NASA's Artemis II Orion One-Way Doppler Measurements Tracking
Response to RFI-ArtemisII-Tracking-ScaN-2025 – Tilley
Date: August 28, 2025

Summary

NASA has requested a Request for Information (RFI) from interested parties to supply them with one-way Doppler data from the upcoming Artemis II mission.

During the Artemis I mission we responded to RFI-GSFC-CIS-2022 and provided data for the complete mission using a 1.8m dish antenna. Since Artemis I we have improved the capability of the station by arranging the feed system to allow the antenna to be used as a polarimeter and upgrading the station reference to a Rubidium (Rb) standard disciplined to GPS. We have since used the system to track a number of cis-lunar missions on S-band including:

- JAXA’s SLIM,
- Intuitive Machines IM-1,
- Firefly’s Blue Ghost M1,
- Intuitive Machines IM-2,
- China’s TIANDU-1 and -2,
- China’s Queqiao-2,
- Epic Aerospace’s Chimera-1.

By again including our contribution in the RFI, NASA will be able to quantify the contribution of a relatively small sensor in relation to other larger sensors and determine to which extent small inexpensive sensors could benefit future Cis-Lunar missions in the collection of one-way Doppler data.

Response to Request for Information

- **Aperture size and relevant performance characteristics for antenna(s) which would be used to support this demonstration.**

Measured characteristics of our prime focus dish antenna at 2295MHz.:

Parameter	Value
Station Name	RobertsCreek-1
Antenna Diameter (m)	1.8
Beam-width (°)	5
System Noise Temperature (Ts)	101.7
Effective Area (Ae)	1.581
Efficiency (η)	62.1 %
G/T (dB/K)	10.18
Polarization	RHCP / LHCP / Horizontal / Vertical
Tracking Accuracy (°)	0.5

We are presently using a Stanford Research Systems (SRS) Rubidium Frequency Standard Model PRS10 as our primary station reference. The PRS10 is disciplined to GPS. ***Figure 1*** provides the PRS10 phase noise, Allan deviation over observation times [τ].

Output

Output frequency	10 MHz sine wave
Amplitude	0.5 Vrms, ±10 %
Phase noise (SSB)	< –130 dBc/Hz (10 Hz)
	< –140 dBc/Hz (100 Hz)
Spurious	< –130 dBc (100 kHz BW)
Harmonic distortion	< –25 dBc
Return loss	>25 dB (at 10 MHz)
Accuracy at shipment	$\pm 5 \times 10^{-11}$
Aging (after 30 days)	$<5 \times 10^{-11}$ (monthly)
	$<5 \times 10^{-10}$ (yearly)
Short-term stability	$<2 \times 10^{-11}$ (1 s)
(Allan variance)	$<1 \times 10^{-11}$ (10 s)
	$<2 \times 10^{-12}$ (100 s)
Holdover	72 hour Stratum 1 level
Frequency retrace	$\pm 5 \times 10^{-11}$ (72 hrs. off, then 72 hrs. on)
Settability	$<5 \times 10^{-12}$
Trim range	$\pm 2 \times 10^{-9}$ (0 to 5 VDC)
	±1 ppm (via RS-232)
Warm-up time	<6 minutes (time to lock)
	<7 minutes (time to 1×10^{-9})
Voltage sensitivity	$<2 \times 10^{-11}$ (1 VDC supply change)

Figure 1: PRS10 phase noise, Allan deviation over observation times [τ].

Further information on the SRS PRS10:
https://www.thinksrs.com/products/prs10.html

The S-Band antenna system is arranged as a polarimeter allowing for the measurement of Strokes parameters in addition to Doppler data. ***Figure 2*** provides a block system diagram of the antenna system.

