Cloud-Based Demodulation and Data Distribution of a Satellite Downlink

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TechEdSat-13: Neuromorphic Processors in Space

TechEdSat-13 is the latest in a series of low-cost, quick turnaround technology demonstration nanosatellites.

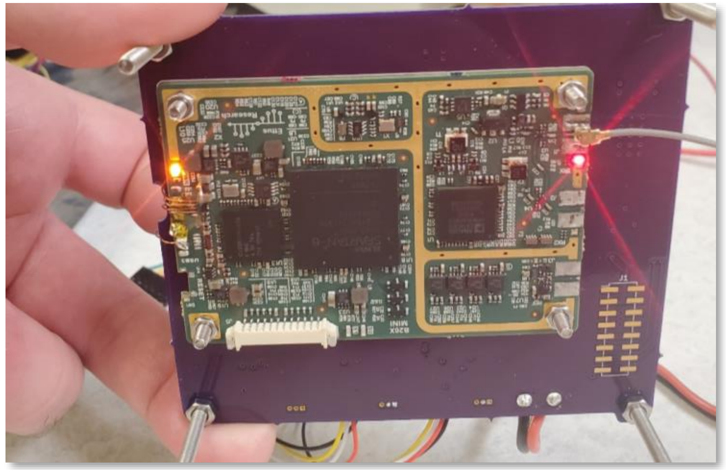
Program run from NASA Ames Research Center, TES-13 flight in collaboration with NASA Glenn Research Center.

Launched on January 13, 2022 on a Virgin Orbit flight.

Goal to perform on-orbit testing and characterization of neuromorphic chip hosting spiking neural networks. Believed to be first neuromorphic processor in space.

Photo Credit: NASA (left, https://blogs.nasa.gov/kennedy/tag/techedsat-13/) and Virgin Orbit (right, https://www.nasaspaceflight.com/2022/01/launcherone-above-the-clouds/)

TES-13 Communications Paths



Iridium 9602N Short Burst Data Modem

- Delivers packets up to 270 bytes (to spacecraft) or 340 bytes (from spacecraft). Connections can be intermittent due to orbital dynamics.
- Main path for low-rate telemetry and commanding. As order of practice, commands uplinked 24 hours in advance of when they are needed.
- Small files can be transferred but latency and packet size are limiting factors.

Lunar Radio S-band Transmitter

- Custom PCB with Ettus B205mini and Digi ConnectCore embedded processor.
- Implements QPSK transmitter following CCSDS standards.
- Antenna mounted on +Y (ram-facing) face of the satellite for S-band downlink.
- Transmit time scheduled with Iridium command. Sends data files during pass.
- Service with NASA-owned stations in Virginia (Wallops) and Ohio (Glenn).

Photo Credit: Iridium (top, https://www.iridium.com/products/iridium-9602/)

Ground Station as a Service

- Follows the transformative “X as a Service” business model.
  - Allows satellite operators to use global communications coverage with zero capital expenditure.
  - Similar infrastructure enables scaling without large development costs, important for small missions.
- Located for coverage and connectivity into the Internet.
  - Allows cloud-based automated processing without on-premises equipment installations.

Amazon Web Services (AWS) Ground Station

- 11 locations across 6 continents
- Sites correspond to AWS cloud regions
- Identical ground station hardware
- Digital IF output for cloud demodulation
- Federated identity management and security for NASA users via Mission Cloud Platform office at Goddard Space Flight Center.

