



## INTELSAT EARTH STATION STANDARDS (IESS)

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### EARTH STATION POINTING DATA

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1. INTRODUCTION

This document describes a method by which earth station operators may compute the pointing direction from any earth station to any selected Intelsat owned or operated spacecraft. The method may be implemented on a variety of computers ranging from a hand-held scientific calculator to personal computers. This document describes the required algorithms. The particular steps in the process are described in words and algebraic notation. A Microsoft Windows-based software program (*Earth Station Pointing Data*) that performs all of the necessary computations described in this module has been developed by Intelsat and is available for downloading from Intelsat Business Network's (IBN) web site at <https://ibn.intelsat.com/ephemeris/ephemeris.asp>.

2. DESCRIPTION OF SIMPLIFIED METHOD

2.1 Simplification by Approximation

The traditional method of predicting a satellite's motion involves the use of a large mainframe-type computer to integrate all of the known physical effects acting on the satellite with respect to time. However, once this has been done for a particular satellite over a limited time period, it is possible to specify the satellite's predicted position over this limited time by means of a much simplified process. Instead of computing all of the physical effects acting on a satellite, it is possible to describe the sum of all these effects in terms of three equations. This approximation contains eleven parameters obtained via least-squares curve fitting. This process specifies the optimum set of 11 parameters that will, when used with a specified algorithm, approximate the same satellite locations as predicted by the originating program. It has been demonstrated that, by using only 11 parameters, the simplified model approximates the integration prediction to better than  $0.01^\circ$  for a period of up to 7 days.

2.2 Use of Eleven Parameters

After the particular 11 parameters for a specified satellite and time period have been generated by Intelsat, they are posted on the IBN web site <https://ibn.intelsat.com/ephemeris/ephemeris.asp>. Earth stations can then compute the satellite's position for the particular time of interest using the algorithm described in this document and embodied in the software program discussed in Section 3. From the satellite's predicted position and the earth station's known position, the geometric pointing angles are calculated. Finally these pointing angles are corrected for the effects of atmospheric refraction and

the coordinate system modified if needed for the earth station's type of mount. The above process will typically be repeated, changing the time, to produce a table of pointing angles at sequential times. Each set of 11 parameters can be used for a period of up to 7 days from the epoch date.

In the case of earth stations equipped with programmed tracking systems, this table will be entered into the antenna controller. It is possible that future designs of antenna tracking controllers may have these algorithms incorporated into their design, thus requiring only the entry of the parameters specified by the IOC.

### 2.3 Eleven Parameters and Associated Information

The following are the set of 11 ephemeris parameters, which are used in the algorithm:

a)	<u>UNIT</u>	<u>QUANTITY</u>	<u>SYMBOL</u>
1.	Mean Longitude (East of Greenwich)	$L_0$	deg
2.	Drift Rate	$L_1$	deg/day
3.	Drift Acceleration	$L_2$	deg/day/day
4.	Longitude Oscillation—amplitude	$L_c$	deg
5.	and rate of change, cosine term	$L_{c1}$	deg/day
6.	Longitude Oscillation—amplitude	$L_s$	deg
7.	and rate of change, sine term	$L_{s1}$	deg/day
8.	Latitude Oscillation—amplitude	$l_c$	deg
9.	and rate of change, cosine term	$l_{c1}$	deg/day
10.	Latitude Oscillation—amplitude	$l_s$	deg
11.	and rate of change, sine term	$l_{s1}$	deg/day

In addition to the 11 ephemeris parameters, the following additional information will be supplied with each set of ephemeris data:

1. Satellite Identification
2. Nominal Center of Box Position

3. Epoch time on which the ephemeris is based
4. Estimated satellite position at 170 hours after the epoch.

The final item, the estimated position, is used to verify the transmission accuracy of the ephemeris information by calculating the position at Epoch + 170 hours. The end user should compare his result with that obtained by Intelsat. Any significant discrepancy will indicate an error in the user's calculation. An example of the IOC ephemeris message which is posted on the IBN web site <https://ibn.intelsat.com/ephemeris/ephemeris.asp> is provided in Section 3.5.

