IMPROVED DOPPLER TRACKING SYSTEMS FOR DEEP SPACE NAVIGATION

Luciano Iess(1)**, Mauro Di Benedetto**(1)**, Manuela Marabucci**(1)**, Paolo Racioppa**(1)

luciano.iess@uniroma1.it
mauro.dibenedetto@uniroma1.it
manuela.marabucci@uniroma1.it
paolo.racioppa@uniroma1.it

(1)*Dipartimento di Ingegneria Meccanica e Aerospaziale, Sapienza, Università di Roma, Via Eudossiana 18, 00184 Italy*

Keywords: *tracking, Doppler, range rate*

ABSTRACT

Spacecraft Doppler tracking is the most commonly used technique for navigation of deep space probes, where the orbit is inferred from the repeated measurements of the frequency shift of a microwave carrier. Doppler measurements are also crucially important in radio science and planetary geodesy experiments, where the spacecraft range rate is used for the determination of gravity fields and to carry out tests of general relativity. Currently ESA and NASA Doppler navigation systems rely on X-band, two-way radio links (7.2-8.4 GHz). However these radio links are quite sensitive to plasma noise, an error source limiting the measurement accuracy to an average value of 0.05 mm/s at 60 s integration time.

Recently, ESA's General Studies Programme (GSP) funded a study ("*Interdisciplinary Study for Enhancement of the End-To-End Accuracy for Spacecraft Tracking Techniques*"), requiring a systematic statistical assessment of ESA's tracking system accuracies (range, range rate and Delta-DOR) and guidelines for future improvements. The target accuracies were set to 0.01 mm/s for Doppler (at 60 s integration time), 20 cm for range and 1 nrad for Delta-DOR. The study was a collaborative effort of Sapienza University of Rome (prime contractor), ALMASpace, BAE Systems and Thales Alenia Space Italy.

The work presented here focuses only on Doppler systems. The primary data set for the statistical analysis was obtained from radio metric observables acquired during the operations of the missions Cassini and Rosetta. While Rosetta Doppler measurements are only available at X-band, a significant amount of Ka-band coherent data (34-32.5 GHz) is available from the Cassini radio science experiments carried out in the cruise phase to Saturn. As expected, path delay variations induced by charged particle in the solar wind are the main noise source in X-band Doppler data for a broad range of solar elongation angles. Thanks to the dispersive characteristics of plasma noise (inversely proportional to the square of the frequency), Ka-band data are much less affected by charged particles. In addition, Cassini was endowed with a multi-frequency radio system based upon three simultaneous, coherent two-way radio links in X/X, X/Ka and Ka/Ka bands. This unique configuration allowed a complete cancellation of plasma noise up to impact parameters of a few solar radii [1].

The richness of the Cassini data set allowed a quite accurate breakdown of the intervening noise contributions. Thanks to the multifrequency radio link, plasma contributions were singled out, while tropospheric delay measurements generated by the Advanced Media Calibration system (AMCs) were used in the reduction and the characterization of the tropospheric noise at the ground station. The core of the AMC is an advanced microwave radiometer, expressly developed for the Cassini radio science experiments. This instrument provides accurate calibrations of the wet path delay from measurements of the sky brightness temperature. The combined operation of a multifrequency link and AMC ended up in a 9×10^{-3} mm/s range rate accuracy at 60 s (Allan deviation of ~ 1.5×10^{-14} at 1000 s), even close to solar conjunctions [2]. Currently only the DSS-25 34m BWG antenna at NASA Deep Space Network complex in Goldstone (California) is equipped with Ka-band up- and downlink capabilites. This tracking station is also expected to support precision radio science experiments of BepiColombo/ESA mission to Mercury.

In addition to plasma and tropospheric noise, a third relevant contribution is due to numerical noise induced by orbit determination (OD) codes. Numerical errors stem from truncation and round off errors in the algorithms for computed observables and show up in range rate residuals. Although the new JPL OD software (MONTE, now replacing ODP) is much less affected by this problem, numerical noise is still a major errors source in ESA's OD system. Contributions from onboard and ground electronics is always negligible at the integration times of interest for navigation and radio science.

The statistical analysis of the data provided an accurate and robust breakdown of the error contributions, from which error models for each noise source were built. We compared these models against Cassini X-band data from the Saturn tour (spanning over six years) and one year of Rosetta X-band data acquired during the interplanetary cruise. The excellent agreement between predicted and observed noise provided a validation of the error models and was used to build guidelines and strategies for future upgrades of deep space tracking systems. We identified architectural solutions offering different levels of improvements, often capable to meet or exceed the study targets. Should the proposed solutions be implemented, the navigation accuracies of planetary missions could be significantly increased.

REFERENCES

[1] Tortora P., Iess L., Bordi J. J., Ekelund J. E., Roth D. C., "Precise Cassini navigation during solar conjunction through multifrequency plasma calibrations", J. Guidance Control Dyn., Vol. 27, 2004, pp. 251-257

[2] Asmar S. W., Armstrong J. W., Iess L., Tortora P., "Spacecraft Doppler tracking: noise budget and accuracy achievable in precision radio science observations", Radio science, Vol. 40, 2005