Improving Doppler with Enhanced Water Vapor Radiometry and Antenna Mechanical Stability

Principal Investigator: James Border (335)

A. Jongeling (333), A. Tanner (386), E. Long (333), H. Lin (333),

James S Border
818-354-8338
James.S.Border@jpl.nasa.gov

Program: Strategic Initiative

Project Objectives:

1.Enhance science data return for solar system missions that acquire Doppler data using the communication radio link to Earth in order to measure gravity fields of solar system bodies and to test General Relativity.
2.Improve calibration of the leading remaining error sources in the Doppler data: uncalibrated portion of atmospheric water vapor and mechanical vibrations of the large Earth-based antennas used for the radio links.
3.Design and prototype an Embedded Water Vapor Radiometer (EWVR) to operate in-line (use same optics) with the spacecraft Doppler tracking antenna. Design to allow integration into existing DSN 34m BWG antenna feed.
4.Look for collaboration opportunities to use stiff small antenna (~12m diameter), along with large DSN tracking antenna, to reduce antenna mechanical noise.

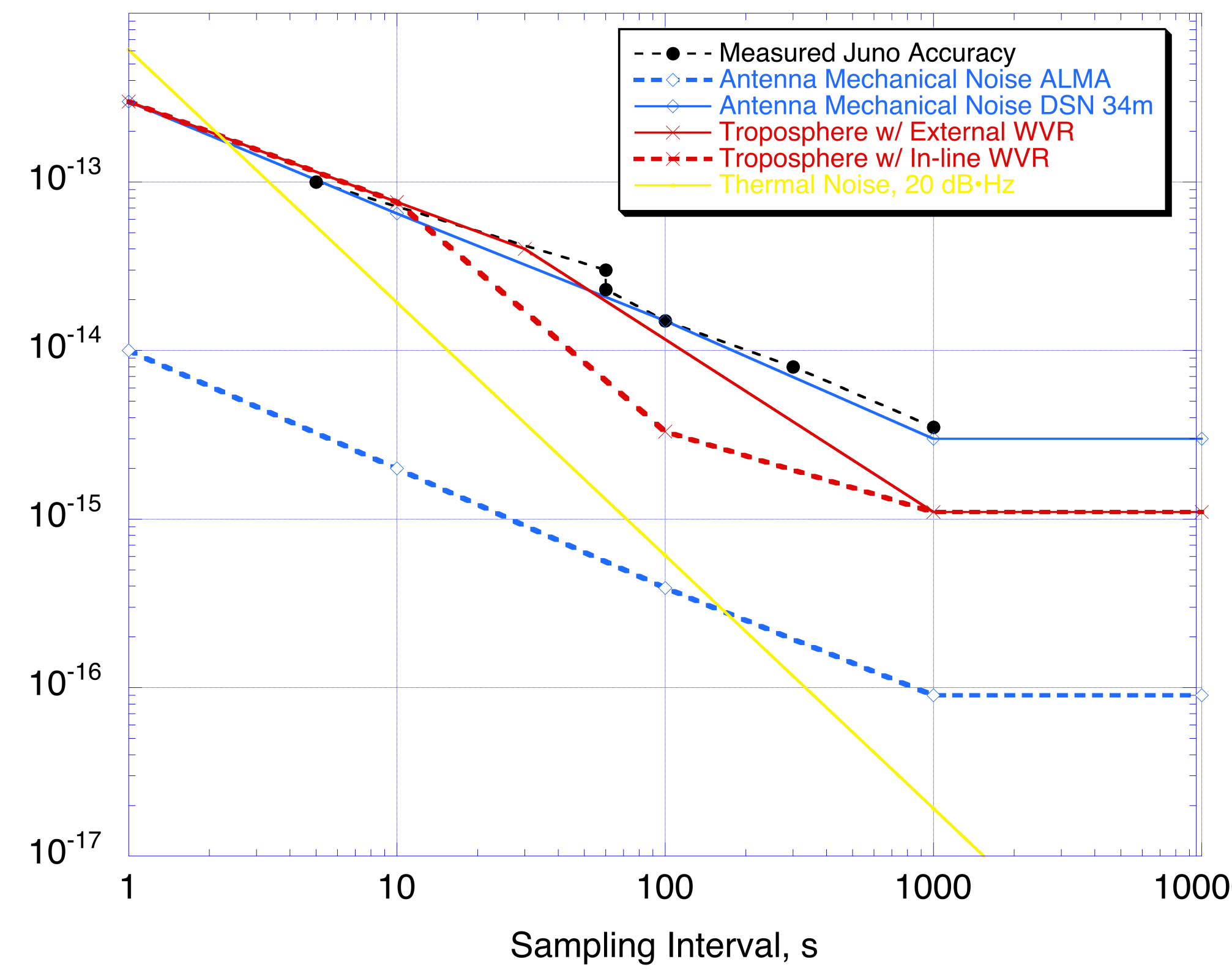

Figure 1. Leading Doppler errors for X/Ka uplink and downlink. Current state-of-the-art levels of leading error sources are shown with solid red/blue lines while the improved levels enabled by this task shown with dotted red/blue lines. Also shown are the best current total Doppler accuracies (with Juno) and the underlying thermal noise for Juno at a 12m antenna.

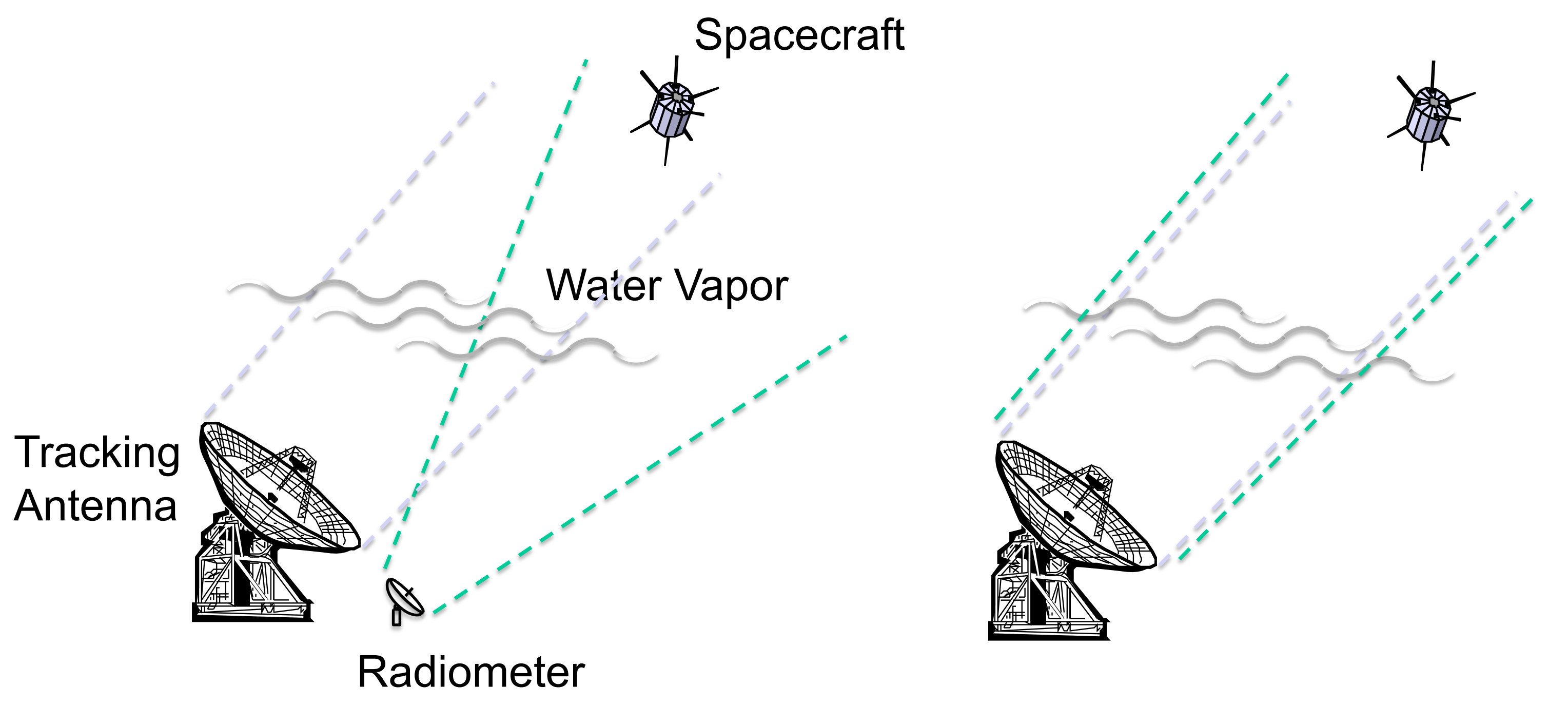

Figure 2. In the current system a radiometer on a small antenna adjacent to the 34m BWG makes measurements of the water vapor resulting in beam offset errors. In the proposed system the radiometer is integrated into the 34m BWG electronics allowing water vapor calibration through the same beam. The integrated atmospheric water vapor content along antenna to spacecraft direction is estimated by measuring sky brightness at different frequencies near and off a water emission line.

