ARTEMIS I ORION ONE-WAY DOPPLER TRACKING DEMONSTRATION
Response to RFI-GSFC-CIS-2022 - Artemis I Tracking _RFI_SEE_TILLEY.pdf
Date: August 20, 2022

Summary

NASA has requested a Request for Information (RFI) from interested parties to supply them with one-way Doppler data from the upcoming Artemis-1 mission. In the RFI, NASA suggests large (relative) antenna apertures may be needed to collect useful one-way Doppler data from cis-lunar missions. We have proven experience over the years that useful one-way Doppler data can be obtained with small apertures and with simple equipment relative to larger assets from objects in Cis-Lunar space and beyond.

This response is made by ***Space Exploration Engineering (SEE)*** and ***Scott Tilley, AScT*** as part of their ongoing collaboration to test the ability of small sensors to conduct useful Doppler analysis on missions in the cis-lunar space environment.

By 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 1.8m prime focus dish antenna at 2295MHz.

System Parameters:

D = 1.8 m
Beam-width = 5°
Ts = 101.7 K
Ae = 1.581 m^2
n = 0.621 or 62.1%
G/T = 10.18 dB/K
Polarization RHCP, LHCP, horizontal and vertical.
Frequency measurement is GPS referenced.
Tracking accuracy = 0.5°

The S-band sensor block diagram is detailed in ***Figure 1***.

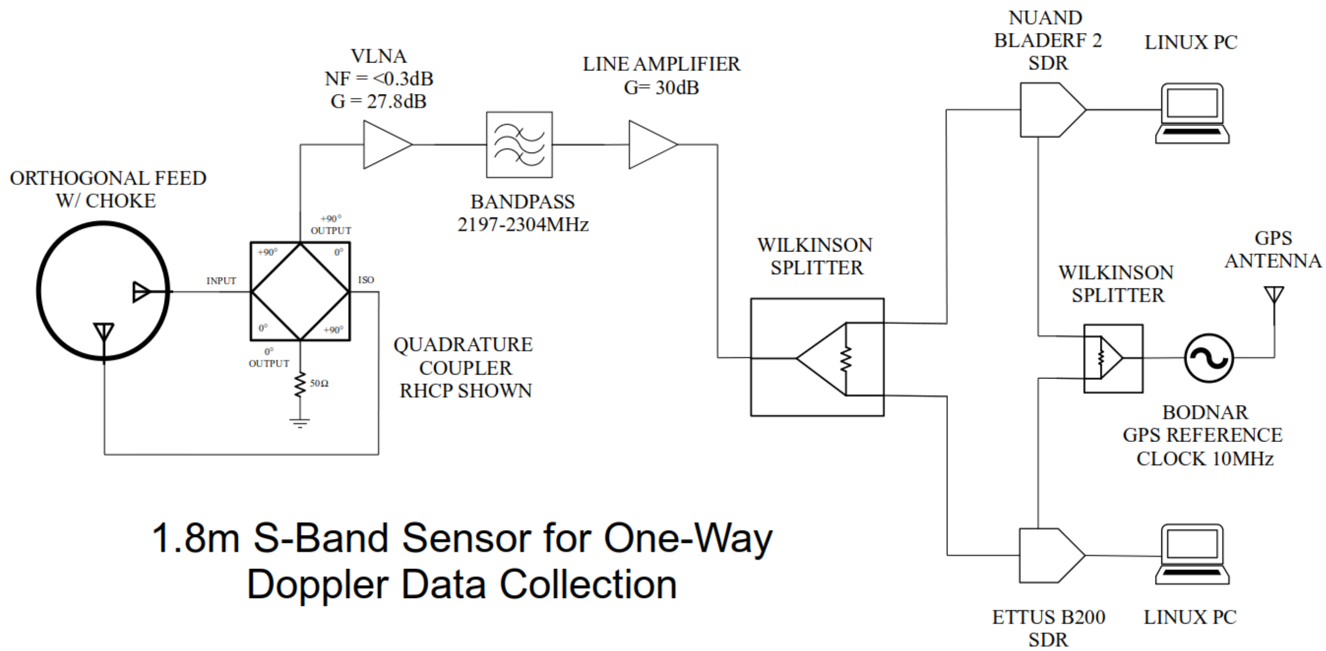


Figure 1: *Block diagram of 1.8m S-Band sensor system.*

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

We have tracked many cis-lunar missions on S-band over the years and surrounding space using apertures ranging from 0.66m, 0.8m, 1.8m and 3m.

