

Development of CCSDS DCT to Support Spacecraft Dynamic Events

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Abstract and Introduction

This report discusses the development of Consultative Committee for Space Data Systems (CCSDS) Design Control Table (DCT) to support spacecraft dynamic events.

The Consultative Committee for Space Data Systems (CCSDS) Design Control Table (DCT) is a versatile link calculation tool to analyze different kinds of radio frequency links. It started out as an Excel-based program, and is now being evolved into a Mathematica-based link analysis tool. The Mathematica platform offers a rich set of advanced analysis capabilities, and can be easily extended to a web-based architecture. Last year the CCSDS DCT's for the uplink, downlink, two-way, and ranging models were developed as well as the corresponding input and output interfaces. Another significant accomplishment is the integration of the NAIF SPICE library into the Mathematica computation platform.

This summer, the attitude models for the CCSDS DCT are being developed along with a Smart GUI that incorporates the different components needed to model the spacecraft attitude. The attitude heuristics model the spacecraft dynamic events of earth-pointing, sun-pointing, spinning, coning, and lander orientation. The attitude heuristics will also include models for "safemode" scenarios that depend on the mission phase (cruising, mapping, etc.). Based on the knowledge of antenna pointing relative to the spacecraft frame, the cone and clock angles of the antenna pattern with respect to the target of interest can be computed, and this provides the antenna pointing loss of the link equation. Thus modeling of spacecraft attitude behavior enables one to provide accurate link prediction during spacecraft dynamic events.

Background

Consultative Committee for Space Data Systems (CCSDS) Design Control Table (DCT) is a link calculations tool with many variable values and formulas. Previously, DCT was built using Excel software because Excel can support a tabular way of handling calculations. However, multiple versions of the CCSDS DCT had to be created because the new versions of Excel were not backwards compatible with a considerable number of new functions and procedures, and had to be re-written completely anew. This required considerable amount of time and energy to re-write in newer versions of Excel. It was determined that a new software platform for the DCT should be selected which supported certain requirements such as backwards compatibility. Considering all these requirements of the platform to build the CCSDS software, Wolfram Research's Mathematica software was selected out of a pool of software such as Mathcad, and MATLAB. Mathematica was selected to be the new platform for the CCSDS DCT because it is backward compatible, and contains a rich and powerful set of numerical and analytical functions.

During Summer 2010, 6 employees of JPL (3 full time employees, 2 academic part time, and 1 summer intern) started to re-engineer the CCSDS DCT tool. The effort include converting from excel to Mathematica, and developing a user-friendly and smart Graphical User Interface (GUI). This group initially faced many challenged because of their lack of knowledge in Mathematica. Over the summer, they created the CCSDS DCT for the Downlink channel and

Uplink channel without ranging. They also developed an input GUI and Output DCT's. Between Summer 2010 and Summer 2011, the team included ranging and simultaneous uplink and downlink channel, multiple channels in the DCT. They also completed comprehensive testing and developed Smart GUI that models parameter dependencies, added charting functionalities and have the ability to take trajectory inputs and to vectorize computations.

Objectives

This summer, the attitude models for the CCSDS DCT was developed along with a Smart GUI that incorporates the different components needed to model the spacecraft attitude. The attitude heuristics model the spacecraft dynamic events of earth-pointing, sun-pointing, spinning, coning, and lander orientation. Based on the knowledge of antenna pointing relative to the spacecraft frame, the cone and clock angles of the antenna pattern with respect to the target of interest can be computed, and this provides the antenna pointing loss of the link equation. Thus modeling of spacecraft attitude behavior enables one to provide accurate link prediction during spacecraft dynamic events.

Computing attitude from heuristics

Cone angle is the degrees-off-boresight and clock is the angle around the boresight measured from a reference vector (unit vector from spacecraft to ground station) in the plane perpendicular to the boresight. To compute these two angles, we need to know the antenna frame. To compute the antenna frame, we first compute the attitude for the spacecraft (described below) and then

rotate the spacecraft frame into the antenna frame for consistent definition of "clock" angles. The antenna frame is an offset angle from the spacecraft frame.

Definitions:

Atx – Unit vector describing the attitude of the spacecraft X-axis with respect to J2000 (km)

Aty – Unit vector describing the attitude of the spacecraft Y-axis with respect to J2000 (km)

Atz – Unit vector describing the attitude of the spacecraft Z-axis with respect to J2000 (km)

J2000 is the inertial reference system.

