T-REX: Early Ground Prototyping: Developing and Validating the Software and Instrumentation Pipeline for Future Space-Space VLBI Software

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T-REX: Ground Prototypes for Space VLBI Software

Incrementally validating the interfaces needed for a future low-Earth-orbit VLBI mission

Ground testbed

Affordable ASTRA-based radio telescopes

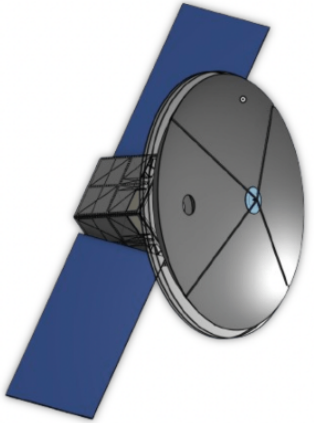
Repeatable experiments • easy access • fast iteration

Moving baseline

Introduce changing geometry, delay, timing, and automation challenges before orbit

Orbital VLBI

Adapt validated workflows to the more demanding space-space measurement



Why a ground prototype?

Timing

Accurate timestamps and synchronization must survive the full data path.

Motion

A moving baseline creates time-varying geometry and delay. Various ground set-up allow testing of moving baselines using small ground stations.

Data

High-rate samples must stay tied to configuration and metadata.

Automation

Orbital operations leave fewer opportunities for manual recovery, perfecting automation on the ground increases mission readiness.

Ground tests let us make these problems observable.

We can inspect intermediate signals and metadata.

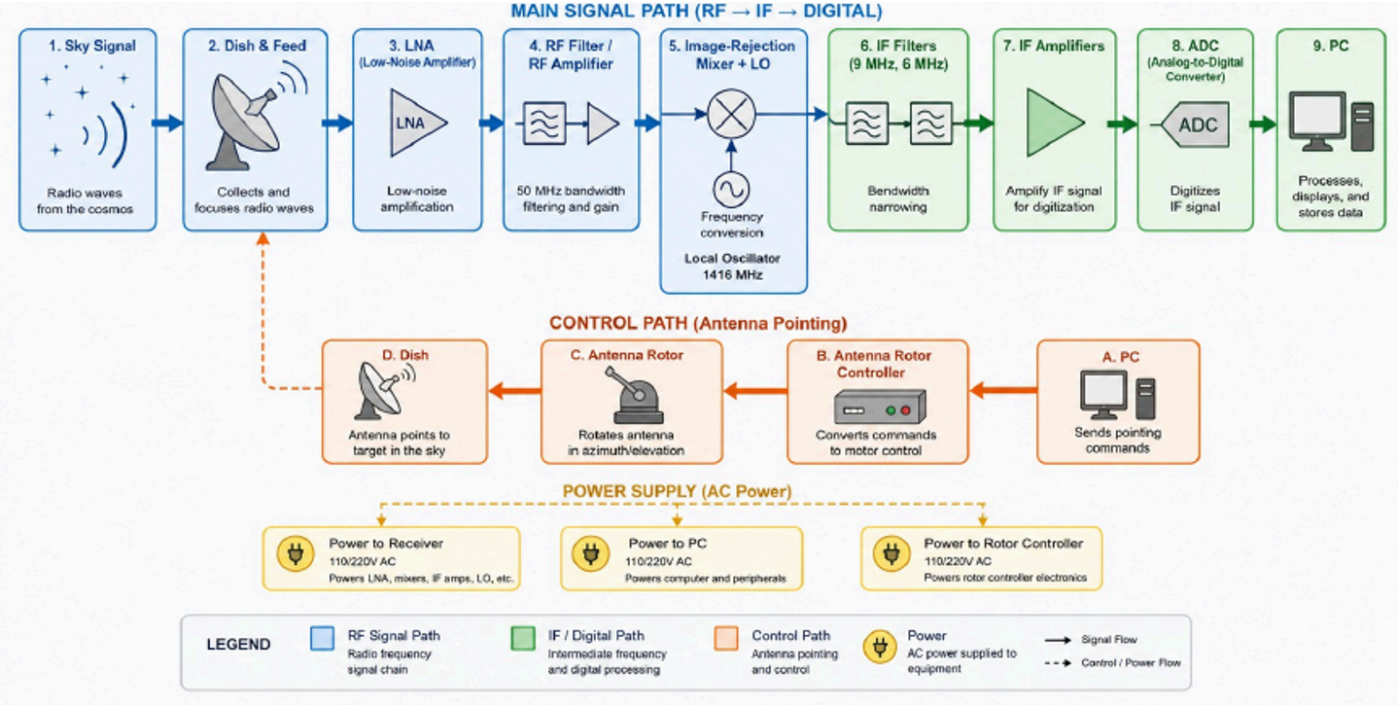
We can repeat the same observation after a software change.

