. This routine has been modified for repeated calls. It needs to be called whenever the origin position in GVAR changes.

Usage:

```
CALL SETCONS (NSCYC1, NSINC1, EWCYC1, EWINC1, NSCYC2,
              NSINC2, NSCYC2, NSINC2)
```

Input arguments:

- NSCYC1, NSINC1 — north/south cycles and increments of the Imager nadir (I*4)
- EWCYC1, EWINC1 — east/west cycles and increments of the Imager nadir (I*4)
- NSCYC2, NSINC2 — north/south cycles and increments of the Sounder nadir (I*4)
- EWCYC2, EWINC2 — east/west cycles and increments of the Sounder nadir (I*4)

5.9 Function EVLN

EVLN converts a single-precision line number to a single-precision elevation (north/south) angle in radians.

Usage:

```
E = EVLN (inst, line)
```

Input arguments:

- inst — instrument code (I*4); inst = 1 for the Imager, = 2 for the Sounder
- line — line number (R*4)

5.10 Subroutine SCPX

SCPX converts a single-precision pixel number to a single-precision scan (east/west) angle in radians.

Usage:

```
SC = SCPX (inst, pixel)
```

Input arguments:

inst — instrument code (I*4); inst = 1 for the Imager, = 2 for the Sounder
pixel — pixel number (R*4)

5.11 Subroutine EVSC2LPF

EVSC2LPF converts elevation (north/south) and scan (east/west) angles to single-precision line and pixel numbers.

Usage:

CALL = EVSC2LPF (inst, EV, SC, line, pixel)

Input arguments:

- inst — instrument code (I*4); inst = 1 for the Imager, = 2 for the Sounder
- EV, SC — elevation and scan angles in radians (R*4)

Output arguments:

- line — line number (R*4)
- pixel — pixel number (R*4)

Section 6.0 Test Cases (for GOES I-M Only)

The TEST program generates nine test cases that enable the users to validate their software implementation. TEST uses a predefined O&A set from the include file ELREC.INC. The expected output results are presented below.

```
EXPECTED RESULTS:
******** ********

EPOCH TIME = 20557829.57612  (MINUTES SINCE 1950 1.0)

IMC ENABLED;  SUBSATELLITE LAT =-1.9824, LON =-100.1249

IMC DISABLED; SUBSATELLITE LAT = 0.0509, LON =-100.0017

NOTE: ALL ANGLES ARE IN DEGREES.


CASE 1.

LATITUDE/LONGITUDE TO LINE/PIXEL COORDINATES TRANSFORMATION FOR THE IMAGER, IMC
ENABLED.

      LAT = 50.0000    LON =-150.0000

      N-S = 7.0688     E-W =-4.5246

      LINE =  3487.42  PIXEL = 10405.45

CASE 2.

LINE/PIXEL TO LATITUDE/LONGITUDE COORDINATES TRANSFORMATION FOR THE IMAGER, IMC
ENABLED.


      LINE =  3487.42  PIXEL = 10405.45

      N-S = 7.0688     E-W =-4.5246

      LAT = 50.0000    LON =-150.0000

CASE 3.

LATITUDE/LONGITUDE TO LINE/PIXEL COORDINATES TRANSFORMATION FOR THE SOUNDER, IMC
ENABLED.

      LAT =-50.0000    LON = -50.0000

      N-S =-6.8659     E-W = 4.5781

      LINE =  1219.38  PIXEL =  1162.93

CASE 4.

LINE/PIXEL TO LATITUDE/LONGITUDE COORDINATES TRANSFORMATION FOR THE SOUNDER, IMC
ENABLED.

      LINE =  1219.38  PIXEL =  1162.93

      N-S =-6.8659     E-W = 4.5781

      LAT =-50.0000    LON = -50.0000
```

CASE 5.

LATITUDE/LONGITUDE TO LINE/PIXEL COORDINATES TRANSFORMATION FOR THE IMAGER, IMC DISABLED.

```
LAT = 50.0000    LON =-150.0000
N-S = 6.8594     E-W =-4.6513
LINE =  3617.98  PIXEL = 10267.21
```

CASE 6.

LINE/PIXEL TO LATITUDE/LONGITUDE COORDINATES TRANSFORMATION FOR THE IMAGER, IMC DISABLED.

```
LINE =  3617.98  PIXEL = 10267.21
N-S = 6.8594     E-W =-4.6513
LAT = 49.9999    LON =-149.9997
```

CASE 7.

LATITUDE/LONGITUDE TO LINE/PIXEL COORDINATES TRANSFORMATION FOR THE SOUNDER, IMC DISABLED.

```
LAT =-50.0000    LON = -50.0000
N-S =-7.1800     E-W = 4.4052
LINE =  1238.96  PIXEL =  1152.15
```

CASE 8.

LINE/PIXEL TO LATITUDE/LONGITUDE COORDINATES TRANSFOR MATION FOR THE SOUNDER, IMC DISABLED.

```
LINE =  1238.96  PIXEL =  1152.15
N-S =-7.1800    E-W = 4.4052
LAT =-49.9999    LON = -50.0003
```

CASE 9.

CYCLES/INCREMENTS TO LATITUDE/LONGITUDE COORDINATES TRANSFORMATION FOR THE FOUR DETECTORS OF A SELECTED SOUNDER CHANNEL, IMC DISABLED. THE MIRROR POSITION IS CORRECTED FOR SERVO ERRORS, THE DETECTOR POSITIONS WITHIN THE INSTRUMENT FIELD OF VIEW ARE CORRECTED FOR THE FACTORY-MEASURED OFFSETS.

E-W CYCLES/INCREMENTS = 1, 2715

N-S CYCLES/INCREMENTS = 5, 2580

E-W SERVO ERROR = -21.00 (μrad)

N-S SERVO ERROR = 14.00 (μrad)

DETECTOR	#1	#2	#3	#4	
E-W OFFSET	28.00	56.00	-28.00	-56.00	(μrad)
N-S OFFSET	84.00	112.00	14.00	42.00	(μrad)

DETECTOR #1 LAT = 25.0705 LON =-118.7632

DETECTOR #2 LAT = 24.9337 LON =-118.2963

DETECTOR #3 LAT = 24.8339 LON =-118.7582

DETECTOR #4 LAT = 24.6996 LON =-118.3148

Appendix A. Example of OGE Earth Location Software Usage (for GOES I-M Only)

```
C   Beginning of a program:
      REAL*8          T, T50, TIME50
      INTEGER*4    IMC, INSTR, IERR, ICX, INCX, ICY, INCY
      REAL*4          E, S, RL, RP, LAT, LON, SLAT, SLON
      REAL*4          SVX, SVY, DOFF(4,2), GEO(4,2)
C         Imager nadir location in cycles/increments.
      INTEGER*4    NSCYC1, NSINC1, EWCYC1, EWINC1
C         Sounder nadir location in cycles/increments.
      INTEGER*4    NSCYC2, NSINC2, EWCYC2, EWINC2
C................................................................
      REAL*4    REC(336)     ! O@A set in the GVAR block 0 format
C................................................................
C   Common   INSTCOMM.INC  contains instrument-related constants.
C   Common   ELCONS.INC  contains Earth-related constants.
      INCLUDE 'INSTCOMM.INC'
      INCLUDE 'ELCONS.INC'
C     Subroutine  SETCONS  sets constants in common  INSTCOMM.
C     It must be called before using USERS GUIDE software.
      CALL  SETCONS(NSCYC1, NSINC1, EWCYC1, EWINC1,
     X                           NSCYC2, NSINC2, EWCYC2, EWINC2)
C
C    Function TIME50 converts date and time given in BCD format
C to R*8 minutes from Jan.10, 1950. For instance, epoch time from
C    O&A parameter set can be obtained as
C
      TE = TIME50(REC(12))
C
C  LMODEL  uses  O&A  parameter set in the GVAR block 0 format to
C compute the instrument state vector and the instrument to Earth coordinates
C    transformation matrix at time T from  January 1.0, 1950.
C    Argument IMC specifies the IMC on/off status (0 or 1).C    LMODEL  must
C  be called prior to  LPOINT  and  GPOINT.
C
      CALL LMODEL(T, TE, REC, IMC, SLAT, SLON)
C
C    GPOINT  transforms geographic coordinates of a point on the Earth surface
C    (LAT, LON) to related elevation  (N-S)  and scan  (E-W) angles of the
C    instrument.  The instrument is defined by the O&A parameter set used in
C     LMODEL.  If  IERR=1, the point is invisible by the instrument.
C
      CALL  GPOINT(INSTR, FLIP_FLG, LAT, LON, E, S, IERR)
C
C    Subroutine  EVSC2LPF  converts instrument pointing angles  (E,S)  to the
C    related line and pixel numbers  (RL, RP)
C
      IF  (IERR. EQ. 0)   CALL  EVSC2LPF(INSTR, E, S, RL, RP)
C
C    Functions  EVLN  and  SCPX  convert, respectively, line and pixel
C    numbers  (RL, RP)  to the instrument elevation  (N-S)  and scan  (E-W)
C     angles.
C
      E = EVLN(INSTR, RL)
      S = SCPX(INSTR, RP)
C
```

```
C    LPOINT transforms elevation and scan angles to geographic coordinates.
C    Output flag  IERR=1  if the instrument looks off the Earth.
C    The instrument is defined by the O&A parameter set used in  LMODEL.
C
      CALL LPOINT(INSTR, FLIP_FLG, E, S, LAT, LON, IERR)
C
C    SNDELOC  computes latitudes and longitudes related to four detectors
C    of the Sounder instrument.   The instrument pointing is given by the E-W
C    cycles/increments (ICX, INCX)  and the N-S  cycles/increments
C    (ICY, INCY).
C
      CALL SNDELOC(FLIP_FLG, ICX, INCX, ICY, INCY, SVX, SVY, DOFF, GEO)
```

Appendix B. OGE Earth Location Software Listings (for GOES I-M Only)

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   PROGRAM   : TEST
C**   SOURCE    : TEST.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  ---------------------------------------------
C**   1     10/03/89  IL   INITIAL CREATION
C**   2     06/06/94  IL   NOW SETCONS IS CALLED WITH 8 ARGUMENTS
C**
C***********************************************************************
C**
C**   THIS PROGRAM GENERATES TEST CASES TO VALIDATE THE USER'S
C**   IMPLEMENTATIONS OF SOFTWARE FOR TRANSFORMATIONS BETWEEN
C**   THE LATITUDE/LONGITUDE AND LINE/PIXEL COORDINAT SYSTEMS.
C**   THE RELATED O&A PARAMETER SET IS DEFINED IN INCLUDE FILE I.ELREC.
C**
C***********************************************************************
C**
C**   CALLED BY       : NONE
C**   COMMONS MODIFIED: NONE
C**   INPUTS          : NONE
C**   OUTPUTS         : NONE
C**   ROUTINES CALLED : SETCONS,LMODEL,EVLN,SCPX,LPOINT,
C**                     GPOINT,EVSC2LPF,SNDELOC
C**
C***********************************************************************
C***********************************************************************
      PROGRAM TEST
      IMPLICIT NONE
C
C     CALLING PARAMETERS
C
C
C     LOCAL VARIABLES
C
      REAL*8 T,TIME50,TU,DLAT(2),DLON(2)
      REAL DOFF(4,2),GEO(4,2),RLAT,RLON,E,S,RL,RP,EVLN,SCPX,SVX,SVY
      INTEGER   INSTR,IMC,IER,ICX,INCX,ICY,INCY,I,J,FLIP_FLG
C
C     INCLUDE FILES
C
      INCLUDE 'ELCONS.INC'
      INCLUDE 'INSTCOMM.INC'
      INCLUDE 'ELCOMM.INC'
      INCLUDE 'ELREC.INC'
```

```
      DATA DLAT,DLON/50.,-50.,-150.,-50./
      DATA SVX,SVY/-21.E-6,14.E-6/
      DATA DOFF/28.E-6,56.E-6,-28.E-6,-56.E-6,84.E-6,112.E-6,
     *           14.E-6,42.E-6/
      DATA ICX,INCX,ICY,INCY/1,2715,5,2580/

C***********************************************************************
C
C     EXPECTED RESULTS:
C     ******** ********
C
C     EPOCH TIME = 20557829.57612
C
C   NORMAL SPACECRAFT
C
C     IMC = 0 (ENABLED)  SUBSATELLITE LAT =-1.9824   LON =-100.1249
C
C     INSTRUMENT = 1   (IMAGER)
C
C       LAT/LON TO LINE/PIXEL TRANSFORMATION:
C         LAT = 50.0000    LON =-150.0000
C         N-S = 7.0688     E-W =-4.5246
C         LINE =  3487.36  PIXEL = 10405.39
C       LINE/PIXEL TO LAT/LON TRANSFORMATION:
C         LINE =  3487.36  PIXEL = 10405.39
C         N-S = 7.0688     E-W =-4.5246
C         LAT = 50.0000    LON =-150.0000
C
C     INSTRUMENT = 2   (SOUNDER)
C
C       LAT/LON TO LINE/PIXEL TRANSFORMATION:
C         LAT =-50.0000    LON = -50.0000
C         N-S =-6.8659     E-W = 4.5781
C         LINE =  1219.41  PIXEL =  1162.87
C       LINE/PIXEL TO LAT/LON TRANSFORMATION:
C         LINE =  1219.41  PIXEL =  1162.87
C         N-S =-6.8659     E-W = 4.5781
C         LAT =-50.0000    LON = -50.0000
C
C
C     IMC = 1 (DISABLED)  SUBSATELLITE LAT = 0.0509   LON =-100.0017
C
C     INSTRUMENT = 1   (IMAGER)
C
C       LAT/LON TO LINE/PIXEL TRANSFORMATION:
C         LAT = 50.0000    LON =-150.0000
C         N-S = 6.8594     E-W =-4.6513
C         LINE =  3617.92  PIXEL = 10267.15
C       LINE/PIXEL TO LAT/LON TRANSFORMATION:
C         LINE =  3617.92  PIXEL = 10267.15
C         N-S = 6.8594     E-W =-4.6513
C         LAT = 49.9999    LON =-149.9997
C
C     INSTRUMENT = 2   (SOUNDER)
C
C       LAT/LON TO LINE/PIXEL TRANSFORMATION:
C         LAT =-50.0000    LON = -50.0000
C         N-S =-7.1650     E-W = 4.3902
C         LINE =  1238.05  PIXEL =  1151.16
C       LINE/PIXEL TO LAT/LON TRANSFORMATION:
```