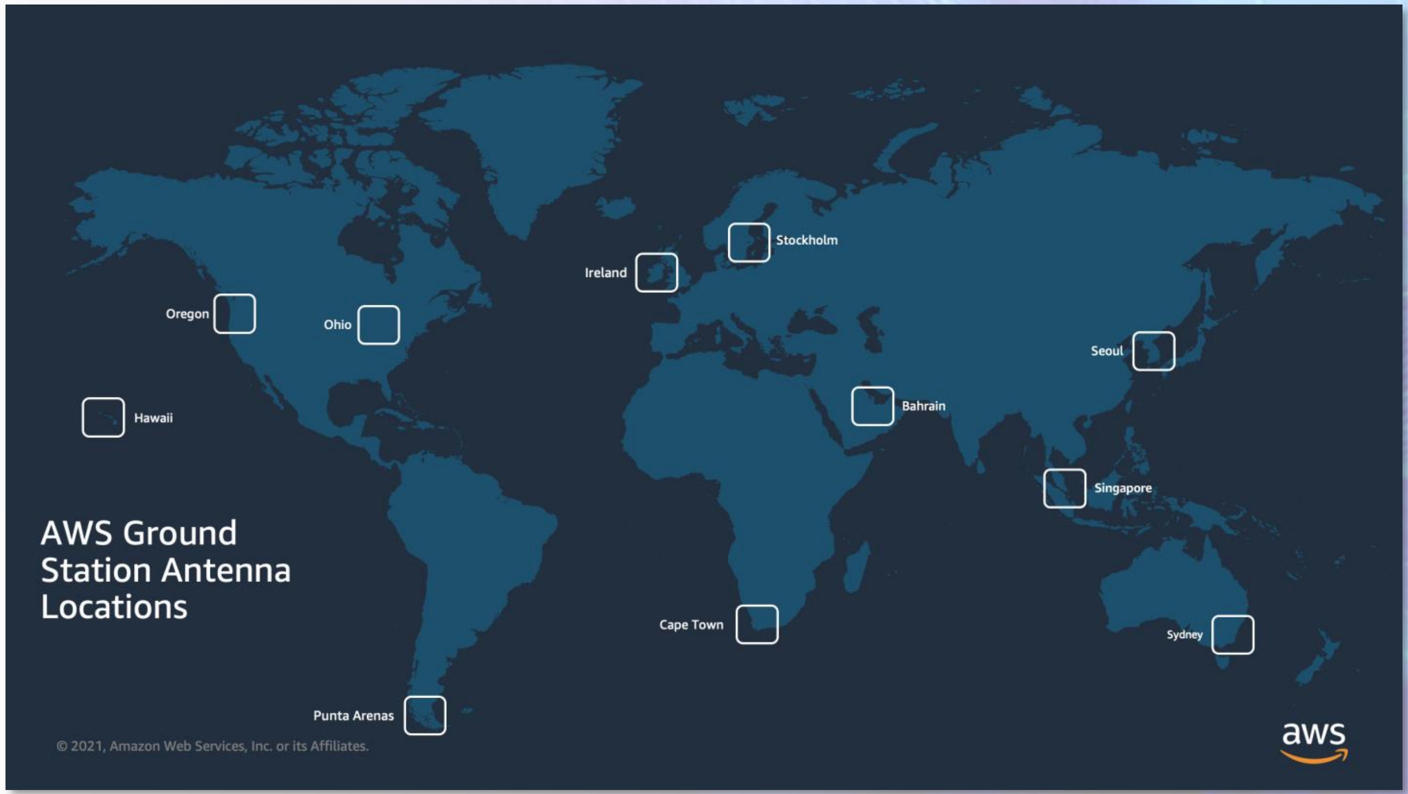
