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Space Systems Laboratory

NavIC-Reflectometry Receiver Development for Remote Sensing Application

United Nations/Finland Workshop on the Applications of Global Navigation Satellite Systems

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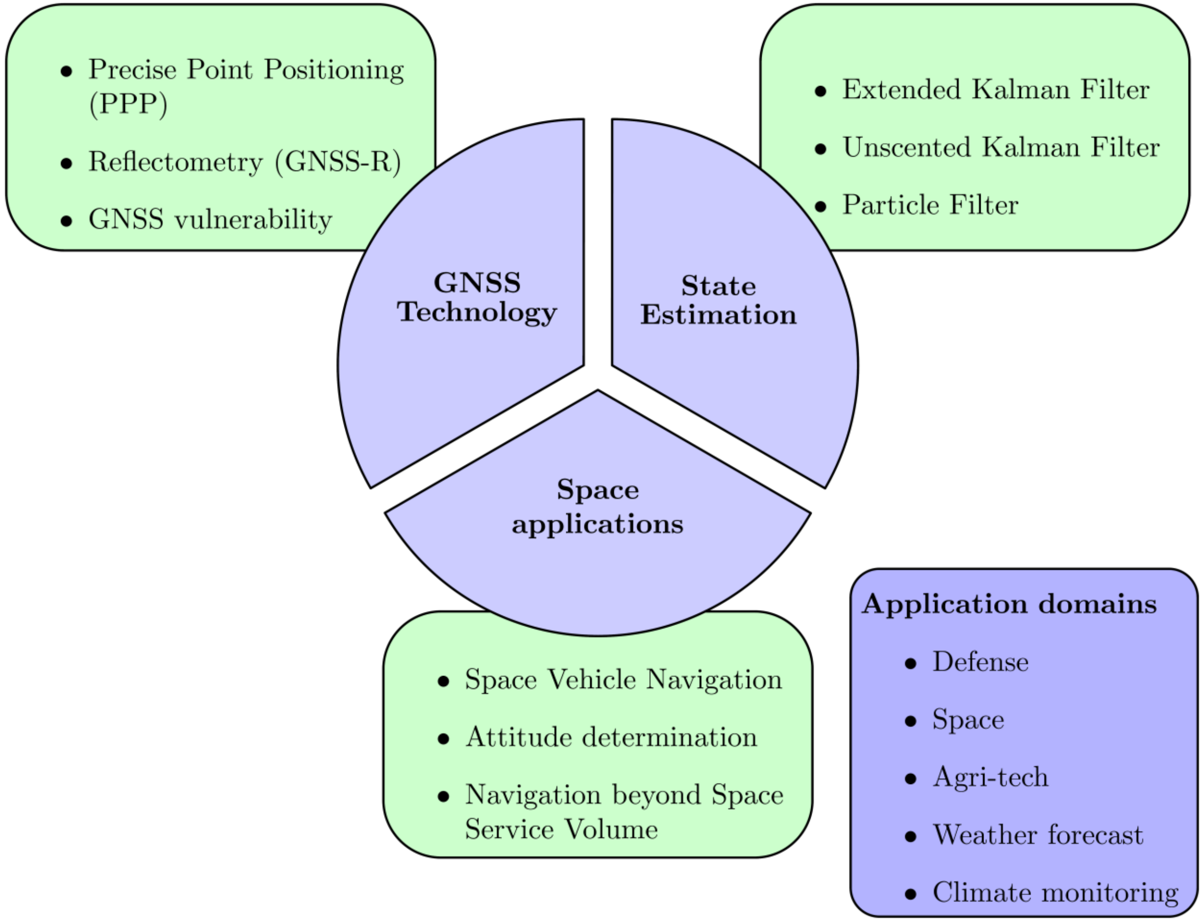

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Space Systems Laboratory

Outline

- Introduction
  - GNSS
  - GNSS-R
- Theoretical Concepts
- NavIC-R Receiver Development
- Results and Discussion
- Conclusion and Future work

What is GNSS

- GNSS is a generalized term referred to the constellation of global and regional satellite systems that provides Positioning, Navigation and Timing (PNT) services.

