Time and Frequency Distribution Overview and Issues

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Session Topics

- Requirements and parameter space for time and frequency distribution systems.
- Scalability, and limitations, of current approaches.
- Technical risks and issues.
- Emerging technologies and opportunities.
- Candidate architectures for ngVLA reference distribution.

Functional Requirements – Frequency Reference

- Clock distribution for digital samplers
- Coherent frequency reference for up/down conversion
  - Both signals have strict requirements for phase noise in order to preserve coherence.
  - Phase stability is important on similar time scales to the integration period in order to preserve visibility phase.

- Phase noise
  - Degrades sensitivity, spatial resolution, and dynamic range.
  - Phase noise of the atmosphere should dominate, not the system.

Atmospheric Phase Noise (100GHz)

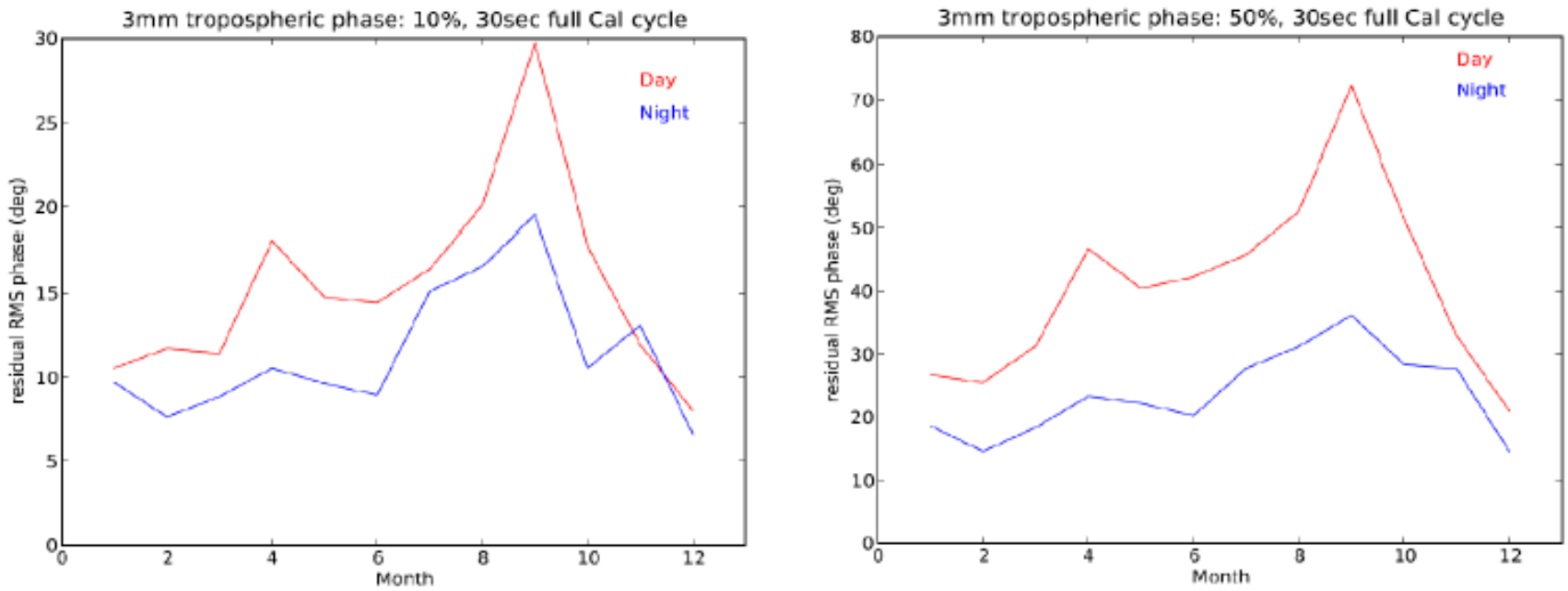


Figure 3: *Predicted rms phase noise after fast switching phase calibration as a function of month and day/night (red/blue; derived from STI data presented in Butler & Desai 1999). A 30sec total calibration cycle was used, and 10% and 50% conditions are plotted.*

NGVLA Memo #1. Carilli, 2015.

