FY24 Strategic Initiatives Research and Technology Development (SRTD)

Cubesat Bistatic Radar for Small Body Tomography

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Strategic Focus Area: Radar Advances to Accelerate Earth and Planetary Missions | **Strategic Initiative Leader:** Darmindra D Arumugam

Objectives:

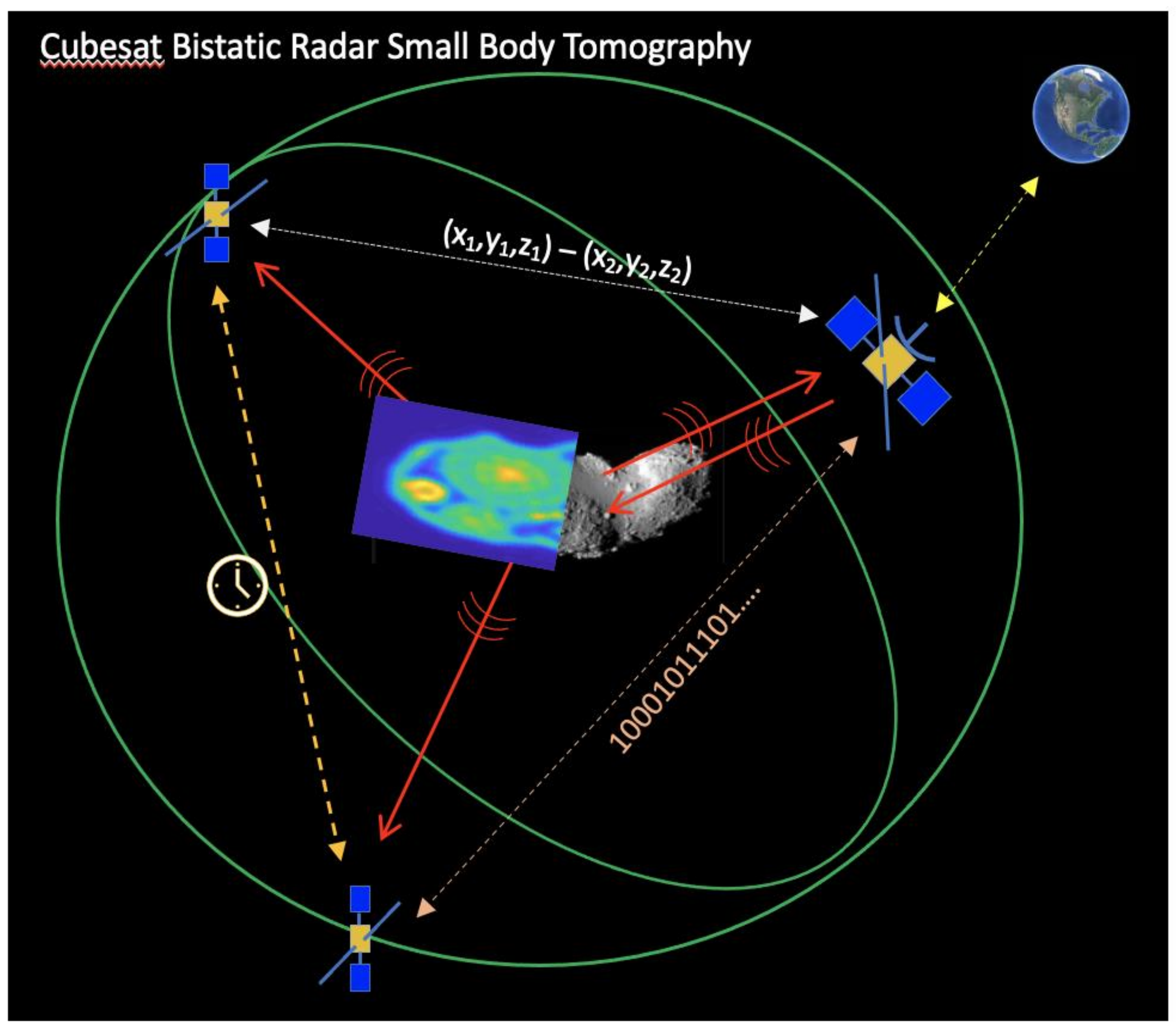
The objective of this 3-year effort is to advance to TRL 5 key subsystems of cubesat low-frequency (VHF) bistatic radar sounders built to map the dielectric interiors of solar system small bodies using advanced radar tomography.

Approach:

Hardware design and testing is driven by answering:

- What part of the distributed radar system requires knowledge vs control in real-time vs post?
- What part of the distributed radar system must be managed by the instrument vs the flight system?