We can intentionally stress interfaces and failure handling.

We can build reproducible pipelines before adding orbital constraints.

ASTRA gives us a real hardware–software testbed

The existing Haystack SRT architecture already contains the interfaces we need to exercise.



Sky signal
Dish + feed

→

RF chain
LNA + filters + mixer

→

Digitization
IF → ADC

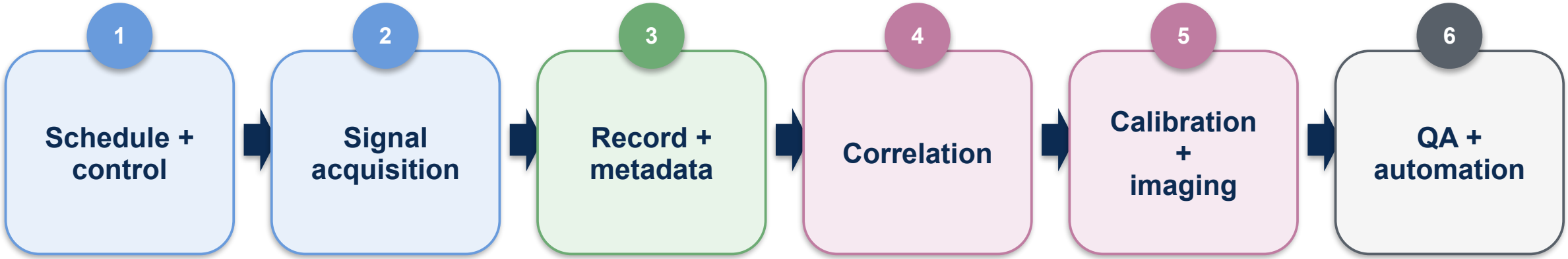
→

Computer
Control + acquisition

Control path: PC → rotor controller → antenna pointing
The same prototype exposes signal, control, timing, and data interfaces in one system.

Software and signal pathway

The prototype lets us test the complete chain from observation to science-ready products.



Signal collection

srt-py — public educational SRT software

Post-processing option

HOPS — analysis of data produced by DiFX VLBI correlators

Imaging option

Regularized likelihood / smili workflow

Development plan: add difficulty one layer at a time

Each test should preserve the previous pipeline while introducing one new class of constraint while building towards a final mission model.

Tier 1

Stationary ground–ground

- Timestamped blocks
- Offline / batched correlation
- End-to-end reproducibility
- Mimics “On-Earth” Correlation

Tier 2

Moving-baseline test

- Time-varying geometry
- Dynamic delay handling
- Real-Time correlation between two antennas (mimics ”In-Orbit” Correlation)

Mission

Orbital VLBI adaptation

- Spacecraft constraints
- Link + storage strategy
- Mission operations

Same core software → increasingly realistic timing, geometry, and operational constraints