#### 2.4 Expression for Satellite Position with Time

The expressions for predicting the satellite's position at any relative time “t” (days) from the start of the prediction interval (the epoch) are:

##### 2.4.1 Satellite East Longitude, $\Theta_{sat}$

$$\Theta_{sat} = L_0 + L_1 t + L_2 t^2 + (L_c + L_{c1} t) \cos(Wt) + (L_s + L_{s1} t) \sin(Wt) + \left(\frac{K}{2}\right) (I_c^2 - I_s^2) \sin(2Wt) - K I_c I_s \cos(2Wt) \dots \dots \dots (1)$$

##### 2.4.2 Satellite Geocentric Latitude, $\Phi_{sat}$

$$\Phi_{sat} = (I_c + I_{c1} t) \cos(Wt) + (I_s + I_{s1} t) \sin(Wt) \dots \dots \dots (2)$$

##### 2.4.3 Satellite Radius, $r_{sat}$

$$r_{sat} = R_s \left[ 1 - \frac{2L_1}{3(W - L_1)} \right] \left[ 1 + KL_c \sin(Wt) - KL_s \cos(Wt) \right] \dots \dots \dots (3)$$

where W,  $R_s$  and K in the above formulas are given by:

- W =  $L_1 + 360.98564$  degrees / day  
 $R_s$  = 42,164.57 km (Synchronous Radius)  
 K =  $\pi / 360$  (i.e., 0.0087266462)  
 t = Time, in days

2.5 Description of the Calculation of the Earth Station Coordinates in the Earth Fixed Geocentric Coordinate System

Since the satellite's position is expressed with respect to a geocentric coordinate system that rotates with the earth, the earth station's position is time-invariant and is calculated only once. The earth station's coordinates are generally expressed in terms of geodetic latitude and longitude and height above a reference ellipsoid (altitude). Intelsat has adopted the IAU-1976 reference ellipsoid as its reference. This reference is based on an equatorial radius of 6378.140 km and a flattening constant which recognizes that the polar radius is less than the equatorial radius by 1 part in 298.257.

The earth station's position is calculated in terms of radial distance from the rotational axis of the earth  $R_a$ , and axial distance north of the equatorial plane of the earth,  $R_z$ .

$f$  = flattening constant of earth ellipsoid (0.0033528131)

$R_{eq}$  = equatorial radius of earth ellipsoid (6378.14 km)

$\Phi_{sta}$  = geodetic latitude of station

$h$  = geodetic height of station above ellipsoid (km)

$R_a$  = earth station radial distance from earth rotation axis

$R_z$  = earth station distance above earth equatorial plane

$$R = \frac{R_{eq}}{\left[ 1 - f(2 - f)(\sin(\Phi_{sta}))^2 \right]^{1/2}} \dots\dots\dots (4)$$

2.5.1 Earth Station Radial Distance From Earth Rotation Axis,  $R_a$

$$R_a = (R + h) \cos(\Phi_{sta}) \dots\dots\dots (5)$$

2.5.2 Earth Station Distance Above Earth Equatorial Plane,  $R_z$

$$R_z = \left[ R(1 - f)^2 + h \right] \sin(\Phi_{sta}) \dots\dots\dots (6)$$

2.6 Description of the Calculation of the Earth Station Pointing Angles

With the satellite's position defined as a function of time in terms of a geocentric system aligned with the earth station's meridian, the satellite's position with

respect to the earth station and the appropriate pointing angles can be calculated:

$$\Delta r = r_{\text{satellite}} - r_{\text{station}} \quad (\text{vector subtraction}) \dots\dots\dots (7)$$

$$\Delta r_x = r_{\text{sat}} \cos(\Phi_{\text{sat}}) \cos(\Theta_{\text{sat}} - \Theta_{\text{sta}}) - R_a \dots\dots\dots (8)$$

$$\Delta r_y = r_{\text{sat}} \cos(\Phi_{\text{sat}}) \sin(\Theta_{\text{sat}} - \Theta_{\text{sta}}) \dots\dots\dots (9)$$

$$\Delta r_z = r_{\text{sat}} \sin(\Phi_{\text{sat}}) - R_z \quad \dots\dots\dots (10)$$

where:

$r_{\text{sat}}$  = satellite radius (Equation 3)

$\Phi_{\text{sat}}$  = satellite latitude (geocentric) (Equation 2)

$\Theta_{\text{sat}}$  = satellite longitude (Equation 1)

$\Theta_{\text{sta}}$  = earth station longitude east of Greenwich

$R_a$  = earth station radial distance from earth rotation axis (Equation 5)