Further reading on the S-Band polarimeter can be found here:
https://github.com/ScottTilley/polarization/blob/main/paper/An%20S-band%20Polarimeter%20for%20the%20Determination%20of%20Spacecraft%20Attitude%20Behaviour.pdf

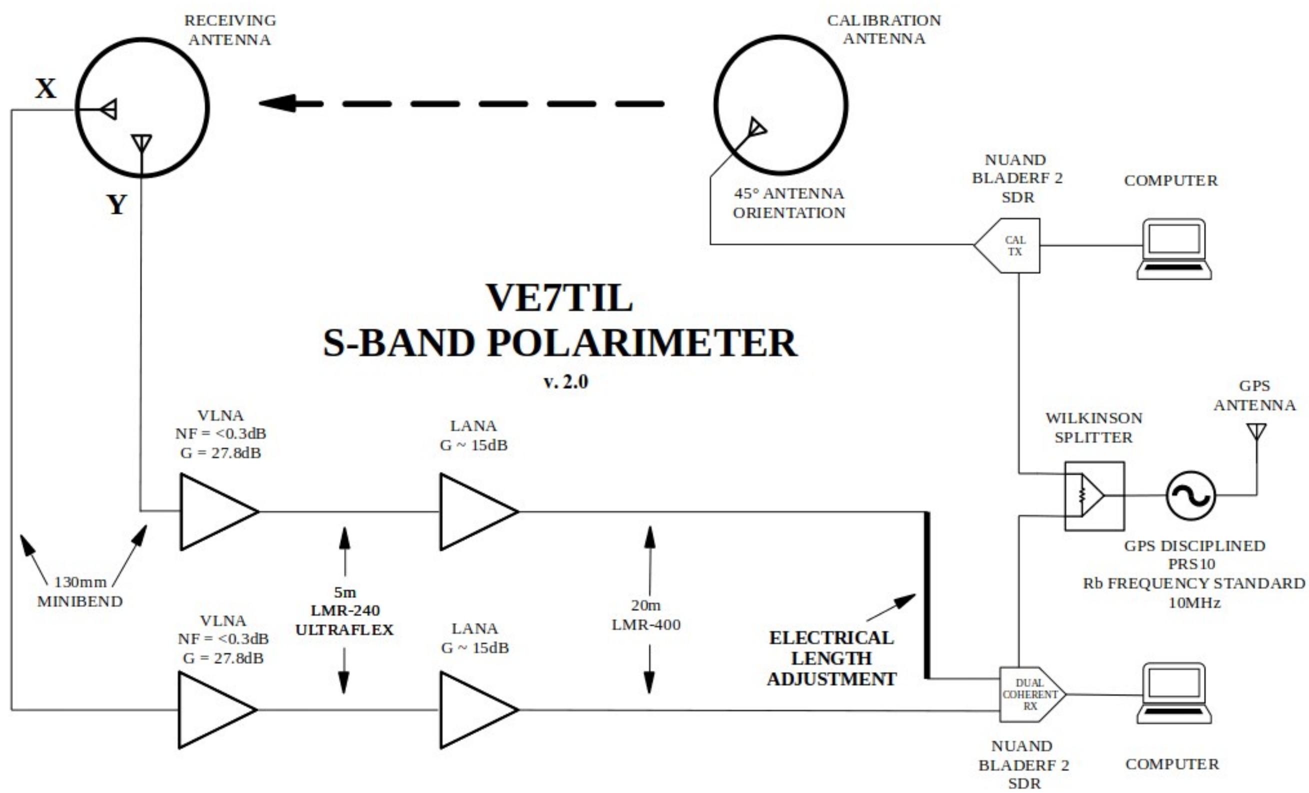

Figure 2: Block system diagram of the 1.8m S-Band polarimeter implementation.

- **Ability to acquire and track the Orion signal.**

We successfully tracked Artemis I on during everyday of the mission and compared the Doppler data we obtained to the JPL Horizons data provided. ***Figure 3*** provides a comparison of the Doppler data to the predictions from JPL Horizons.

Figure 4 provides the range-rate residuals of our data in comparison to JPL Horizons data for Artemis I.

A summary of our Artemis I analysis can be found here:
https://github.com/ScottTilley/Artemis1/blob/main/Artemis1_Doppler_Running.ipynb