```
C         LINE =  1238.05  PIXEL =  1151.16
C         N-S =-7.1650     E-W = 4.3902
C         LAT =-49.9999    LON = -50.0003
C
C       CYCLES/INCREMENTS TO LAT/LON TRANSFORMATION:
C         E-W CYCLES/INCREMENTS = 1, 2715
C         N-S CYCLES/INCREMENTS = 5, 2580
C         E-W SERVO ERROR = -21.00 (mrad)
C         N-S SERVO ERROR =  14.00 (mrad)
C
C         DETECTOR      #1      #2      #3      #4
C         E-W OFFSET   28.00   56.00  -28.00  -56.00 (mrad)
C         N-S OFFSET   84.00  112.00   14.00   42.00 (mrad)
C
C         DETECTOR #1   LAT = 25.1035  LON =-118.8478
C         DETECTOR #2   LAT = 25.0270  LON =-118.3774
C         DETECTOR #3   LAT = 24.8625  LON =-118.8069
C         DETECTOR #4   LAT = 24.7853  LON =-118.3595
C
C   FLIPPED (INVERTED SPACECRAFT
C
C     IMC = 0 (ENABLED)  SUBSATELLITE LAT =-1.9824   LON =-100.1249
C
C     INSTRUMENT = 1   (IMAGER)
C
C       LAT/LON TO LINE/PIXEL TRANSFORMATION:
C         LAT = 50.0000    LON =-150.0000
C         N-S = 7.0688     E-W =-4.5246
C         LINE =  3487.36  PIXEL = 10405.39
C       LINE/PIXEL TO LAT/LON TRANSFORMATION:
C         LINE =  3487.36  PIXEL = 10405.39
C         N-S = 7.0688     E-W =-4.5246
C         LAT = 50.0000    LON =-150.0000
C
C     INSTRUMENT = 2   (SOUNDER)
C
C       LAT/LON TO LINE/PIXEL TRANSFORMATION:
C         LAT =-50.0000    LON = -50.0000
C         N-S =-6.8659     E-W = 4.5780
C         LINE =  1219.35  PIXEL =  1162.99
C       LINE/PIXEL TO LAT/LON TRANSFORMATION:
C         LINE =  1219.35  PIXEL =  1162.99
C         N-S =-6.8659     E-W = 4.5780
C         LAT =-50.0000    LON = -50.0000
C
C
C     IMC = 1 (DISABLED)  SUBSATELLITE LAT = 0.0509   LON =-100.0017
C
C     INSTRUMENT = 1   (IMAGER)
C
C       LAT/LON TO LINE/PIXEL TRANSFORMATION:
C         LAT = 50.0000    LON =-150.0000
C         N-S = 6.8450     E-W =-4.6370
C         LINE =  3626.88  PIXEL = 10282.76
C       LINE/PIXEL TO LAT/LON TRANSFORMATION:
C         LINE =  3626.88  PIXEL = 10282.76
C         N-S = 6.8450     E-W =-4.6370
C         LAT = 49.9998    LON =-149.9996
C
C     INSTRUMENT = 2   (SOUNDER)
```

```
C
C       LAT/LON TO LINE/PIXEL TRANSFORMATION:
C         LAT =-50.0000    LON = -50.0000
C         N-S =-7.1800     E-W = 4.4052
C         LINE =  1238.93  PIXEL =  1152.22
C       LINE/PIXEL TO LAT/LON TRANSFORMATION:
C         LINE =  1238.93  PIXEL =  1152.22
C         N-S =-7.1800     E-W = 4.4052
C         LAT =-49.9998    LON = -50.0003
C
C       CYCLES/INCREMENTS TO LAT/LON TRANSFORMATION:
C         E-W CYCLES/INCREMENTS = 1, 2715
C         N-S CYCLES/INCREMENTS = 5, 2580
C         E-W SERVO ERROR = -21.00 (mrad)
C         N-S SERVO ERROR =  14.00 (mrad)
C
C         DETECTOR      #1      #2      #3      #4
C         E-W OFFSET   28.00   56.00  -28.00  -56.00 (mrad)
C         N-S OFFSET   84.00  112.00   14.00   42.00 (mrad)
C
C         DETECTOR #1   LAT =-22.5543  LON = -80.4361
C         DETECTOR #2   LAT =-22.6288  LON = -79.9716
C         DETECTOR #3   LAT =-22.7889  LON = -80.3995
C         DETECTOR #4   LAT =-22.8645  LON = -79.9554
C
C     NOTE: LAT, LON, AND N-S, E-W ANGLES ARE IN DEGREES.
C
C***********************************************************************

C     SET CONSTANTS IN COMMON INSTCOMM
      CALL SETCONS(4,3068,2,3068,4,1402,2,1402)

C     COMPUTE EPOCH TIME
C      TU=TIME50(REC(12))
      TU=20557829.57612
      PRINT 500,TU
      T=TU+20.
      DO FLIP_FLG = 1, -1, -2
         DO IMC=0,1

C     COMPUTE DATA NEEDED FOR INSTRUMENT TO EARTH COORDINATES
C     TRANSFORMATION
            CALL LMODEL(T,TU,REC,IMC,RLAT,RLON)
            PRINT 510,IMC,RLAT*DEG,RLON*DEG

            DO INSTR=1,2

C     GEOGRAPHIC TO LINE/PIXEL COORDINATES TRANSFORMATION:
C       SET INPUT LATITUDE AND LONGITUDE
               RLAT=DLAT(INSTR)*RAD
               RLON=DLON(INSTR)*RAD
               PRINT 520,INSTR,DLAT(INSTR),DLON(INSTR)

C       TRANSFORM LAT/LON TO N-S AND E-W INSTRUMENT ANGLES
               CALL GPOINT(INSTR,FLIP_FLG,RLAT,RLON,E,S,IER)
               IF (IER.EQ.0) THEN

C     CONVERT N-S AND E-W ANGLES TO LINE/PIXEL COORDINATES
                  CALL EVSC2LPF(INSTR,E,S,RL,RP)
                  PRINT 530,E*DEG,S*DEG,RL,RP
```

```
C     REVERSE TRANSFORMATION: LINE/PIXEL TO GEOGRAPHIC COORDINATES

C       CONVERT LINE/PIXEL NUMBERS TO N-S AND E-W INSTRUMENT ANGLES
                  E=EVLN(INSTR,RL)
                  S=SCPX(INSTR,RP)
                  PRINT 540,RL,RP,E*DEG,S*DEG

C       TRANSFORM N-S AND E-W ANGLES TO GEOGRAPHIC COORDINATES
                  CALL LPOINT(INSTR,FLIP_FLG,E,S,RLAT,RLON,IER)
                  IF (IER.EQ.0) PRINT 550,RLAT*DEG,RLON*DEG
               END IF
            ENDDO
         ENDDO

C     TRANSFORM CYCLES/INCREMENTS, SERVO ERROR VALUES AND THE
C     FACTORY-MEASURED DETECTOR OFFSETS TO LAT/LON COORDINATES
C     FOR THE FOUR DETECTORS OF THE SOUNDER INSTRUMENT

         CALL SNDELOC(FLIP_FLG,ICX,INCX,ICY,INCY,SVX,SVY,DOFF,GEO)

         PRINT 560,ICX,INCX,ICY,INCY,SVX*1.E6,SVY*1.E6
         PRINT 570,((DOFF(I,J)*1.E6,I=1,4),J=1,2)
         PRINT 580, (I,GEO(I,1)*DEG,GEO(I,2)*DEG,I=1,4)
         CALL SETCONS(4,3068,2,3068,4,1403,2,1403)
      ENDDO

 500  FORMAT(1X,'EPOCH TIME =',F15.5)
 510  FORMAT(//1X,'IMC =',I2,3X,'SUBSATELLITE LAT =',
     *          F7.4,3X,'LON =',F9.4)
 520  FORMAT(/1X,'INSTRUMENT =',I2/
     *       /3X,'LAT/LON TO LINE/PIXEL TRANSFORMATION:'/
     *        5X,'LAT =',F8.4,4X,'LON =',F9.4)
 530  FORMAT(5X,'N-S =',F7.4,5X,'E-W =',F7.4/
     *       5X,'LINE =',F9.2,2X,'PIXEL =',F9.2)
 540  FORMAT(3X,'LINE/PIXEL TO LAT/LON TRANSFORMATION:'/
     *        5X,'LINE =',F9.2,2X,'PIXEL =',F9.2/
     *        5X,'N-S =',F7.4,5X,'E-W =',F7.4)
 550  FORMAT(5X,'LAT =',F8.4,4X,'LON =',F9.4)
 560  FORMAT(/3X,'CYCLES/INCREMENTS TO LAT/LON TRANSFORMATION:'/
     *        5X,'E-W CYCLES/INCREMENTS =',I2,',',I5/
     *        5X,'N-S CYCLES/INCREMENTS =',I2,',',I5/
     *        5X,'E-W SERVO ERROR =',F7.2,' (mrad)'/
     *        5X,'N-S SERVO ERROR =',F7.2,' (mrad)')
 570  FORMAT(/5X,'DETECTOR',6X,'#1',6X,'#2',6X,'#3',6X,'#4'/
     *       5X,'E-W OFFSET',4F8.2,' (mrad)'/
     *       5X,'N-S OFFSET',4F8.2,' (mrad)'/)
 580  FORMAT(5X,'DETECTOR #',I1,3X,'LAT =',F8.4,2X,'LON =',F9.4)
      END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   ROUTINE   : EVLN
C**   SOURCE    : EVLN.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  ---------------------------------------------
C**   A     10/27/88  IL   INITIAL CREATION
C***********************************************************************
C**
C**   THIS FUNCTION CONVERTS FRACTIONAL LINE NUMBER TO ELEVATION ANGLE
C**   IN RADIANS.
C**
C***********************************************************************
C**
C**   CALLED BY       : ANY
C**   COMMONS MODIFIED: NONE
C**   INPUTS          : NONE
C**   OUTPUTS         : NONE
C**   ROUTINES CALLED : NONE
C**
C***********************************************************************
C***********************************************************************
      REAL FUNCTION EVLN(INSTR,RLINE)
      IMPLICIT NONE
C
C     CALLING PARAMETERS
C
      INTEGER INSTR
C                       INSTRUMENT CODE (1-IMAGER, 2-SOUNDER)
      REAL*4  RLINE
C                       FRACTIONAL LINE  NUMBER
C
C     LOCAL VARIABLES - NONE
C
C     INCLUDE FILES
C
      INCLUDE 'INSTCOMM.INC'
C***********************************************************************
      IF (INSTR.EQ.1) THEN
           EVLN=ELVMAX(INSTR)-(RLINE-4.5)*ELVLN(INSTR)
      ELSE
           EVLN=ELVMAX(INSTR)-(RLINE-2.5)*ELVLN(INSTR)
      END IF
      RETURN
      END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   ROUTINE   : EVSC2LPF
C**   SOURCE    : EVSC2LPF.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  ---------------------------------------------
C**   A     10/27/88  IL   INITIAL CREATION
C**
C***********************************************************************
C**
C**   THIS SUBROUTINE CONVERTS ELEVATION AND SCAN ANGLES
C**   TO THE FRACTIONAL LINE AND PIXEL NUMBERS.
C**
C***********************************************************************
C**
C**   CALLED BY       : ANY
C**   COMMONS MODIFIED: NONE
C**   INPUTS          : NONE
C**   OUTPUTS         : NONE
C**   ROUTINES CALLED : NONE
C**
C***********************************************************************
C***********************************************************************
      SUBROUTINE EVSC2LPF(INSTR,ELEV,SCAN,RL,RP)
      IMPLICIT NONE
C
C     CALLING PARAMETERS
C
      INTEGER INSTR
C                       INSTRUMENT CODE (1-IMAGER, 2-SOUNDER)
      REAL ELEV
C                       ELEVATION ANGLE IN RADIANS
      REAL SCAN
C                       SCAN ANGLE IN RADIANS
      REAL RL
C                       LINE NUMBER
      REAL RP
C                       PIXEL NUMBER
C
C     LOCAL VARIABLES - NONE
C
C
C     INCLUDE FILES
C
      INCLUDE 'INSTCOMM.INC'
C**************************************************************
C
C     COMPUTE FRACTIONAL LINE NUMBER
C
         RL=(ELVMAX(INSTR)-ELEV)/ELVLN(INSTR)
```

```
         IF (INSTR.EQ.1) THEN
              RL=RL+4.5
         ELSE
              RL=RL+2.5
         END IF
C
C     COMPUTE FRACTIONAL PIXEL NUMBER
C
         RP=(SCNMAX(INSTR)+SCAN)/SCNPX(INSTR)+1.
         RETURN
         END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   ROUTINE   : GATT
C**   SOURCE    : GATT.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  ---------------------------------------------
C**   A     12/01/88  IL   INITIAL CREATION
C**
C***********************************************************************
C**
C**    THIS FUNCTION COMPUTES AN ATTITUDE/MISALIGNMENT ANGLE FROM A
C**    GIVEN SUBSET OF THE O&A PARAMETERS IN GVAR BLOK 0.
C**    ARGUMENT K0 INDICATES THE FIRST WORD OF THE SUBSET.
C**
C***********************************************************************
C**
C**   CALLED BY        : LMODEL
C**   COMMONS MODIFIED: NONE
C**   INPUTS           : NONE
C**   OUTPUTS          : NONE
C**   ROUTINES CALLED : NONE
C**
C***********************************************************************
C***********************************************************************
      REAL*4 FUNCTION GATT(K0,REC,WA,TE)
      IMPLICIT NONE
C
C     CALLING PARAMETERS
C
      INTEGER K0
C                    STARTING POSITION OF A PARAMETER SUBSET IN THE
C                    O&A SET
      REAL*4 REC(336)
C                    INPUT O&A PARAMETER SET
      REAL WA
C                    INPUT SOLAR ORBIT ANGLE IN RADIANS
      REAL TE
C                    INPUT EXPONENTIAL TIME DELAY FROM EPOCH (MINUTES)
C
C     LOCAL VARIABLES
C
      INTEGER*4 I,J,M,L,LL,K
      REAL*4 IR,JR,MR,ATT
      EQUIVALENCE (I,IR),(J,JR),(M,MR)
C
C     INCLUDE FILES
C
C***********************************************************************
C
C  CONSTANT COMPONENT
```

```
C
      K=K0
      ATT=REC(K+2)
C
C  COMPUTES THE EXPONENTIAL TERM
C
      IF (TE.GE.0.AND.REC(K+1).GT.0.) ATT=ATT+REC(K)*EXP(-TE/REC(K+1))
C
C     EXTRACTS THE NUMBER OF SINUSOIDS
C
      IR=REC(K+3)
C
C  CALCULATION OF SINUSOIDS
C
      DO 10 L=1,I
            ATT=ATT+REC(K+2*L+2)*COS(WA*L+REC(K+2*L+3))
  10  CONTINUE
C
C     POINTER TO THE NUMBER OF MONOMIAL SINUSOIDS
C
         K=K+34
C
C     EXTACTS NUMBER OF MONOMIAL SINUSOIDS
C
         IR=REC(K)
C
C     COMPUTES MONOMIAL SINUSOIDS
C
         DO 20 L=1,I
              LL=K+5*L
C
C           ORDER OF SINUSOID
C
              JR=REC(LL-4)
C
C           ORDER OF MONOMIAL SINUSOID
C
              MR=REC(LL-3)
              ATT=ATT+REC(LL-2)*((WA-REC(LL))**M)*COS(J*WA+REC(LL-1))
  20     CONTINUE
         GATT=ATT
         RETURN
         END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   ROUTINE   : GPOINT
C**   SOURCE    : GPOINT.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  ---------------------------------------------
C**   1     12/10/87  IL   INITIAL CREATION
C**   2     06/10/88  IL   REPLACED ASIN WITH ATAN TO SAVE TIME
C**   3     06/02/89  IL   COORDINATE AXES CHANGED ACCORDING TO
C**                        FORD'S DEFINITION IN SDAIP, DRL 504-01
C**   4     12/01/93  IL   IMPLEMENTED NEW FORMULAE FOR SCAN ANGLE
C**                        CORRECTIONS DUE TO MISALIGNMENTS.
C**
C***********************************************************************
C**
C**   THIS SUBROUTINE CONVERTS GEOGRAPHIC LATITUDE AND LONGITUDE
C**   TO THE RELATED ELEVATION AND SCAN ANGLES.
C**
C***********************************************************************
C**
C**   CALLED BY       : ANY
C**   COMMONS MODIFIED: NONE
C**   INPUTS          : NONE
C**   OUTPUTS         : NONE
C**   ROUTINES CALLED : NONE
C**
C***********************************************************************
C***********************************************************************
      SUBROUTINE GPOINT(INSTR,FLIP_FLG,RLAT,RLON,ALF,GAM,IERR)
      IMPLICIT NONE
C
C     CALLING PARAMETERS
C
      INTEGER*4 INSTR
C                    INSTRUMENT CODE (1=IMAGER,2=SOUNDER)
      INTEGER*4 FLIP_FLG
C                   S/C ORIENTATION FLAG (1=NORMAL,-1=INVERTED)
      REAL*4   RLAT
c             GEOGRAPHIC LATITUDE IN RADIANS (INPUT)
      REAL*4   RLON
c             GEOGRAPHIC LONGITUDE IN RADIANS (INPUT)
      REAL*4   ALF
c             ELEVATION ANGLE IN RADIANS (OUTPUT)
      REAL*4   GAM
c             SCAN ANGLE IN RADIANS (OUTPUT)
      INTEGER IERR
c           OUTPUT STATUS; 0 - SUCCESSFUL COMPLETION,
c                          1 - POINT WITH GIVEN LAT/LON IS INVISIBLE
C
C     LOCAL VARIABLES
```