Assuming that the positions and velocities of the bodies of interest are available:

- Compute unit vectors for directions of interest. Usually would be Earth-to-Sun (UnitSun), Earth-to-spacecraft (UnitSc), Earth-to-Body (UnitBody), spacecraft-to-Sun (UnitScSun), spacecraft-to-Body (UnitScBody), and spacecraft velocity (UnitScVel). (Jet Propulsion Laboratory)
- For “Earth Pointed” heuristic, the spacecraft antenna points toward the Earth center and *not* toward a DSN site or station. For example, +X at the Sun ($Atx = -UnitScSun$) or +Z in nadir direction ($Atz = -UnitSc$). If the most specific heuristic is not to point in the direction of one of the unit vectors, point to the closest unit vector specified. For instance, +X at 60 ° from the Sun in the direction of Earth implies pointing the +X axis at the Sun in this step (Jet Propulsion Laboratory). The spacecraft can be pointed at any body in space such as a planet, asteroid, etc. .

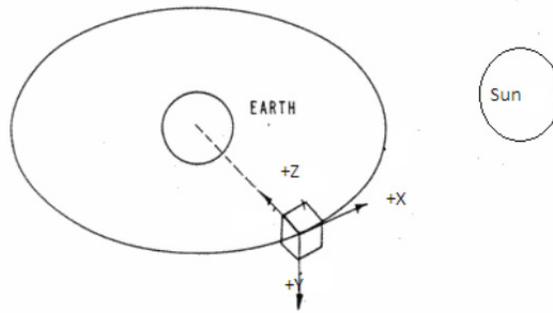


Figure 1 +Z pointed at Earth

- Take the second most specific pointing heuristic and implement it. For example, +Y perpendicular to the plane of the Earth, Sun, and spacecraft [$A_{tz} = \text{UnitSc}(-Z \text{ point to earth})$, $A_{ty} = A_{tz} \times \text{UnitScSun}$], (Jet Propulsion Labrotory).
- Determine the attitude of the third spacecraft axis by taking the cross product of the other two (Jet Propulsion Labrotory).
- Rotate axes if necessary (not spinning currently) using the appropriate rotation matrix. For example, +60 deg from the Sun in the direction of Earth. If the rotation is around an axis which is not one of the primary axes, implement the rotation as two separate rotations around primary axes. To do rotation, build the rotation matrix R and the direction cosine matrix (DC) corresponding to each time point. Multiply direction cosine matrix by the rotation matrix ($A = DC * R$), then pull out the unit vectors (columns of A) to determine the new attitudes (Jet Propulsion Labrotory).
- Generate matrices for spinning (RS) and coning (RC), which are matrices that rotate the axes a fixed number of degrees each time step. If desired, construct initial phase rotation matrices (IPS, IPC). If there is no coning, $RC = I$ (identity matrix); if there is no spinning, $RS = I$. Determine the direction cosine matrix (DC) corresponding to

each time point. The new inertial frame at a given time step j is found from the equation: $A = DC*RC^{(j-1)}*IPC*RS^{(j-1)}*IPS$. The attitude of the spacecraft axes is represented by the columns of the resulting matrix (Jet Propulsion Labrotory).

Euler Angles

When using Euler Angles, basically multiply Euler Rotation Matrix to an initial reference frame that aligns the Euler angles frame to S/C bus frame (usually Identity matrix because the two frames are aligned) to get the spacecraft frame.

Computing Cone and Clock Angles

Definitions of cone and clock angles. Rotate spacecraft frame into antenna frames for consistent definition of "clock" angles.

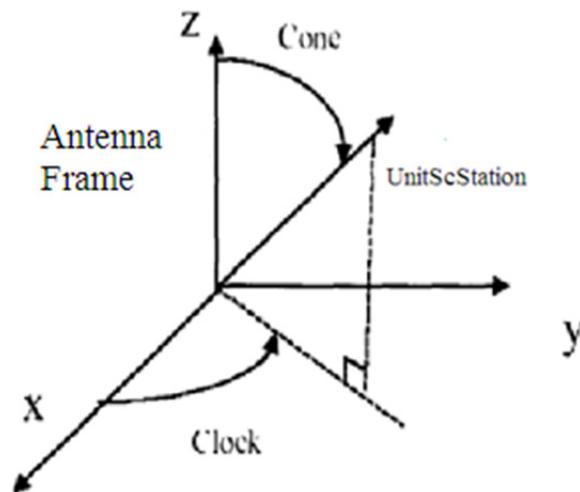


Figure 2 Definition of Cone and Clock Angle

Approach

1. Understand what models were needed for attitude models for the CCSDS DCT
2. Determine models on pen and paper
3. Create models in Mathematica
4. Vectorize Models
5. Debug
6. Write codes to compute antenna gain and pointing losses from antenna attitude information (Cone/Clock angle).
7. Optimize code
8. Compare results to Telecom Forecaster Predictor(TFP)
9. Create GUI
10. Documentation

Results

The results computed in the CCSDS DCT were compared the results computed in TFP, thus validating the work done for the CCSDS DCT.