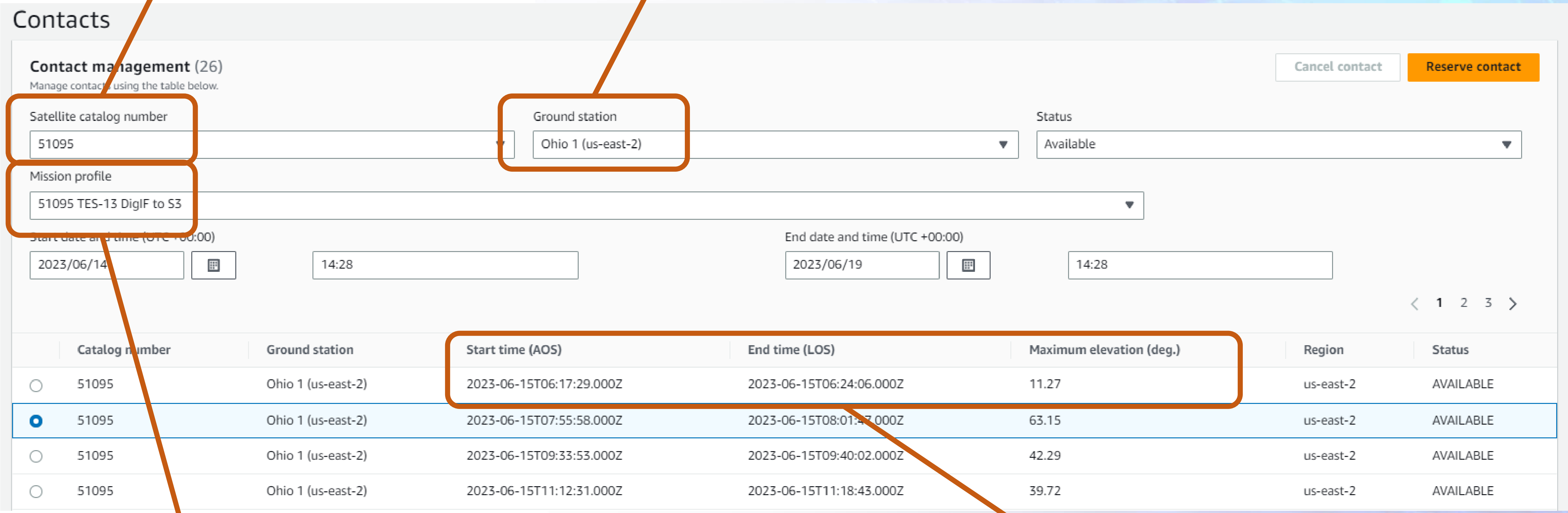