```
C
      REAL*8 F(3)
c              POINTING VECTOR IN EARTH-CENTERED COORDINATES
      REAL*4 FT(3)
c              POINTING VECTOR IN INSTRUMENT COORDINATES
      REAL*4 U(3)
c              COORDINATES OF THE EARTH POINT (KM)
      REAL*4 SING,SLAT,W1,W2,Z,CZ,SA,FF,DOFF,ALPHA,ALPHA1
C                    WORK SPACE
C
C     INCLUDE FILES
C
      INCLUDE 'ELCONS.INC'
      INCLUDE 'ELCOMM.INC'
      INCLUDE 'INSTCOMM.INC'
C*********************************************************************
C
C  COMPUTES SINUS OF GEOGRAPHIC (GEODETIC) LATITUDE
C
         SING=SIN(RLAT)
         W1=AEBE4*SING*SING
C
C       COMPUTE SIGN OF MISALIGNMENT CORRECTIONS AND ORIGIN OFFSET CORRECTIONS
C
      FF = FLIP_FLG
      IF (INSTR.EQ.2) FF = - FF
      DOFF = SCNMAX(INSTR) - EWNOM(INSTR)
C
C     SINUS OF THE GEOCENTRIC LATITUDE
C
         SLAT=((0.375*W1-0.5)*W1+1.)*SING/AEBE2
C
C    COMPUTES LOCAL EARTH RADIUS AT SPECIFIED POINT
C
         W2=SLAT*SLAT
         W1=AEBE3*W2
         W1=(0.375*W1-0.5)*W1+1.
C
C     COMPUTES CARTESIAN COORDINATES OF THE POINT
C
         U(3)=SLAT*W1
         W2=W1*SQRT(1.-W2)
         U(1)=W2*COS(RLON)
         U(2)=W2*SIN(RLON)
C
C     POINTING VECTOR FROM SATELLITE TO THE EARTH POINT
C
         F(1)=U(1)-XS(1)
         F(2)=U(2)-XS(2)
         F(3)=U(3)-XS(3)
         W2=U(1)*SNGL(F(1))+U(2)*SNGL(F(2))+
     1      U(3)*SNGL(F(3))*AEBE2
C
C     VERIFIES VISIBILITY OF THE POINT
C
         IF (W2.GT.0.) THEN
                   IERR=1
                   ALF=99999.
                   GAM=99999.
                   RETURN
```

```
          END IF
C
C    CONVERTS POINTING VECTOR TO INSTRUMENT COORDINATES
C
         FT(1)=BT(1,1)*F(1)+BT(2,1)*F(2)+BT(3,1)*F(3)
         FT(2)=BT(1,2)*F(1)+BT(2,2)*F(2)+BT(3,2)*F(3)
         FT(3)=BT(1,3)*F(1)+BT(2,3)*F(2)+BT(3,3)*F(3)
C
C     CONVERTS POINTING VECTOR TO SCAN AND ELEVATION ANGLES AND
C     CORRECTS FOR THE ROLL AND PITCH MISALIGNMENTS
C
         GAM=ATAN(FT(1)/SQRT(FT(2)**2+FT(3)**2))
         ALF=-ATAN(FT(2)/FT(3))
         W1=SIN(ALF)
         W2=COS(GAM)
         ALPHA1=ALF+RMA*(1.-COS(ALF)/W2)+PMA*W1*(FF/W2+TAN(GAM))
         GAM=GAM-FF*RMA*W1
         ALF = ALPHA1 + ALPHA1*GAM*DOFF
         GAM = GAM - 0.5*ALPHA1*ALPHA1*DOFF
         IERR=0
         RETURN
         END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   ROUTINE   : INST2ER
C**   SOURCE    : INST2ER.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  ---------------------------------------------
C**   1     08/16/88  IL   INITIAL CREATION
C**   2     11/11/88  IL   TRIGONOMETRIC FUNCTIONS REPLACED WITH
C**                        SMALL ANGLE APPROXIMATIONS
C**   3    06/02/89   IL   COORDINATE AXES CHANGED ACCORDING TO
C**                        FORD'S DEFINITION IN SDAIP, DRL 504-01
C**
C***********************************************************************
C**
C**   INST2ER ACCEPTS THE SINGLE PRECISION ROLL, PITCH AND YAW ANGLES
C**   OF AN INSTRUMENT AND RETURNS THE DOUBLE PRECISION INSTRUMENT TO
C**   EARTH COORDINATES TRANSFORMATION MATRIX.
C**
C***********************************************************************
C**
C**   CALLED BY       : ANY
C**   COMMONS MODIFIED: NONE
C**   INPUTS          : NONE
C**   OUTPUTS         : NONE
C**   ROUTINES CALLED : NONE
C**
C***********************************************************************
C***********************************************************************
      SUBROUTINE INST2ER(R,P,Y,A,AT)
      IMPLICIT NONE
C
C     CALLING PARAMETERS
C
      REAL*4 R
C                                   ROLL ANGLE IN RADIANS
      REAL*4 P
C                                   PITCH ANGLE IN RADIANS
      REAL*4 Y
C                                   YAW ANGLE IN RADIANS
      REAL*8 A(3,3)
C                                   SPACECRAFT TO ECEF COORDINATES
C                                   TRANSFORMATION MATRIX
      REAL*8 AT(3,3)
C                                   INSTRUMENT TO ECEF COORDINATES
C                                   TRANSFORMATION MATRIX
C
C     LOCAL VARIABLES
C
      REAL*8    RPY(3,3)
C                                   INSTRUMENT TO BODY COORDINATES
```

```
C                                    TRANSFORMATION MATRIX
      REAL SR,CR,SP,CP,SY,CY
      INTEGER*4 I,J
C                                    INDICES
C
C     INCLUDE FILES
C
C**********************************************************************
C
C     COMPUTE INSTRUMENT TO BODY COORDINATES TRANSFORMATION MATRIX
C
      SP=SIN(P)
      CP=COS(P)
      SR=SIN(R)
      CR=COS(R)
      SY=SIN(Y)
      CY=COS(Y)
      RPY(1,1)=CY*CP
      RPY(2,1)=CY*SP*SR+SY*CR
      RPY(3,1)=SY*SR-CY*SP*CR
      RPY(1,2)=-SY*CP
      RPY(2,2)=CY*CR-SP*SR*SY
      RPY(3,2)=CY*SR+SY*SP*CR
      RPY(1,3)=SP
      RPY(2,3)=-CP*SR
      RPY(3,3)=CP*CR
C
C     MULTIPLICATION OF MATRICES A AND RPY
C
      DO 10 I=1,3
         DO 10 J=1,3
 10         AT(I,J)=A(I,1)*RPY(1,J)+A(I,2)*RPY(2,J)+A(I,3)*RPY(3,J)
      RETURN
      END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   ROUTINE   : LMODEL
C**   SOURCE    : LMODEL.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  ---------------------------------------------
C**   1     01/09/89  IL   INITIAL CREATION
C**   2     06/02/89  IL   COORDINATE AXES CHANGED ACCORDING TO
C**                        FORD'S DEFINITION IN SDAIP, DRL 504-01
C**   3     08/21/89  IL   CORRECTED ORBIT ANGLE COMPUTATIONS
C**   4     02/27/90  IL   S/C COMPENSATION APPLIED UNCONDITIONALLY;
C**                        REFERENCE RADIAL DISTANCE, LATITUDE AND
C**                        ORBIT YAW SET TO ZERO IF IMC DISABLED.
C**   5     12/01/93  IL   ADDED TRAP FOR SLAT=SYAW=0; CORRECTED
C**                        EXPRESSION FOR LAM.
C**
C***********************************************************************
C**
C**   THIS SUBROUTINE COMPUTES THE POSITION OF THE SATELLITE AND THE
C**   ATTITUDE OF THE IMAGER OR SOUNDER.  THE CALCULATIONS ARE BASED
C**   ON THE OATS ORBIT AND ATTITUDE MODEL REPRESENTED BY THE O&A
C**   PARAMETER SET IN GVAR BLOCK 0.
C**        INPUTS:
C**          TIME, EPOCH TIME, O&A PARAMETER SET, IMC STATUS.
C**
C**        OUTPUTS:
C**          THE SPACECRAFT POSITION VECTOR IN EARTH-FIXED COORDINATES;
C**          THE GEOMETRIC ROLL, PITCH, YAW ANGLES AND THE ROLL,
C**          PITCH MISALIGNMENTS FOR EITHER THE IMAGER OR THE SOUNDER;
C**          THE EARTH-FIXED TO INSTRUMENT FRAME TRANSFORMATION MATRIX;
C**          GEOGRAPHIC LATITUDE AND LONGITUDE AT SUBSATELLITE POINT.
C**
C**   DESCRIPTION
C**   LMODEL ACCEPTS AN INPUT DOUBLE PRECISION TIME IN MINUTES FROM
C**   1950, JAN.1.0 AND AN INPUT SET OF O&A PARAMETERS AND COMPUTES
C**   POSITION OF THE SATELLITE, THE ATTITUDE ANGLES AND ATTITUDE
C**   MISALIGNMENTS AND THE INSTRUMENT TO EARTH-FIXED COORDINATES
C**   TRANSFORMATION MATRIX.
C**
C***********************************************************************
C**
C**   CALLED BY       : ANY
C**   COMMONS MODIFIED: /ELCOMM/ XS,Q3,PITCH,ROLL,YAW,PMA,RMA,BT
C**   INPUTS          : NONE
C**   OUTPUTS         : NONE
C**   ROUTINES CALLED : INST2ER,GATT
C**
C***********************************************************************
C***********************************************************************
      SUBROUTINE LMODEL(T,TU,REC,IMC,RLAT,RLON)
```

```
      IMPLICIT NONE
C
C     CALLING ARGUMENTS
C
      REAL*8 T
C                                   INPUT TIME FROM 1950, JAN 1.0 (MIN)
      REAL*8 TU
C                                   EPOCH TIME FROM 1950, JAN 1.0 (MIN)
      REAL*4 REC(336)
C                                   INPUT O&A PARAMETER SET
      INTEGER IMC
C                                   INPUT IMC STATUS: 0 - ON, 1 - OFF
      REAL*4 RLAT
C                                   SUBSATELLITE GEODETIC LATITUDE (RAD)
      REAL*4 RLON
C                                   SUBSATELLITE LONGITUDE IN RADIANS
C
C     LOCAL VARIABLES
C
      REAL*8  R
C                    NORMALIZED SATELLITE DISTANCE (IN UNITS OF KMER9)
      REAL*8 TS
C                    TIME FROM EPOCH IN MINUTES
      REAL*8 B(3,3)
C                    SPACCRAFT TO EARTH-FIXED COORDINATES TRANSFORMATION
C                    MATRIX
      REAL*4 TE
C                    EXPONENENTIAL TIME DELAY FROM EPOCH (IN MINUTES)
      REAL*4 PHI
C                    SUBSATELLITE GEOCENTRIC LATITUDE IN RADIANS

      REAL*8 DR
C                    RADIAL DISTANCE FROM THE NOMINAL (KM)
      REAL*4 PSI
C                    ORBITAL YAW (IN RADIANS)
      REAL*8  LAM
C                    IMC LONGITUDE (IN RADIANS)
      REAL*4  U
C                    ARGUMENT OF LATITUDE (IN RADIANS)
      REAL*4 SU,CU
C                    SIN(U), COS(U)
      REAL*4 SI,CI
C                    SINE AND COSINE OF THE ORBIT INCLINATION
      REAL*4 SLAT
C                    SINE OF GEOCENTRIC LATITUDE
      REAL*4 ASC
C                    LONGITUDE OF THE ASCENDING NODE IN RADIANS
      REAL*4 SA,CA
C                    SINE AND COSINE OF ASC
      REAL*4 SYAW
C                    SINE OF THE ORBIT YAW
      REAL*4 WA
C                    SOLAR ORBIT ANGLE IN RADIANS
      REAL*4 W
C                    ORBIT ANGLE IN RADIANS
      REAL*4 SW,CW
C                    SIN(W),  COS(W)
      REAL*4 S2W,C2W
C                    SIN(2*W),  COS(2*W)
      REAL*4 SW1,CW1
```

```
C                     SIN(0.927*W),  COS(0.927*W)
      REAL*4 SW3,CW3
C                     SINE AND COSINE OF 1.9268*W
      REAL*8 DLAT
C                     CHANGE IN SINE OF GEOCENTRIC LATITUDE
      REAL*8 DYAW
C                     CHANGE IN SINE OF ORBIT YAW
      REAL*4 GATT
C                     SUBROUTINE FUNCTION
      REAL*4 A1,A2
C                     WORK AREAS
C
C     INCLUDE FILES
C
      INCLUDE 'ELCONS.INC'
      INCLUDE 'ELCOMM.INC'
C
C***********************************************************************
C
C     ASSIGN REFERENCE VALUES TO THE SUBSATELLITE LONGITUDE AND
C     LATITUDE, THE RADIAL DISTANCE AND THE ORBIT YAW.
C
      LAM=REC(5)
      DR=REC(6)
      PHI=REC(7)
      PSI=REC(8)
C
C     ASSIGN REFERENCE VALUES TO THE ATTITUDES AND MISALIGNMENTS
C
      ROLL=REC(9)
      PITCH=REC(10)
      YAW=REC(11)
      RMA=0.
      PMA=0.
C
C     IF IMC IS OFF, COMPUTE CHANGES IN THE SATELLITE ORBIT
C
      IF (IMC.NE.0) THEN
C
C     SET REFERENCE RADIAL DISTANCE, LATITUDE AND ORBIT YAW TO ZERO
C
      DR=0.
      PHI=0.
      PSI=0.
C
C     COMPUTE TIME SINCE EPOCH (IN MINUTES)
C
      TS=T-TU
C
C     COMPUTES ORBIT ANGLE AND THE RELATED TRIGONOMETRIC FUNCTIONS.
C     EARTH ROTATIONAL RATE=.7292115E-4 (rad/s)
C
      W=0.7292115D-4*60.0D0*TS
      SW=SIN(W)
      CW=COS(W)
      SW1=SIN(0.927*W)
      CW1=COS(0.927*W)
      S2W=SIN(2.*W)
      C2W=COS(2.*W)
      SW3=SIN(1.9268*W)
```