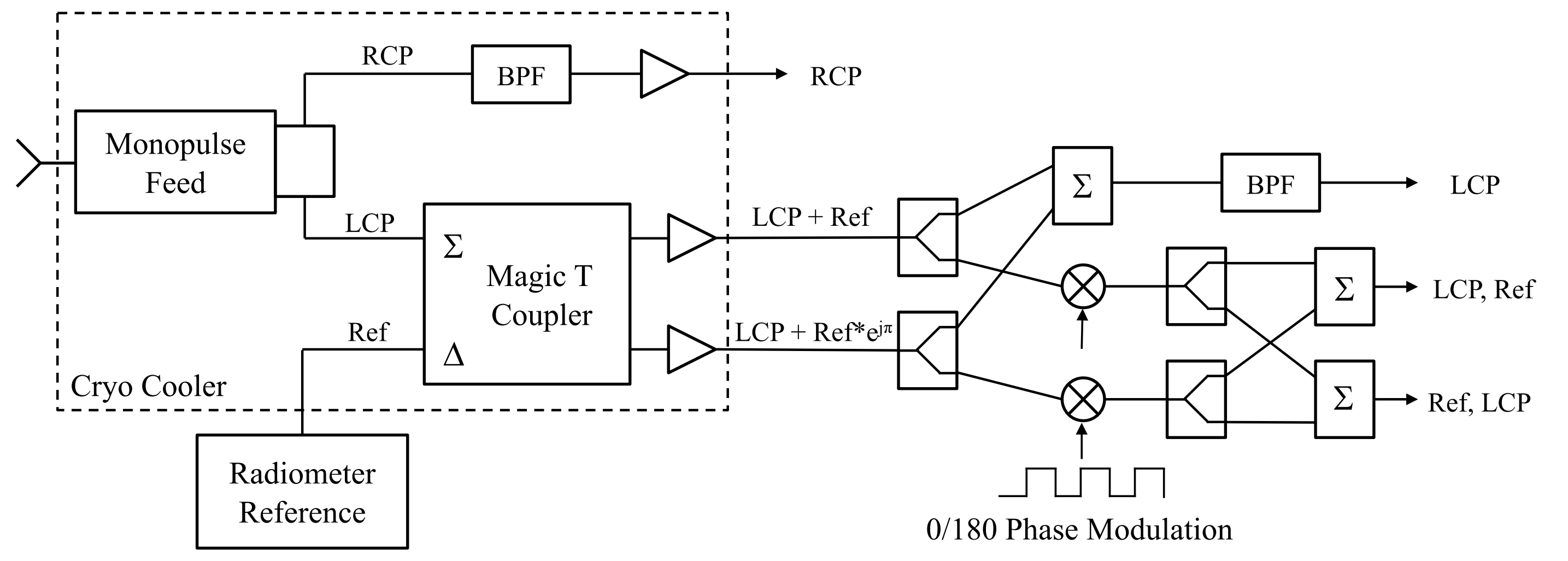

Figure 3. New Technology: An embedded water vapor radiometer has been prototyped to provide improved calibration of water vapor fluctuations that affect spacecraft Doppler at short time scales. The pseudo-correlation radiometer topology allows the front end cryogenic receiver to simultaneously handle the Antenna and Reference signals without compromising the performance of either system.