To accelerate the path to flight, the Section 337 Common Instrument Electronics (CIE) Swift+RAC will be used to implement the bistatic radar.



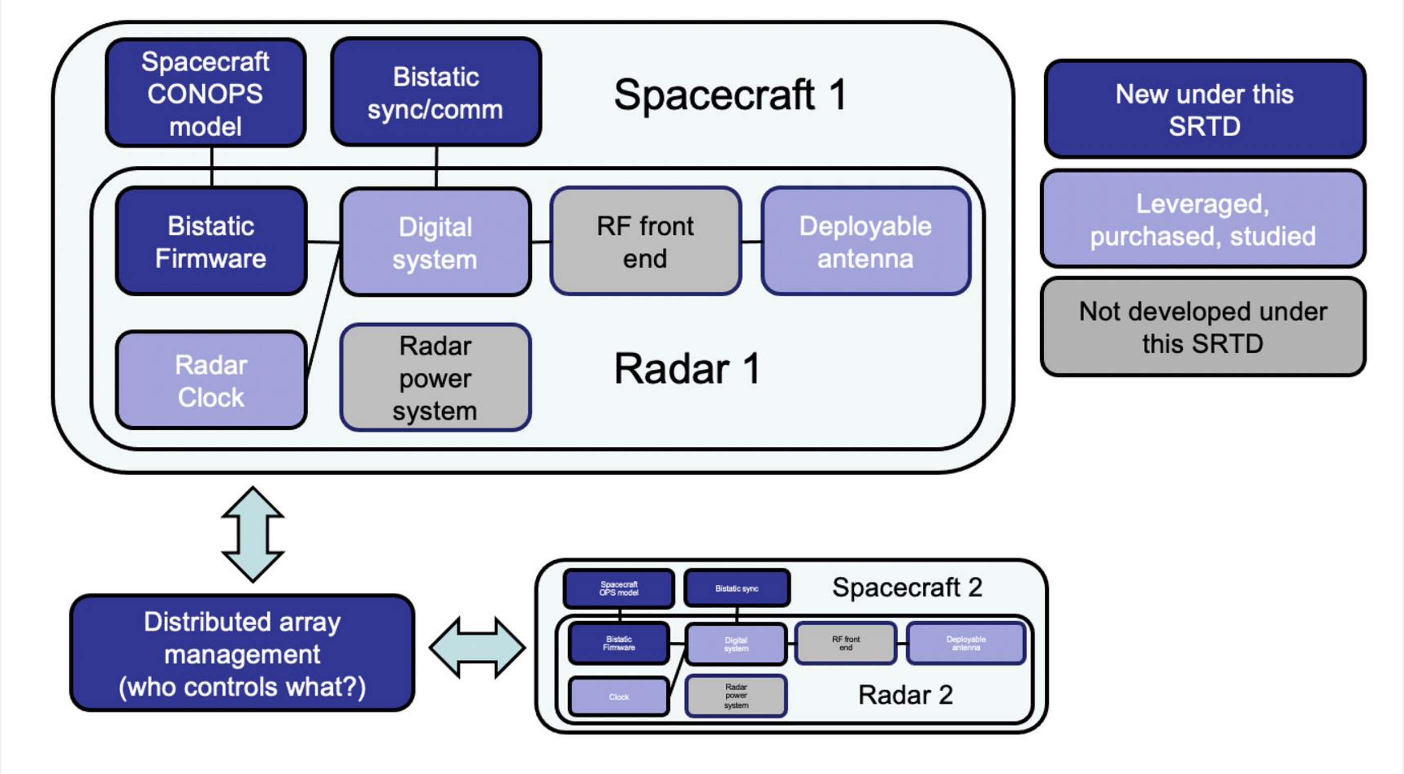
Background:

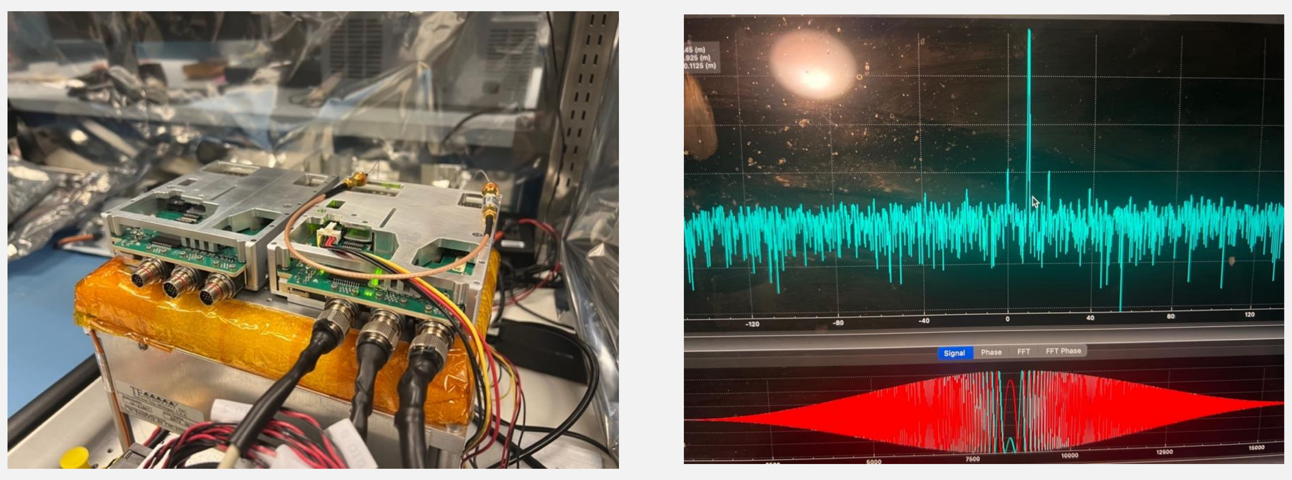
A low-frequency bistatic radar instrument will enable future planetary missions that are capable of multi-spacecraft proximity imaging of small body dielectric interiors using advanced tomography techniques. These techniques create images of volumetric backscatter and 3D dielectric via model-based inversion that reveal both structure and dielectric distribution of the interior. This information is required in order to resolve outstanding hypothesis about small body interior structure, which provides constraints on their formation and the origin of planets. Interior structure is also of vital importance for developing mitigation strategies for potentially-hazardous near-Earth asteroids (NEAs).

Technical challenges:

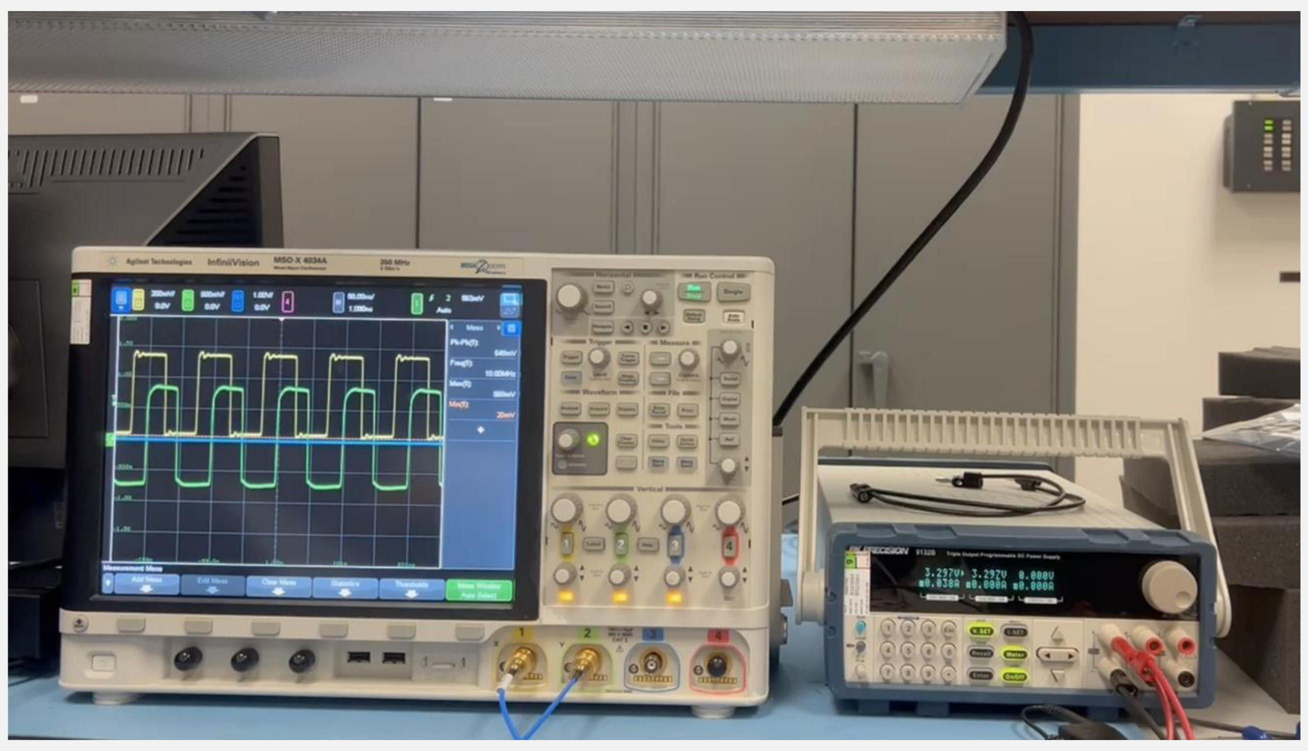
Three technical challenges specific to small body bistatic radar:

1) Bistatic scheduler to command and control two distributed radars
2) GPS-denied radar synchronization better than 1/20th wavelength (<25 cm at 60 MHz)
3) Dynamic range to capture line-of-sight signal and scattered signal from the object.

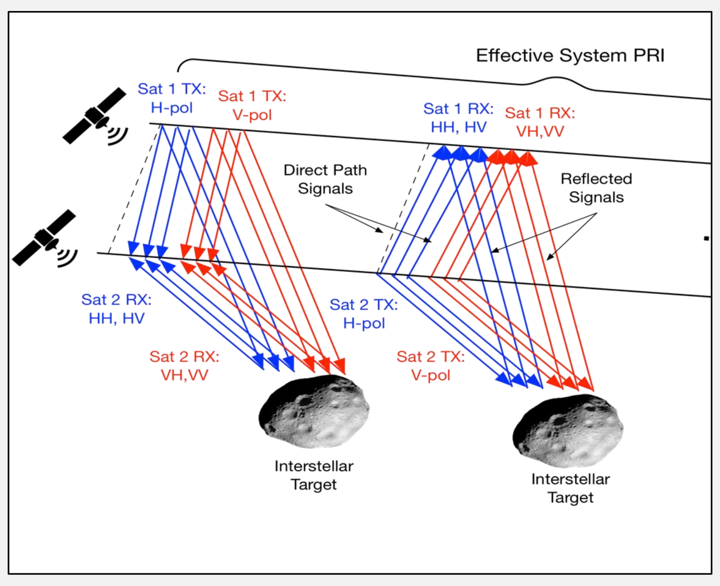




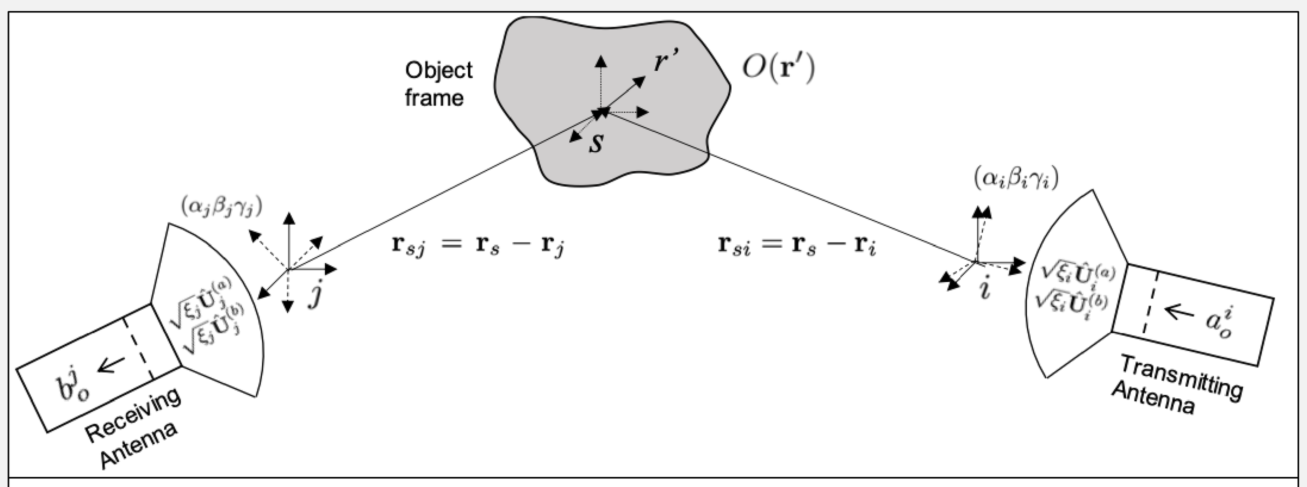
(Left) Digital test bed (COTS RF System on a Chip) for developing bistatic timing synchronization firmware. (Right) Range compressed pulse from SDRadar FPGA core.