$R_z$  = earth station distance above earth equatorial plane (Equation 6)

If the antenna equipment requires pointing in terms of azimuth and elevation angles, the following calculations are performed:

$$\Delta r_{\text{north}} = -\Delta r_x \sin(\Phi_{\text{sta}}) + \Delta r_z \cos(\Phi_{\text{sta}}) \dots\dots\dots (11)$$

$$\Delta r_{\text{zenith}} = \Delta r_x \cos(\Phi_{\text{sta}}) + \Delta r_z \sin(\Phi_{\text{sta}}) \dots\dots\dots (12)$$

2.6.1 Earth Station Azimuth Angle, Az

$$Az = \arctan \left[ \frac{\Delta r_y}{\Delta r_{\text{north}}} \right] \dots\dots\dots (13)$$

The result can be corrected with following expression if  $\Delta r_{\text{north}}$  is less than or equal to 0.0:

$$Az = Az + 180.0 \quad \dots\dots\dots (14)$$

2.6.2 Earth Station Elevation Angle,  $EL_{\text{geometric}}$

$$EL_{\text{geometric}} = \arctan \left[ \frac{\Delta r_{\text{zenith}}}{\left( \Delta r_{\text{north}}^2 + \Delta r_y^2 \right)^{1/2}} \right] \dots\dots\dots (15)$$

2.7 Description of the Correction to the Earth Station-to-Satellite Pointing Due to Atmospheric Refraction

As radio waves pass through the atmosphere, their direction of travel is deflected due to the atmospheric refractivity. For high elevation angles, a simple correction accurately accounts for this deflection. At low elevation angles, however, the correction below, based on actual observational data, must be used. The indicated amount of correction at low elevation angles will be valid for most of the time but may be subject to random time-varying errors on exceptional occasions, depending on atmospheric conditions:

If  $EL_{\text{geometric}} > 10.2^\circ$ :

$$EL_{\text{observed}} = EL_{\text{geometric}} + 0.01617 \cot(EL_{\text{geometric}}) \dots\dots\dots (16)$$

This may also be coded as:

$$EL_{\text{observed}} = EL_{\text{geometric}} + 0.01617 \left[ \frac{\cos(EL_{\text{geometric}})}{\sin(EL_{\text{geometric}})} \right] \dots\dots\dots (17)$$

If  $EL_{\text{geometric}} < 10.2^\circ$ :

$$EL_{\text{observed}} = EL_{\text{geometric}} + a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 \dots\dots\dots (18)$$

where:

$EL_{\text{observed}}$  = apparent elevation angle

$EL_{\text{geometric}}$  = actual geometric elevation angle

$x$  =  $EL_{\text{geometric}} + 0.589^\circ$

$a_0$  = 0.58804392

$a_1$  = -0.17941557

$a_2$  =  $0.29906946 \times 10^{-1}$

$$a_3 = -0.25187400 \times 10^{-2}$$

$$a_4 = 0.82622101 \times 10^{-4}$$

## 2.8 Conversion of Pointing Angles for Polar-Mount Antenna Systems

For antennas using polar mounts, pointing is defined in terms of the traditional hour-angle and declination, where hour angle is referenced to the earth station's local meridian and declination angle is referenced to the equatorial plane. For these stations, the following calculations are performed to convert the previously calculated and corrected azimuth and elevation angles to hour-angle and declination angle.

### 2.8.1 Hour Angle

$$\text{Hour Angle} = \arctan \left[ \frac{-\cos(\text{EL}) \sin(\text{Az})}{\sin(\text{EL}) \cos(\Phi_{\text{sta}}) - \cos(\text{EL}) \sin(\Phi_{\text{sta}}) \cos(\text{Az})} \right] \dots\dots\dots (19)$$

### 2.8.2 Declination

$$\text{Declination} = \arcsin \left[ \sin(\text{EL}) \sin(\Phi_{\text{sta}}) + \cos(\text{EL}) \cos(\Phi_{\text{sta}}) \cos(\text{Az}) \right] \dots\dots\dots (20)$$

Where EL = EL<sub>observed</sub>, as computed in Equation (17) or (18).

## 3. OPERATIONAL SOFTWARE PROGRAM

This section describes the Microsoft Windows-based *Earth Station Pointing Data* program that is available for downloading from the IBN web site (<https://ibn.intelsat.com/ephemeris/ephemeris.asp>) and the data message that the IOC issues for use with this program (see Section 3.5).