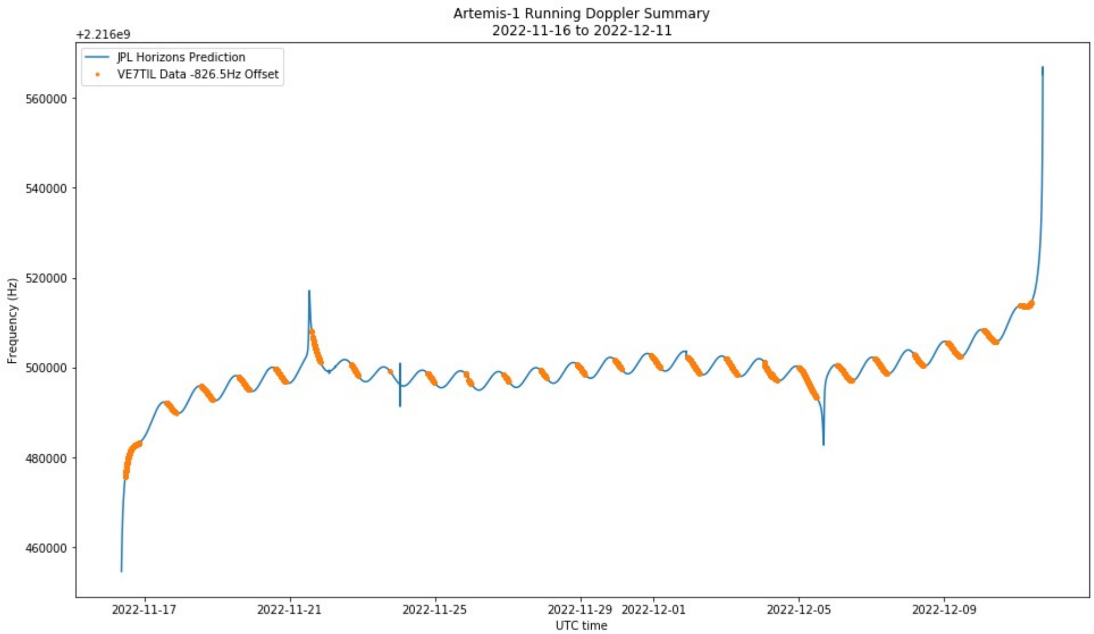

Figure 3: Artemis I Running Doppler summary comparing our Doppler data to JPL Horizons predictions.

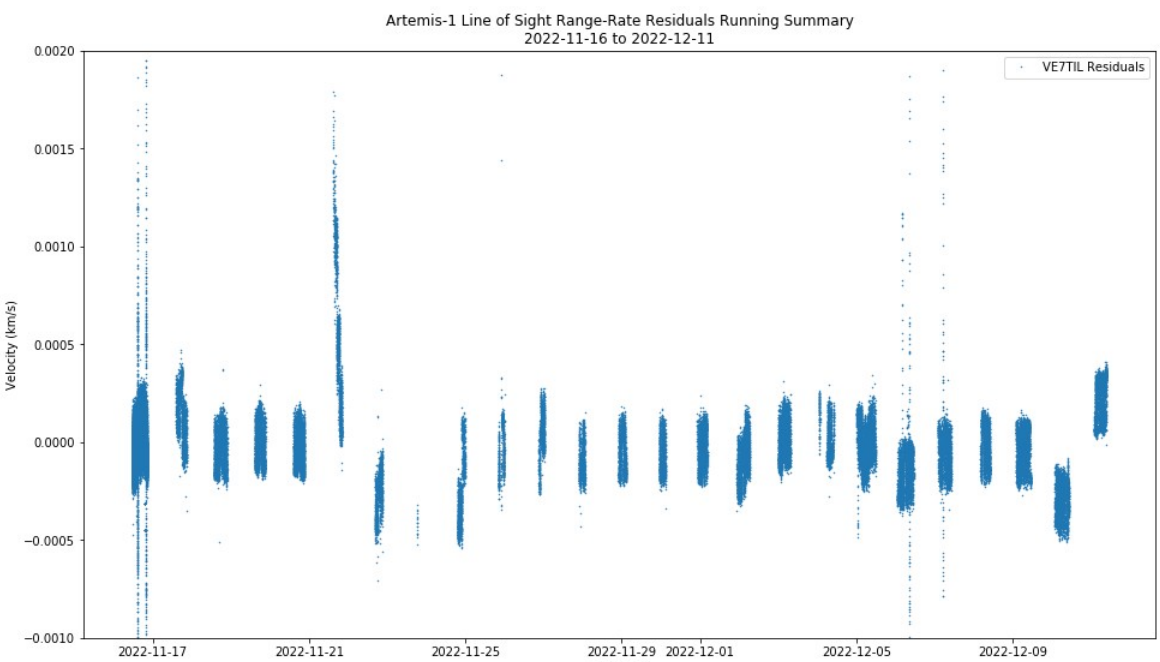

Figure 4: Artemis I Range-Rate comparison of our Doppler data to JPL Horizons.