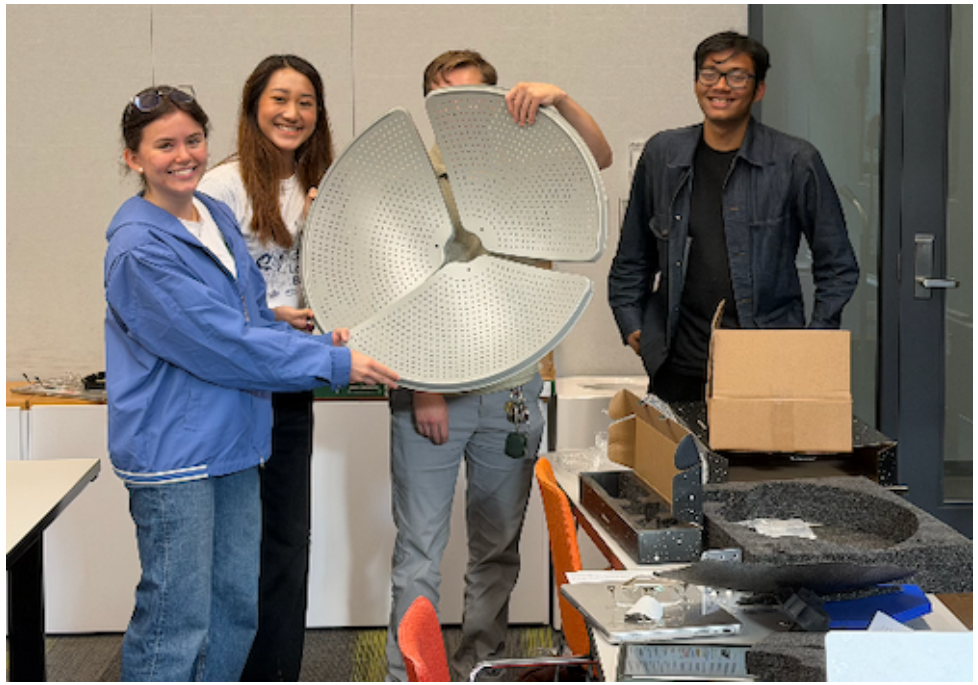
What the software team is solving now

Timing + geometry
Make timestamps, station state, and baseline geometry trustworthy enough for correlation.

Data + metadata
Keep samples, configuration, provenance, and observing state synchronized through the pipeline.

Reproducibility
Turn successful one-off observations into repeatable workflows with diagnosable failure modes.

Automation
Reduce manual steps so the same architecture can scale toward moving and orbital baselines.



(We Work Parallel to the Hardware Team!)

A failure discovered on the ground becomes a requirement clarified before flight.

Takeaway

Ground prototypes are a software de-risking strategy for T-REX.