Photo Credit: Amazon Web Services, Inc.

Scheduling and Configuration

Onboarded satellite number, by NORAD ID

Target ground station, physical location and AWS region

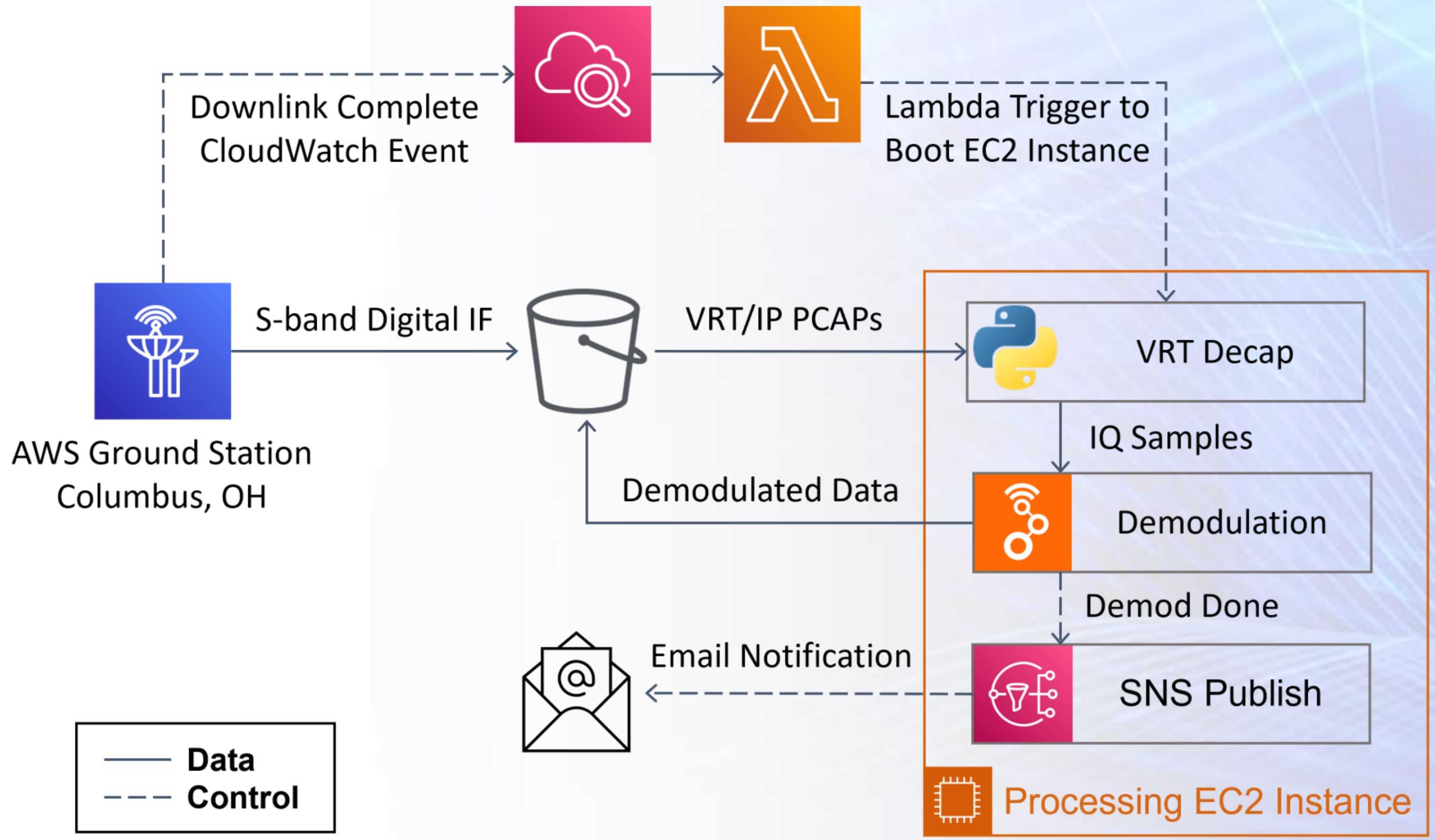


Mission Profile, contains RF parameters such as frequency, bandwidth, polarization. Also destinations for data and configurations of pre-post/pass notifications.

Contact windows, solved from latest TLEs and site availability.

Processing Automation with AWS Services

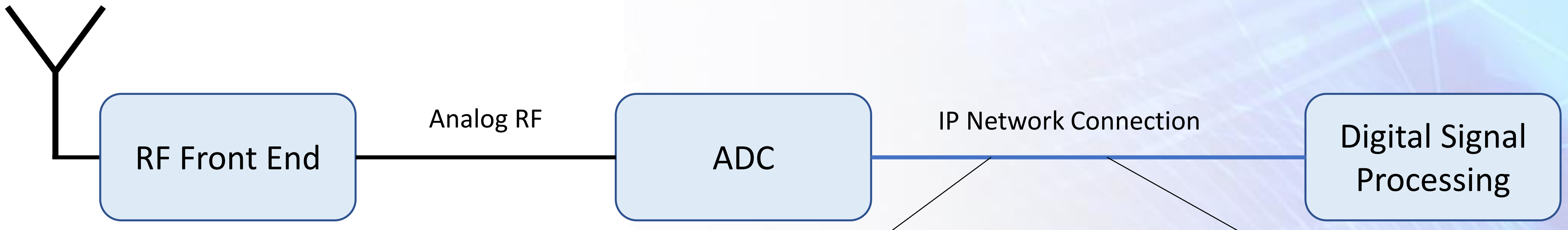
- After initial scheduling, all processes are run fully-automated without monitoring from mission personnel.



- Leverage open-source software to maximize ease of customization and avoid costly vendor lock in.
- Use of the `libvrt` library for VRT decoding, Python formatting, GNU Radio for signal processing.

VITA-49: VITA Radio Transport (VRT) Standard

- Standardizes data transfer of samples between signal processing components from on-chip to off-premises.