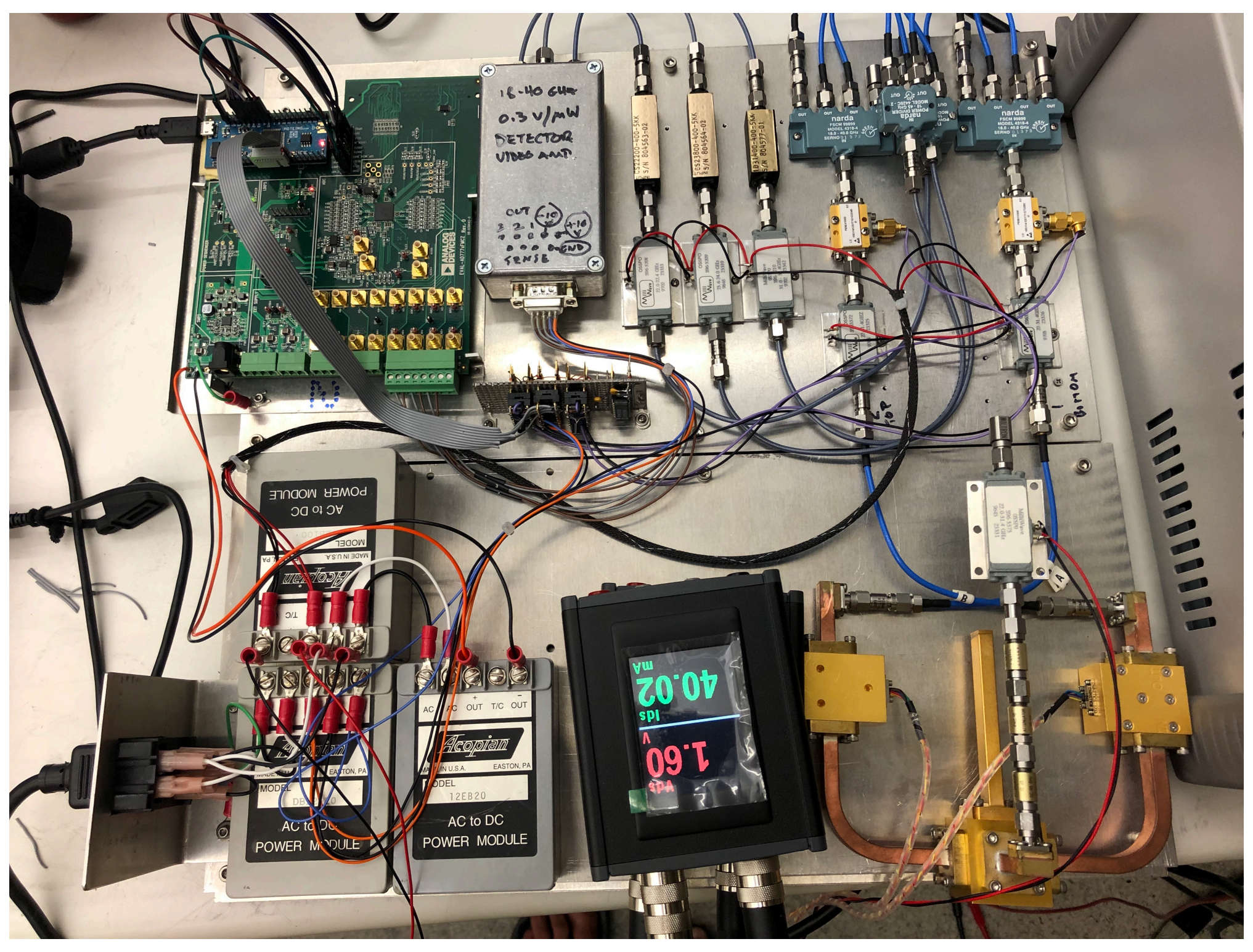

Figure 4. Bench top EWVR setup in laboratory at JPL. The alternating Antenna and Reference signals are sampled and recorded. The implemented system includes additional circuitry to allow power measurements of these signals in three different frequency bands, 22.2 GHz, 23.8 GHz and 31.4 GHz.