### 3.1 Microsoft Windows Version Compatibility

The Microsoft Windows-based *Earth Station Pointing Data* program implements the simplified pointing algorithm described in this module. The current version (4.0) of this program is compatible with PCs using Windows 95, 98, NT / 2000 and XP operating systems.

### 3.2 Earth Station Pointing Data

The program calculates the pointing angles from a specified earth station to a specified satellite, based on the 11 parameter ephemeris and other data provided (see example IOC message in Section 3.5). The output from this program would normally be used by earth stations using a program track system or as a backup method for stations operating with steptrack or monopulse tracking systems. Care should be used when operating in a program track mode that the earth station antenna position indicators are corrected for the true pointing angle. Typically, the indicated Azimuth (Az) and Elevation (El) angles will be offset from the true angles by a fixed amount that results from mechanical or electronic drifting in their calibration. The amount of offset can be determined by peaking the antenna on the satellite and comparing the indicated antenna position with the pointing angles calculated from the satellite ephemeris. The observed offset should then be used to modify or bias the calculated pointing angles appropriately before they are given to the program track mechanism. Some tracking systems will provide a way to enter these offsets separately to the unit. Alternatively, the offsets can be entered in the earth station's description file, thus allowing the program to compute the indicated pointing angles.

### 3.3 Stationkeeping Box

The program can compute the satellite's position whenever the satellite is within a specified box around its nominal position. The program provides the times that the satellite will be close to the center of its stationkeeping position. This information is useful for fixed pointed (non-tracking) antennas that need to know the optimum time to re-peak their antenna on the satellite.

### 3.4 Additional Computational Capabilities

In addition to computing an earth station's pointing angles to the satellite, the software program can also predict sun interference outages, which occur twice yearly, once in the Spring and once in the Fall, as well as pointing data to well-known radio stars for the purposes of determining the G/T of an earth station.

#### 3.4.1 Sun Interference

The program can predict the occurrences of the sun interference which is experienced during the Spring and Fall. The data predicted includes the start and end dates of the sun interference, the time of the peak interference and the duration of the interference.

#### 3.4.2 Radio Star Pointing

The preferred method of determining the G/T of an earth station is by radio star measurement whenever feasible and, where possible, at a high elevation angle.

For radio star measurements, Cassiopeia A, Taurus A, and Cygnus A are recommended sources. (A discussion of G/T measurement methods, sources of measurement error and measurement correction factors may be found in Rec. ITU-R S.733-1). The *Earth Station Pointing Data* program can calculate the azimuth and elevation angles to a desired radio star at time intervals ranging from 5 minutes to a maximum of 120 minutes for a given start and end date to assist in determining the most desirable radio star to use.

### 3.5 IOC Ephemeris Information Message

The following is an example of the message containing the current 11 parameter ephemeris for each of Intelsat's owned or operated spacecraft:

FROM: INTELSAT WASHINGTON DC

TO: ALL STATIONS OPERATING AT 304.5 DEG EAST

SUBJECT: ELEVEN PARAMETER EPHEMERIS FOR INTELSAT 805/304.50 DEG E

EARTH STATIONS PLEASE ON-PASS TO YOUR ADMINISTRATION

WEEKLY 11-PARAMETER DATA 20021012

THE 11-PARAMETER EPHEMERIS AND EPOCH PREDICTING THE SPACECRAFT MOTION ARE PROVIDED BELOW.

PLEASE ENTER THIS DATA INTO THE EPHEM.DAT FILE

YEAR	MONTH	DAY	HOUR	MINUTE	SECOND
2002	10	12	20	00	00

THE EPHEMERIS VALUES ARE:

LM0 DEG. E 304.5114	LM1 DEG/DAY 0.0019	LM2 DEG/DAY/DAY -0.000929 (MINUS)	
LONC DEG. E 0.0223	LONC1 DEG/DAY 0.0010	LONS DEG. E -0.0221 (MINUS)	LONS1 DEG/DAY 0.0008
LATC DEG. N -0.0241 (MINUS)	LATC1 DEG/DAY -0.0007 (MINUS)	LATS DEG. N -0.0269 (MINUS)	LATS1 DEG/DAY -0.0018 (MINUS)

THE NOMINAL ORBITAL LOCATION FOR THIS SATELLITE IS 304.5 DEG. E

THE PREDICTED SATELLITE LONGITUDE AND LATITUDE AT 170 HOURS AFTER EPOCH ARE 304.4948 DEG. E. AND -0.0471 DEG. N.