```
      CW3=COS(1.9268*W)
C
C     COMPUTES CHANGE IN THE IMC LONGITUDE FROM THE REFERENCE
C
      LAM=LAM+REC(18)+(REC(19)+REC(20)*W)*W
     1        +(REC(27)*SW1+REC(28)*CW1+REC(21)*SW+REC(22)*CW
     2        +REC(23)*S2W+REC(24)*C2W + REC(25)*SW3+REC(26)*CW3
     3        +W*(REC(29)*SW+REC(30)*CW))*2.
C
C     COMPUTES CHANGE IN RADIAL DISTANCE FROM THE REFERENCE (KM)
C
      DR=DR + REC(31) + REC(32)*CW+REC(33)*SW
     1        +REC(34)*C2W+REC(35)*S2W + REC(36)*CW3+REC(37)*SW3
     2        +REC(38)*CW1+REC(39)*SW1 + W*(REC(40)*CW+REC(41)*SW)
C
C     COMPUTES THE SINE OF THE CHANGE IN THE GEOCENTRIC LATITUDE
C
      DLAT=REC(42) + REC(43)*CW+REC(44)*SW
     1        +REC(45)*C2W+REC(46)*S2W
     2        +W*(REC(47)*CW+REC(48)*SW)
     3        +REC(49)*CW1+REC(50)*SW1
C
C     COMPUTES GEOCENTRIC LATITUDE BY USING AN EXPANSION FOR ARCSINE
C
      PHI=PHI+DLAT*(1.+DLAT*DLAT/6.)
C
C     COMPUTES SINE OF THE CHANGE IN THE ORBIT YAW
C
      DYAW=REC(51) + REC(52)*SW+REC(53)*CW
     1        +REC(54)*S2W+REC(55)*C2W
     2        +W*(REC(56)*SW+REC(57)*CW)
     3        +REC(58)*SW1+REC(59)*CW1
C
C     COMPUTES THE ORBIT YAW BY USING AN EXPANSION FOR ARCSINE.
C
      PSI=PSI+DYAW*(1.+DYAW*DYAW/6.)
C
C     CALCULATION OF CHANGES IN THE SATELLITE ORBIT ENDS HERE
C
      END IF
C
C     CONVERSION OF THE IMC LONGITUDE AND ORBIT YAW TO THE SUBSATELLITE
C     LONGITUDE AND THE ORBIT INCLINATION (REF: GOES-PCC-TM-2473, INPUTS
C     REQUIRED FOR EARTH LOCATION AND GRIDDING BY SPS,  JUNE 6, 1988)
C
      SLAT=SIN(PHI)
      SYAW=SIN(PSI)
      SI=SLAT**2+SYAW**2
      CI=SQRT(1.-SI)
      SI=SQRT(SI)
      IF (SLAT.EQ.0. .AND. SYAW.EQ.0.) THEN
         U=0.
      ELSE
         U=ATAN2(SLAT,SYAW)
      END IF
      SU=SIN(U)
      CU=COS(U)
C
C     COMPUTES LONGITUDE OF THE ASCENDING NODE
C
```

```
      ASC=LAM-U
      SA=SIN(ASC)
      CA=COS(ASC)
C
C     COMPUTES THE SUBSATELLITE GEOGRAPHIC LATITUDE
C
      RLAT=ATAN(AEBE2*TAN(PHI))
C
C     COMPUTES THE SUBSATELLITE LONGITUDE
C
      RLON=ASC+ATAN2(CI*SU,CU)
C
C     COMPUTES THE SPACECRAFT TO EARTH-FIXED COORDINATES TRANSFORMATION
C     MATRIX:
C         (VECTOR IN ECEF COORDINATES) = B * (VECTOR IN S/C COORDINATES)
C
      B(1,2)=-SA*SI
      B(2,2)= CA*SI
      B(3,2)=-CI
      B(1,3)=-CA*CU+SA*SU*CI
      B(2,3)=-SA*CU-CA*SU*CI
      B(3,3)=-SLAT
      B(1,1)=-CA*SU-SA*CU*CI
      B(2,1)=-SA*SU+CA*CU*CI
      B(3,1)= CU*SI
C
C     COMPUTES THE NORMALIZED SPACECRAFT POSITION VECTOR IN EARTH-FIXED
C     COORDINATES - XS.
C
      R=(NOMORB+DR)/AE
      XS(1)=-B(1,3)*R
      XS(2)=-B(2,3)*R
      XS(3)=-B(3,3)*R
C
C     PRECOMPUTES Q3 (USED IN LPOINT)
C
      Q3=XS(1)**2+XS(2)**2+AEBE2*XS(3)**2-1.0
C
C     COMPUTES THE ATTITUDES AND MISALIGNMENTS IF IMC IS OFF
C
      IF (IMC.NE.0) THEN
C
C     COMPUTES THE SOLAR ORBIT ANGLE
C
         WA=REC(60)*TS
C
C     COMPUTES THE DIFFERENCE BETWEEN CURRENT TIME, TS, AND THE
C     EXPONENTIAL TIME, REC(61). NOTE THAT BOTH TIMES ARE SINCE EPOCH.
C
         TE=TS-REC(61)
C
C     COMPUTES ROLL
C
         ROLL=ROLL+GATT(62,REC,WA,TE)
C
C     COMPUTES PITCH
C
         PITCH=PITCH+GATT(117,REC,WA,TE)
C
C     COMPUTES YAW
```

```
C
         YAW=YAW+GATT(172,REC,WA,TE)
C
C     COMPUTES ROLL MISALIGNMENT
C
         RMA=GATT(227,REC,WA,TE)
C
C     COMPUTES PITCH MISALIGNMENT
C
         PMA=GATT(282,REC,WA,TE)
C
C     APPLY THE SPACECRAFT COMPENSATION
C
         ROLL=ROLL+REC(15)
         PITCH=PITCH+REC(16)
         YAW=YAW+REC(17)
      END IF
C
C     COMPUTES THE INSTRUMENT TO EARTH-FIXED COORDINATES TRANSFORMATION
C     MATRIX - BT
C
      CALL INST2ER(ROLL,PITCH,YAW,B,BT)
      RETURN
      END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   ROUTINE   : LPOINT
C**   SOURCE    : LPOINT.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  -------------------------------------------
C**   1     01/09/89  IL   INITIAL CREATION
C**   2     06/02/89  IL   COORDINATE AXES CHANGED ACCORDING TO
C**                        FORD'S DEFINITION IN SDAIP, DRL504-01
C**   3     12/01/93  IL   IMPLEMENTED NEW FORMULAE FOR SCAN ANGLE
C**                        CORRECTIONS DUE TO MISALIGNMENTS
C**
C***********************************************************************
C**
C**   THIS SUBROUTINE CONVERTS THE INSTRUMENT ELEVATION AND SCAN
C**   ANGLES TO THE RELATED GEOGRAPHIC LATITUDE AND LONGITUDE.
C**
C***********************************************************************
C**
C**   CALLED BY       : ANY
C**   COMMONS MODIFIED: NONE
C**   INPUTS          : NONE
C**   OUTPUTS         : NONE
C**   ROUTINES CALLED : NONE
C**
C***********************************************************************
C***********************************************************************
      SUBROUTINE LPOINT(INSTR,FLIP_FLG,ALPHA0,ZETA0,RLAT,RLON,IERR)
      IMPLICIT NONE
C
C     CALLING PARAMETERS
C
      INTEGER*4 INSTR
C                    INSTRUMENT CODE (1=IMAGER,2=SOUNDER)
      INTEGER*4 FLIP_FLG
C                   S/C ORIENTATION FLAG (1=NORMAL,-1=INVERTED)
      REAL*4   ALPHA0
c             ELEVATION ANGLE (RAD)
      REAL*4   ZETA0
c             SCAN ANGLE (RAD)
      REAL*4   RLAT
c             LATITUDE IN RADIANS (OUTPUT)
      REAL*4   RLON
c             LONGITUDE IN RADIANS (OUTPUT)
      INTEGER IERR
c             OUTPUT STATUS; 0 - POINT ON THE EARTH
c                            1 - INSTRUMENT POINTS OFF EARTH
C
C     LOCAL VARIABLES
C
```

```
      REAL*8 G1(3)
c             POINTING VECTOR IN EARTH-CENTERED COORDINATES
      REAL*8 H
c             SLANT DISTANCE TO THE EARTH POINT (KM)
      REAL*8 Q1,Q2,D
c             WORK SPACE
      REAL*4 G(3)
c             POINTING VECTOR IN INSTRUMENT COORDINATES
      REAL*4 U(3)
c             COORDINATES OF THE EARTH POINT (KM)
      REAL*4 SA,CA,DA,DZ,D1,CZ,SZ,FF,DOFF,ALPHA,ZETA
c             WORK SPACE
C
C     INCLUDE FILES
C
      INCLUDE 'ELCONS.INC'
      INCLUDE 'ELCOMM.INC'
      INCLUDE 'INSTCOMM.INC'
C**********************************************************************
         IERR=1
C
C      COMPUTE SIGN OF MISALIGNMENT CORRECTIONS AND ORIGIN OFFSET CORRECTIONS
C
      FF = FLIP_FLG
      IF (INSTR.EQ.2) FF = - FF
      DOFF = SCNMAX(INSTR) - EWNOM(INSTR)
C
C     ADD THE NEW SECOND ORDER ORIGIN OFFSET CORRECTION
C
      ALPHA = ALPHA0 - ALPHA0*ZETA0*DOFF
      ZETA  = ZETA0 + 0.5*ALPHA0*ALPHA0*DOFF
C
C     COMPUTES TRIGONOMETRIC FUNCTIONS OF THE SCAN AND ELEVATION
C     ANGLES CORRECTED FOR THE ROLL AND PITCH MISALIGNMENTS
C
         CA=COS(ALPHA)
         SA=SIN(ALPHA)
         CZ=COS(ZETA)
         DA=ALPHA-PMA*SA*(FF/CZ+TAN(ZETA))-RMA*(1.-CA/CZ)
         DZ=ZETA+FF*RMA*SA
C
C    COMPUTES POINTING VECTOR IN INSTRUMENT COORDINATES
C
         CZ=COS(DZ)
         G(1)=SIN(DZ)
         G(2)=-CZ*SIN(DA)
         G(3)=CZ*COS(DA)
C
C     TRANSFORMS THE POINTING VECTOR TO EARTH-FIXED COORDINATES
C
         G1(1)=BT(1,1)*G(1)+BT(1,2)*G(2)+BT(1,3)*G(3)
         G1(2)=BT(2,1)*G(1)+BT(2,2)*G(2)+BT(2,3)*G(3)
         G1(3)=BT(3,1)*G(1)+BT(3,2)*G(2)+BT(3,3)*G(3)
C
C     COMPUTES COEFFICIENTS AND SOLVES A QUADRATIC EQUATION TO
C     FIND THE INTERSECT OF THE POINTING VECTOR WITH THE EARTH
C     SURFACE
C
         Q1=G1(1)**2+G1(2)**2+AEBE2*G1(3)**2
         Q2=XS(1)*G1(1)+XS(2)*G1(2)+AEBE2*XS(3)*G1(3)
```

```
      D=Q2*Q2-Q1*Q3
      IF (DABS(D).LT.1.D-9) D=0.
C
C     IF THE DISCIMINANTE OF THE EQUATION, D, IS NEGATIVE, THE
C     INSTRUMENT POINTS OFF THE EARTH
C
      IF (D.LT.0) THEN
         RLAT=999999.
         RLON=999999.
         RETURN
      END IF
      D=DSQRT(D)
C
C     SLANT DISTANCE FROM THE SATELLITE TO THE EARTH POINT
C
      H=-(Q2+D)/Q1
C
C     CARTESIAN COORDINATES OF THE EARTH POINT
C
      U(1)=XS(1)+H*G1(1)
      U(2)=XS(2)+H*G1(2)
      U(3)=XS(3)+H*G1(3)
C
C     SINUS OF GEOCENTRIC LATITUDE
C
      D1=U(3)/SQRT(U(1)**2+U(2)**2+U(3)**2)
C
C     GEOGRAPHIC (GEODETIC) COORDINATES OF THE POINT
C
      RLAT=ATAN(AEBE2*D1/SQRT(1.-D1*D1))
      RLON=ATAN2(U(2),U(1))
      IERR=0
      RETURN
      END
```

```
C**********************************************************************
C**********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C**********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   ROUTINE   : SCPX
C**   SOURCE    : SCPX.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  ----------------------------------------------
C**   A     09/22/87  IL   INITIAL CREATION
C**********************************************************************
C**
C**   THIS FUNCTION CONVERTS FRACTIONAL PIXEL NUMBER TO SCAN ANGLE
C**   IN RADIANS.
C**
C**********************************************************************
C**
C**   CALLED BY        : ANY
C**   COMMONS MODIFIED: NONE
C**   INPUTS           : NONE
C**   OUTPUTS          : NONE
C**   ROUTINES CALLED : NONE
C**
C**********************************************************************
C**********************************************************************
      REAL FUNCTION SCPX(INSTR,PIX)
      IMPLICIT NONE
C
C  CALLING PARAMETERS
C
      INTEGER INSTR
C                       INSTRUMENT CODE (1-IMAGER, 2-SOUNDER)
      REAL PIX
C                       FRACTIONAL PIXEL NUMBER
C
C     LOCAL VARIABLES
C
C
C     INCLUDE FILES
C
      INCLUDE 'INSTCOMM.INC'
C**********************************************************************
      SCPX=(PIX-1.)*SCNPX(INSTR)-SCNMAX(INSTR)
      RETURN
      END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT    : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM     : EARTH LOCATION USERS GUIDE
C**   ROUTINE    : SETCONS
C**   SOURCE     : SETCONS.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA     BY   COMMENT
C**   ----  --------  ---  ------------------------------------------
C**   1     02/16/89  IL   INITIAL CREATION
C**   2     05/27/94  IL   ADDED ARGUMENTS NSCYC1,..,EWINC2
C**
C***********************************************************************
C**
C**   THIS SUBROUTINE GENERATES CONSTANTS IN COMMON  INSTCOMM
C**
C***********************************************************************
C**
C**   CALLED BY       : ANY
C**   COMMONS MODIFIED: INSTCOMM
C**   INPUTS          : NONE
C**   OUTPUTS         : NONE
C**   ROUTINES CALLED : NONE
C**
C***********************************************************************
C***********************************************************************
      SUBROUTINE SETCONS(NSCYC1, NSINC1, EWCYC1, EWINC1,
     1                   NSCYC2, NSINC2, EWCYC2, EWINC2)
      IMPLICIT NONE
C
C     CALLING PARAMETERS
C
      INTEGER  NSCYC1
C                        N-S CYCLES OF THE IMAGER OFFSET
      INTEGER  NSINC1
C                        N-S INCREMENTS OF THE IMAGER OFFSET
      INTEGER  EWCYC1
C                        E-W CYCLES OF THE IMAGER OFFSET
      INTEGER  EWINC1
C                        E-W INCREMENTS OF THE IMAGER OFFSET
      INTEGER  NSCYC2
C                        N-S CYCLES OF THE SOUNDER OFFSET
      INTEGER  NSINC2
C                        N-S INCREMENTS OF THE SOUNDER OFFSET
      INTEGER  EWCYC2
C                        E-W CYCLES OF THE SOUNER OFFSET
      INTEGER  EWINC2
C                        E-W INCREMENTS OF THE SOUNDER OFFSET
C
C     LOCAL VARIABLES
C
      REAL*4 W, DY, DX, DEG2RAD
         PARAMETER ( DEG2RAD = 0.01745329 )
```

```
      LOGICAL*4 FIRST
C
C     INCLUDE FILES
C
      INCLUDE 'ELCONS.INC'
      INCLUDE 'INSTCOMM.INC'

