Jet Propulsion Laboratory
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A GNSS-Reflectometry Instrument for Wetland Extent and Dynamics

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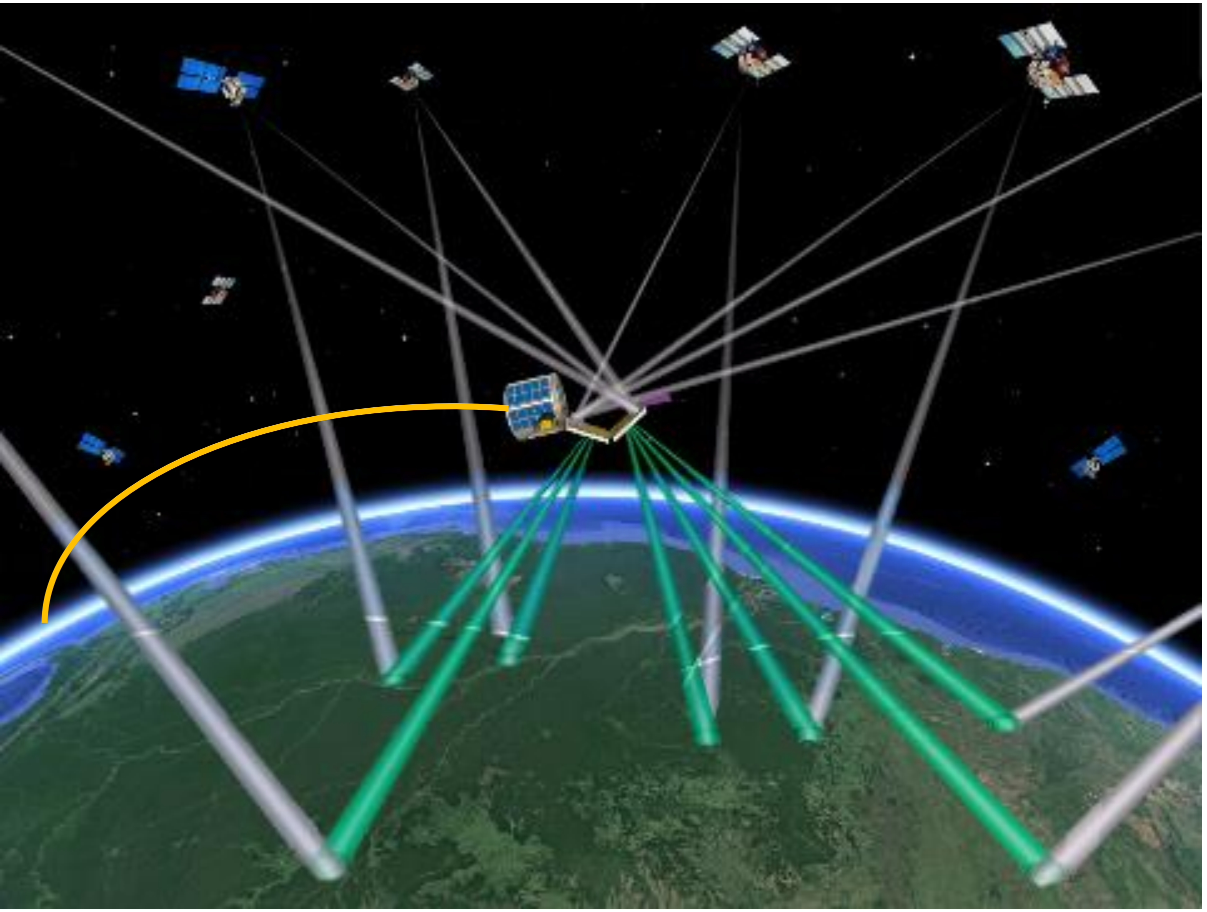
Outline

- Measurement concept
- Science motivation and requirements
- Instrument design
  - Front end: Low-power RF ASIC
  - Real-time navigation/timing: Real-Time Gipsy X (RTGx)
  - Processing surface-reflected signals: Delay Doppler Map
  - Noise calibration system
- Current status & near-term work
- Summary

GeNeSiS

GNSS-Reflections Multistatic Radar for Wetland Dynamics



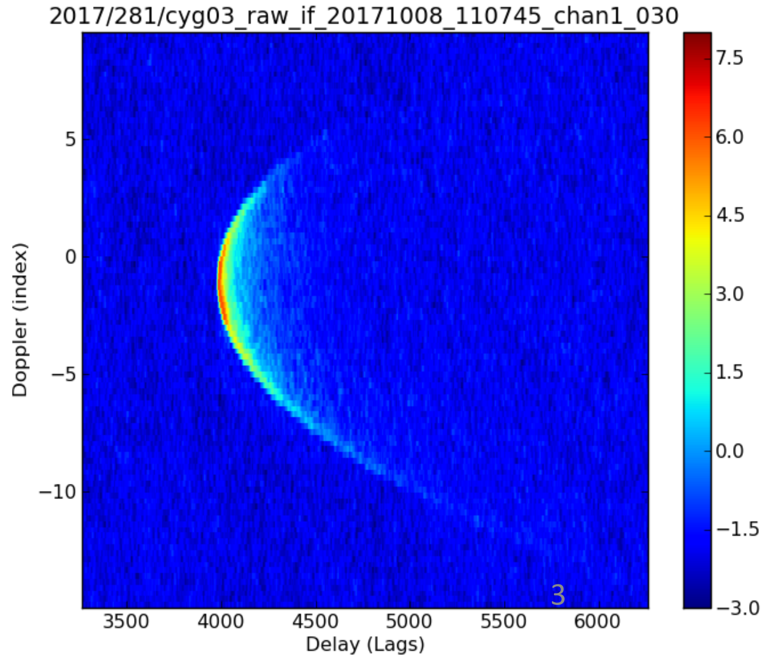
Instrument collects reflected GNSS signals (green) for remote sensing the Earth's surface, direct signals (upper white) for POD, and rising/setting signals (orange) for radio occultations