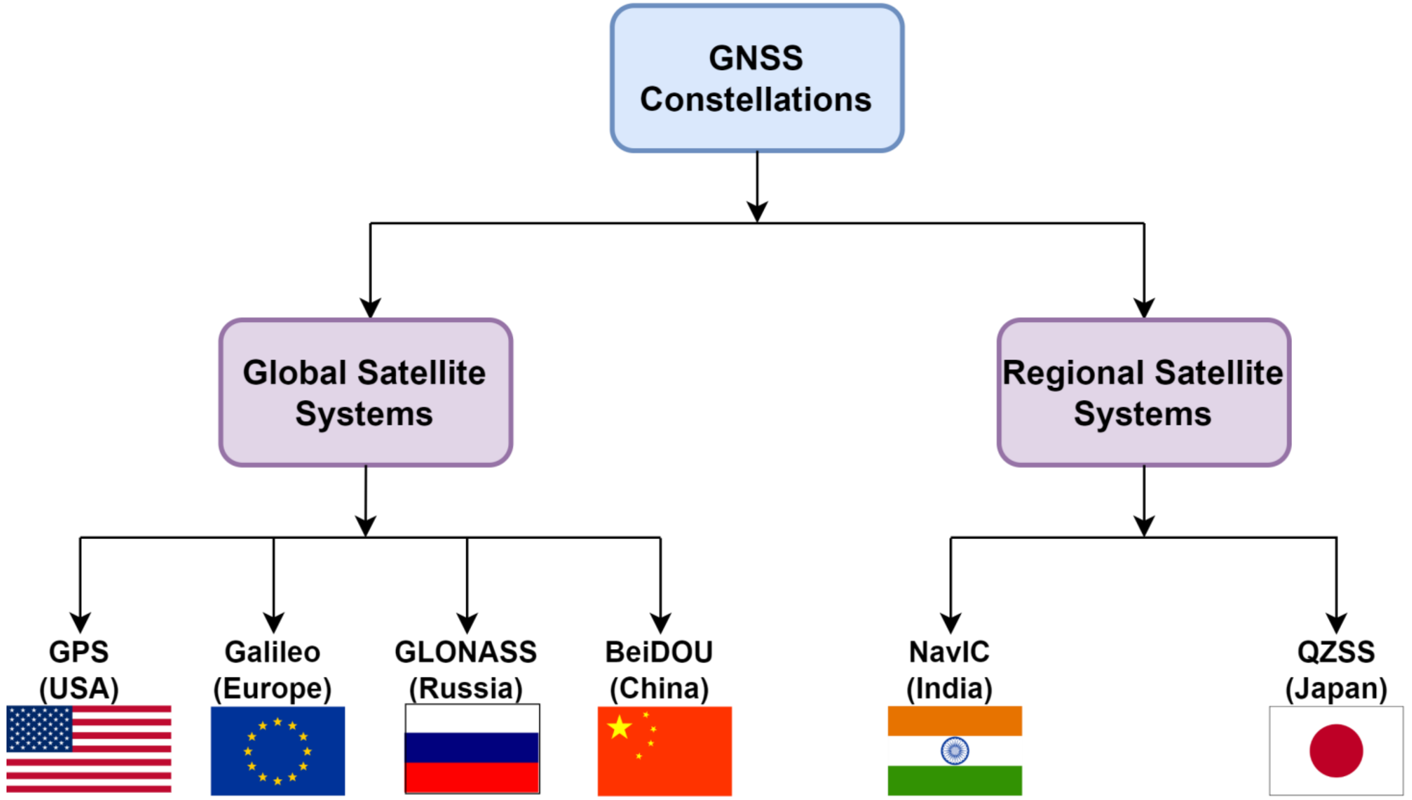


Fig 1. GNSS Constellations

NavIC: A Brief Introduction

- The IRNSS constellation consist of 7 satellites with 3 satellites in the geostationary orbit and 4 satellites are in geosynchronous orbits.

- IRNSS is an independent and autonomous regional navigation system aiming a service area of about 1500 km around India.

- The IRNSS SPS (Standard Positioning Service) is transmitted on L5, S and L1 band.

What is GNSS-Reflectometry (GNSS-R)

- It is a remote sensing technique that uses GNSS signals to study underlying Earth's surface.
- It uses the navigation signals in the bi-static or the multi-static radar configuration.
- GNSS-R intends to analyze the direct and multi-path signal reflected from the Earth's surface, as shown in Fig 2.

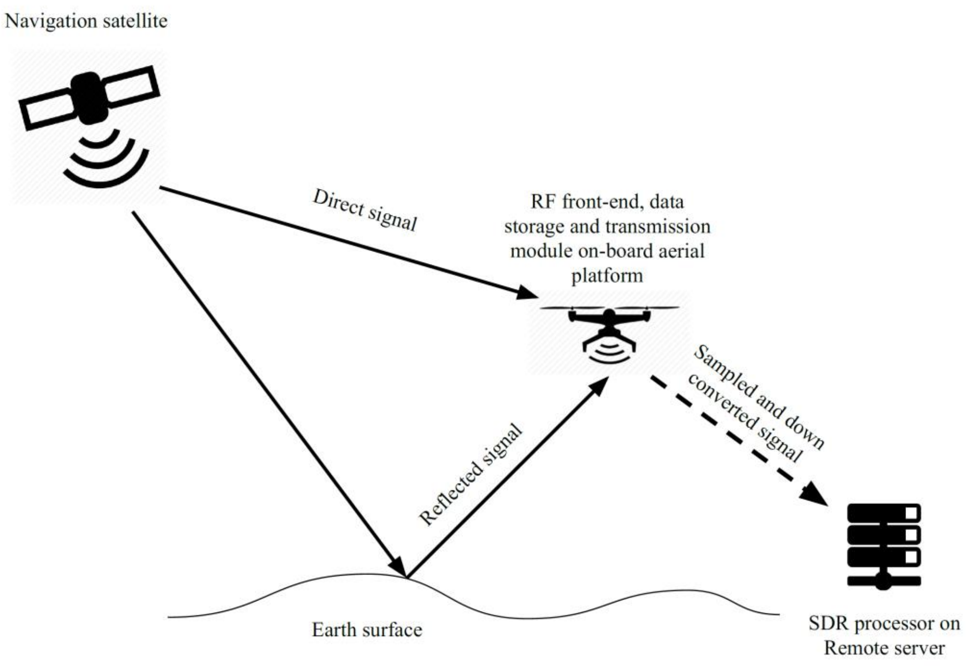


Fig 2. GNSS-R Concept

GNSS-R (contd.)

- When the GNSS signals propagates through the atmosphere and gets reflected from the Earth’s surface the amplitude, phase, signal power and the polarization characteristics of the signal changes.

- The change in the characteristics of reflected GNSS signals are used to study the geophysical parameters of the underlying surface.

- The utility of GNSS signals to perform reflectometry and scatterometry was first proposed in 1988 and then for ocean altimetry in 1993 [1].