- **Ability to generate and record one-way Doppler tracking measurements.**

Our work flow to record Doppler data is capable of sub-Hz resolution. For cis-lunar missions we use 10s samples to produce 0.1Hz resolution Doppler data. During the Blue Ghost lunar landing mission we compared our new Rubidium (Rb) reference to an earlier reference and noted about an order of magnitude of improvement. ***Figure 5*** provides a comparison of the two reference systems when 10s samples where obtained from the lander outbound to the Moon.

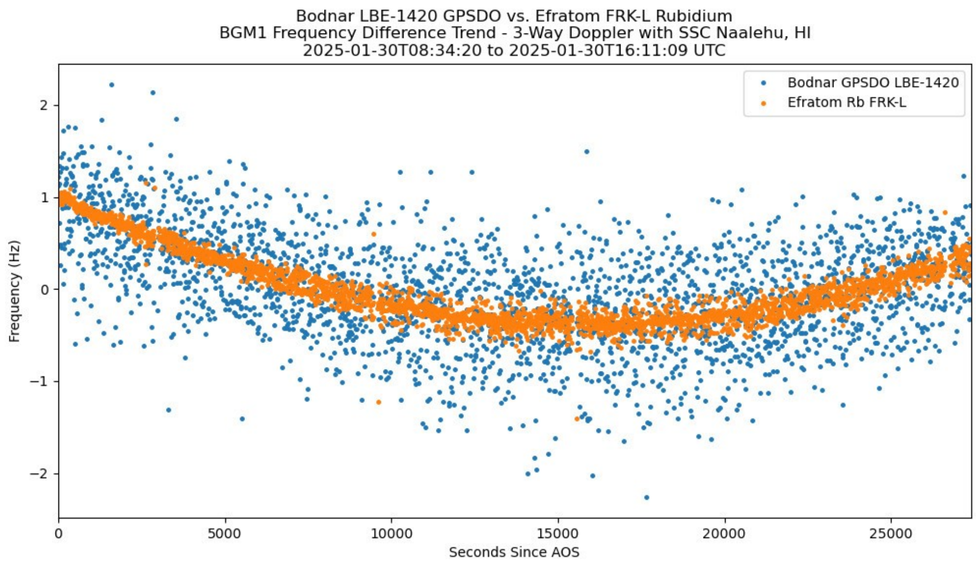

Figure 5: Comparison of Blue Ghost lunar lander Doppler using the reference oscillator system used for Artemis I and the new Rubidium (Rb) reference now used at the station.

- **Ability to mute/silence ground station transmit functionality to ensure no radiation towards Orion.**

The Earth station we are using has no transmit capability ensuring no risk of interference with the mission.

- **Compatible data format(s) and the ability to transmit information back to NASA.**

We can provide Doppler data in Tracking Data Message format conforming to CCSDS 503.0-B-2 as we did during the Artemis I mission.

- **Geodetic Information**

WGS-84 with east-longitude, Geodetic Latitude and height in km:

Station Name	East Longitude (°E)	Geodetic Latitude (°N)	Height (km)
RobertsCreek-1	236.331444	49.434778	0.04

Participant Details

Scott Tilley, AScT **–** Is an amateur radio astronomer with an interest in tracking spacecraft in low Earth orbit (LEO) into deep space. He has over 10 years of experience tracking various objects in space using optical, radio position and Doppler techniques on various radio bands from VHF to X-Band. Scott has built and maintains the S-band sensors to be used to support this RFI at his residence on the Sunshine Coast of British Columbia, Canada. NASA may recall that Scott re-acquired the lost IMAGE mission in Early 2018 and has also contributed time to present how amateurs track space missions to NASA-JPL in 2021. Professionally he holds the title Applied Science Technologist (AScT) and practices independently as a consultant in marine electrical and electronics systems.

A short video on the recovery of IMAGE:
https://www.youtube.com/watch?v=hMsE1rxeOw4

You can follow his activities on X @coastal8049