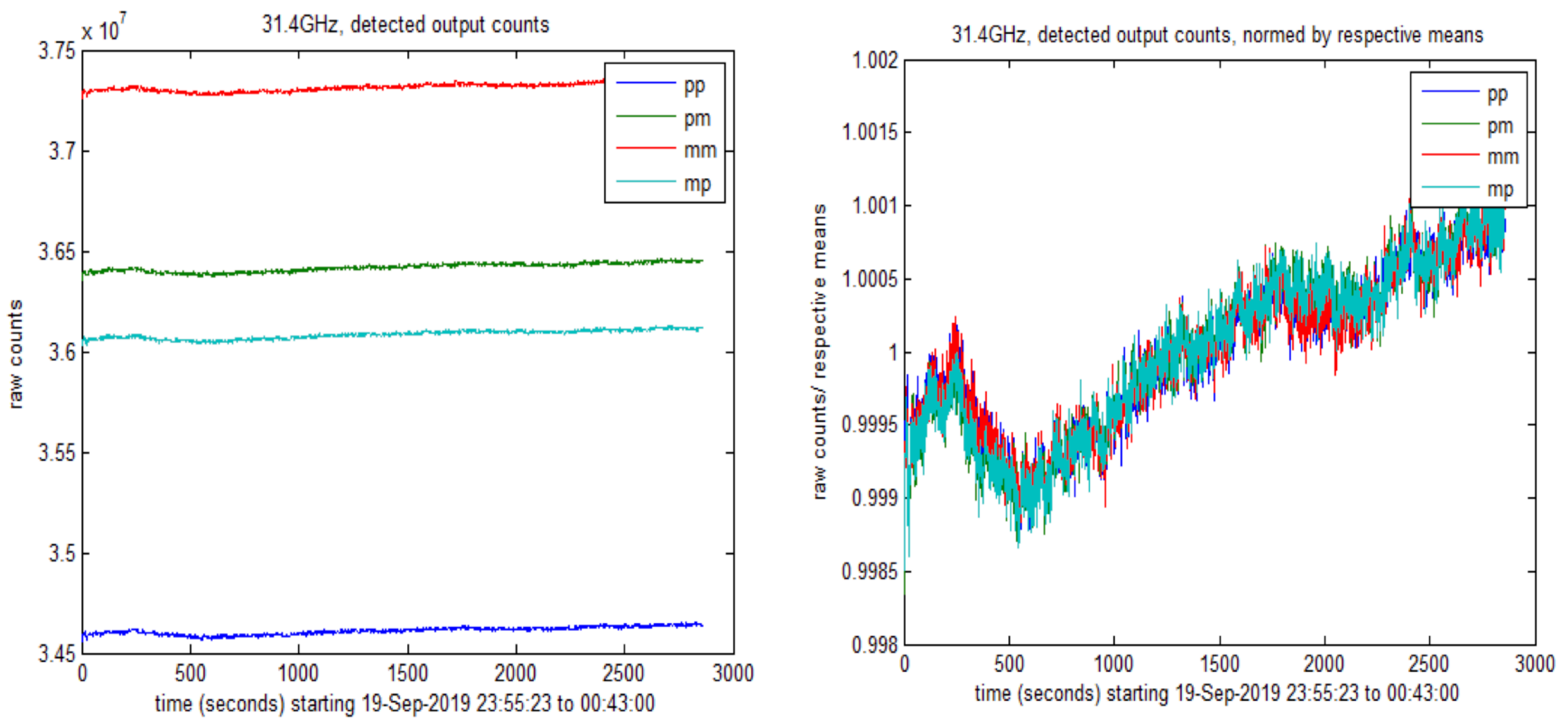

Figure 5. Raw counts (left) and normalized counts (counts/mean of counts), from the testbed while observing matched ambient loads. There are four states in which each of two RF phase switches in Figure 3 are switched among “p”lus and “m”inus states. Antenna signal is obtained for the two states that add in phase, pp and mm, while the Reference signal is obtained for the other two states. Antenna and Reference signals are about the same magnitude and track each other well.