Concept:
GeNeSiS collects Earth-reflected GNSS signals for remote sensing

Primary Science: Wetland inundation/extent

Primary Measurement: Delay-Doppler Map

Small size/cost/power: Deploy 6-8 in single launch for dense surface coverage



GeNeSiS

Concept Advantages:

- Multiple, simultaneous bistatic measurements
- No transmitter - lower cost
- Low power (RF ASIC developed under ACT)
- Constellations feasible (e.g. CyGNSS) - High spatial/temporal coverage
- Forward scattering, L-Band - Improved penetration through vegetation
- Increasing number of GNSS/SBAS transmitters - Currently ~100 transmitters
- Long-term GNSS stability

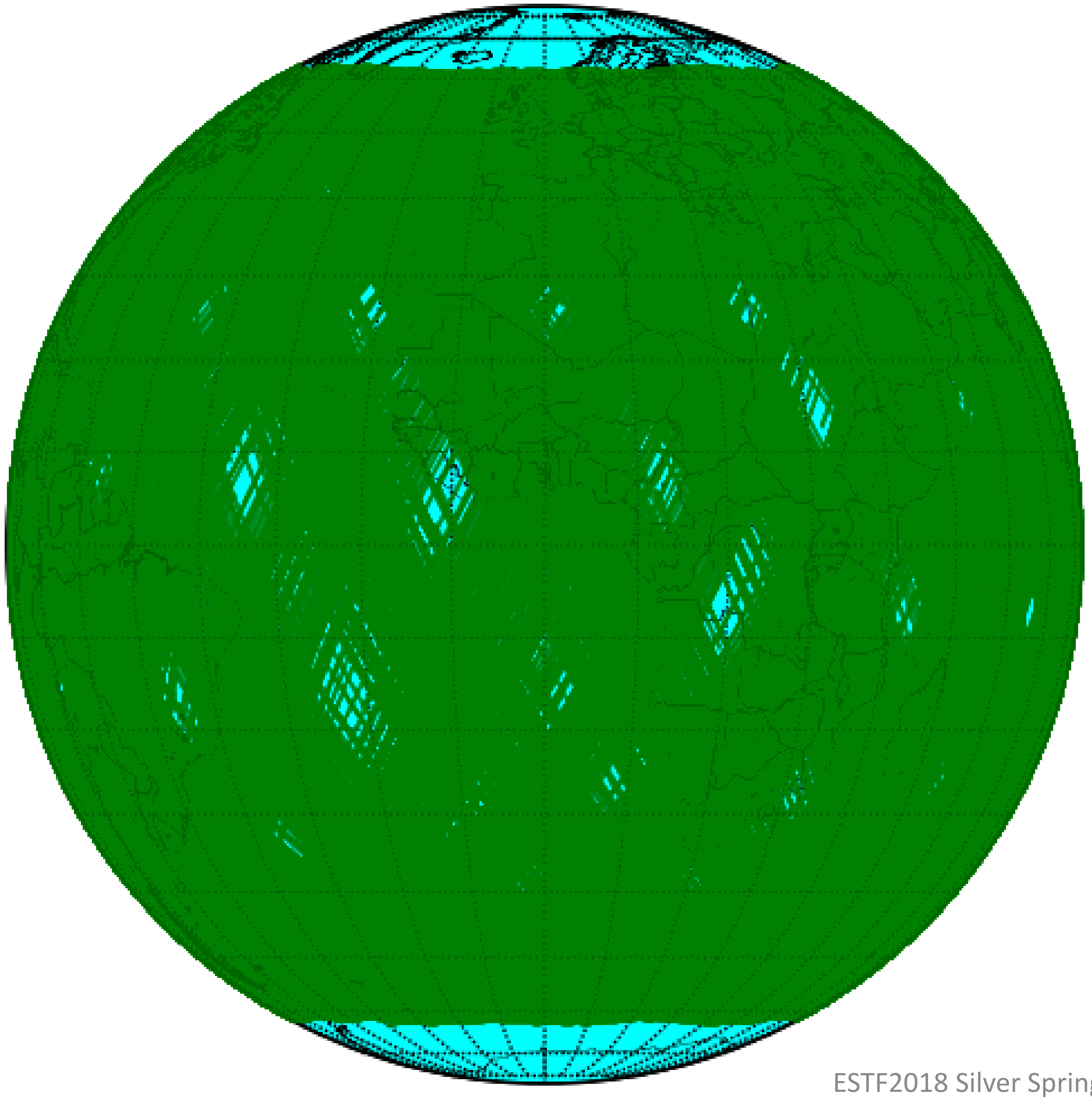
Decadal Survey Priorities Addressed:

- “Understanding the sources and sinks of carbon dioxide and methane, and how they may change in the future.”
- “Quantifying trends in water storage…”

Decadal Survey Goals Addressed:

- Cost Effectiveness
- Science Continuity

Spatial Coverage – Concept Mission



24 hour coverage simulation:

- 8 satellites
- 60^o inclination orbit
- GNSS + SBAS

Science

Wetlands: 177-284 Tg/yr
Fossil Fuels: 85-105 Tg/yr
Livestock: 87-94 Tg/yr

Primary Science: Wetland Inundation and Dynamics

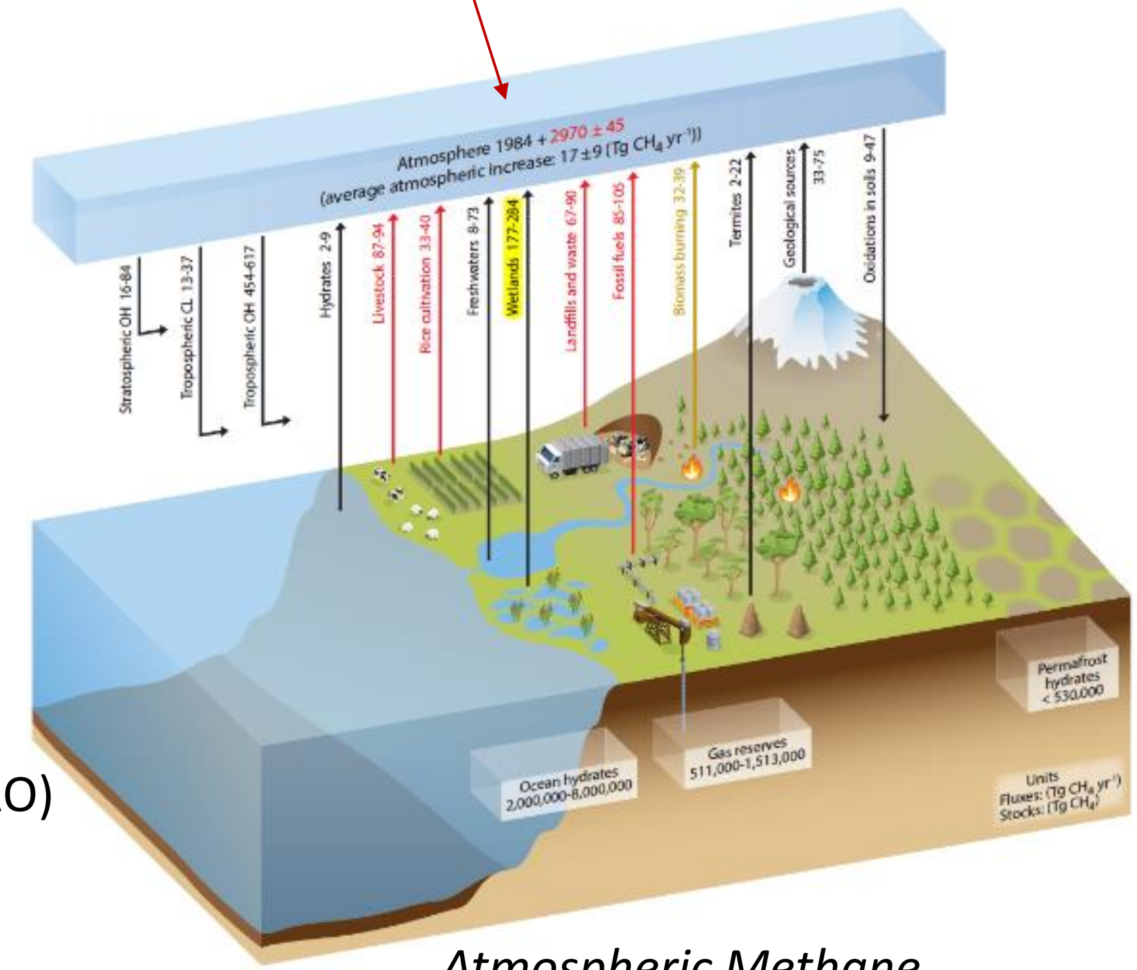
- Wetlands largest contributor to atmospheric methane
  - Largest contribution uncertainty
- Connections to carbon and water cycles
- Dynamics studies possible with high sampling rates

Secondary Science:

- Soil Moisture
- Freeze/Thaw Cycle
- Sea-ice extent (polar orbit)
- Ocean surface winds (CyGNSS)

Other Capabilities:

- Simultaneous Radio Occultation measurements (GNSS-RO)
  - Atmospheric temperature and humidity
- Precise Orbit Determination (POD)



Atmospheric Methane
From IPCC AR5 Report

Science Requirements

Wetland/Hydrology Science Requirements

Hydrologic cycle:

- Dynamics: runoff operates on ~4 week time scales

  Brakenridge, G. R., S. V. Nghiem, E. Anderson, and S. Chien (2005), Space-based measurement of river runoff, Eos Trans. AGU,86(19), 185–188, doi:10.1029/2005EO190001