      DATA FIRST / .TRUE. /
C***********************************************************************
      IF (FIRST) THEN
         FIRST = .FALSE.
         INCMAX(1)  = 6136
         INCMAX(2)  = 2805
         ELVINCR(1) = 2.8125 * DEG2RAD / INCMAX(1)
         ELVINCR(2) = 2.8125 * DEG2RAD / INCMAX(2)
         SCNINCR(1) = 5.6250 * DEG2RAD / INCMAX(1)
         SCNINCR(2) = 5.6250 * DEG2RAD / INCMAX(2)
         ELVLN(1)   = ELVINCR(1) * 28 / 8
         ELVLN(2)   = ELVINCR(2) * 64 / 4
         SCNPX(1)   = SCNINCR(1)
         SCNPX(2)   = SCNINCR(2) * 8
         NSNOM(1)   = 4.5*INCMAX(1)*ELVINCR(1)
         NSNOM(2)   = 4.5*INCMAX(2)*ELVINCR(2)
         EWNOM(1)   = 2.5*INCMAX(1)*SCNINCR(1)
         EWNOM(2)   = 2.5*INCMAX(2)*SCNINCR(2)
      ENDIF
C
C     SET NEW OFFSETS
C
      ELVMAX(1) = (INCMAX(1)*NSCYC1+NSINC1)*ELVINCR(1)
      SCNMAX(1) = (INCMAX(1)*EWCYC1+EWINC1)*SCNINCR(1)

      ELVMAX(2) = 2.*NSNOM(2) - (INCMAX(2)*NSCYC2+NSINC2)*ELVINCR(2)
      SCNMAX(2) = (INCMAX(2)*EWCYC2+EWINC2)*SCNINCR(2)
      RETURN
      END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   ROUTINE   : SNDELOC
C**   SOURCE    : SNDELOC.FOR
C**   LOAD NAME : ANY
C**   PROGRAMMER: IGOR LEVINE
C**
C**   VER.    DATA    BY   COMMENT
C**   ----  --------  ---  ---------------------------------------------
C**   1     02/16/89  IL   INITIAL CREATION
C**   2     03/09/90  IL   CORRECTED ANGULAR DETECTOR OFFSETS
C***********************************************************************
C**
C**   SNDELOC ACCEPTS THE MIRROR POSITION IN CYCLES AND INCREMENTS,
C**   SERVO ERROR VALUES, AND THE POSITIONAL OFFSETS FOR FOUR DETECTORS
C**   OF A SELECTED SOUNDER CHANNEL AND COMPUTES THE DETECTOR EARTH
C**   LOCATIONS IN LATITUDE/LONGITUDE COORDINATES.
C**
C***********************************************************************
C**
C**   CALLED BY       : ANY
C**   COMMONS MODIFIED: NONE
C**   INPUTS          : NONE
C**   OUTPUTS         : NONE
C**   ROUTINES CALLED : LPOINT
C**
C***********************************************************************
C***********************************************************************
      SUBROUTINE SNDELOC(FLIP, CYEW,INCEW,CYNS,INCNS,SVEW,SVNS,DOFF,GEO)
      IMPLICIT NONE
C
C     CALLING PARAMETERS
C
      INTEGER*4 FLIP
C                   S/C ORIENTATION FLAG (1=NORMAL,-1=INVERTED)
      INTEGER CYEW
C                         E-W CYCLES
      INTEGER INCEW
C                         E-W INCREMENTS
      INTEGER CYNS
C                         N-S CYCLES
      INTEGER INCNS
C                         N-S INCREMENTS
      REAL*4 SVEW
C                         E-W SERVO ERROR IN RADIANS
      REAL*4 SVNS
C                         N-S SERVO ERROR IN RADIANS
      REAL*4 DOFF(4,2)
C                     OFFSETS FOR 4 DETECTORS (RADIANS)
C                          DOFF(*,1) = E-W OFFSET
C                          DOFF(*,2) = N-S OFFSET
C                     NOTE: OFFSETS ARE GIVEN RELATIVE TO NOMINAL
C                           POSITIONS OF DETECTORS
```

```fortran
      REAL*4 GEO(4,2)
C                     GEOGRAPHIC COORDINATES RELATED TO 4 DETECTORS
C                           GEO(*,1) = LATITUDE IN RADIANS
C                           GEO(*,2) = LONGITUDE IN RADIANS
C
C     LOCAL VARIABLES
C
      REAL E,S,H,EV,SC,DE,DS,SINE,COSE
      INTEGER I,IER
C
C     INCLUDE FILES
C
      INCLUDE 'INSTCOMM.inc'
C***********************************************************************
C
C     CONVERT THE MIRROR POSITION, GIVEN IN CYCLES AND
INCREMENTS, TO
C     ELEVATION AND SCAN ANGLES
C
      IF (FLIP .EQ. 1) THEN
         E=ELVMAX(2) + ((CYNS-9)*INCMAX(2)+INCNS)*ELVINCR(2) + SVNS
         S=(CYEW*INCMAX(2)+INCEW)*SCNINCR(2)-SCNMAX(2) + SVEW
      ELSE
         E=ELVMAX(2) - (CYNS*INCMAX(2)+INCNS)*ELVINCR(2) - SVNS
         S=((5-CYEW)*INCMAX(2)-INCEW)*SCNINCR(2)-SCNMAX(2) - SVEW
      ENDIF
C
C     CORRECT ELEVATION AND SCAN ANGLES FOR SERVO ERRORS OBTAINING THE
C     TRUE MIRROR POINTING
C
      SINE=FLIP*SIN(E)
      COSE=COS(E)
      H=-2.*SCNPX(2)
C
C     COMPUTE EARTH LOCATIONS FOR FOUR DETECTORS
C
      DO 10 I=1,4
C
C     COMPUTE POSITIONAL OFFSETS OF I-TH DETECTOR
C
           DE=(2.5-I)*ELVLN(2)+DOFF(I,2)
           DS=H+DOFF(I,1)
C
C     CONVERT POSITIONAL OFFSETS TO ANGULAR OFFSETS AND
C     CORRECT ELEVATION AND SCAN ANGLES
C
      EV=E + DE*COSE + DS*SINE
      SC=S - DE*SINE + DS*COSE
C
C     TRANSFORM DETECTOR'S POINTING ANGLES TO GEOGRAPHIC COORDINATES
C     OF THE CORRESPONDING POINT ON THE EARTH SURFACE.
C     NOTE:  IF A DETECTOR LOOKS OFF THE EARTH, THE RELATED LATITUDE
C            AND LONGITUDE ARE SET TO 999999.
C
           CALL LPOINT(2,FLIP,EV,SC,GEO(I,1),GEO(I,2),IER)
           H=-H
  10  CONTINUE
      RETURN
      END
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   NAME      : ELCOMM
C**   TYPE      : DATA AREA
C**   SOURCE    : ELCOMM.INC
C**
C**   VER.    DATA    BY                COMMENT
C**   ----  --------  ----------------  ---------------------------------
C**   A     01/09/89  I. LEVINE         INITIAL CREATION
C**
C***********************************************************************
C**
C**   DESCRIPTION
C**   INSTRUMENT POSITION AND ATTITUDE VARIABLES AND TRANSFORMATION
C**   MATRIX
C**
C***********************************************************************
C***********************************************************************
C
C     COMMON VARIABLES
C
      REAL*8 XS(3)
C                      NORMALIZED S/C POSITION IN ECEF COORDINATES
      REAL*8 BT(3,3)
C                      ECEF TO INSTRUMENT COORDINATES TRANSFORMATION
      REAL*8  Q3
C                      USED IN SUBROUTINE LPOINT
      REAL*4 PITCH,ROLL,YAW
C                          PITCH,ROLL,YAW ANGLES OF INSTRUMENT (RAD)
       REAL*4 PMA,RMA
C                          PITCH,ROLL MISALIGNMENTS OF INSTRUMENT (RAD)
         COMMON /ELCOMM/ XS,BT,Q3,PITCH,ROLL,YAW,PMA,RMA
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   NAME      : ELCONS
C**   TYPE      : DATA AREA
C**   SOURCE    : ELCONS.INC
C**
C**   VER.    DATA    BY                COMMENT
C**   ----  --------  ----------------  --------------------------------
C**   A     01/09/89  I. LEVINE         INITIAL CREATION
C**
C***********************************************************************
C**
C**   DESCRIPTION
C**   MATHEMATICAL AND EARTH-RELATED CONSTANTS
C**
C***********************************************************************
C***********************************************************************
C
      REAL*8 PI
           PARAMETER (PI=3.141592653589793D0)
      REAL*8 DEG
           PARAMETER (DEG=180.D0/PI)
      REAL*8 RAD
           PARAMETER (RAD=PI/180.D0)
C                     DEGREES TO RADIANS CONVERSION PI/180
      REAL*8 NOMORB
           PARAMETER (NOMORB=42164.365D0)
C                     NOMINAL RADIAL DISTANCE OF SATELLITE (km)
      REAL*8 AE
           PARAMETER (AE=6378.137D0)
C                     EARTH EQUATORIAL RADIUS (km)
      REAL*8 FER
           PARAMETER (FER=1.D0/298.25D0)
C                     EARTH FLATTENING COEFFICIENT = 1-(BE/AE)
      REAL*4 AEBE2
           PARAMETER (AEBE2=1.D0/(1.D0-FER)**2)
      REAL*4 AEBE3
           PARAMETER (AEBE3=AEBE2-1.)
      REAL*4 AEBE4
           PARAMETER (AEBE4=(1.D0-FER)**4-1.)
C
C***********************************************************************
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   NAME      : INSTCOMM
C**   TYPE      : DATA AREA
C**   SOURCE    : INSTCOMM.INC
C**
C**   VER.    DATA    BY                 COMMENT
C**   ----  --------  ----------------  --------------------------------
C**   A     02/16/89  I. LEVINE         INITIAL CREATION
C**
C***********************************************************************
C**
C**   DESCRIPTION
C**   COMMON AREA FOR INSTRUMENT-RELATED CONTROL PARAMETERS
C**
C***********************************************************************
C***********************************************************************
C
C     VARIABLES
C        CONSTANTS NEEDED TO PERFORM TRANSFORMATIONS BETWEEN THE
C        LATITUDE/LONGITUDE, LINE/PIXEL AND INSTRUMENT CYCLES/INCREMENTS
C        COORDINATES.
C
      INTEGER*4 INCMAX(2)
C                       NUMBER OF INCREMENTS PER CYCLE
      REAL*4 ELVMAX(2)
C                       BOUNDS IN ELEVATION (RADIANS)
      REAL*4 SCNMAX(2)
C                       BOUNDS IN SCAN ANGLE (RADIANS)
      REAL*4 ELVINCR(2)
C                       CHANGE IN ELEVATION ANGLE PER INCREMENT (RAD)
      REAL*4 SCNINCR(2)
C                       CHANGE IN SCAN ANGLE PER INCREMENT (RADIANS)
      REAL*4 ELVLN(2)
C                       ELEVATION ANGLE PER DETECTOR LINE (RADIANS)
      REAL*4 SCNPX(2)
C                       SCAN ANGLE PER PIXEL (RADIANS)
      REAL*4 EWNOM(2)
C                       EW CENTER OF INSTRUMENT
      REAL*4 NSNOM(2)
C                       NS CENTER OF INSTRUMENT

      COMMON /INSTCOMM/ INCMAX,ELVMAX,SCNMAX,
     1   ELVINCR,SCNINCR,ELVLN,SCNPX,EWNOM,NSNOM

C***********************************************************************
```

```
C***********************************************************************
C***********************************************************************
C**
C**   INTEGRAL SYSTEMS, INC.
C**
C***********************************************************************
C**
C**   PROJECT   : OPERATIONS GROUND EQUIPMENT FOR GOES-NEXT
C**   SYSTEM    : EARTH LOCATION USERS GUIDE
C**   NAME      : REC
C**   TYPE      : DATA AREA
C**   SOURCE    : ELREC.INC
C**
C**   VER.    DATA    BY                COMMENT
C**   ----  --------  ----------------  --------------------------------
C**   A     01/19/89  I. LEVINE         INITIAL CREATION
C**
C***********************************************************************
C**
C**   DESCRIPTION
C**   TEST SET OF O&A PARAMETERS IN THE GVAR BLOCK 0 FORMAT
C**
C***********************************************************************
C***********************************************************************
C   CONTENT OF CORRESPONDING WORDS:
C     REC(5) - REFERENCE LONGITUDE
C     REC(6) - DISTANCE FROM NOMINAL
C     REC(7) - REFERENCE LATITUDE
C     REC(8) - REFERENCE ORBIT YAW
C     REC(9) - REFERENCE ROLL
C     REC(10) - REFERENCE PITCH
C     REC(11) - REFERENCE YAW
C     REC(12),REC(13) - EPOCH TIME IN THE BCD FORMAT /YYYYDDDH HMMSSLLL/
C                       WHERE Y=YEAR, D=DAY, H=HOUR, M=MINUTE,
C                             S=SECONDS, L=MILLISECONDS.
C     REC(14) - UNUSED
C     REC(15) - SPACECRAFT COMPENSATION, ROLL
C     REC(16) - SPACECRAFT COMPENSATION, PITCH
C     REC(17) - SPACECRAFT COMPENSATION, YAW
C     REC(62) - ROLL COEFFICIENTS BEGIN HERE
C     REC(117) - PITCH COEFFICIENTS BEGIN HERE
C     REC(172) - YAW COEFFICIENTS BEGIN HERE
C     REC(227) - ROLL MISALIGNMENT COEFFICIENTS BEGIN HERE
C     REC(282) - PITCH MISALIGNMENT COEFFICIENTS BEGIN HERE
C***********************************************************************
      REAL*4 REC(336)
      DATA REC/4*0,
C  REFER.  LON=-100.1189, LAT=-1.9813, ORB.YAW=-.34967 deg, DIST=84.066
     1     -1.747405052185, 84.06604003906, -.34368492669E-1,
     1     -.6102979183197E-2,  3*0,
C  EPOCH  02/01/89  6:29:34.567
     1     X'19890320',X'62934567',
C  SPECECRAFT COMPENSATION
     1     0,3.E-4,-3.E-4,-2.E-4,
C  COEFFICIENTS FOR CHANGES IN LON, LAT, RADIAL DISTANCE AND ORBIT YAW
     1     42*2.E-4,
C  DAILY SOLAR RATE (rad/min) AND EXPONENTIAL START TIME FROM EPOCH
     1     4.363E-3, 0.0,
```