- Already existing and completed GNSS-R mission:
  - UK’s Technology Demonstration Satellite, TechDemoSat (TDS-1).
  - NASA Cyclone Global Navigation Satellite System (CYGNSS).

- Benefits of GNSS-R for Earth Observation:
  - Versatile and cost effective complement of existing earth observing systems.
  - It provides 24 hour coverage due to continuous availability of GNSS-signals.

[1] M. Martin-Neira, “A passive reflectometry and interferometry system (PARIS): Application to ocean altimetry," ESA journal, vol. 17, no. 4, pp. 331-355, 1993.

Applications of GNSS-R

- Altimetry Measurement
- Soil Moisture Estimation
- Snow Height Monitoring
- Wetland Estimation
- Wind Speed Determination
- Sea-state Estimation

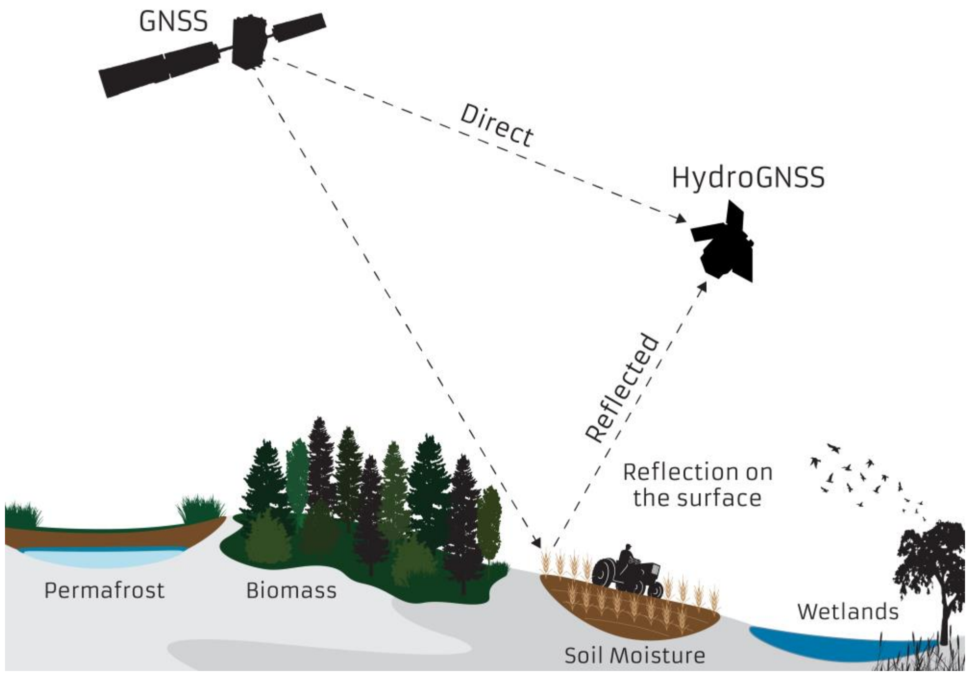


Fig 3. GNSS-R Applications (© ESA)

Goals and Objective

- Performing reflectometry analysis using NavIC signals, and to develop SDR receiver, for receiving the NavIC multipath signals, and further use these signals for soil moisture estimation.

- Obtaining and analyzing Delay Doppler Maps (DDMs) for the direct and reflected GNSS signal for soil moisture application.

- Development of an algorithm to efficiently acquire and modify received NavIC signals to measure soil water content.

- The long term goal is to use NavIC-Reflectometry for various applications including soil moisture measurement, weather forecast, sea-state monitoring etc. and estimating the related variables in real time.

Theoretical concepts (contd.)

- According to the bistatic radar equation the coherent reflected power at the receiver is a function of surface reflectivity Γp [2].

$$P_p^{coh} = \frac{P_t \lambda^2 G_t G_r}{(4\pi)^2 (R_{ts} + R_{rs})^2} \Gamma_p(\epsilon_s, \theta_i) \quad \text{.........(1)}$$

Where Pt- transmitted GNSS signal power,
λ - GNSS signal wavelength,
G_t and G_r - transmitter and receiver antenna gain respectively,
Γ_p - surface reflectivity for a particular polarization p,