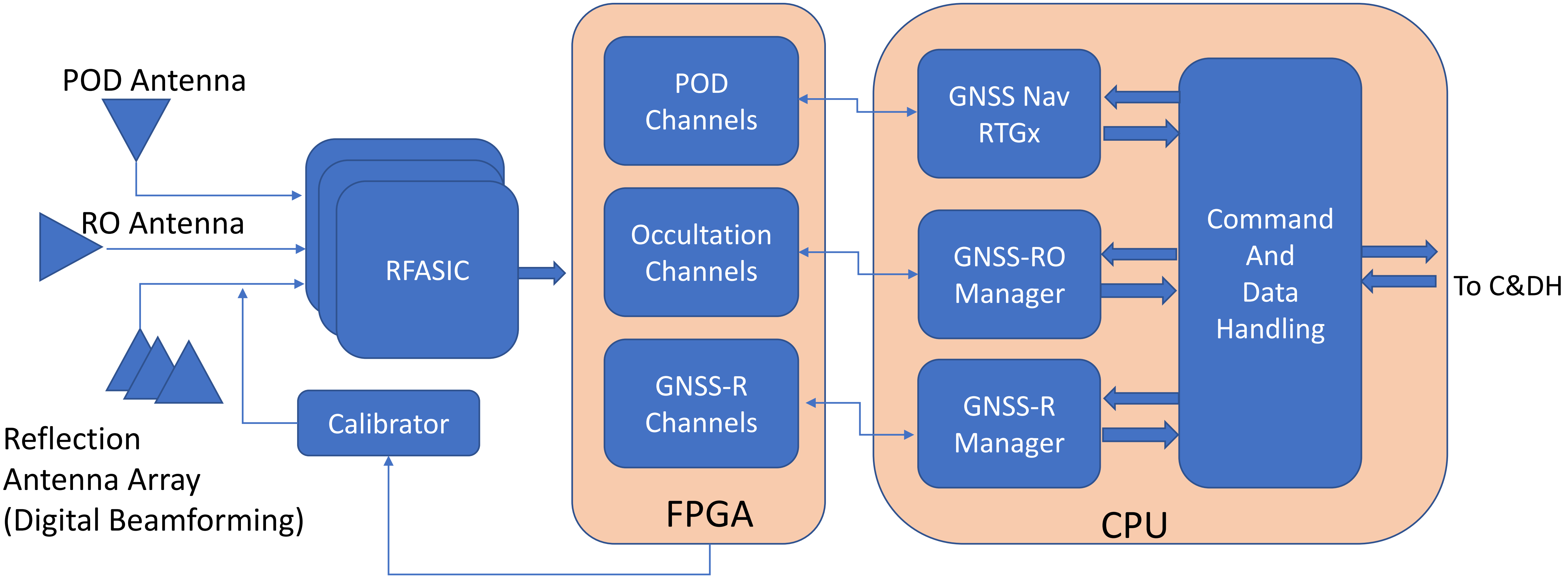
- Catchment area / Wetland inundation extent: 1-2 km spatial resolution

  Nghiem, S. V., C. Zuffada, R. Shah, C. Chew, S. T. Lowe, A. J. Mannucci, E. Cardellach, G. R. Brakenridge, G. Geller, and A. Rosenqvist (2017), "Wetland monitoring with Global Navigation Satellite System reflectometry", Earth and Space Science, 4, 16–39, doi:10.1002/2016EA000194.

⟹ **Require global (+/- 60^o latitude) inundation maps every 10 days**

- Process all GNSS + SBAS signals
- 5 Hz observations: 0.5 km spot travels 1.5 km
- 2 km cell size: ⟹ ~2 receivers