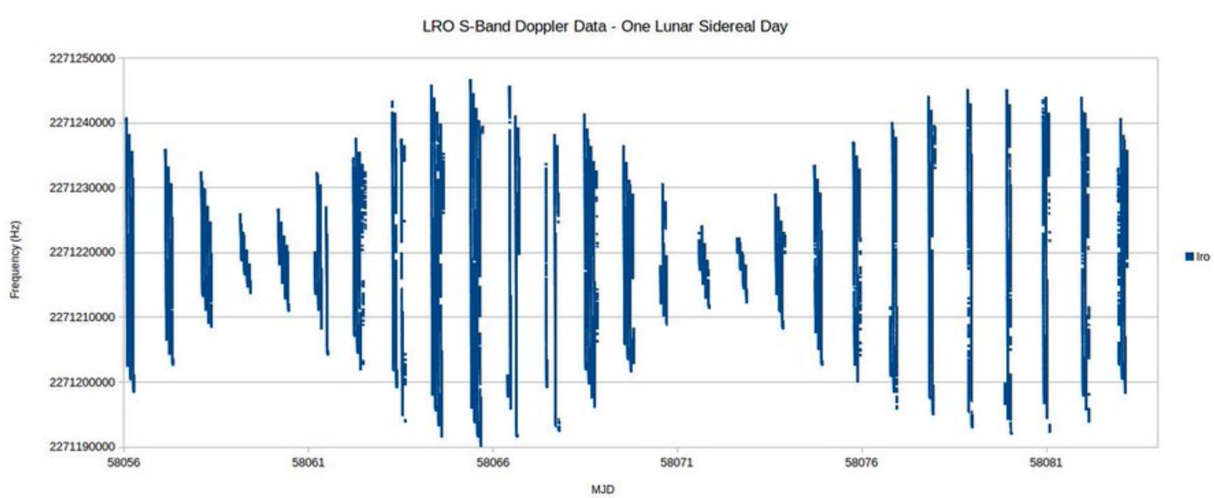
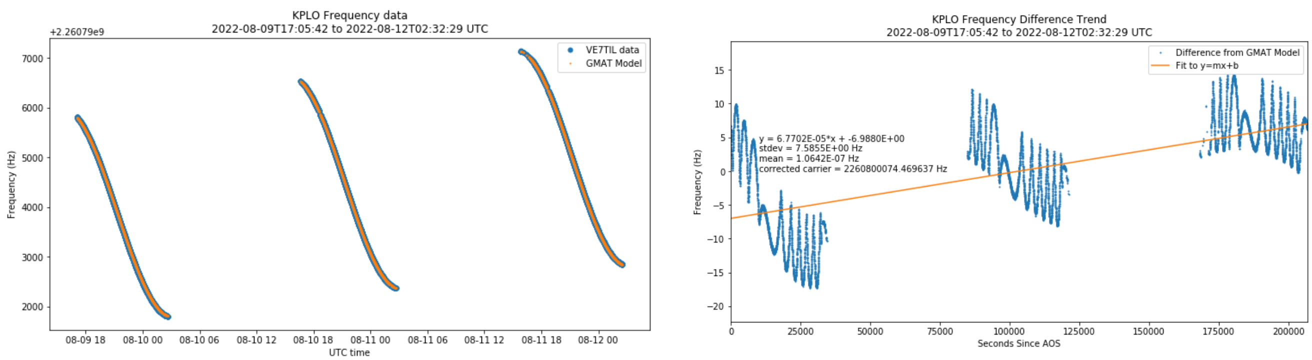


Figure 2, shows the results of one lunar day of Lunar Reconnaissance Orbiter (LRO) one-way Doppler data plotted using a 0.66m sensor.***Figure 2:*** *LRO one-way Doppler plotted over a complete lunar orbit of the Earth by a 0.66m sensor.*

Figures 3 and 4 provides recent one-way Doppler data acquired with our 0.8m sensor of the KPLO mission at distances beyond the orbital distance of the Moon.



Figures 3 and 4*: One-way Doppler data from lunar mission KPLO compared to state vector provided by JPL Horizons. Figure 3 is comparison of expected Doppler modeled in GMAT vs. received data. Figure 4 is the residuals. Note effect of ramped up-link in the Doppler residuals.*

Our station has also accurately tracked uncooperative targets (no publicly available state vectors) such as the Chinese TIANWEN-1 (Mars) and CHANG'E 5 (Lunar Orbit, surface, E-S L1 and Lunar DRO) missions.

Figure 5 provides a sample of the results of monitoring a Trajectory Correction Maneuver (TCM) from TIANWEN-1 on it's way to Mars on X-band.