```
C  ROLL COEFFICIENTS BEGIN HERE (FROM WORD 62):
     1     5.E-4,100.,2.E-3,X'0F',30*.5E-5,
     1     X'04',   X'02',X'02',1.E-5,0,.01,X'02',X'03',-1.E-5,0,.01,
     1              X'03',X'02',1.E-5,0,.01,X'03',X'03',-1.E-5,0,.01,
C  PITCH COEFFICIENTS BEGIN HERE (FROM WORD 117):
     2     5.E-4,100.,2.E-3,X'0F',30*.5E-5,
     2     X'04',   X'02',X'02',1.E-5,0,.01,X'02',X'03',-1.E-5,0,.01,
     2              X'03',X'02',1.E-5,0,.01,X'03',X'03',-1.E-5,0,.01,
C  YAW COEFFICIENTS BEGIN HERE (FROM WORD 172):
     3     5.E-4,100.,1.E-3,X'0F',30*.5E-5,
     3     X'04',   X'02',X'02',1.E-5,0,.01,X'02',X'03',-1.E-5,0,.01,
     3              X'03',X'02',1.E-5,0,.01,X'03',X'03',-1.E-5,0,.01,
C  RMA COEFFICIENTS BEGIN HERE (FROM WORD 227):
     4     -5.E-5,10.,1.E-3,X'0F',30*.5E-5,
     4     X'04',   X'02',X'02',1.E-5,0,.01,X'02',X'03',-1.E-5,0,.01,
     4              X'03',X'02',1.E-5,0,.01,X'03',X'03',-1.E-5,0,.01,
C  PMA COEFFICIENTS BEGIN HERE (FROM WORD 282):
           -5.E-5,10.,1.E-3,X'0F',30*.5E-5,
     5     X'04',   X'02',X'02',1.E-5,0,.01,X'02',X'03',-1.E-5,0,.01,
                         X'03',X'02',1.E-5,0,.01,X'03',X'03',-1.E-5,0,.01/
C***********************************************************************
```

Appendix C. Kamel to Keplerian Transformation

MATHEMATICAL DESCRIPTION

OF THE TRANSFORMATION OF THE

GOES I-M KAMEL ORBITAL PARAMETERS

INTO KEPLERIAN ELEMENTS

Prepared for

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NATIONAL ENVIRONMENTAL SATELLITE, DATA,
AND INFORMATION SERVICE

SATELLITE OPERATIONS CONTROL CENTER

by

COMPUTER SCIENCES CORPORATION

Under

Contract 50-DGNE6-00003

1. MATHEMATICAL BACKGROUND

The Kamel orbital parameters are a set of four parameters used in the GOES I/M Image Navigation and Registration (INR) system. These parameters depict the deviation of the true spacecraft orbit from the reference geostationary orbit.

KAMEL PARAMETER DEFINITIONS

The four Kamel parameters are defined as follows:

DR = The difference between the radial distance to the true instantaneous satellite position, R, and the nominal geostationary radial distance, R_0 ($R_0 = 42164.365$ km.):

$$DR = R - R_0 \tag{1}$$

Dlambda = The difference between the subsatellite longitude of the spacecraft orbit and the reference subsatellite longitude:

$$\begin{aligned}\text{Dlambda} = {} & \text{ATAN2}[(yv_z - zv_y)/(xv_z - zv_x)] \\ & + \text{ATAN2}(L_s/PSI_s) - GHA - \text{Lambda}_0\end{aligned} \tag{2}$$

where (x,y,z) are the Geocentric Inertial Cartesian coordinates of the spacecraft position vector

(v_x,v_y,v_z) are the Geocentric Inertial Cartesian components of the spacecraft velocity vector

L_s and PSI_s are the Kamel parameters defined below

GHA is the Greenwich hour angle

Lambda_0 is the reference subsatellite longitude of the spacecraft (for example, $\text{Lambda}_0 = -75$ degrees East for GOES-East and $\text{Lambda}_0 = -135$ degrees East for GOES-West)

ATAN2 is an arctangent function that determines the proper quadrant of the resultant angle by evaluating the signs of the numerator and denominator terms of the argument.

Figure 1 shows the geometry of the orbit plane and the orbital angular momentum vector, $\vec{H}$, in a Cartesian coordinate system.

The magnitude of the orbital angular momentum is

$$H = \mathrm{sqrt}\ [\ H_x^2 + H_y^2 + H_z^2]$$

where

$$H_x = yv_z - zv_y;\ \ H_y = zv_x - xv_z;\ H_z = xv_y - yv_x$$

In this Figure, $\mathrm{sqrt}[H_x^2 + H_y^2]$ is the magnitude of the projection of the angular momentum vector onto the x-y plane and a is the angle that this projection makes with the x-axis. Then,

$$\cos(a) = H_x/\mathrm{sqrt}[H_x^2 + H_y^2]$$

$$\sin(a) = -H_y/\mathrm{sqrt}[H_x^2 + H_y^2]$$

However, a + RANODE = 90 degrees where RANODE is the right ascension of the ascending node. Consequently,

$$a = (90 - \mathrm{RANODE})$$

$$\cos(a) = \cos(90 - \mathrm{RANODE}) = \sin(\mathrm{RANODE})$$

$$\sin(a) = \sin(90 - \mathrm{RANODE}) = \cos(\mathrm{RANODE})$$

Then

$$\tan(\mathrm{RANODE}) = H_x/(-H_y) = (yv_z - zv_y)/(xv_z - zv_x)$$

and

$$\mathrm{RANODE} = \mathrm{ATAN2}[(yv_z - zv_y)/(xv_z - zv_x)]$$

which is the first term of Dlambda. Thus, Dlambda is

$$\mathrm{Dlambda}\ =\ \mathrm{RANODE} + \mathrm{ATAN2}(L_S/PSI_S) - \mathrm{GHA} - \mathrm{Lambda}_0 \qquad (3)$$

where Lambda_0 is the reference longitude contained in the GVAR documentation block.

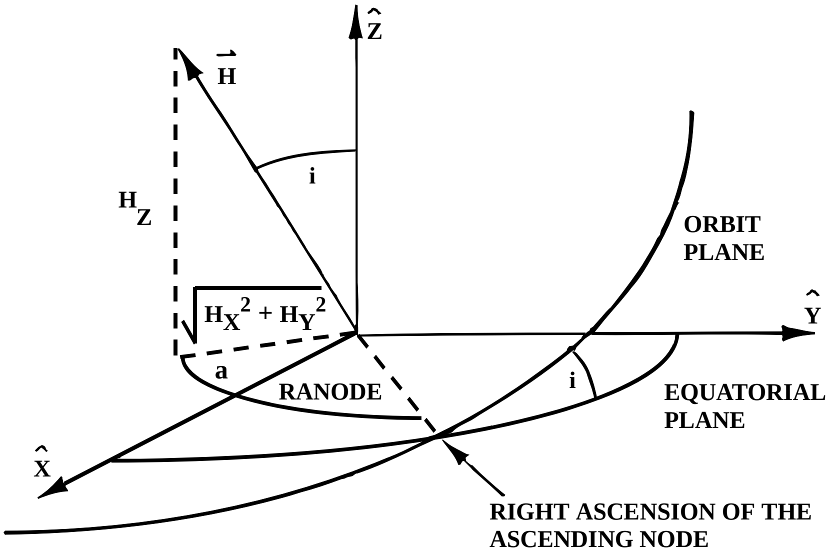


Figure 1. Orbital Angular Momentum Geometry

L_S = the sine of the geocentric latitude (the angle between the equatorial plane and the instantaneous latitude position):

$$L_S = z/R \tag{4}$$

PSI_S = the sine of the orbit yaw (the angle between the equatorial plane and the instantaneous velocity vector):

$$PSI_S = [v_z R - z(xv_x + yv_y + zv_z)/R]/H \tag{5}$$

The parameters L_S and PSI_S can also be expressed in terms of orbital angular variables. Figure 2 shows the geometry of an arc of the true spacecraft orbit relative to the equatorial plane. The arc u is along the orbital plane and is measured from the intersection of the orbital plane and equatorial plane (the ascending node) to the spacecraft position. In orbital mechanics, this angle, u, is called the argument of latitude. The arc S is along the equatorial plane and is measured from the ascending node to a point that is along the meridian containing the spacecraft position. The arc T is the angle measured along that meridian from the equatorial plane to the spacecraft position. This angle, T, is called the geocentric latitude. The arcs (u,S,T) form a spherical right triangle. From spherical trigonometry

$$\sin(T) = \sin(u)\sin(i)$$

where i, the inside angle formed by u and S, is the orbit inclination. Since T is the geocentric latitude, this equation defines the Kamel parameter L_S (the sine of the geocentric latitude) in terms of orbital angles:

$$L_S = \sin(u)\sin(i) \tag{6}$$

Also shown in Figure 2 is the angle a, or the orbit yaw, which is the angle that the instantaneous velocity vector makes with a parallel projection of the equatorial plane. From the geometry of Figure 2 it is evident that

$$a + b = 90 \text{ degrees}$$

Then from spherical trigonometry,

$$\cos(b) = \cos(90 - a) = \sin(a) = \cos(S)\sin(i)$$

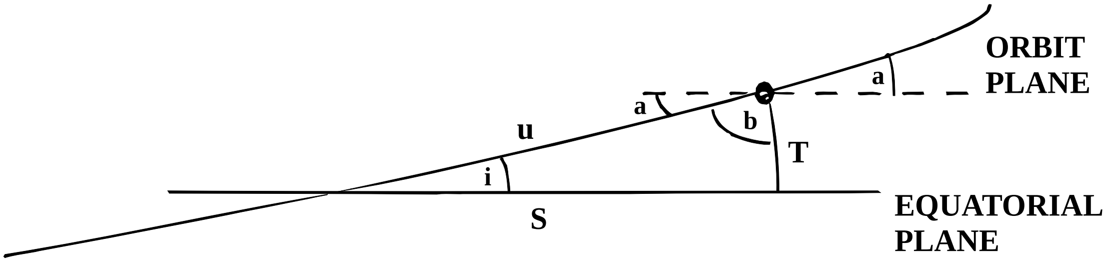


Figure 2. Relationship Between Orbit Geometry and the Angles of Geocentric Latitude and Orbit Yaw

For small inclination orbits, the angle S can be approximated to be the angle u with a high degree of accuracy. (For example, for an orbit with 0.5-degree inclination, this approximation is good to within 0.004 percent). Making this approximation,

$$\sin(a) = \cos(u)\sin(i)$$

Since a is the orbit yaw, this equation defines the Kamel parameter PSI_s (the sine of the orbit yaw) in terms of orbital angles:

$$PSI_S = \cos(u)\sin(i) \qquad (7)$$

Dividing equation (7) by equation (6) gives

$$\tan(u) = L_S/PSI_S$$

or

$$u = ATAN2(L_S/PSI_S)$$

which is the second term in equation (3) for Dlambda. Substituting the above expression for u into equation (3) gives an expression for Dlambda completely in terms of orbital angles:

$$Dlambda = RANODE + u - GHA - Lambda_0 \qquad (8)$$

Note that a singularity exists as PSI_S (or orbit yaw) goes to zero. In the event that this occurs, then u is determined from L_S in the following manner:

- If $L_s > 0$ then u = 90 degrees.
- If $L_s < 0$ then u = 270 degrees.
- If $L_S = PSI_S = 0$ then the inclination and right ascension of the ascending node also go to zero and

$$u = Dlambda + GHA + Lambda_0.$$

EXPRESSION OF KAMEL PARAMETERS IN TERMS OF IMC ORBIT COEFFICIENTS

The four Kamel parameters are obtained from the 42 IMC orbit coefficients in documentation block of the GVAR data for the Imager and Sounder. Table 1 lists the word locations in the respective documentation blocks for these IMC coefficients. In terms of these coefficients, the Kamel parameters are the following:

$$\begin{aligned} DR = {} & A14 + A15\cos(w_0t) + A16\sin(w_0t) + A17\cos(2w_0t) \\ & + A18\sin(2w_0t) + A19\cos(w_1t) + A20\sin(w_1t) \\ & + A21\cos(w_2t) + A22\sin(w_2t) \\ & + w_0t\,\{\, A23\cos(w_0t) + A24\sin(w_0t)\,\} \end{aligned} \tag{9}$$

$$\begin{aligned} Dlambda = {} & A1 + A2w_0t + A3w_0^2t^2 \\ & + 2[\,A4\sin(w_0t) + A5\cos(w_0t) + A6\sin(2w_0t) \\ & + A8\sin(w_1t) + A9\cos(w_1t) + A10\sin(w_2t) \\ & + A7\cos(2w_0t) + A11\cos(w_2t)] \\ & + 2w_0t[\,A12\sin(w_0t) + A13\cos(w_0t)] \end{aligned} \tag{10}$$

$$\begin{aligned} L_s = {} & A25 + A26\cos(w_0t) + A27\sin(w_0t) + A28\cos(2w_0t) \\ & + A29\sin(2w_0t) + w_0t[A30\cos(w_0t) + A31\sin(w_0t)] \\ & + A32\cos(w_2t) + A33\sin(w_2t) \end{aligned} \tag{11}$$

$$\begin{aligned} PSI_s = {} & A34 + A35\sin(w_0t) + A36\cos(w_0t) \\ & + A37\sin(2w_0t) + A38\cos(2w_0t) \\ & + w_0t[\,A39\sin(w_0t) + A40\cos(w_0t)\,] \\ & + A41\sin(w_2t) + A42\cos(w_2t) \end{aligned} \tag{12}$$

where w_0 = 0.7292115D-4 radians/second
= the sidereal rotation rate of the Earth

$2*w_0$ = 1.458423D-4 radians/second
= the second harmonic of the Earth's rotation rate

Table 1. Word Locations of the 42 IMC Orbit Coefficients in the Imager and Sounder Documentation Block 0

Coefficient	Description (Units)	Imager Documentation Block 0 Word Location	Sounder Documentation Block 0 Word Location
A1	Change in longitude from reference (radians)	347	375
A2	Change in longitude from reference (radians)	351	379
A3	Change in longitude from reference (radians)	355	383
A4	Change in longitude from reference (radians)	359	387
A5	Change in longitude from reference (radians)	363	391
A6	Change in longitude from reference (radians)	367	395
A7	Change in longitude from reference (radians)	371	399
A8	Change in longitude from reference (radians)	375	403
A9	Change in longitude from reference (radians)	379	407
A10	Change in longitude from reference (radians)	383	411
A11	Change in longitude from reference (radians)	387	415
A12	Change in longitude from reference (radians)	391	419
A13	Change in longitude from reference (radians)	395	423
A14	Change in radial distance from reference (km)	399	427
A15	Change in radial distance from reference (km)	403	431
A16	Change in radial distance from reference (km)	407	435
A17	Change in radial distance from reference (km)	411	439
A18	Change in radial distance from reference (km)	415	443
A19	Change in radial distance from reference (km)	419	447
A20	Change in radial distance from reference (km)	423	451
A21	Change in radial distance from reference (km)	427	455
A22	Change in radial distance from reference (km)	431	459
A23	Change in radial distance from reference (km)	435	463
A24	Change in radial distance from reference (km)	439	467
A25	Sine of geocentric latitude (no units)	443	471
A26	Sine of geocentric latitude (no units)	447	475
A27	Sine of geocentric latitude (no units)	451	479
A28	Sine of geocentric latitude (no units)	455	483
A29	Sine of geocentric latitude (no units)	459	487
A30	Sine of geocentric latitude (no units)	463	491
A31	Sine of geocentric latitude (no units)	467	495
A32	Sine of geocentric latitude (no units)	471	499
A33	Sine of geocentric latitude (no units)	475	503
A34	Sine of orbit yaw (no units)	479	507