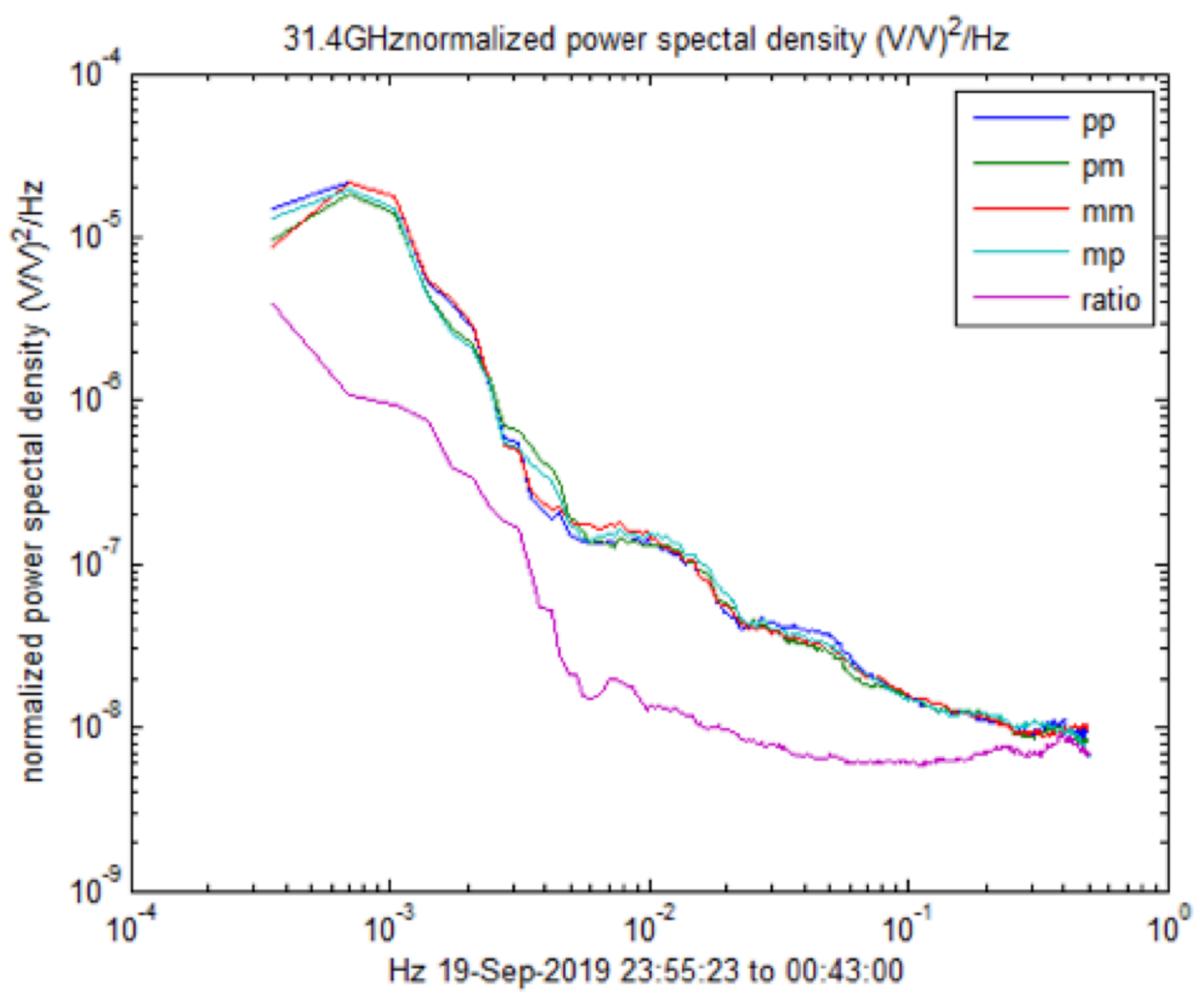

Figure 6. Power spectral density of the detected signals, and of the “Dicke normalized ratio” which will be used as the brightness temperature measurement once scaled by the system noise.

Results:

1.Design was completed for an Embedded WVR that could be integrated with existing DSN front ends.
2.Parts including broadband LNA and polarizer to receive radiometer and spacecraft signals from 22 to 32 GHz were designed and procured.
3.A bench top prototype WVR has been assembled and tested.
4.Agreement has been reached to integrate the prototype into the DSS-13 cryogenic XXKa feed in the next FY. Roof top tests will be conducted at JPL.
5.Initial discussions with the Large Latin American Millimeter Array (LLAMA) group for collaboration are encouraging. The LLAMA antenna's stiff mechanical design and its location in the dry Atacama Desert in Argentina are ideal for precision Doppler tracking. Doppler received at the 12m antenna would be combined with Doppler from the large tracking antenna by the technique of Time Delay Mechanical Correction (TDMC).

Benefits to NASA and JPL (or significance of results):

One of the few remote sensing means for studying interiors of solar system bodies is via the technique of spacecraft precision Doppler tracking by the DSN, which allows measurement of the gravity field generated by an object’s mass distribution. In the case of icy moons, the determination of the existence and details of sub-surface oceans is crucial to establishing whether they may be possible habitats for life. For any potential human exploration of small bodies (including Phobos and Deimos), a recognized strategic knowledge gap is their porosity or the existence of interior voids. The design work started here is expected to significantly improve Doppler accuracy and improve science return.

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
www.nasa.gov

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