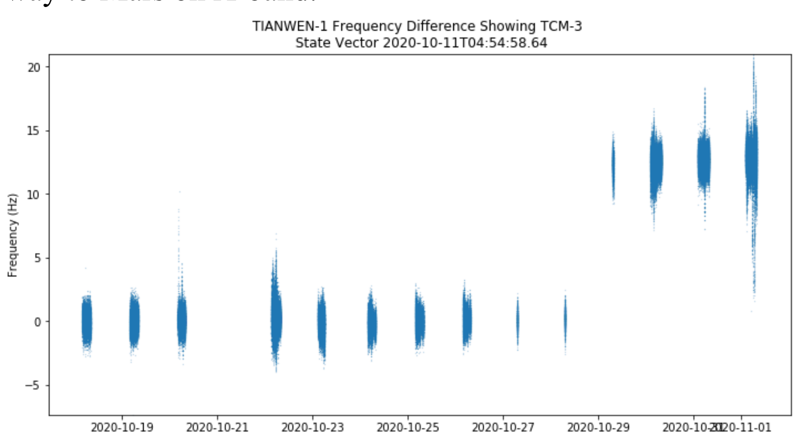


Figure 5: *TIANWEN-1 transmitted state vectors, which observers decoded and used to model the expected one-way Doppler and monitor TCMs during the mission to Mars on X-band.*

The story of how we tracked CHANG'E-5's arrival in Distant Retrograde Orbit (DRO) of the Moon is here:
https://skyriddles.wordpress.com/2022/01/25/change-5-returns-to-the-moon/

During the recent Rocket Lab Lunar Photon mission to send CAPSTONE on the way to the Moon the SEE team and Scott Tilley shared information on Lunar Photon's state vector and Scott's system was able to accurately track the object and record one-way and ***three-way (ground station, spacecraft, third party)*** Doppler. ***Figure 6*** shows some of the analysis of the Photon signal just before Trans-lunar injection (TLI). During this process Scott was able to tweak his methods with the feedback from SEE and others contributors.

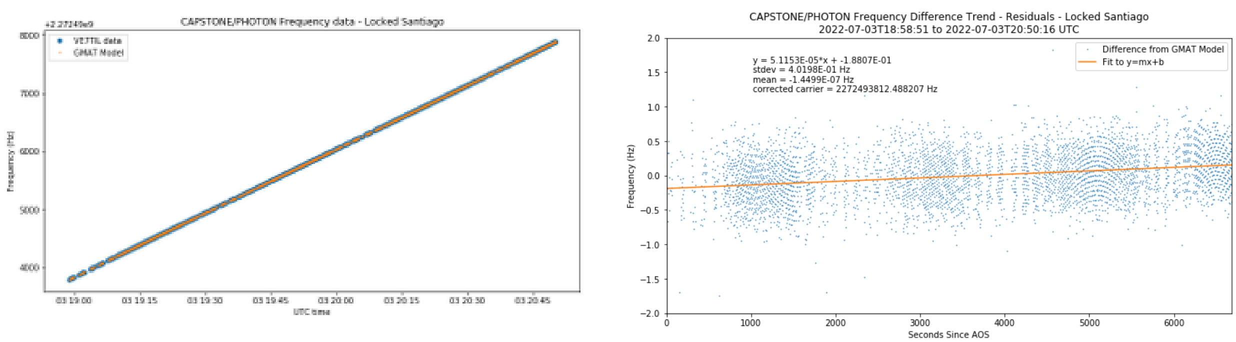


Figure 6: *A controlled test with Rocket Lab's Lunar Photon was conducted where an accurate state vector was supplied to the ground station. Here the spacecraft is in ground lock with SSC Santiago and our ground station is performing a three-way (ground station, spacecraft, third party observer) Doppler analysis. Three-way analysis generally produces better results due to the stability of the ground station signal.*

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

Our work flow to record Doppler data is capable of sub-Hz resolution. A sample of the tabular raw Doppler data below.

59805.670474	*2260794270.667083*	*0.002239*	*8049*
59805.670590	*2260794409.567638*	*0.002106*	*8049*
59805.670706	*2260793922.465690*	*0.002420*	*8049*
59805.670821	*2260797416.979668*	*0.002628*	*8049*

Where each column represents:
MJD (modified Julian date), Frequency (Hz), Arbitrary signal intensity, Station ID (COSPAR)

We use NASA's ***General Mission Analysis Tool (GMAT)*** to generate range-rates to compare to our Doppler data and also to correct errors in the state vectors to generate more accurate models.

- **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.**

If NASA provides a format definition our station can generate a compatible output file format.

Participant Details

Space Exploration Engineering (SEE) - offer a variety of technical services to help make missions successful. We provide training courses and workshops in astrodynamics, mission planning, trajectory analysis, orbit determination, and operations. We act as advisors and mentors, increasing the expertise of your team. We perform technical due diligence on mission concepts and space business plans. We engage in long-term contracts, providing technical support through all mission phases, including surge support during operations.

Website: www.see.com

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 Twitter @coastal8049.