BEST REGARDS

MANAGER IOC

4. Earth Station Pointing Data Program (Version 4.0) User's Guide
- 4.1 Requirements
  - (1) As a minimum, Excel 97 is needed.
  - (2) There is no installation needed. The program is self-contained and does not require any special files.
- 4.2 Usage
  - (1) Open the Excel file. In the event that the "Macro security" option has been turned on, there will be a prompt to that effect. Please note that the Excel file has been written using Visual Basic for Applications and hence the program treats these as macros. Click "OK" to have the macros enabled.
  - (2) To begin, click on the "Start" button. This should bring up a user form.
  - (3) In the user form, choose the satellite for which you need to perform the calculations.
  - (4) In the "Antenna" tab, choose from the existing list. You can always update/add new antennas one at a time. In case you need to import several antennas at a time, refer to Section 4.3.1 ("Special Operations").
  - (5) Choose the tab that you would like to run the calculations for. The result will be displayed in the user form as well as in the various sheets of the spreadsheet.
  - (6) To switch between the user form and the sheets, select the "Hide" button in the user form or the "Show Form" in the first sheet of the spreadsheet.
  - (7) Upon closing the spreadsheet, it will be saved automatically, thus preserving the results of your analysis/run.
  - (8) When you re-open the spreadsheet and click on the "Start" button, however, all previous results will be cleared. This will also occur when you choose a new satellite. Note that only the results will be cleared; the list of antennas and the satellite information will be preserved.

- (9) Note that the buttons are like context-sensitive menus. Based on the active tab, the corresponding buttons will be activated.

#### 4.3 Special Operations

##### 4.3.1 Import Antennas

Using the user form, you may add your antenna information one at a time. If you wish to import several antennas at a time, however, click on the “Import Antennas” button. This operation will read a list of antennas from an Import\_Antenna spreadsheet and attempt to import uniquely named ones. The ones that were not imported are marked as such in the Import\_Antenna spreadsheet that was imported.

To create the Import\_Antenna spreadsheet, use the following procedure:

- (a) Copy the first row of the “Antenna” sheet from the IESS spreadsheet. Paste this in the first sheet of the Import\_Antenna spreadsheet.
- (b) Enter the list of antennas that you have into this spreadsheet. Save, then close this spreadsheet.
- (c) From the IESS spreadsheet, launch the user form. Go to the “Antenna” tab.
- (d) The “Import Antennas” button will now be activated. Click this.
- (e) You will be prompted to choose an Excel file. Choose the “Import\_Antenna” spreadsheet that you saved earlier.

At the end of the operation, you will have your antenna list loaded into the user form for future use.

##### 4.3.2 Refresh Satellite Information

The ephemeris/satellite information may be obtained from the IBN web site (<https://ibn.intelsat.com/ephemeris/ephemeris.asp>). Store this information in the “Sat\_Info” sheet. Whenever you wish to refresh the list, click on the “Refresh Sat Info” button, which is activated when you are in the first tab of the user form. In case you are unable to reach the Internet, the old data will be left unchanged. If you need to have the latest data and are planning to travel to a remote site where an Internet connection might not be available, remember to update the satellite information prior to leaving by clicking on the “Refresh Sat Info”.

APPENDIX A  
REVISION HISTORY

<u>Revision No.</u>	<u>Approval Date</u>	<u>Major Purpose</u>
Original	15 Mar 1988	<ul style="list-style-type: none"><li>• New module</li></ul>
1	09 Mar 1990	<ul style="list-style-type: none"><li>• Update and removal of “Provisional” status of the document</li></ul>
2	06 Dec 2002	<ul style="list-style-type: none"><li>• Modify to conform with Intelsat standard document format</li><li>• Update text to reflect the replacement of the Fortran / DOS-based software programs with a Windows NT / 2000 / XP compatible software program with additional computational capability for sun interference and radio star pointing</li></ul>
3	31 May 2003	<ul style="list-style-type: none"><li>• Update to reflect the availability of Version 4.0 of the <i>Earth Station Pointing Data</i> program on the IBN only and inclusion of a User’s Guide (Section 4).</li></ul>