A35	Sine of orbit yaw (no units)	483	511
A36	Sine of orbit yaw (no units)	487	515
A37	Sine of orbit yaw (no units)	491	519
A38	Sine of orbit yaw (no units)	495	523
A39	Sine of orbit yaw (no units)	499	527
A40	Sine of orbit yaw (no units)	503	531
A41	Sine of orbit yaw (no units)	507	535
A42	Sine of orbit yaw (no units)	511	539

w_1 = 0.1405004D-3 radians/second

= $2*w_0 - 2*w_m$

= the frequency of twice the mean spacecraft orbital motion relative to the mean lunar motion, w_m

w_2 = 0.6759791D-4 radians/second

= $w_0 - 2*w_m$

= the frequency of the mean spacecraft orbital motion relative to the mean lunar motion

w_m = 0.0533219D-4 radians/second

= the mean lunar motion defined as the rate of change of the mean longitude of the moon, measured along the ecliptic from the mean equinox of date of the ecliptic plane to the ascending node of the lunar orbit, then along the lunar orbit

t = the time elapsed since epoch in seconds

DERIVATION OF THE SATELLITE POSITION VECTOR

The equations (1), (6), (7), and (8) can be used to find the spacecraft position vector in the following manner. Figure 3 shows two coordinate systems—the Cartesian coordinate system (x,y,z) and the Coordinate system (U,V,W) where:

U is in the direction pointing to the spacecraft position

W is in the direction of orbit normal

V completes the right-handed coordinate system

A vector in the Cartesian coordinate system can be rotated into the (UVW)-system through the following three rotations:

$$\begin{bmatrix} \cos(RANODE) & \sin(RANODE) & 0 \\ -\sin(RANODE) & \cos(RANODE) & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad (13)$$

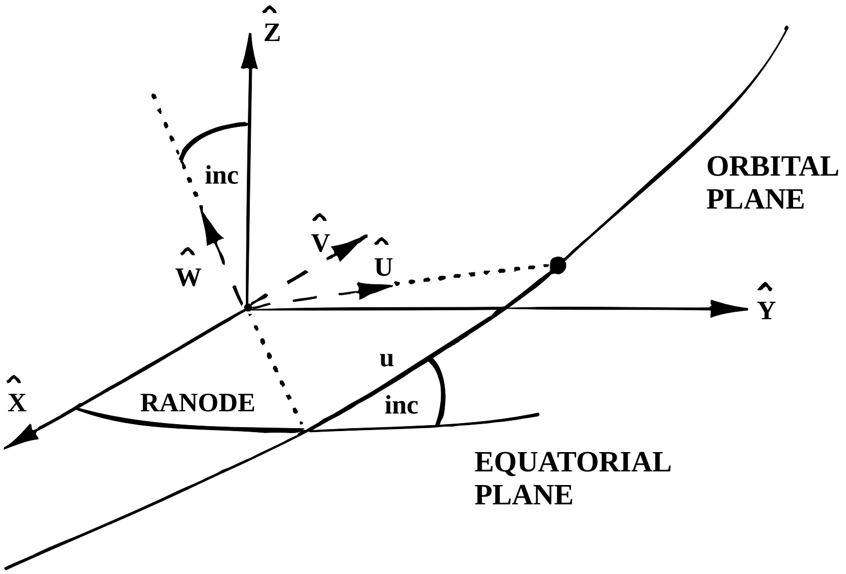


Figure 3. Geometry of Rotation from Inertial Coordinates to Orbital Coordinates

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(i) & \sin(i) \\ 0 & -\sin(i) & \cos(i) \end{bmatrix} \tag{14}$$

$$\begin{bmatrix} \cos(u) & \sin(u) & 0 \\ -\sin(u) & \cos(u) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{15}$$

The full rotation is a product of these three rotations:

$$T = \begin{bmatrix} \begin{matrix} (\cos(u)\cos(RANODE) \\ -\sin(u)\ \sin(RANODE)\ \cos(i)) \end{matrix} & \begin{matrix} (\cos(u)\ \sin(RANODE) \\ +\sin(u)\ \cos(RANODE)\ \cos(i)) \end{matrix} & \sin(u)\ \sin(i) \\ \begin{matrix} (-\sin(u)\ \cos(RANODE) \\ -\cos(u)\ \sin(RANODE)\ \cos(i)) \end{matrix} & \begin{matrix} (-\sin(u)\ \sin(RANODE) \\ +\cos(u)\ \cos(RANODE)\ \cos(i)) \end{matrix} & \cos(u)\ \sin(i) \\ \sin(RANODE)\ \sin(i) & -\sin(i)\cos(RANODE) & \cos(i) \end{bmatrix}$$

The (xyz)-system is then rotated into the (UVW)-system through

$$T \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} U \\ V \\ W \end{bmatrix} \tag{16}$$

Using this rotation, the Cartesian components of the unit vector U, which is the unit vector pointing to the spacecraft position vector, are the following:

$$U_x = \cos(u)\cos(RANODE) - \sin(u)\sin(RANODE)\cos(i) \quad (17)$$

$$U_y = \cos(u)\sin(RANODE) + \sin(u)\cos(RANODE)\cos(i) \quad (18)$$

$$U_Z = \sin(u)\sin(i) \quad (19)$$

The angles u, RANODE, and i can be obtained from the Kamel parameter equations (6), (7), and (8):

$$u = ATAN2(L_s/PSI_s) \quad (20)$$

where

if $PSI_s = 0$ and $L_s > 0$ then $u = 90$ degrees;

if $PSI_s = 0$ and $L_s < 0$ then $u = 270$ degrees;

if $L_s = PSI_s = 0$ then $u = Dlambda + GHA + Lambda_0$

$$RANODE = Dlambda - u + GHA + Lambda_0 \quad (21)$$

$$i = \arcsin[sqrt(L_s^2 + PSI_s^2)] \quad (22)$$

The Kamel parameter equation (1) can then be used to obtain the spacecraft position vector. From equation (1), the magnitude of the spacecraft position vector is

$$R = R_0 + DR \quad (23)$$

Then the (x,y,z) Cartesian components of the spacecraft position are:

$$x = RU_X \quad (24)$$

$$y = RU_y \quad (25)$$

$$z = RU_z \quad (26)$$

DERIVATION OF THE SATELLITE VELOCITY VECTOR

The velocity is derived using the partial derivatives of the position vector given in equations (24) through (26) as follows:

$$v_x = dx/dt = (dR/dt)U_x + R(dU_x/dt) \qquad (27)$$

$$v_y = dy/dt = (dR/dt)U_y + R(dU_y/dt) \qquad (28)$$

$$v_z = dz/dt = (dR/dt)U_z + R(dU_z/dt) \qquad (29)$$

Using equations (17) through (23) the following expressions are obtained for the quantities dR/dt and dU_i/dt ($i = x,y,z$) in terms of the four Kamel parameters and their time derivatives:

$$dR/dt = d(DR)/dt \qquad (30)$$

$$\begin{aligned} dU_x/dt = &- (du/dt)\sin(u)\cos(RANODE) \\ &- (dRANODE/dt)\cos(u)\sin(RANODE) \\ &- (du/dt)\cos(u)\sin(RANODE)\cos(i) \\ &- (dRANODE/dt)\sin(u)\cos(RANODE)\cos(i) \\ &+ (di/dt)\sin(u)\sin(RANODE)\sin(i) \qquad (31) \end{aligned}$$

$$\begin{aligned} dU_y/dt = &- (du/dt)\sin(u)\sin(RANODE) \\ &+ (dRANODE/dt)\cos(u)\cos(RANODE) \\ &+ (du/dt)\cos(u)\cos(RANODE)\cos(i) \\ &- (dRANODE/dt)\sin(u)\sin(RANODE)\cos(i) \\ &- (di/dt)\sin(u)\cos(RANODE)\sin(i) \qquad (32) \end{aligned}$$

$$dU_z/dt = dL_s/dt \qquad (33)$$

where

$$du/dt = [(dL_s/dt)PSI_s - (dPSI_s/dt)L_s]/\sin^2(i) \qquad (34)$$

$$dRANODE/dt = dDlambda/dt - du/dt + dGHA/dt \qquad (35)$$

(dGHA/dt is the sidereal rate of the Earth's rotation
= w_0 = 0.7292115D-4 radians/second)

$$di/dt = [L_s(dL_s/dt) + PSI_s(dPSI_s/dt)]/(\sin(i)\cos(i)) \qquad (36)$$

Equations (34) and (36) encounter singularities when the inclination goes to zero. These singularities are avoided, however, when these equations, along with equation (35), are directly substituted into equations (31) and (32). Using the following three trigonometric relations

$$(1 - \cos i)/\sin^2 i = 1/[2\cos^2(i/2)]$$

$$\sin(RANODE)\cos(u) - \cos(RANODE)\sin(u) = \sin(RANODE - u)$$

$$\sin(RANODE)\sin(u) + \cos(RANODE)\cos(u) = \cos(RANODE - u)$$

the expressions for dU_x/dt (equation (31)) and dU_y/dt (equation (32)) reduce to forms that are more appropriate for small inclination orbits:

$$\begin{aligned} dU_x/dt = {} & ((dL_s/dt)PSI_s - (dPSI_s/dt)L_s)\sin(RANODE - u)/(2\cos^2(i/2)) \\ & + ((dL_s/dt)L_s + (dPSI_s/dt)PSI_s)(\sin(u)\sin(RANODE)/\cos(i)) \\ & - dDlambda/dt(\cos(u)\sin(RANODE) + \sin(u)\cos(RANODE)\cos(i)) \qquad (37) \\ & - dGHA/dt[\cos(u)\sin(RANODE) + \sin(u)\cos(RANODE)\cos(i)] \end{aligned}$$

$$\begin{aligned} dU_y/dt = {} & ((dPSI_s/dt)L_s - (dL_s/dt)PSI_s)\cos(RANODE - u)/[2\cos^2(i/2)] \\ & - ((dL_s/dt)L_s + (dPSI_s/dt)PSI_s)\sin(u)\cos(RANODE)/\cos(i) \\ & + dDlambda/dt(\cos(u)\cos(RANODE) - \sin(u)\sin(RANODE)\cos(i)) \qquad (38) \\ & + dGHA/dt[\cos(u)\cos(RANODE) - \sin(u)\sin(RANODE)\cos(i)] \end{aligned}$$

Using equations (9) through (12) the time derivatives of the Kamel parameters are the following:

$$\begin{aligned} \mathrm{dDR/dt} = {} & w_0[-\mathrm{Al5}\sin(w_0t) + \mathrm{Al6}\cos(w_0t)] \\ & + 2w_0[-\mathrm{Al7}\sin(2w_0t) + \mathrm{Al8}\cos(2w_0t)] \\ & + w_1[-\mathrm{A19}\sin(w_1t) + \mathrm{A20}\cos(w_1t)] \\ & + w_2[-\mathrm{A21}\sin(w_2t) + \mathrm{A22}\cos(w_2t)] \\ & + w_0[\mathrm{A23}\cos(w_0t) + \mathrm{A24}\sin(w_0t)] \\ & + w_0^2t[-\mathrm{A23}\sin(w_0t) + \mathrm{A24}\cos(w_0t)] \end{aligned} \tag{39}$$

$$\begin{aligned} \mathrm{dDlambda/dt} = {} & \mathrm{A2}w_0 + 2\mathrm{A3}w_0^2t + 2w_0[\mathrm{A4}\cos(w_0t) - \mathrm{A5}\sin(w_0t)] \\ & + 4w_0[\mathrm{A6}\cos(2w_0t) - \mathrm{A7}\sin(2w_0t)] \\ & + 2w_1[\mathrm{A8}\cos(w_1t) - \mathrm{A9}\sin(w_1t)] \\ & + 2w_2[\mathrm{A10}\cos(w_2t) - \mathrm{A11}\sin(w_2t)] \\ & + 2w_0[\mathrm{A12}\sin(w_0t) + \mathrm{A13}\cos(w_0t)] \\ & + 2w_0^2t[\mathrm{A12}\cos(w_0t) - \mathrm{A13}\sin(w_0t)] \end{aligned} \tag{40}$$

$$\begin{aligned} \mathrm{d}L_s\mathrm{/dt} = {} & w_0[-\mathrm{A26}\sin(w_0t) + \mathrm{A27}\cos(w_0t)] \\ & + 2w_0[-\mathrm{A28}\sin(2w_0t) + \mathrm{A29}\cos(2w_0t)] \\ & + w_0[\mathrm{A30}\cos(w_0t) + \mathrm{A31}\sin(w_0t)] \\ & + w_0^2t[-\mathrm{A30}\sin(w_0t) + \mathrm{A31}\cos(w_0t)] \\ & + w_2[-\mathrm{A32}\sin(w_2t) + \mathrm{A33}\cos(w_2t)] \end{aligned} \tag{41}$$

$$\begin{aligned} \mathrm{dPSI}_s\mathrm{/dt} = {} & w_0[\mathrm{A35}\cos(w_0t) - \mathrm{A36}\sin(w_0t)] \\ & + 2w_0[\mathrm{A37}\cos(2w_0t) - \mathrm{A38}\sin(2w_0t)] \\ & + w_0[\mathrm{A39}\sin(w_0t) + \mathrm{A40}\cos(w_0t)] \\ & + w_0^2t[\mathrm{A39}\cos(w_0t) - \mathrm{A40}\sin(w_0t)] \\ & + w_2[\mathrm{A41}\cos(w_2t) - \mathrm{A42}\sin(w_2t)] \end{aligned} \tag{42}$$

The velocity vector components (equations (27) through (29)) are then obtained with substitutions of equations (39) through (42) into equations (30), (33), (37), and (38) followed by substitution of equations (30), (33), (37), and (38) into equations (27) through (29).

CARTESIAN ELEMENT CONVERSION TO KEPLERIAN ELEMENTS

The Keplerian elements can now be obtained from the position and velocity vectors through the following:

Semi-major axis (sma):

$$\text{sma} = R/[2 - (RV^2)/\text{mu}] \tag{43}$$

where R = the magnitude of the position vector
V = the magnitude of the velocity vector
mu = the Earth's gravitational constant

Eccentricity (ecc):

$$\text{ecc} = \text{sqrt}[\ 1 - (p/\text{sma})\ ] \tag{44}$$

where $p = [(RV)^2 - (\vec{R} \bullet \vec{V})^2]/\text{mu}$
$\vec{R} \bullet \vec{V} = xv_x + yv_y + zv_z$

Inclination (inc):

$$\text{inc} = \arcsin[\text{sqrt}(L_s^2 + PSI_s^2)] \tag{45}$$

Right ascension of the ascending node (RANODE):

$$\text{RANODE} = \text{Dlambda} - u + \text{GHA} + \text{Lambda}_0 \tag{46}$$

True anomaly (TA):

$$\text{TA} = \text{ATAN2}\ [\{(\vec{R} \bullet \vec{V})\text{sqrt}(p/\text{mu})\}\ /(p - R)] \tag{47a}$$

If (p - R) is zero (or, equivalently, if the eccentricity is zero) then the argument of perigee is undefined. (Note: When the eccentricity is near zero the argument of perigee is ill-defined due to limitations in mathematical algorithms and floating point computations.) In that case, the argument of perigee is set to zero and the true anomaly is

$$\text{TA} = u \tag{47b}$$

Argument of perigee (ARGPER):

If the eccentricity is zero then

$$\text{ARGPER} = 0 \tag{48a}$$

else

$$\text{ARGPER} = u - \text{TA} \tag{48b}$$

Eccentric anomaly (EA):

$$\text{arg} = \text{sqrt}[(1 - \text{ecc})/(1 + \text{ecc})]$$
$$\text{EA} = 2*\text{arctangent}[\text{arg}*\text{tangent}\ (\text{TA}/2)] \tag{49}$$

Mean anomaly (MA):

$$\text{MA} = \text{EA} - \text{ecc}*\sin(\text{EA}) \tag{50}$$

2. GENERAL ALGORITHM

The following algorithm can be used as the basis for a computer program that will obtain the Keplerian elements from the 42 IMC coefficients contained in the imager and sounder documentation blocks (see Table 1). It is organized in four steps, each of which can be programmed as subroutines if desired. These steps are the following:

1. Compute the four Kamel parameters and their time derivatives from the 42 IMC coefficients.
2. Compute three orbit angles, their time derivatives, and the magnitude of the spacecraft position from the four Kamel parameters and their time derivatives.
3. Compute the position and velocity vectors from three orbit angles, their time derivatives, and the magnitude of the spacecraft position.
4. Compute the Keplerian elements from the position and velocity vectors.

The algorithm is written in pseudocode form with variable names given in FORTRAN like form. Comments that are not part of the algorithm are contained within double parentheses.