GeNeSiS Block Diagram

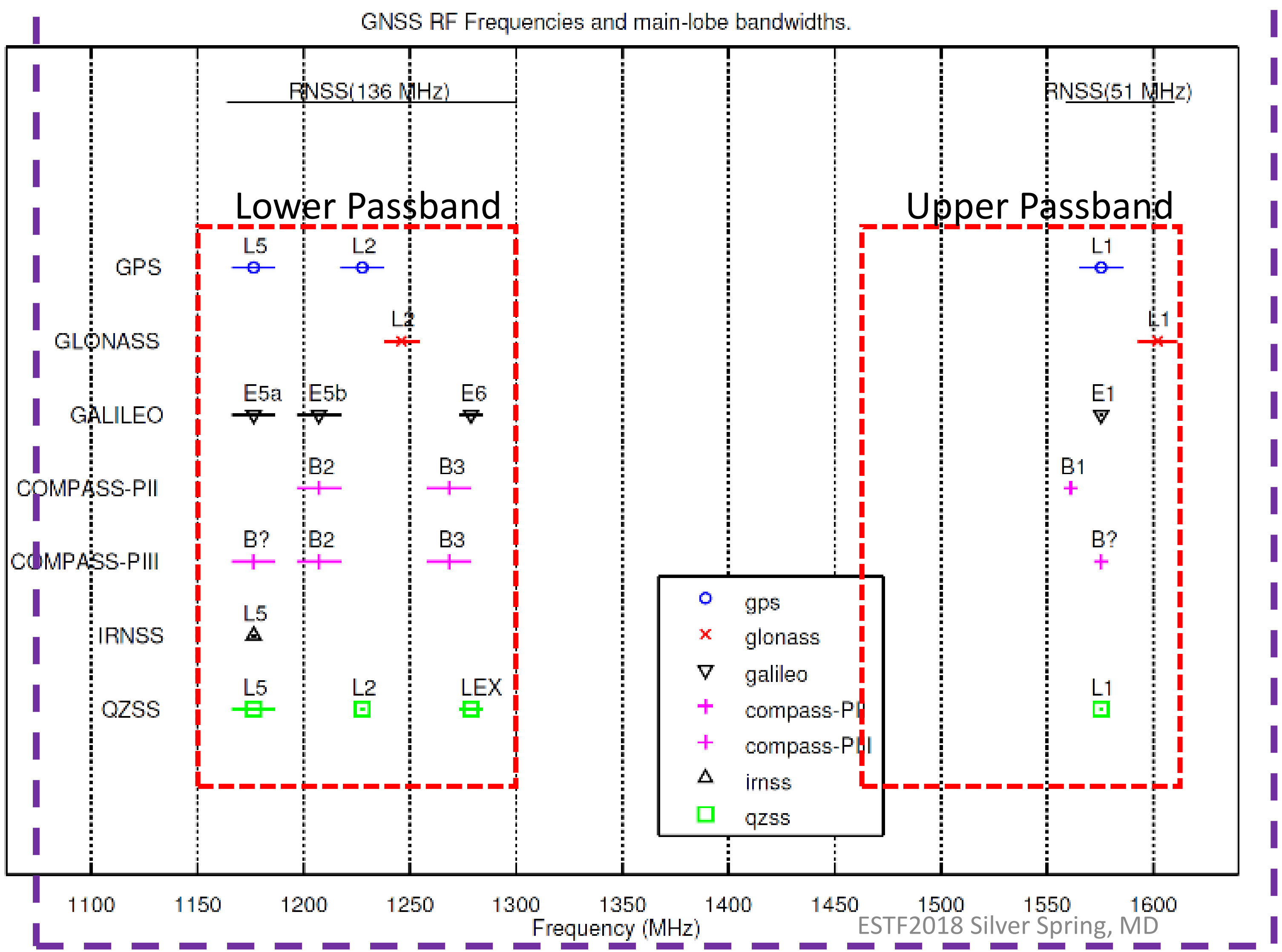


Instrument Specifications

	GENESIS	Current State-of-the Art	Motivation
Surface Spatial Res.	1 km (wetlands) 7 km (oceans)	25 km (ocean)	Required for wetlands
Polarization	H+V (Dual Pol)	LCP	May help remove vegetation effects
Simultaneous Reflections	32	4	Improved coverage
GNSS Signals	>=1 signal from all GNSS	GPS L1CA	Improved coverage
Power	15 W	12 W	Small sat
Radiation	100 kRad	5 kRad	Good for all LEO orbits
Channel Bandwidth	43 MHz	4 MHz	Better delay precision
Radio Occultation Support	Yes	No	Additional science
Beamforming Support	Yes	No	Improved Coverage
Antenna Inputs	12	2	Improved coverage
Science Data Rate	10 Hz	1 Hz	Wetland cell size

RF-ASIC

Digitized Frequencies: 690 MHz



Developed under ACT

Digitizes all L-band GNSS signals

- GPS L1/L2/L5
- GLONASS L1/L2
- GALILEO E1/E5a/E5b/E6
- Beidou B1/B2/B3
- IRNSS L5
- QZSS L1/L2/L5 LEX
- WAAS, EGNOS, MSAS, GAGAN, SDCM

RF-ASIC
3 antenna input
1 W total

Reflections Processing: Delay Doppler Map

- Delay doppler map (DDM): matrix of received signal power vs. doppler and delay
- Primary observable for GNSS scatterometry
- Accumulation of incoming signal with signal model for various values of doppler and PN code delay

$$\text{DDM} = \int s(t) e^{j2\pi t(f_C + f_D)} c(t+\tau)\,dt,\ \forall f_D, \tau$$