1

Exercise the whole pipeline

Control → acquisition → data → correlation → imaging

2

Increase realism incrementally

Stationary → moving baseline → orbital constraints

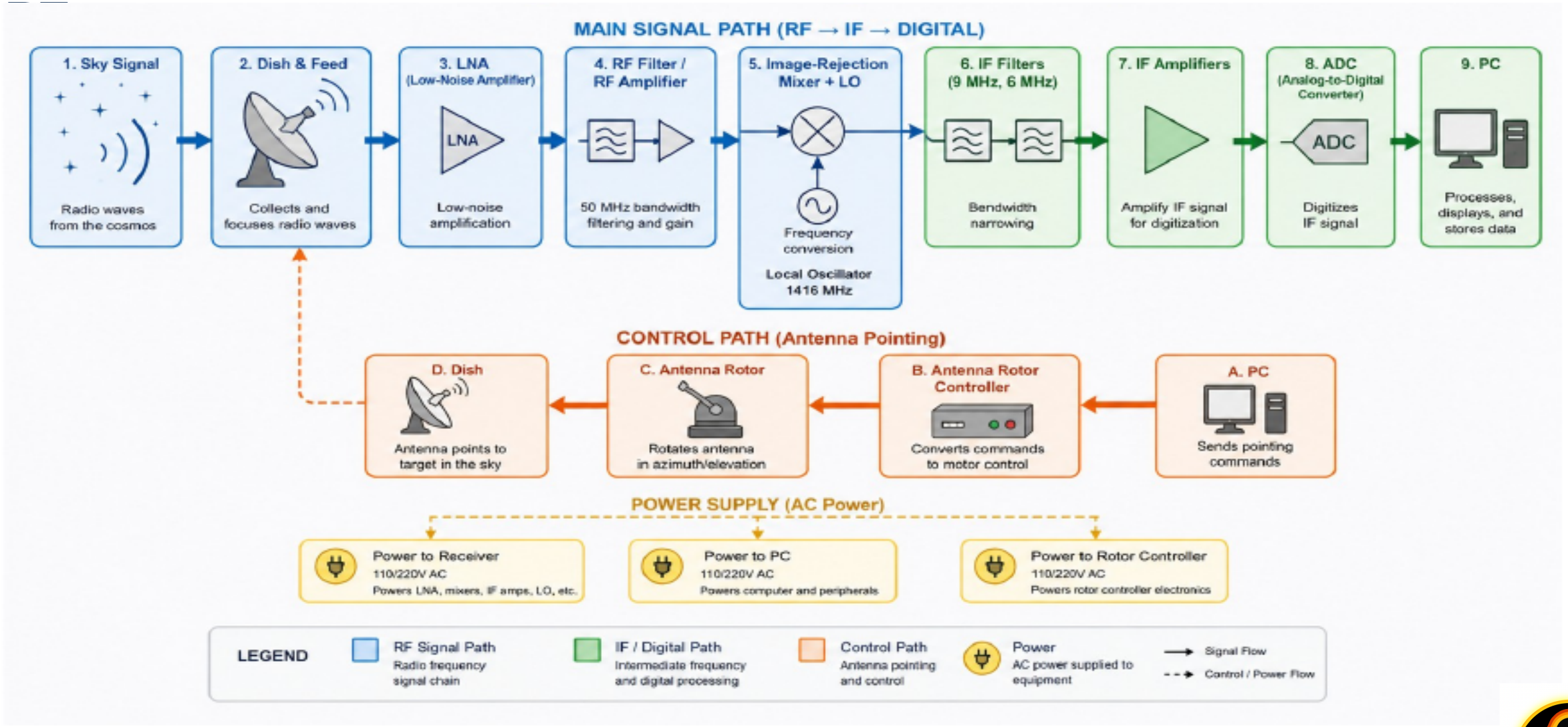
3

Carry validated interfaces forward

Turn test results into mission-ready software requirements

Questions

Appendix 1: original software and signal pathway based on MIT Haystack



Appendix 2: Component Table

#	Component	Form (What it is)	Function (What it does)
1	**Parabolic dish and feed**	Collecting antenna and feed horn at focus	Collects radio waves and converts them to an RF electrical signal.
2	**Antenna rotor**	Motorized mount	Points the dish.
3	**Antenna rotor controller**	Control box	Drives the rotor based on PC commands.
4	**LNA (Low-Noise Amplifier)**	Low-noise RF amplifier near the antenna	Boosts the weak astronomical signal with minimal added noise.
5	**RF filters (50 MHz bandwidth)**	Band-pass filters	Reject out-of-band interference.
6	**Receiver RF amplifier**	Amplifier stage	Increases signal level before mixing.
7	**Local oscillator (1416 MHz)**	Stable frequency source	Provides the reference signal for frequency conversion.
8	**Image-rejection mixer**	Mixer network with 0° and 90° phase paths	Translates RF to IF while suppressing the unwanted image frequency.
9	**IF filters (9 MHz and 6 MHz bandwidth)**	Intermediate-frequency filters	Narrow the bandwidth and reduce noise/interference.
10	**IF amplifiers**	Amplifier stages	Raise the IF signal to a usable level.
11	**ADC**	Analog-to-digital converter	Digitizes the IF signal.
12	**PC**	Computer	Processes data, displays observations, and sends pointing commands.
13	**Power connections**	AC power inputs	Power the receiver, PC, and rotor controller.