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Measuring angles, distances and velocities in the solar system: Can microwave tracking systems still be improved?

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Extended Abstract. Since the beginning of solar system exploration, the science community realized that microwave links between ground antennas and distant spacecraft constituted a powerful scientific instrument. In many cases this vital component of every deep space mission led to break-through discoveries. Radio links have been used to probe planetary interiors, determine the dynamics of solar system bodies, test laws of gravity, not to mention other applications in atmospheric and planetary surface science. With the notable exception of ultrastable oscillators (USO) for radio occultations, the radio science experiments relied in most cases on the hardware (both onboard and on ground) used for telecommunications and navigation, without any additional design requirement. Radio science was just piggybacking on telecommunication and tracking system.

Cassini was the first mission endowed with a dedicated frequency translator enabling a two-way radio link at Ka-band (32-34 GHz), devoted to the search of low frequency gravitational waves and to test relativistic gravity. The Cassini solar conjunction experiment, carried out in 2002, is the most accurate verification of Einstein's theory so far. Following the success of the Cassini radio science experiments, Ka-band links were later used for the gravity science investigation of the Juno mission to Jupiter. With just 16 hours of precise Doppler tracking in December 2016 and May 2017, Juno measured very accurately the gravity field of the planet, revealing new and unexpected details of its interior structure and wind circulation. ESA's missions BepiColombo to Mercury (launched in October 2018) and JUICE to the Jovian system host even more performing radio systems.

State of the art Ka-band radio system have reached exquisite accuracies. Thanks to an extremely stable platform and the use of advanced water vapor radiometers for tropospheric delay calibrations, Cassini still holds the record of range rate measurement accuracy, at the level of 0.001 mm/s over 1000 s integration time. Recently, cruise tests of the BepiColombo radio science investigation (MORE) showed that the novel PN ranging system at 24 Mcps can provide range accuracies with a RMS value of 7 mm after only 4 s integration, stable over the entire pass duration. Angular measurements enabled by Delta-DOR are also expected to benefit from Ka-band radio links.

Have microwave-based tracking systems reached their ultimate performance limit, or is there still room for improvement? While the current infrastructure seems adequate for the navigation needs of most planetary exploration missions, many science investigations in planetary geodesy, solar system dynamics and relativistic gravity would certainly benefit from better accuracies in the measurement of angles, distances and velocities.

The outlook is favorable. Single dish same beam interferometry (SBI) and time-delay noise cancellation system based on multi-station tracking offer the possibility to strongly suppress driving noise sources affecting Doppler measurements in current radio links, such as tropospheric and antenna mechanical noise. The BepiColombo ranging system, still under assessment, could show that absolute range accuracies at centimetric level are possible with microwave radio links, paving the way to a planetary-wide ranging similar to that established for the Moon with laser ranging. New, simpler configurations of intersatellite radio links could enable low cost gravity missions to many planetary bodies. We review the current state of microwave tracking systems and outline some future developments under consideration.