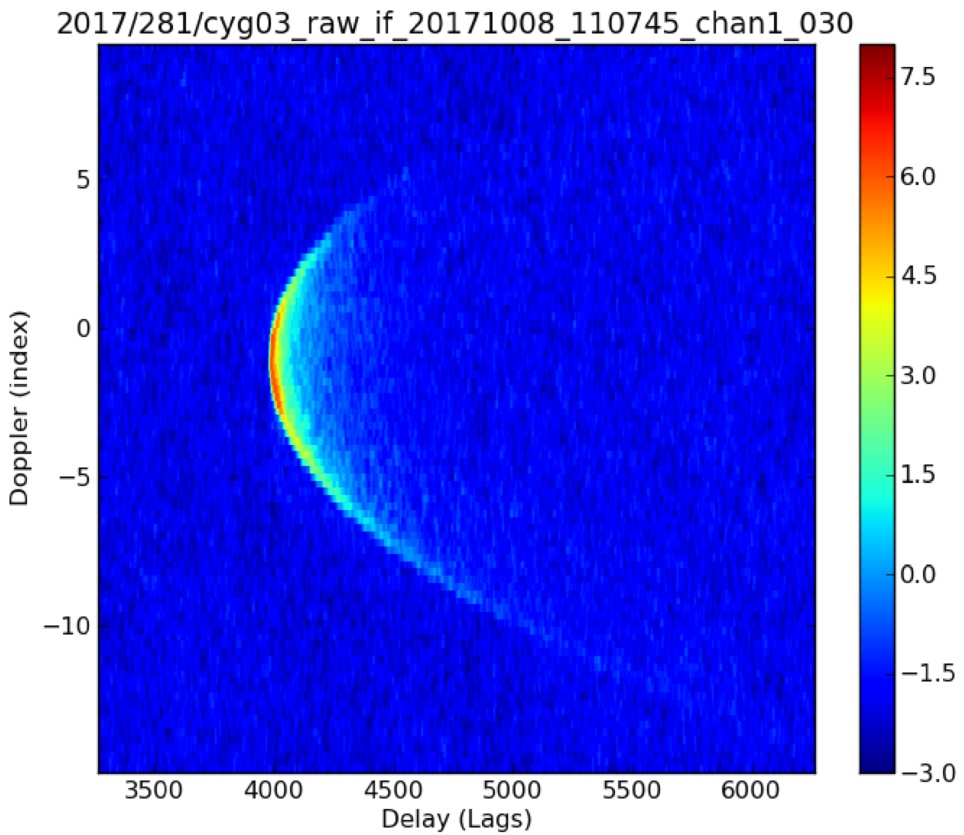
$s(t)$: *incoming signal*

$c(t)$: *PRN code sequence*

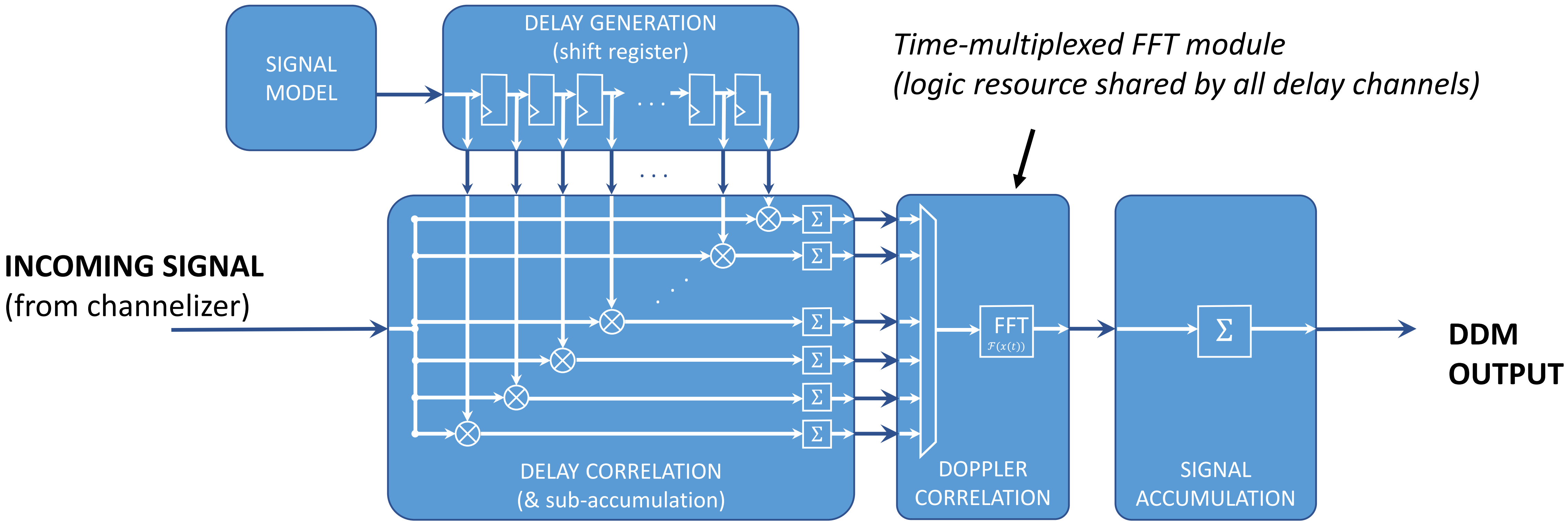
f_C : *signal carrier frequency*

f_D : *doppler frequency (local signal model)*

τ : *code delay (local signal model)*



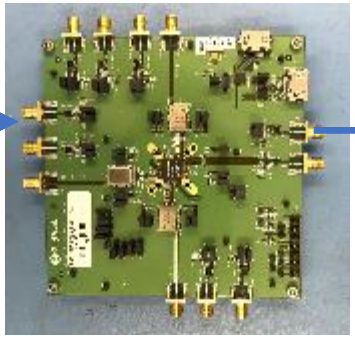
DDM Algorithm



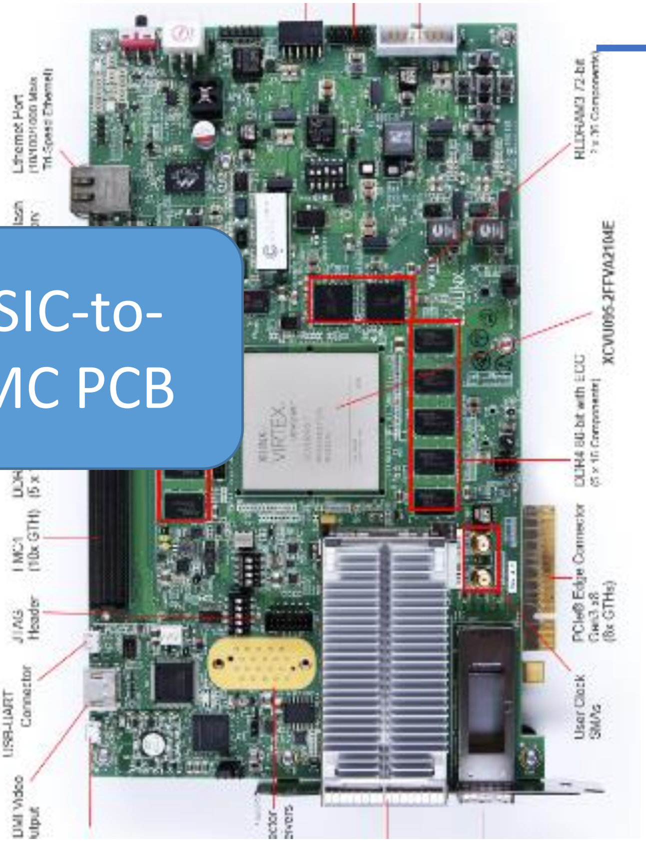
Hardware Demonstration (Feb 2018)