```
((  ALGORITHM TO CONVERT THE KAMEL PARAMETERS TO                    ))
((  KEPLERIAN ELEMENTS.                                             ))
((                                                                  ))
((          NOTES:                                                  ))
((                                                                  ))
((                                                                  ))
((          1.  THIS ALGORITHM SHOULD BE PROGRAMMED IN DOUBLE       ))
((              PRECISION.                                          ))
((                                                                  ))
((          2.  INTRINSIC FUNCTIONS (SUCH AS SINE, COSINE, ETC.)    ))
((              ARE LISTED IN LOWER CASE IN THIS ALGORITHM.         ))
((                                                                  ))
((                                                                  ))
((          INPUT PARAMETERS:                                       ))
((                                                                  ))
((          A(42) - A 1 X 42 ARRAY CONTAINING THE 42 IMC ORBIT      ))
((          COEFFICIENTS                                            ))

((                                                                  ))
((          T - TIME IN SECONDS SINCE EPOCH                         ))
((                                                                  ))
((                                                                  ))
((          GHA - THE GREENWICH HOUR ANGLE (IN RADIANS) AT THE      ))
((          TIME OF THE ABOVE COEFFICIENTS                          ))
((                                                                  ))
```

```
((          LAM0 - THE REFERENCE SUBSATELLITE LONGITUDE FOR                 ))
((          THE SPACECRAFT IN RADIANS (FOR EXAMPLE, -1.308997               ))
((          RADIANS (-75 DEGREES EAST) FOR GOES-EAST OR                     ))
((          -2.356194 RADIANS (-135 DEGREES EAST) FOR                       ))
((          GOES-WEST)                                                      ))
((                                                                          ))
((                                                                          ))
((         CONSTANT PARAMETERS:                                             ))
((                                                                          ))
((             W0  -   (THE FUNDAMENTAL FREQUENCY IN THE IMC                ))
((                     EXPANSION) = 0.7292115D-4 RADIANS/SECOND             ))
((                                                                          ))
((                                                                          ))
((             W1  -   (THE FREQUENCY OF TWICE THE MEAN                     ))
((                     SPACECRAFT ORBITAL MOTION RELATIVE TO THE            ))
((                     MEAN LUNAR MOTION) = 0.1405004D-3 RADIANS/           ))
((                     SECOND                                               ))
((                                                                          ))
((                                                                          ))
((             W2  -   (THE FREQUENCY OF THE MEAN SPACECRAFT                ))
((                     ORBITAL MOTION RELATIVE TO THE MEAN LUNAR            ))
((                     MOTION) = 0.6759791D-4 RADIANS/SECOND                ))
((                                                                          ))
((                                                                          ))
((             MU -    (THE EARTH'S GRAVITATIONAL CONSTANT)                 ))
((                     = 3.9860044D5 KM**3/SECOND**2                        ))
((                                                                          ))
((                                                                          ))
((             R0 -    (THE NOMINAL GEOSTATIONARY ORBIT RADIAL              ))
((                     DISTANCE) = 42164.365D0 KM                           ))
((                                                                          ))
((                                                                          ))
((             GHADT -   (THE RATE OF CHANGE OF THE GREENWICH               ))
((                       HOUR ANGLE) = 0.7292115D-4 RADIANS/SECOND          ))
((                                                                          ))
((                                                                          ))
((          BEGIN COMPUTATION:                                              ))
((                                                                          ))
((          1.  COMPUTE THE FOUR KAMEL PARAMETERS AND THEIR                 ))
((              TIME DERIVATIVES FROM THE 42 IMC COEFFICIENTS:              ))
((                                                                          ))
((              1.1   COMPUTE INTERMEDIATE SINE AND COSINE VALUES:          ))
((                                                                          ))

                   C0 = cosine(W0*T)

                   S0 = sine(W0*T)

                   C20 = cosine(2.0D0*W0*T)
```

```
            S20 = sine(2.0D0*W0*T)

            Cl = cosine(W1*T)

            S1 = sine(W1*T)

            C2 = cosine(W2*T)

            S2 = sine(W2*T)


((                                                              ))
((          1.2   COMPUTE DR, THE RADIAL DISTANCE KAMEL         ))
((                PARAMETER:                                    ))
((                                                              ))

            DR =  A(14) + A(l5)*C0 + A(16)*S0 + A(17)*C20 + A(18)*S20
                  + A(19)*C1 + A(20)*S1 + A(21)*C2 + A(22)*S2
                  + W0*T*(A(23)*C0 + A(24)*S0)

((                                                              ))
((          1.3   COMPUTE DRDT, THE TIME DERIVATIVE OF THE      ))
((                RADIAL DISTANCE KAMEL PARAMETER:              ))
((                                                              ))

            DRDT =W0*(-A(15)*S0 + A(16)*C0) + 2.0D0*W0*(-A(17)*S20
                     + A(18)*C20) + W1*(-A(19)*S1 + A(20)*C1)
                     + W2*(-A(21)*S2 + A(22)*C2) + W0*(A(23)*C0
                     + A(24)*S0) + (W0**2)*T*(-A(23)*S0 + A(24)*C0)


((                               ))
((          1.4   COMPUTE DLAM, THE LONGITUDINAL KAMEL          ))
((                PARAMETER:                                    ))
((                                                              ))

            DLAM =A(1) + A(2)*W0*T + A(3)*((W0*T)**2)
                     + 2.0D0*(A(4)*S0 + A(5)*C0 + A(6)*S20 + A(7)*C20
                     + A(8)*S1 + A(9)*C1 + A(10)*S2 + A(11)*C2)
                     + 2.0D0*W0*T*(A(12)*S0 + A(13)*C0)
```

```
((                                                                      ))
((          1.5   COMPUTE DLAMDT, THE TIME DERIVATIVE OF THE            ))
((                LONGITUDINAL KAMEL PARAMETER:                         ))
((                                                                      ))

                  DLAMDT = A(2)*W0 + 2.0D0*A(3)*(W0**2)*T
                         + 2.0D0*W0*(A(4)*C0 - A(5)*S0)
                         + 4.0D0*W0*(A(6)*C20 - A(7)*S20)
                         + 2.0D0*(W1*(A(8)*C1 - A(9)*S1) + W2*(A(10)*C2
                         - A(11)*S2)) + 2.0D0*W0*(A(12)*S0 + A(13)*C0)
                         + 2.0D0*(W0**2)*T*(A(12)*C0 - A(13)*S0)

((                                                                      ))
((          1.6   COMPUTE LS, THE LATITUDINAL KAMEL PARAMETER:          ))
((                                                                      ))

                  LS =     A(25) + A(26)*C0 + A(27)*S0 + A(28)*C20 + A(29)*S20
                         + W0*T*(A(30)*C0 + A(31)*S0) + A(32)*C2 + A(33)*S2

((                                                                      ))
((          1.7   COMPUTE LSDT, THE TIME DERIVATIVE OF THE              ))
((                LATITUDINAL KAMEL PARAMETER:                          ))
((                                                                      ))

                  LSDT = W0*(-A(26)*S0 + A(27)*C0) + 2.0D0*W0*(-A(28)*S20
                       + A(29)*C20) + W0*(A(30)*C0 + A(31)*S0
                       + (W0**2)*T*(-A(30)*S0 + A(31 )*C0)
                       + W2*(-A(32)*S2 + A(33)*C2)

((                                                                      ))
((          1.8   COMPUTE PSIS, THE ORBIT YAW KAMEL PARAMETER:          ))
((                                                                      ))

                  PSIS = A(34) + A(35)*S0 + A(36)*C0 + A(37)*S20
                       + A(38)*C20 + W0*T*(A(39)*S0 + A(40)*C0)
                       + A(41)*S2 + A(42)*C2
```

```
((                                                              ))
((          1.9   COMPUTE PSISDT, THE TIME DERIVATIVE OF THE    ))
((                ORBIT YAW KAMEL PARAMETER:                    ))
((                                                              ))

                  PSISDT =  W0*(A(35)*C0 - A(36)*S0) + 2.0D0*W0*(A(37)*C20
                            - A(38)*S20) + W0*(A(39)*S0 + A(40)*C0)
                            + (W0**2)*T*(A(39)*C0 - A(40)*S0)
                            + W2*(A(41)*C2 - A(42)*S2)


((       2.  COMPUTE THREE ORBIT ANGLES, THEIR TIME                 ))
((           DERIVATIVES AND THE MAGNITUDE OF THE SPACECRAFT        ))
((           POSITION FROM THE FOUR KAMEL PARAMETERS AND            ))
((           THEIR TIME DERIVATIVES:                                ))
((                                                                  ))

((                                                                  ))
((          2.1   COMPUTE R, THE MAGNITUDE OF THE SPACECRAFT        ))
((                POSITION:                                         ))
((                                                                  ))

                  R = R0 + DR

((                                                                  ))
((          2.2   COMPUTE RDOT, THE TIME DERIVATIVE OF THE          ))
((                MAGNITUDE OF THE SPACECRAFT POSITION:             ))
((                                                                  ))

                  RDOT = DRDT

((                                                                  ))
((          2.3   COMPUTE I, THE INCLINATION:                       ))
((                                                                  ))


                  I = arcsine(sqrt(LS**2 + PSIS**2))
```

```
((                                                                      ))
((          2.4  COMPUTE ULAT, THE ARGUMENT OF LATITUDE:                ))
((                                                                      ))

                 IF absolute-value(PSIS) > 0.0D0 THEN
                     ULAT = ATAN2(LS/PSIS)
                  ELSE
                     IF LS > 0.0D0 THEN
                         ULAT = 1.570796D0
                     ELSEIF LS = 0.0D0 THEN
                         ULAT = DLAM + GHA + LAM0
                     ELSE
                         ULAT = 4.712389D0
                      ENDIF
                 ENDIF

((                                                                      ))
((          2.5  COMPUTE RA, THE RIGHT ASCENSION OF THE                 ))
((               ASCENDING NODE:                                        ))
((                                                                      ))

                 RA = DLAM - ULAT + GHA + LAM0

 ((                                                                     ))
((        3.  COMPUTE THE POSITION AND VELOCITY VECTORS FROM            ))
((            THREE ORBIT ANGLES, THEIR TIME DERIVATIVES AND THE        ))
((            MAGNITUDE OF THE SPACECRAFT POSITION:                     ))
((                                                                      ))
((                                                                      ))
((          3.1  COMPUTE INTERMEDIATE SINE AND COSINE VALUES:           ))
((                                                                      ))

                  SU = sine(ULAT)

                  CU = cosine(ULAT)

                  SI = sine(I)

                  CI = cosine(I)

                  SRA = sine(RA)

                  CRA = cosine(RA)
((                                                                      ))
```

```
((          3.2   COMPUTE RU(I) (I=1,2,3), THE (X,Y,Z) COMPONENTS              ))
((                OF THE UNIT VECTOR POINTING TO THE SPACECRAFT                ))
((                POSITION:                                                    ))

                    RU(1) = CU*CRA - SU*SRA*CI

                    RU(2) = CU*SRA + SU*CRA*CI

                    RU(3) = LS

((                                                                             ))
((          3.3   COMPUTE FUDOT(I) (I=1,2,3), THE TIME DERIVATIVE              ))
((                OF THE (X,Y,Z) COMPONENTS OF THE UNIT VECTOR                 ))
((                POINTING TO THE SPACECRAFT POSITION:                         ))

                  SRAU = sine(RA - ULAT)

                  CRAU = cosine(RA - ULAT)

                  C2I2 = (cosine(I/2))**2

                  RUDOT(1) =   (LSDT*PSIS - PSISDT*LS)*(SRAU/2.0D0/C2I2)
                               + (LSDT*LS + PSISDT*PSIS)*(SU*SRA/CI)
                               - DLAMDT*(CU*SRA + SU*CRA*CI)
                               - GHADT*(CU*SRA + SU*CRA*CI)

                  RUDOT(2) =   (PSISDT*LS - LSDT*PSIS)*(CRAU/2.0D0/C2I2)
                               - (LSDT*LS + PSISDT*PSIS)*(SU*CRA/CI)
                               + DLAMDT*(CU*CRA - SU*SRA*CI)
                               + GHADT*(CU*CRA - SU*SRA*CI)

                  RUDOT(3) =   LSDT

((                                                                             ))
((          3.4   COMPUTE POS(I) (I=1,2,3), THE (X,Y,Z)                        ))
((                COMPONENTS OF THE SPACECRAFT POSITION:                       ))
((                                                                             ))

                  POS(l) = R*RU(1)

                  POS(2) = R*RU(2)

                  POS(3) = R*RU(3)
((                                                                             ))
((          3.5   COMPUTE VEL(I) (I=1,2,3), THE (X,Y,Z)                        ))
((                COMPONENTS OF THE SPACECRAFT VELOCITY:                       ))
```

```
((                                                                  ))

            VEL(1) = RDOT*RU(1) + R*RUDOT(1)

            VEL(2) = RDOT*RU(2) + R*RUDOT(2)

            VEL(3) = RDOT*RU(3) + R*RUDOT(3)


((                                                                  ))
((      4.  COMPUTE THE KEPLERIAN ELEMENTS:                         ))
((                                                                  ))
((                                                                  ))
((          4.1   SEMI-MAJOR AXIS, SMA:                             ))
((                                                                  ))
            VELMAG = sqrt(VEL(1)**2 + VEL(2)**2 + VEL(3)**2)

            SMA = R/(2.0D0 - (R*(VELMAG**2)/MU))


((                                                                  ))
((          4.2   ECCENTRICITY, ECC:                                ))
((                                                                  ))
            RDOTV = POS(1)*VEL(1) + POS(2)*VEL(2) + POS(3)*VEL(3)

            P = ( (R*VELMAG)**2 - RDOTV**2 )/MU

            ECC = sqrt(1 - (P/SMA))


((                                                                  ))
((          4.3   INCLINATION, XINC (THIS HAS ALREADY BEEN          ))
((                COMPUTED FROM THE KAMEL PARAMETERS LS & PSIS):    ))
((                                                                  ))
             XINC = I


((                                                                  ))
((          4.4   RIGHT ASCENSION OF THE ASCENDING NODE, RANODE     ))
((                (THIS HAS ALREADY BEEN COMPUTED FROM THE          ))
((                KAMEL PARAMETER DLAM):                            ))
((                                                                  ))
              RANODE = RA
```

```
((                                                                   ))
((          4.5  TRUE ANOMALY, TA:                                   ))
((                                                                   ))

                    IF (P - R) > 0.0D0 THEN
                         TA = ATAN2((sqrt(P/MU)*RDOTV)/(P-R))
                  ELSE
                         TA = ULAT
                  ENDIF


((                                                                   ))
((          4.6  ARGUMENT OF PERIGEE, ARGPER:                        ))
((                                                                   ))

                  ARGPER= ULAT-TA

((                                                                   ))
((          4.7  ECCENTRIC ANOMALY, EA:                              ))
((                                                                   ))

                  ARG = sqrt[(1.0D0 - ECC)/(1.0D0 + ECC)]

                  EA = 2.0D0*arctangent(arg*tangent(TA/2.0D0))

((                                                                   ))
((               SET THE ECCENTRICITY BETWEEN 0 DEGREES              ))
((               (0 RADIANS) AND 360 DEGREES (2*PI RADIANS):         ))
((                                                                   ))

                  TWOPI = 2.0D0*3.1415926535898D0


                IF EA < 0.0D0 THEN
                     EA = EA + TWOPI
                ENDIF

((                                                                   ))
((          4.8  MEAN ANOMALY                                        ))
((                                                                   ))

                MA = EA - ECC*sine(EA)


((                                                                   ))
((    THIS COMPLETES COMPUTATION OF THE KEPLERIAN ELEMENTS.          ))
```

Appendix D. Acronym List

DocCCR	Document Configuration Change Request
ELUG	Earth Location User's Guide
GOES	Geostationary Operational Environmental Satellite Program
GVAR	GOES Variable
INR	Image Navigation and Registration System
IR	Infrared
IMC	Image Motion Compensation
MSPS	Modernized SPS
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
O&A	Orbit and Attitude
OATS	Orbit and Attitude Tracking System
OGE	Operations Ground Equipment
PDR	Processed Data Relay
SPS	Sensor Processing Subsystem

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