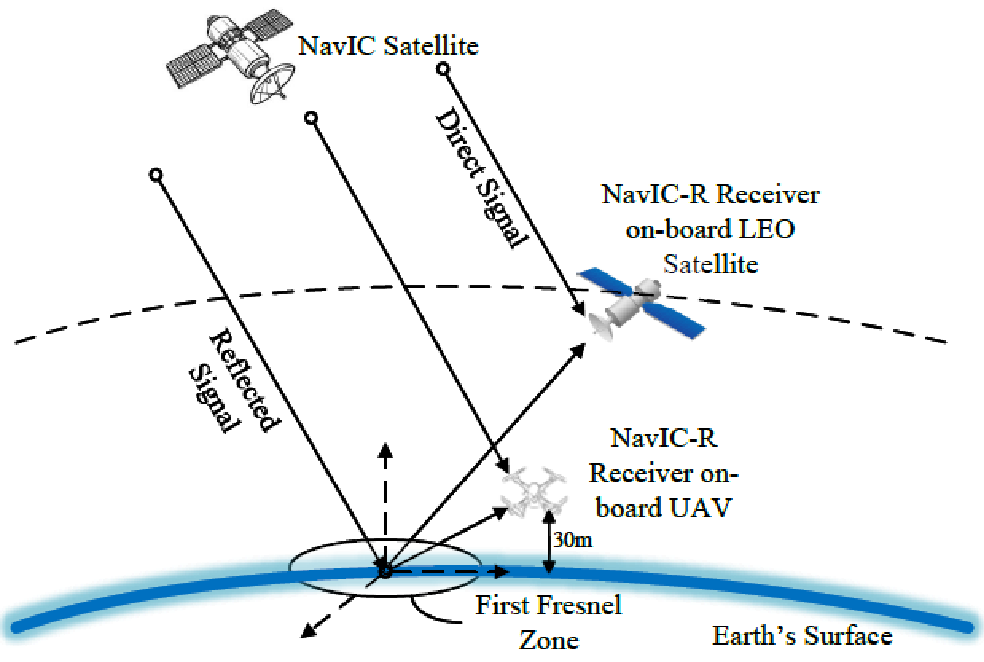


Fig 4. GNSS-R Basic Geometry

[2] Zuffada, Cinzia, Clara Chew, and Son V. Nghiem. "Global navigation satellite system reflectometry (GNSS-R) algorithms for wetland observations." 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS). IEEE, 2017.

Theoretical concepts (contd.)

- The DDM is a function of doppler shifts and delay offset around the specular point.

$$|P(\tau, f)|^2 = \frac{T_i^2 P_t G_t \lambda^2}{(4\pi)^3} \iint_A \frac{G_r(\vec{\rho})}{R_{ts}(\vec{\rho}) R_{rs}(\vec{\rho})} \sigma_{pq}^{\circ} \chi^2(\vec{\rho}; \delta\tau, \delta f) d\vec{\rho} \quad \text{.........(2)}$$

- From peak power levels, the surface reflectivity can be calculated as:

$$\Gamma_p(\epsilon_s, \theta_i) = \frac{(4\pi)^2 (P_{DDM})(R_{ts} + R_{rs})^2}{\lambda^2 P_t G_t G_r} \quad \text{.........(3)}$$

- Surface reflectivity is then used to calculate the surface dielectric constant.
- The dielectric constant is further used to calculate the soil moisture using [3]:

$$m_v = \frac{\epsilon_s}{80} + \frac{0.26}{\epsilon_s - 1} + 0.11 \quad \text{.........(4)}$$

- Increasing moisture content results in an increase in soil permittivity and therefore surface reflectivity, which will result in an increase in the coherent power levels.

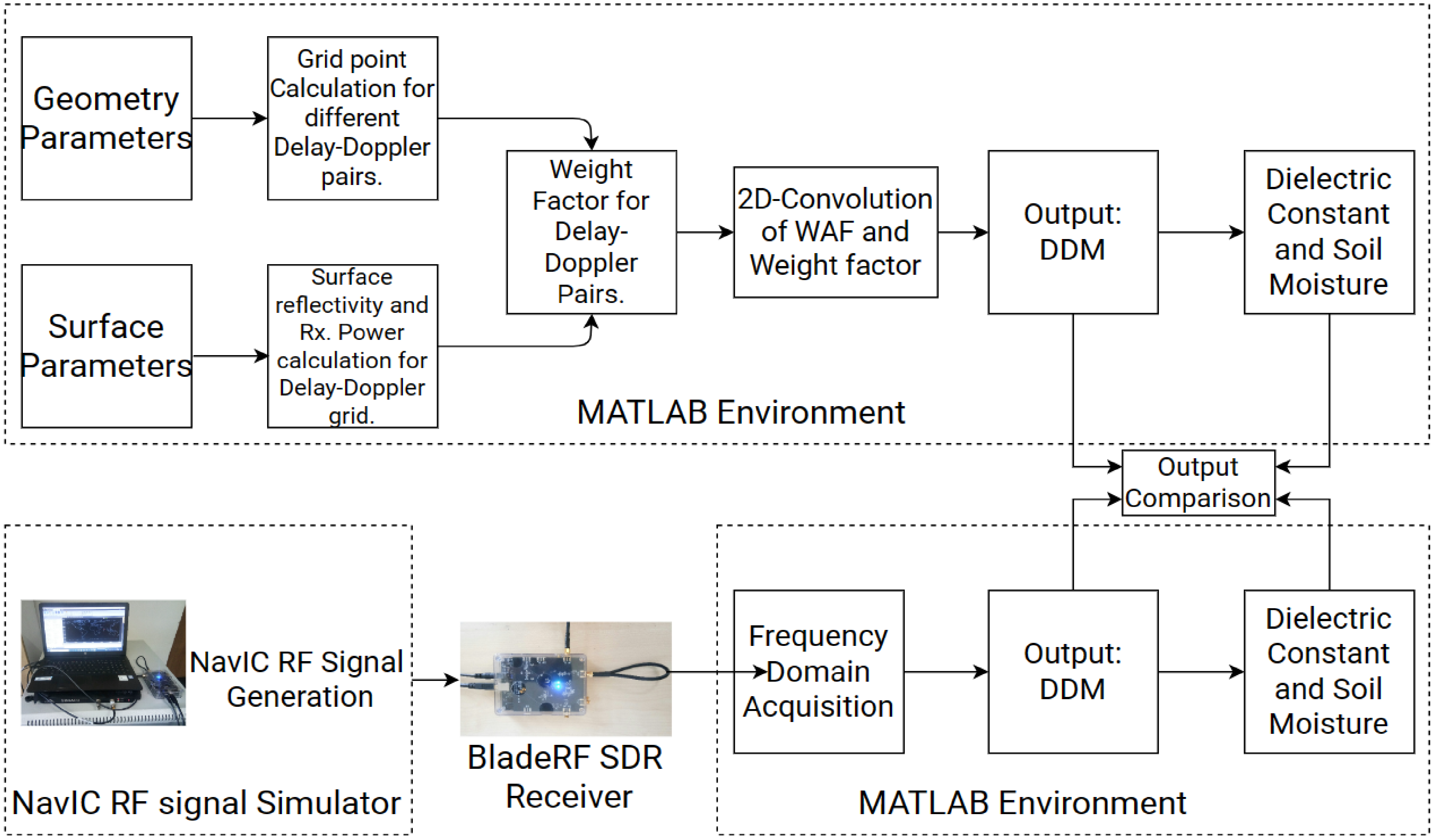
[3] Cihlar, J., & Ulaby, F. T. (1974). Dielectric properties of soils as a function of moisture content (No. NASA-CR-141868).

