HRTRs at VLBA Sites supporting Foundation CORS and beyond

JOHNATHAN YORK
The University of Texas at Austin
jayork@utexas.edu
Overview

- What is the VLBA?
- What is the Foundation CORS network?
- What is a HRTR?
- Why locate HRTRs at VLBA sites?
- What new geodesy does this enable?
Very Long Baseline Array (VLBA) Overview

- VLBA consists of 10 observing stations, spread over the United States
- Performs Very Long Baseline Interferometric (VLBI) observations of celestial radio sources using Earth-sized baselines (8,611km)
- Operated by the National Radio Astronomy Observatory (NRAO)
- Used for radio astronomy and geodesy scientific applications. e.g.
  - Earth Orientation Parameters (VLBA has been vetted to meet NGA EOP requirements)
  - International Celestial Reference Frame

Image Credit: NASA Goddard Space Flight Center
Each Very Long Baseline Array Site has:

- 25m diameter fully steerable parabolic dish antenna
- RF feeds from 0.3 – 96 GHz
- Hydrogen Maser Atomic Clock
- Digitizing / Recording equipment
- (An electrical phase center whose location isn’t as well-known at the millimeter level as we’d like … stay tuned)
NGS Continually Operating Reference Stations

- CORS are fixed GNSS observation sites across U.S. and beyond
  - Data is publicly available
  - Enable GNSS precise positioning relative to U.S. National Spatial Reference System (NSRS)
  - Operated by NOAA National Geodetic Survey (NGS)

- Proposed “NGS Foundation CORS Network” is a subset of sites to be operated at highest standards
  - Signed formal agreements
  - Federally owned
  - Data submitted to IGS
  - Operational availability >90%, outages <14 days
  - Provides definitional support to ITRF
  - Site surveys conducted to IERS standards
  - Sites no more than 800km apart
  - Emphasis on supporting multi-GNSS

Approved for public release, 21-916
Summary of CORS Receiver Requirements

• Receiver
  – Dual frequency (e.g. L1 and L2)
  – At least 10 satellites
  – L1 C/A or P pseudorange
  – Full wavelength carrier phase
  – Receiver/Antenna registered in IGS
  – Data freely available for distribution
  – Recorded on 30 second or shorter interval

• Site
  – Antenna calibration
  – Long lasting, stable monument
  – Good sky view
  – Orienting/leveling
  – Metadata (station logs) provided

GNSS antenna on braced monument
High Rate Tracking Receiver (HRTR)

- The High Rate Tracking Receiver (HRTR)
  - Almost direct to digital software receiver \(^1,2\)
  - Provides both GNSS and VLBI-like data from same digitized RF stream
- Characteristics
  - 3 band configurations
    - 0.1-1 GHz, 1-2 GHz, 2-3 GHz
  - 1 GHz instantaneous direct sample bandwidth
  - FPGA-based digital downconversion and processing
  - Minimal analog front-end to minimize biases

HRTR Signal Chain

- HRTR provides multiple products from the same digitized RF data stream

- GNSS-like geodetic-quality data:
  - Pseudorange
  - Carrier phase
  - SNR
  - Navigation bitstream data
  - Supports all civil GNSS signals
  - Compatible with CORS requirements

- VLBI-like data for DiFX (et al)
  - 9 bands of ~36 MHz each (324 MHz total)
  - Converter to VDIF format standard for VLBI

- Well-characterized, stable timing subsystem, synchronizable to local atomic clocks

![Diagram showing HRTR Signal Chain process](Diagram.png)
HASTE Effort

- HASTE - HRTRs for Awareness of Spectrum and Timing Enhancements
- Collaboration between NGA, NGS, and NRAO
- Goal: Co-locate HRTRs and geodetic monuments at VLBA sites to support time transfer, Foundation CORS and beyond
- Co-located geodetic observing techniques help each technique do geodesy better (e.g. Global Geodetic Observing System, NASA’s Space Geodesy Project)
- Multiple monuments at each VLBA Site
  - Usable for GNSS antennas
  - Usable for optical survey equipment
  - Multiple monuments support maintainability, consistency
- Leverage HRTR as GNSS receiver
  - Provide improved time-transfer capability to VLBA system
  - Provide expanded GNSS data coverage
  - Enable geodetic research
- HRTR Data published to IGS
Conceptual HASTE Architecture

- **GNSS RF**
  - 5 MHz
  - 1PPS
  - NTP Absolute Time

- **High Rate Tracking Receiver (HRTR)**

- **Local Timing Reference (NRAO)**

- **Data Products Flowing from the HRTR**
  - RINEX OBS (1 Hz)
  - RINEX NAV

- **UT Austin**
  - Data archiving
  - Compute resources for post-processing data products

- **NGA Cloud Storage & Compute**
  - TEC Measurements
  - GNSS RINEX OBS and NAV

- **Mission Partners**
  - GSWeb (http)
  - Products (sftp)
  - Analysis Reports (pdf)

- **VLBA Mission Partners**

**Mission Partners**

- GSWeb
- NGA Cloud Storage
- GNSS RINEX OBS and NAV

- TEC Measurements
- Analysis Reports
- Products

- Data archiving
- Compute resources for post-processing data products
Why do this? Reference Frames!

- Geodetic Reference Frame - an abstract coordinate system, realized by physical references at known locations

- Examples:
  - Terrestrial Reference Frames (e.g. ITRF, WGS84)
    - Coordinates for the Earth, realized by points on the earth
    - Primarily derived and disseminated by GNSS observations
  - Celestial Reference Frames (e.g. ICRF)
    - Coordinates for the Stars, realized by extragalactic radio sources
    - Primarily derived by Very Long Baseline Interferometry
  - ICRF and ITRF are relatable via:
    - Earth Orientation Parameters
    - Observing Station Coordinates

- Different techniques/frames are not as consistent as we’d like

A current geodetic research frontier is co-locating observing instruments for multiple techniques, and measuring the baselines between them with goal of supporting ~1mm absolute accuracy, ~0.1mm/year drift
Is it possible to measure GNSS/VLBI baseline by treating the GNSS as part of an interferometer?

Why do this?
- Provide direct measurement between VLBI dish and GNSS antenna phase centers
- Phase center stability of GNSS antennas is good

The goal is measurements of the baselines at reference frame co-location (fundamental) sites directly through the instruments
• Under a NASA grant, ARL:UT conducted an early experiment using HRTRs to detect celestial sources on a baseline involving a GNSS antenna

• Antenna elements
  – Three meter dish
  – GNSS antenna (Topcon)

• Next slides detail results from 2018

• Work is ongoing…
High Power (GNSS) Sources

16 km baseline, 10 s integration, GPS L2
Successful HRTR detect of celestial source

Target: Cyg A 2018-07-19 05:00:18
CAF Surface: 600s integration

Peak power and phase at 25 s integration time through period
Recap

High Rate Tracking Receivers will be fielded to VLBA sites over coming years supporting:

– Time transfer within VLBA
– Precision Geodesy
– Foundation CORS mission
– Emerging geodetic research applications

Portions of this material are supported by the National Geospatial-Intelligence Agency and NASA under awards NNX17AD29G and 80NSSC20K1732.