Sig Gen PRN1

RFASIC Dev Board



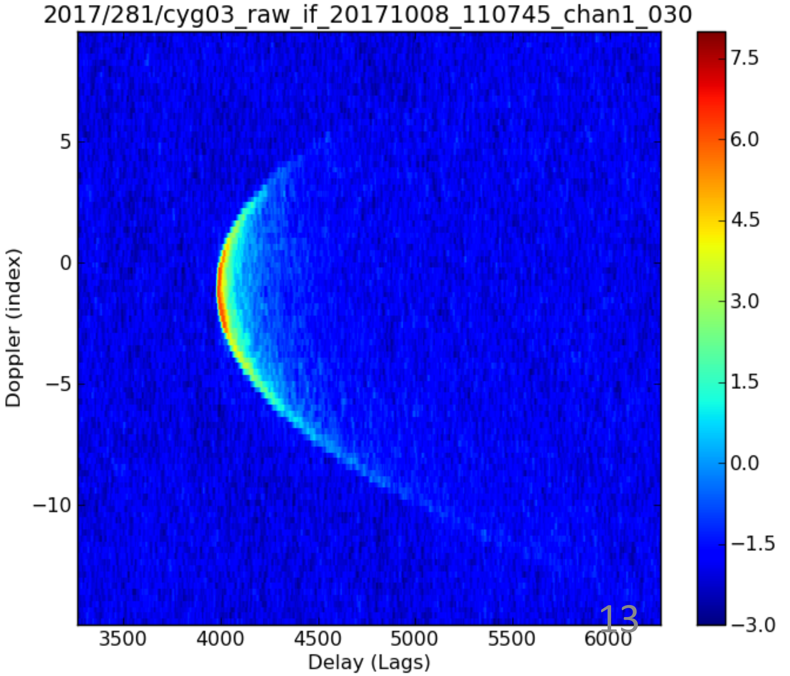
ASIC-to-FMC PCB



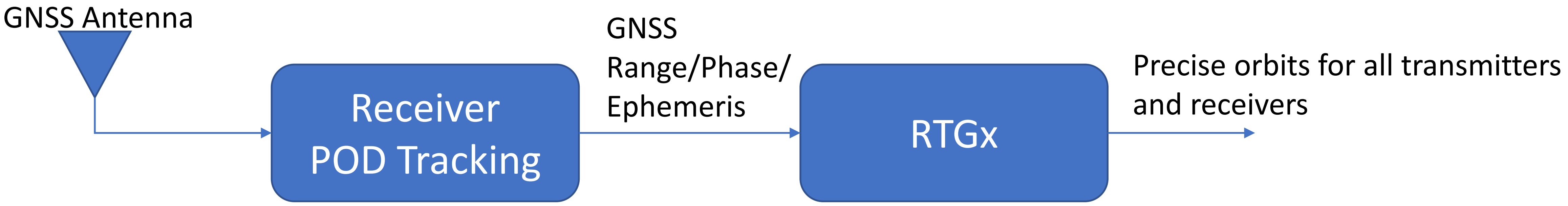
FPGA Board

PC For Display

Generate Real-Time DDM

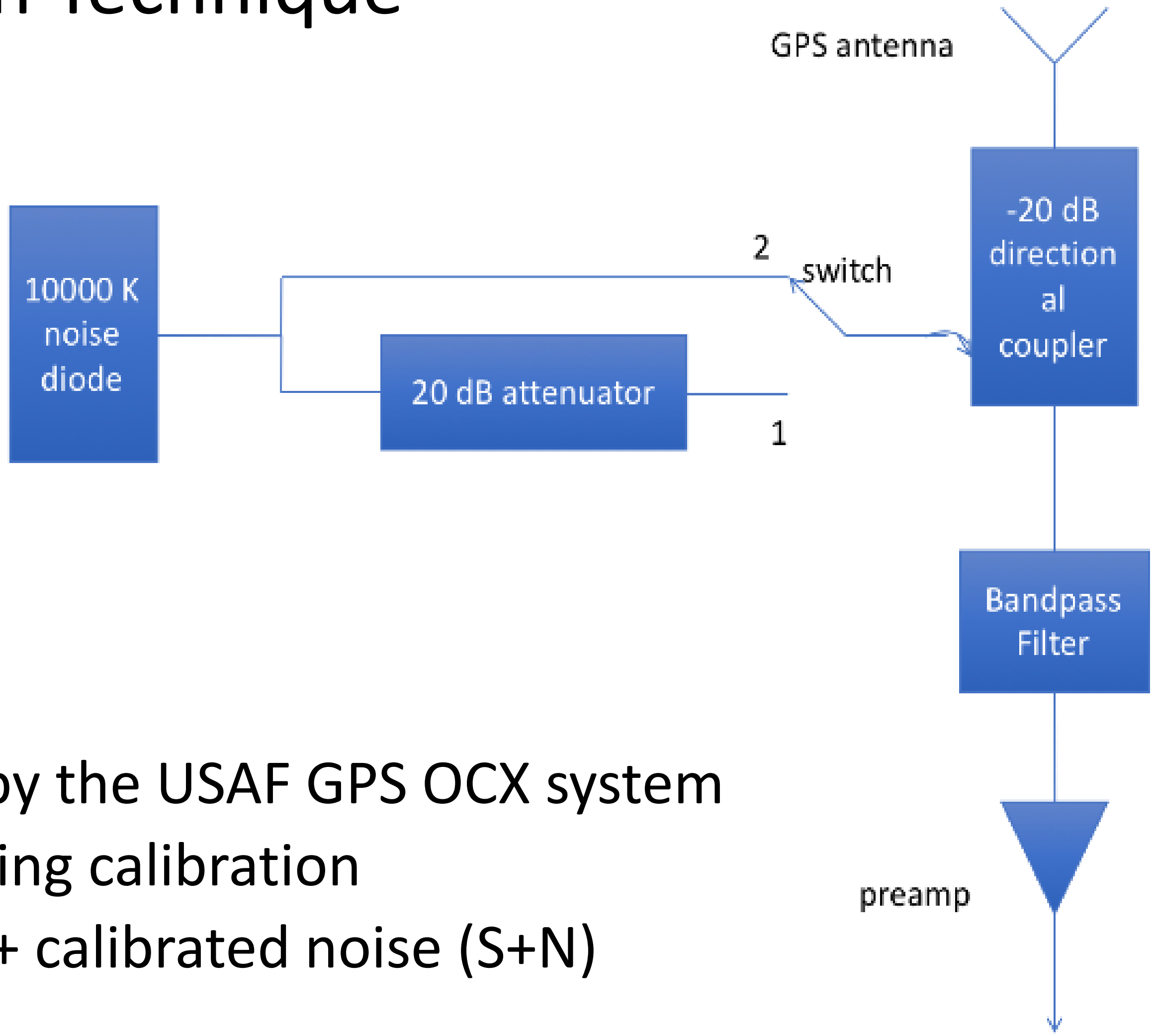


Real-Time Gipsy X (RTGx) Navigation Software



- A state-of-the-art GNSS navigation software package from JPL
- Real-time precise orbit determination (POD)
- For GNSS-R: Provides real-time estimates of current (and future) receiver/transmitter locations.
- Decimeter-level real-time on-board positioning
  - Limited by ephemeris
  - SW good to cm-level
- Predicts for science scheduling

Noise Calibration Technique



Receiver measures Signal-to-Noise ratio

Need to calibrate

- Antenna gain vs angle
  - Measured on satellite to include multipath
- System noise
  - Monitored while tracking

JPL precise noise calibration technique sponsored by the USAF GPS OCX system

- Continuous data collection: no deadtime during calibration
- Rapidly switch between signal (S) and signal + calibrated noise (S+N)
- Separately process S and S+N
- US Patent 20140065994

US Patent 20140065994

Year 1 (Feb 2017 – Feb 2018) Milestone Status

Milestone	**Status**
Instrument requirements definition	Complete
Processor and Operating System (OS) trade study	Complete