NavIC-Reflectometry Receiver Development

- Untill now, the GNSS-R research is mainly focused on using GPS, Galileo or BeiDou satellite constellation signals.
- The existing research on NavIC reflectometry use the commercial NavIC navigation receivers [4], which restricts the scope of the research.
- Assessing the capability of a Software Defined Radio (SDR) based NavIC-Reflectometry (NavIC-R) receiver for estimating the soil moisture using the NavIC L5 satellite signals.
- The development of the hardware-in-loop simulator (using BladeRF SDR) and validation of the simulator results is described in this work.

[4] V. Chamoli, R. Prakash, A. Vidyarthi, and A. Ray, "Sensitivity of NavIC Signal for Soil moisture variation," Tech. Rep.

Theoretical and Experimental Workflow



NavIC-R Receiver Hardware Setup

- Receive signals from SIMAC2 simulator using BladeRF and processing it in Raspberry-Pi on-board computer.
- The whole signal processing is done on RPi, which makes it feasible to use as a payload onboard the drone.
- The GNSS dataset is generally large which is used for remote sensing purpose, hence we have worked on raw GNSS data compression for reflectometry application [5].

Fig 5. NavIC-R Receiver hardware setup

[5] B. Ansari, V. Kaushik and S. K. Biswas, "Raw GNSS Data Compression using Compressive Sensing for Reflectometry Applications," 2020 XXXIIIrd General Assembly and Scientific Symposium of the International Union of Radio Science, Rome, Italy, 2020, pp. 1-4, doi: 10.23919/URSIGASS49373.2020.9232248.

Results and Discussion

- The Hardware-in-loop simulator testbed results are verified by comparing its outcomes with the theoretical simulation results as well as the TDS-1 GPS data results.
- The comparison of DDMs, dielectric constant retrieval and volumetric soil moisture estimation is performed for various surface properties.
- The TDS-1 data from July 03, 2017 and track 145 is selected for this work. This track is selected because of its coverage area over India, which is suitable for comparison with NavIC L5 signals.

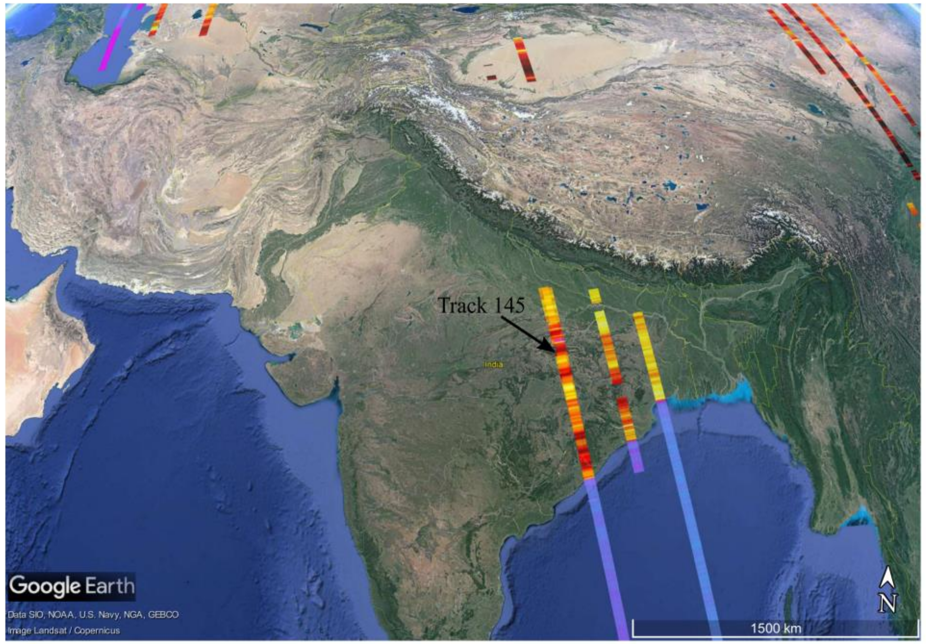


Fig 6. TDS-1 track location

Results and Discussion (contd.)