Green: 10 MHz GPSDO. Used as external reference input for master (A). Yellow: Recovered 10 MHz clock output by follower (B)



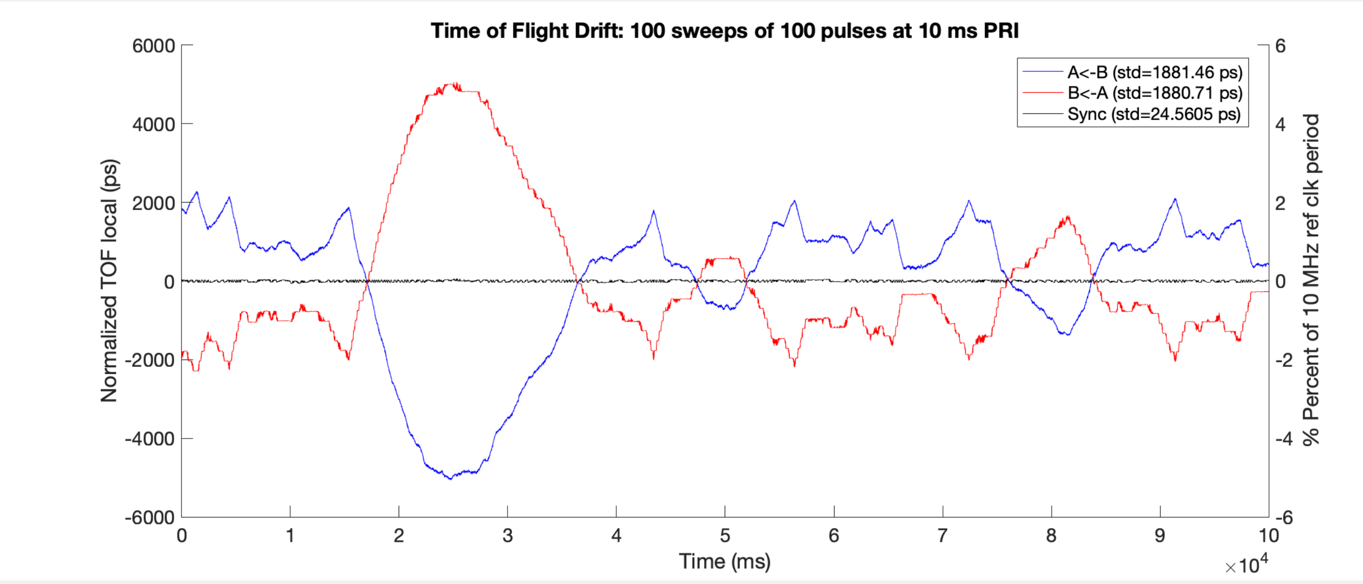
Pulse exchange, scheduling, and synchronization for quad-pol bistatic measurements.



$$b_o^{jpiqk} = a_o^{iqk} \frac{ik}{2} \frac{\sqrt{Z_o^{jpk}}}{\sqrt{Z_o^{iqk}}} \int \mathbf{e}_{inc,u,jpk}(\mathbf{r}') \cdot O(\mathbf{r}') \mathbf{e}_{u,iqk}(\mathbf{r}') dV'$$

$$\mathbf{e}_{u,iqk}(\mathbf{r}) = \mathbf{e}_{inc,u,iqk}(\mathbf{r}) + \int \overline{\mathbf{G}}(\mathbf{r},\mathbf{r}') \cdot O(\mathbf{r}') \mathbf{e}_{u,iqk}(\mathbf{r}') dV',$$

Volume integral equations with calibrated source model for 3D dielectric interior imaging.



Hardware clock synchronization in frequency and with clock phase noise error of ~4 ns (4% of 10 MHz clock period). Using symmetry of the relative clock phase errors, further fine synchronization to ~25 ps is demonstrated.

Significance/Benefits to JPL and NASA:

This effort is advancing critical subsystems of a bistatic tomography radar for a future SIMPLEx, Discovery, or rapid-response planetary defense mission. The instrument serves future distributed radar sounder systems, e.g., for Earth ice sheet sounding and any future low-frequency radar for the Moon, Mars and icy worlds.

National Aeronautics and Space Administration

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Publications:

- M. S. Haynes, I. Fenni, "T-matrix Backprojection Imaging for Scalar and Vector Electromagnetic Waves," IEEE TAP, vol. 71, no. 3, March 2023. 10.1109/TAP.2022.3232741.
- M. S. Haynes, I. Fenni, and B. Davidsson, "Inverse Scattering under the Born Approximation using an Object T-matrix and Full Bistatic Spherical Sampling Geometry," IEEE TAP, 10.1109/TAP.2023.3329645.

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