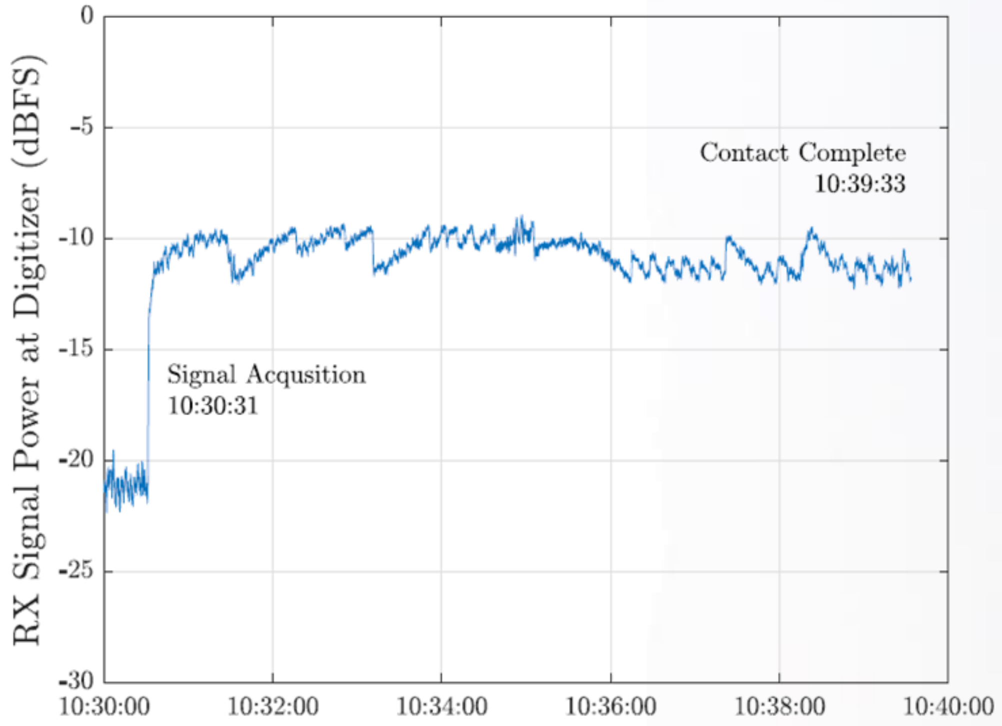
IF Data Packet

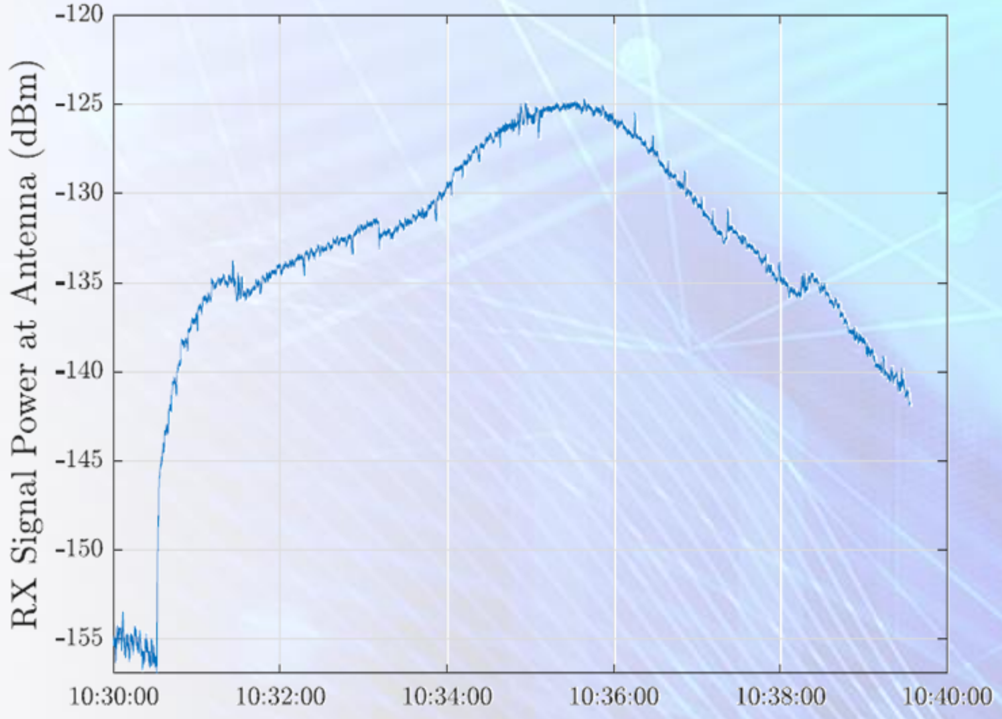
- Packed digital IF samples in a variety of formats.
- In our case, complex-valued, fixed-point I and Q values.

IF Context Packet

Metadata about:
- Signal capture (sample rate, frequency)
- Level at reference point in dBm
- Format of IF Data Packets

Received Signal Power Calculation from VRT Packets





Relative power of ADC samples shows averaging effect of receiver automatic gain control.

$$P_{samp,n} = 20 \log_{10}\left(\frac{|s_n|}{2^{m-1}-1}\right) \quad \text{[dBFS]}$$