- The comparison for TDS-1 DDM and the numerically simulated DDM for the NavIC transmitter configuration is shown here:

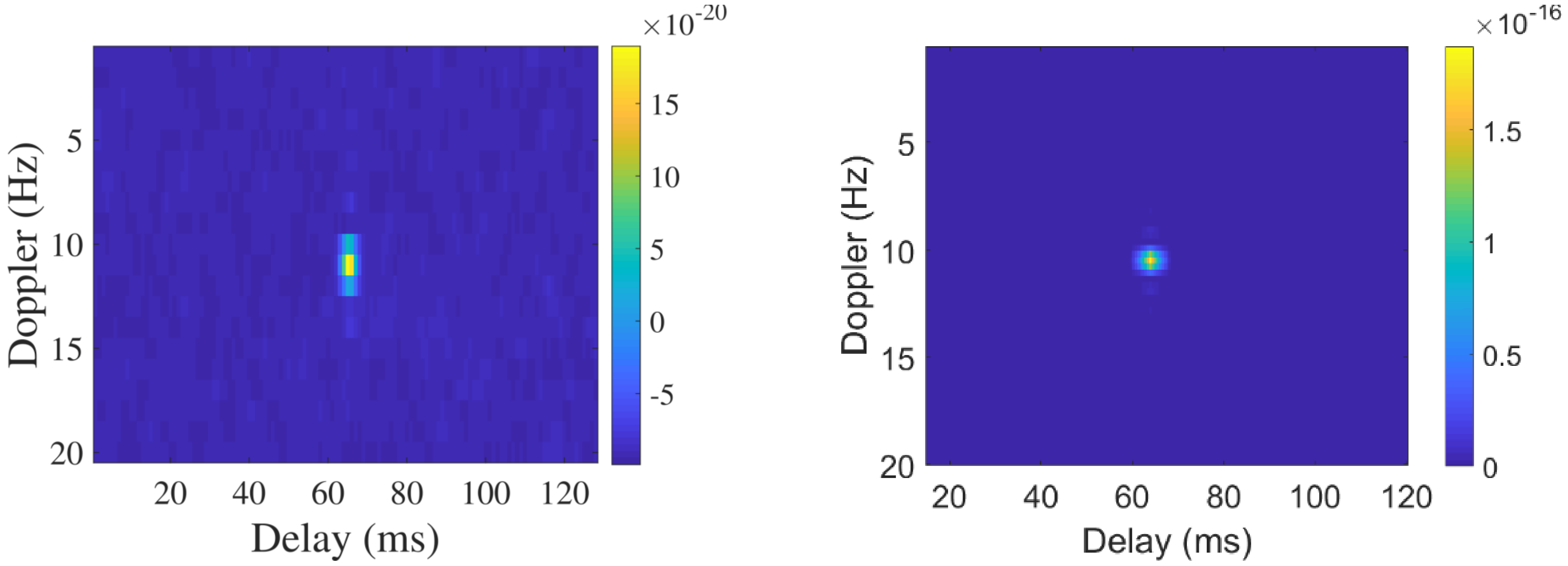


Fig 7. Comparison of TDS-1 obtained DDM (left) and numerically obtained DDM for NavIC L5 signal configuration (right).

Results and Discussion (contd.)

- The received peak power and dielectric constant variation for TDS-1 and numerically simulated scenario is shown below:

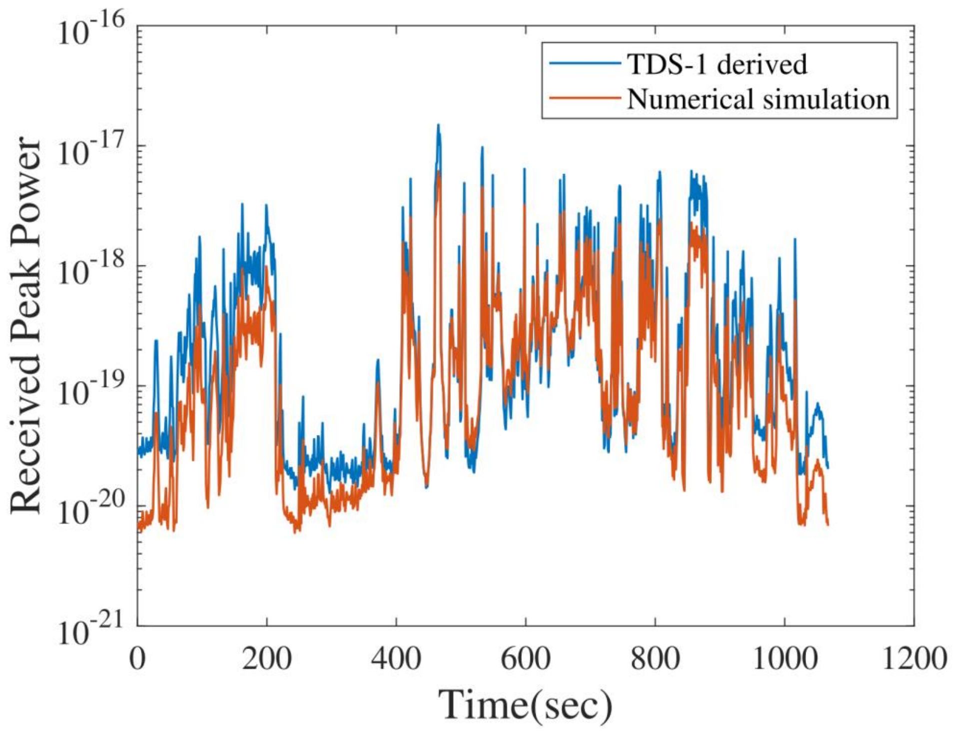


Fig 8. Received Peak Power variation over time

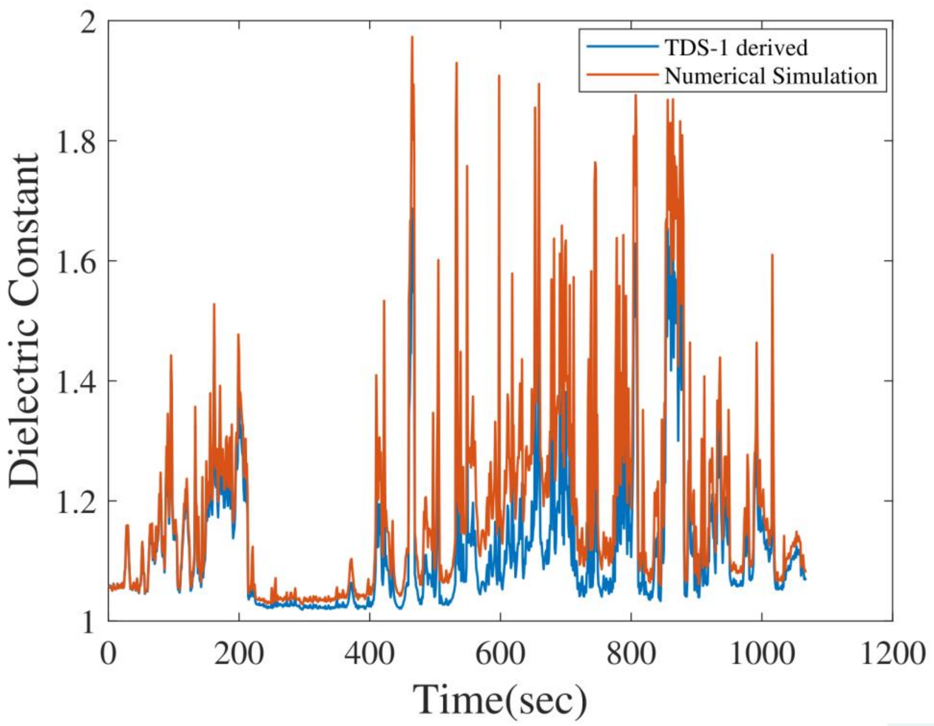


Fig 9. Dielectric constant estimate over time

Results and Discussion (contd.)

- The volumetric soil moisture as obtained using the eq. 4 is shown in Fig 10. The VSM trend is proportional to the Dielectric constant trend.

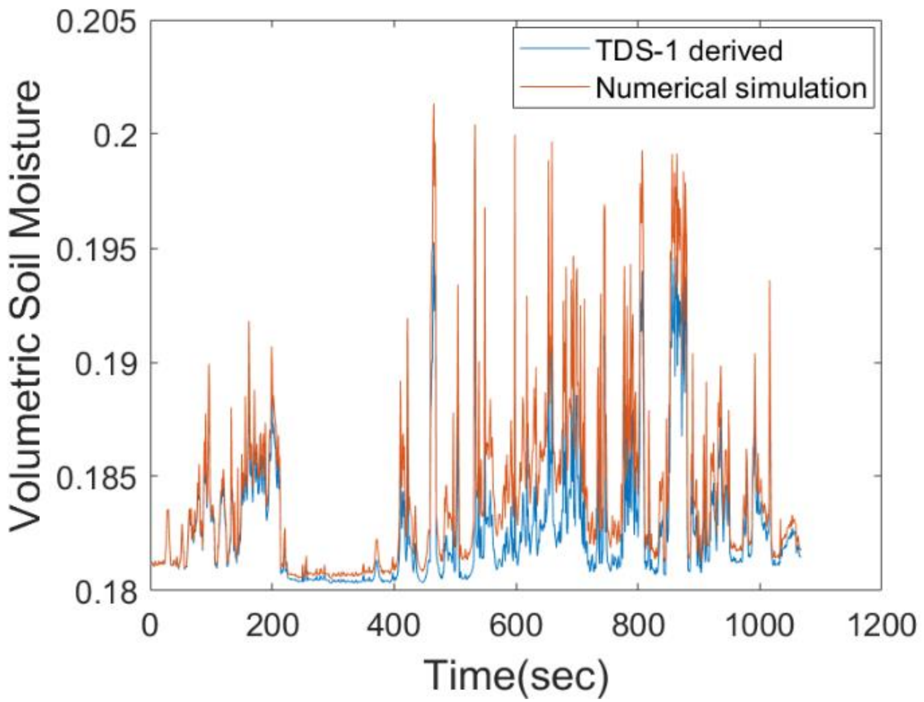


Fig 10. Volumetric Soil moisture estimate over time

Results and Discussion (contd.)

- After verification of the numerical simulation, the HIL simulator test-bed results are verified by comparing its outcomes with the numerical simulation results.
- The reflected signal's Peak power variation and volumetric soil moisture for NavIC signals is shown below:

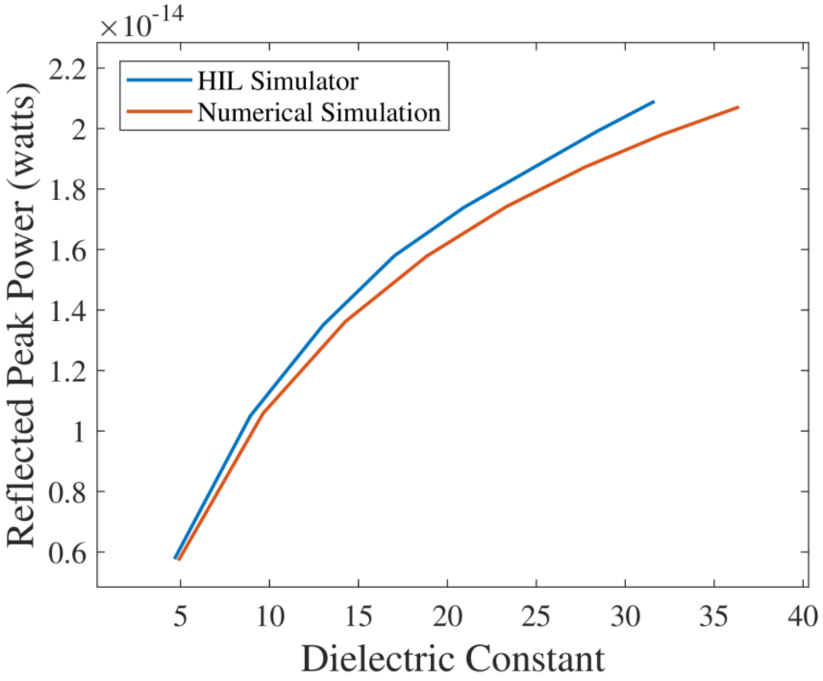


Fig 11. Reflected Peak power variation for NavIC Signals

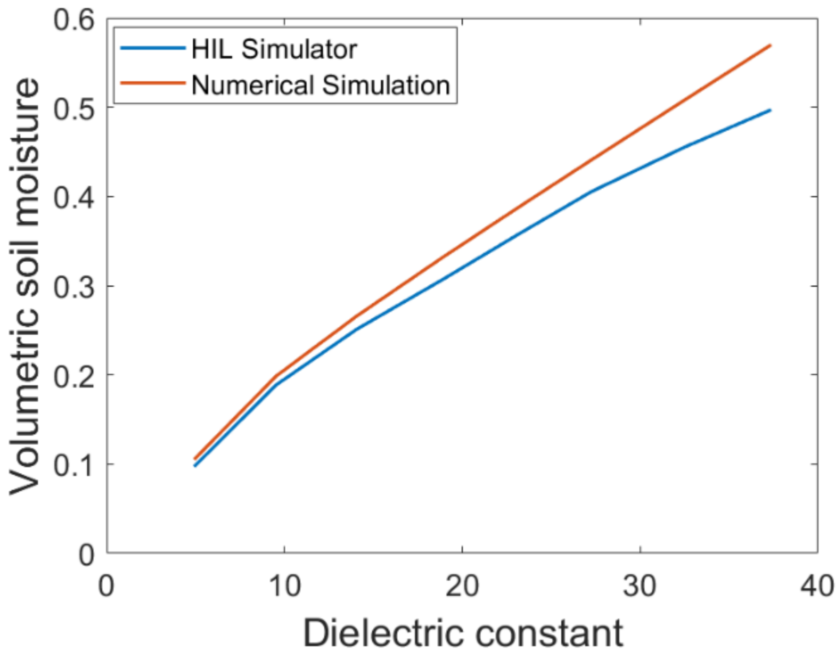


Fig 12. Volumetric Soil Moisture variation for NavIC signals

Results and Discussion (contd.)

- The numerical simulation also demonstrate that despite the NavIC signals being transmitted from the geo-stationary and inclined geosynchronous orbits, it is possible to perform remote sensing using a space-borne or air-borne NavIC-R receiver.

- Further, the soil moisture measured using the SDR receiver in the HIL simulator and the same from the numerical MATLAB simulations are compared, and they show a good agreement.

Conclusion

- The HIL simulator test-bed and numerical simulation results verifies the proposed NavIC-R receiver's functionality in soil moisture monitoring.
- Receive the NavIC signals using the SDR receiver, placed on-board a drone, to study the surface soil moisture.
- Sensitivity analysis of the reflectometry receiver using the NavIC L5-band and S-band will be studied.
- Real-time monitoring and the possibility of on-demand estimation is feasible using the GNSS-R technique.

Future Work

- NavIC-L5 antenna development for reflectometry applications and real-time analysis.

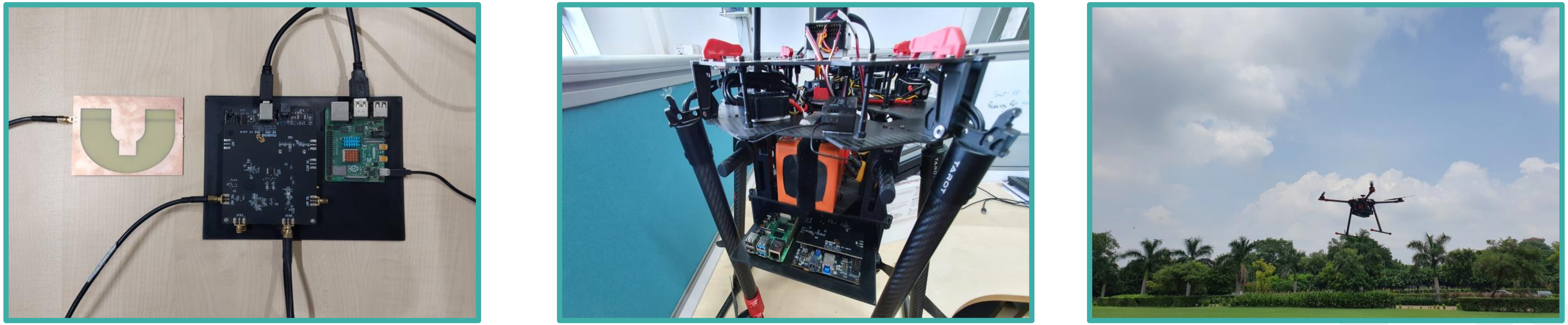


Fig 13. Hardware setup for real-time analysis

Thank You

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