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Delta-DOR Correlator Development at ISTRAC/ISRO

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Delta Differential One-way Ranging (DDOR) is a Very Long Baseline Interferometry (VLBI)-based technique for navigation of interplanetary spacecrafts. ISRO's Mars Orbiter Mission (MOM) launched in November 2013, and orbiting Mars ever-since September 2014, uses this technique along with Ranging and Doppler-based navigation techniques for accurate Spacecraft Orbit Determination.

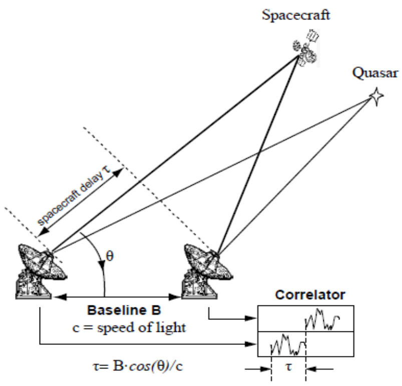

Figure 2-1: Delta-DOR Observation Geometry

Courtesy: CCSDS RDEF Bluebook

Two geographically distant antennas (around 10000 km apart) are made to simultaneously observe the Spacecraft and an angularly nearby Quasar. Spacecraft carries a payload that generates DDOR tone and its harmonics; the Quasar signal however is wide-band Gaussian noise. The planar wave-front arriving from both the sources arrives with a delay (τ) at one station with respect to the other reference station. The base-line distance B is accurately known, and given the accurate τ measurement, the angular position (θ) of the source can be determined accurately (units or tens of nano-radian). Quasar sources are chosen from survey catalogs and their positions are already well-known; being billions of light-years away, they are inertially-fixed point-like radio-sources, and the expected delays can be modeled accurately to 10-20ns range. By observing Spacecraft, and one or more angularly nearby Quasars, Differential One-way Range (DOR) measurements of both can be made. DOR value of Quasar can be used to determine station instrumentation errors, such as clock errors, and atmospheric media effects. These error estimates may then be subtracted out of the Spacecraft DOR measurement to significantly improve the accuracy of instantaneous spacecraft angular measurement (θ).

Three broad areas emerged in this work: Quasar correlator development, Spacecraft correlator development and Model-Delay Estimation. Model-Delay Estimation involves taking several factors into account – accurate determination of Earth rotation and revolution, Sun, Moon and planetary effects, Relativistic corrections and converting to and from the Solar-system barycentric reference. Quasar correlator work involves using the model-delay to align one station data-stream with respect to the other, correcting for Fringe Rotation, Local Oscillator setting differences at the stations, complex multiplication and averaging. Once the first-level correlation is complete, Fringe-fitting based on Multi-band bandwidth synthesis is performed along with Interpolation to give final DOR observable. Spacecraft correlator work involves establishing a Digital Phase-Locked Loop / AGC-based technique to estimate the phase of the DDOR tone, channel-wise, at each station, and then estimating the phase-differences between the stations to determine the DOR observable. In further navigation processing, the DOR observables are extrapolated to the same time, and difference of DOR values is made to determine the DDOR observable. The algorithms, design and implementation aspects shall be discussed in detail in the paper. The preliminary correlation results are matching with the results generated by NASA/JPL team in the units of nano-sec range; model-delay generation is accurate in the 10-20 nano-sec range.