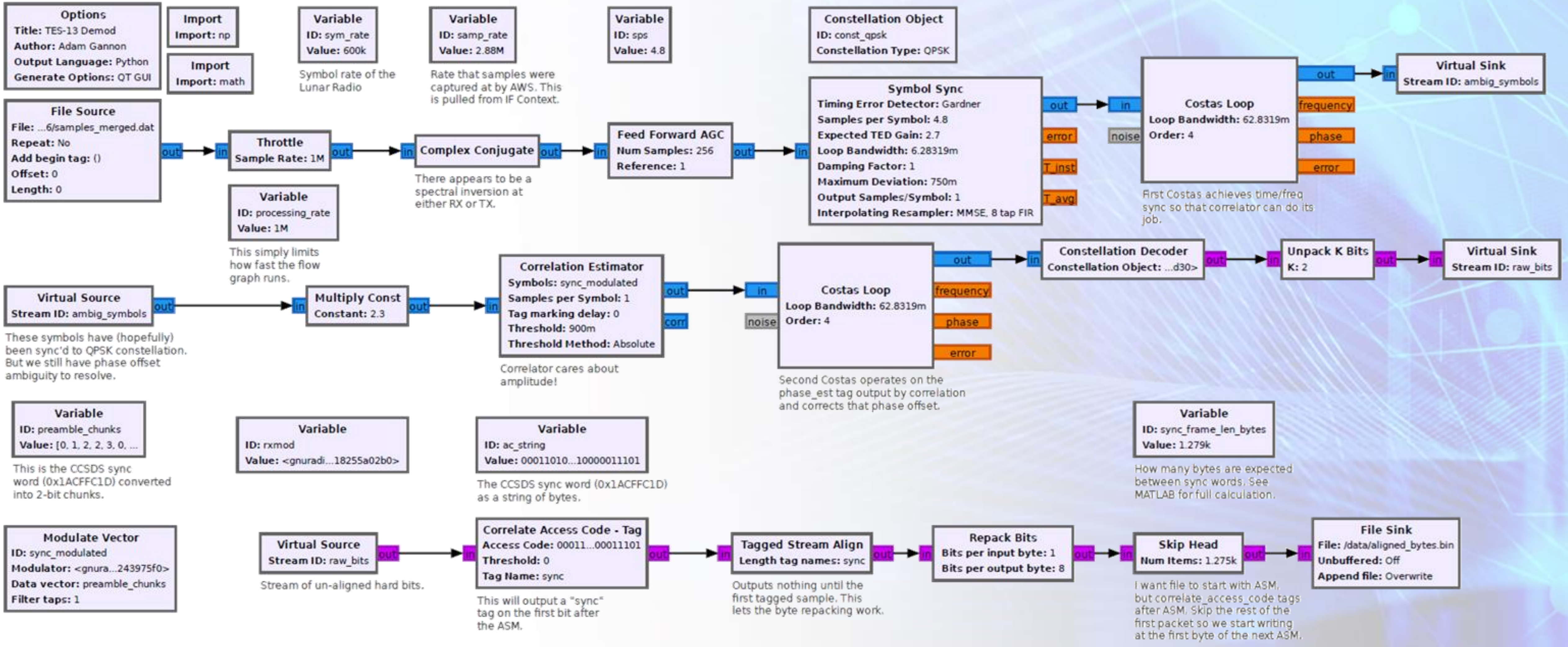
Can be converted into absolute signal power at input of the antenna through parsing IF context packets and knowing fixed system gains.

$$P_{adc,n} = P_{samp,n} + P_{ref,k} \quad \text{[dBm]}$$

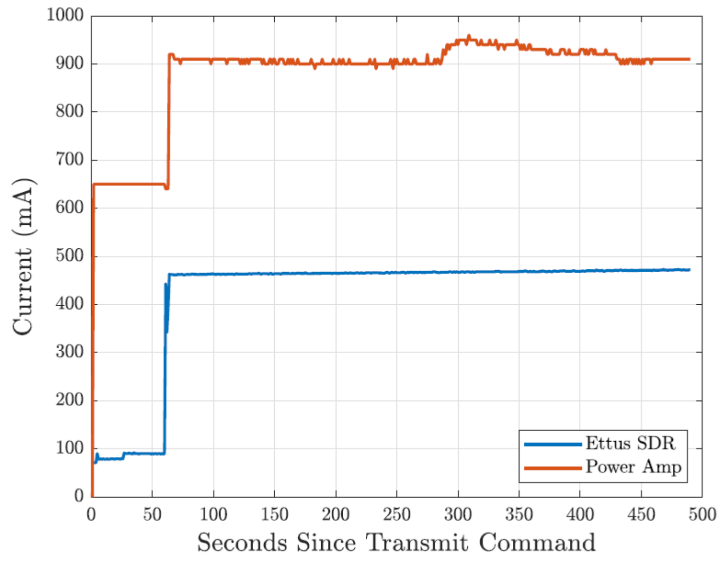
$$P_{ant,n} = P_{adc,n} - G_{rx} - G_{ant} \quad \text{[dBm]}$$