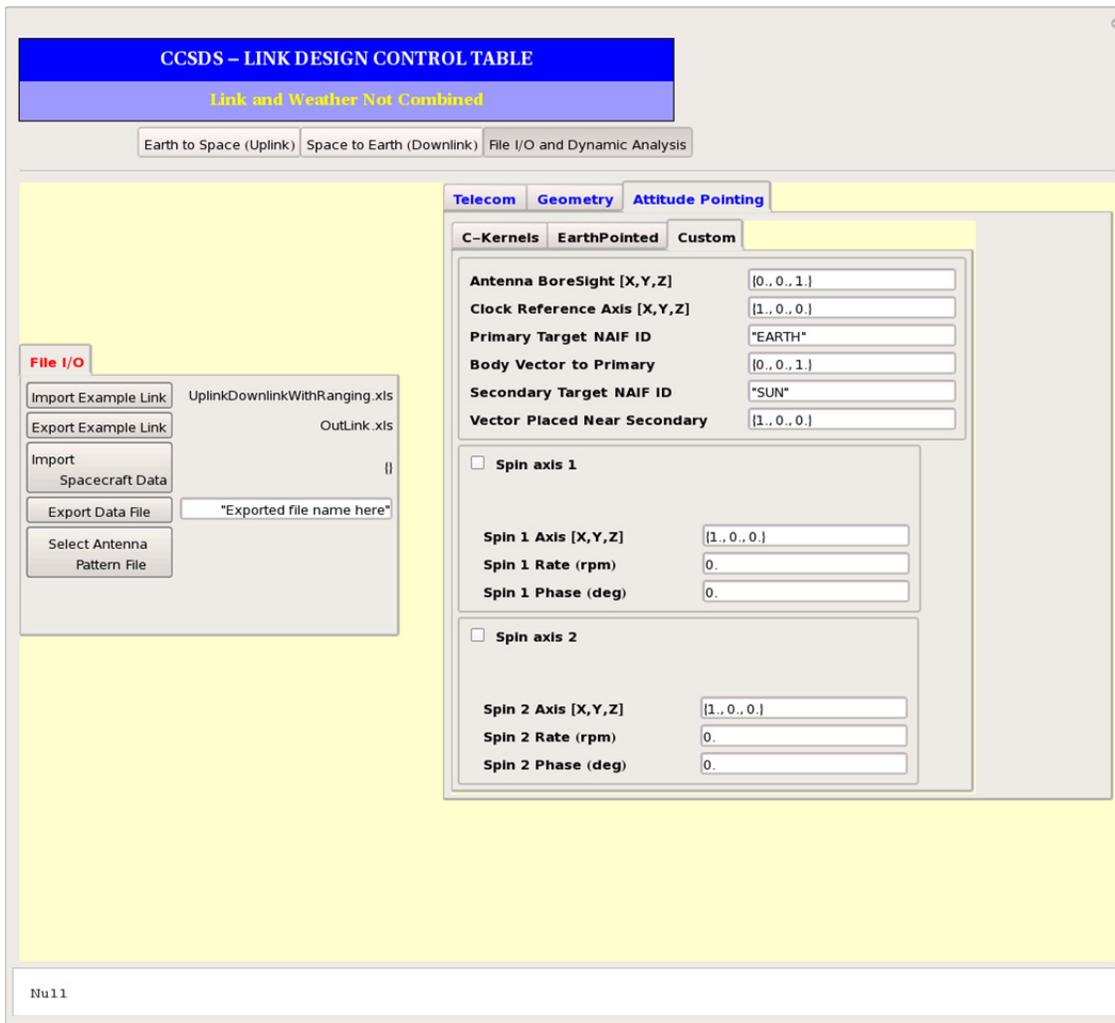


Figure 3 CCSDS DCT GUI

Future Work

We will use the developed attitude pointing model to re-evaluate antenna pointing losses for both downlink and uplink, using analytical model or antenna pattern if supplied by user.

Attitude pointing model is an important part of dynamic link analysis that improves the fidelity of link computation.

After the dynamic link analysis is completed, the CCSDS tool will be made available to the public. This will be achieved via a web Mathematica interface. This way people from the community will be able to use JPL's CCSDS tool through the web to predict the feasibility and quality of planned communication links. The user will be allowed to configure the link, upload their mission specifics, and compute link performances.

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Reference:

Jet Propulsion Laboratory. (n.d.). *Telecom Forecaster Predictor/Unified Telecom Predictor (TFP/UTP)*.

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