Integration of RF ASIC (ACT2013) into existing GNSS testbed	Complete
GNSS software development to support reflections (GPS)	DDM complete
3rd RF ASIC Fabrication run	Deferred to Year 2
Prototype unit using COTS development boards, RF ASIC	Complete

Year 2 (Feb 2018 - Feb 2019) Milestones

- Schematic Design of RF and Digital Processing Board
- Chassis Design and Fabrication (or leverage COTS boards)
- Implementation of Reflection Schedule Software
  - Functionality completed in year 1 – need to integrate into operations
- GNSS software to support reflections (Glonass, Beidou, etc.)
- Port RTGx to selected operating system
  - This work has started in year 1. Evaluating scope to port to RTEMs
- Layout and Fabrication of EM boards
- Evaluate ASIC update plans

Summary

- **We're building highly capable GNSS reflectometry instrument for space applications**
    - Improved number of simultaneous DDMs
    - Improved number/type of GNSS signals processed
    - Improved number of antenna inputs

- **Unique features:**
    - Low-power RF ASIC: enables antenna arraying
    - Antenna arraying
    - RTGx for Position Navigation and Timing (PNT)
    - Continuous noise calibration system (no deadtime)
    - Radio-occultation support

- **On schedule:**
    - 3 months into 2nd year of 3-year program