Signal Demodulation in GNU Radio

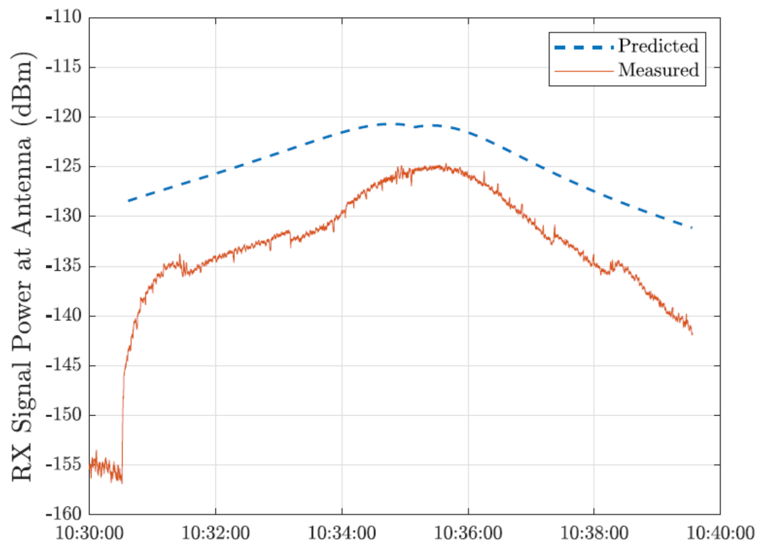
GNU Radio, an open-source software-defined radio framework, used to demodulate IF samples into aligned bytes.



S-Band Operations and Results



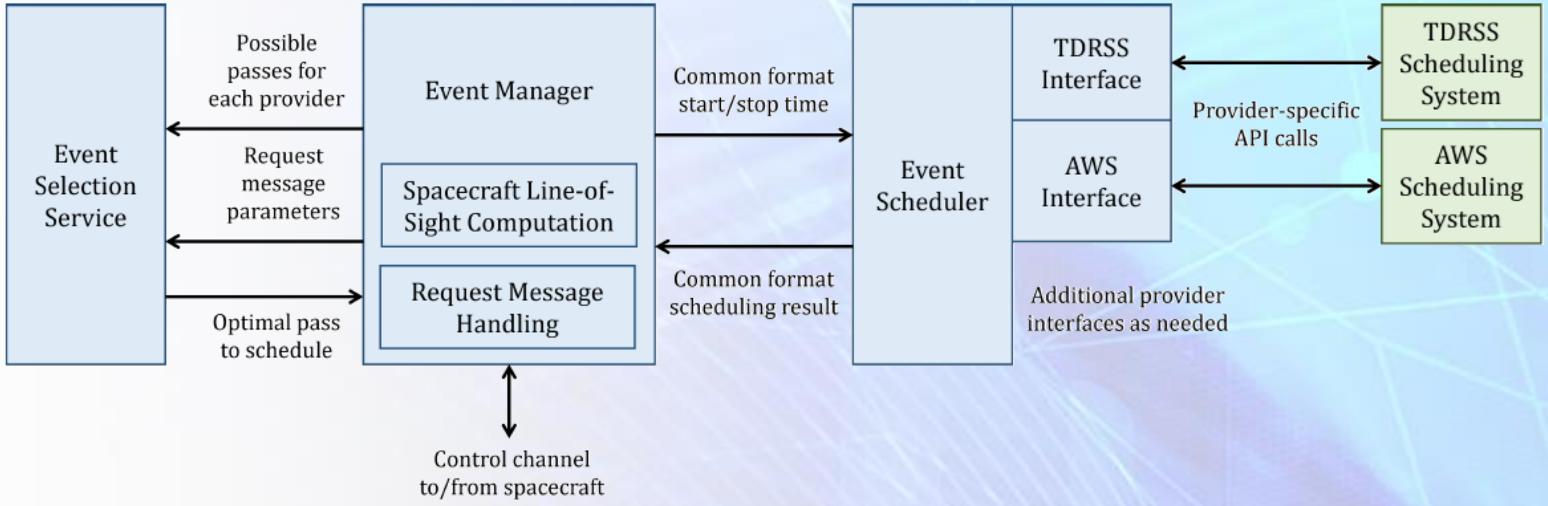
- Reed Solomon decoding, CCSDS AOS deframing, and file recovery are currently performed offline from data retrieved from S3 buckets but will be automated on future flights.
- Telemetry files from S-band radio are transferred along with payload data during the pass.
- Cross-account bucket access allows members from Glenn and Ames Research Centers to access all stored data.

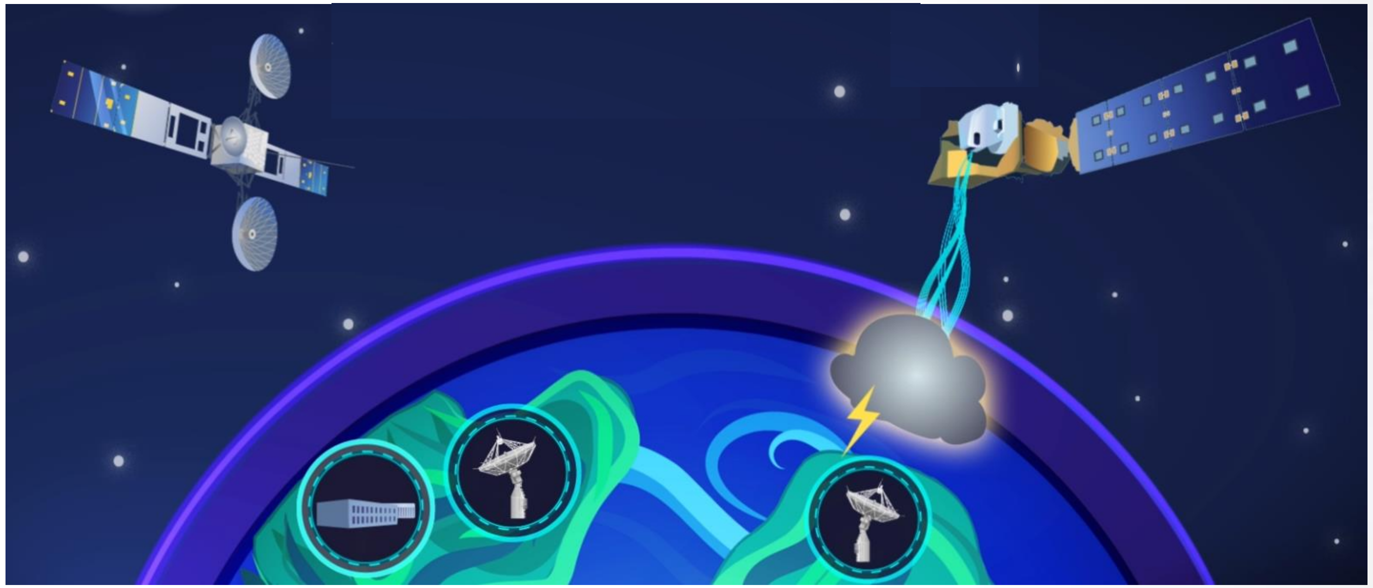


- First successful contact on 3/23/2022 transferred 35MB of data, a throughput several orders of magnitude greater than 300B Iridium SBD.
- Received signal strength roughly in line with predictions, might be additional cabling and radome loss not accounted for in link budget.
- Intermittent performance, with most recent successful downlink on 7/20/2022. Satellite alive and continues to communicate over Iridium.
- Likely root cause is excessive bus voltage drop during transmit causing successive reboots during contact. Future flights will use a larger battery pack which should prevent this issue.

Enabling Technologies and Future Work

- Scheduling API can be used to autonomously allocate service based on the real-time needs of the user spacecraft (user-initiated service).
- Concept with Iridium control channel and AWS service will be demonstrated on future TechEdSat flight.





- Pass failure (mechanical issues, configuration, interference, weather, etc.) can be mitigated automatically be leveraging large network without mission-provided hardware deployed at each ground station site.
- Intelligent agents capable of learning from past selections can refine scheduling process to make increasingly optimal decisions.