SNR vs. Phase Noise

Allowable SNR Degradation	Total Phase Noise (degrees, RMS)	Highest System Frequency (GHz)	Allowable System Jitter (fsec)
1.0%	8.1	120	187.5
2.5%	12.8	120	296.3
5.0%	18.1	120	419.0
10.0%	25.6	120	592.6

EVLA System Requirement for jitter is <500 fs over 1-second interval. Equivalent to a 1% SNR degradation at 50 GHz.

For independent noise processes, variances add in quadrature to the system specification.

Phase Stability

- Temporal stability.
  - Could be important from 30 second to 24 hr. timescales.
  - Requirements vary with calibration strategy.
  - Likely in the 1 picosecond / hour range?
  - Residual after linear fit vs. total drift?
- Stability as a function of temperature/environment.
  - Combination of environmental changes and phase change as a function of environment.
  - Trade-space with environmental control.
  - buried vs over-head fiber.
  - Factor into temporal stability budget.

Other Key Timing System Requirements

- Time reference for synchronization & data time-stamps
  - Absolute accuracy and relative precision depend on the needs of supported systems.
  - A VLBI correlator, or data transmission over commercial networks, would both require higher absolute timing precision.
    - 1 usec accuracy likely sufficient for these cases.
  - Some science cases, like pulsars, may impose their own requirements.
    - Is nsec-level precision required?
- Reduced operations cost
  - Any concept proposed must aim to minimize the operation and maintenance cost for the expected life of the array (20-30 yrs.)
    - Main cost of these systems is the cost of human intervention
  - Reliability, stability, redundancy, remote and local monitoring, local reset, etc…

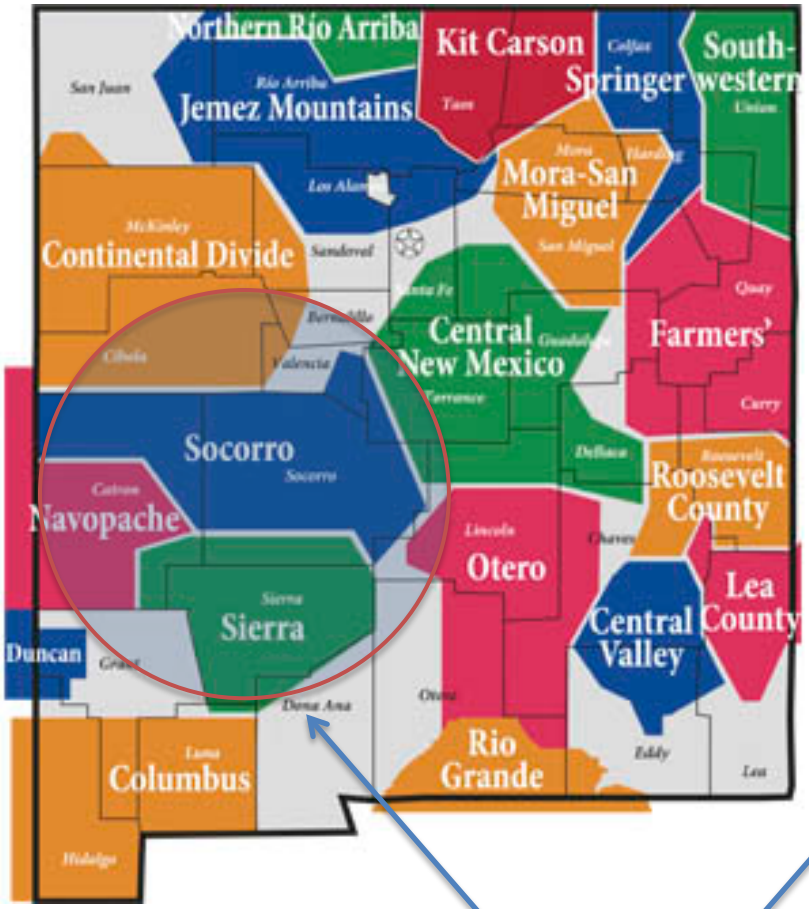
Fiber Constraints / Assumptions

- Due to the expected scale of the array (300km+), may have a mixed fiber optic system.
  - Some NRAO owned fiber (array center, last mile), leased fiber (where available), and leased bandwidth on long hauls.

- Cannot assume that all fiber is buried/thermally stabilized. May need to leverage existing utility easements from telecom and rural electric coops.

- May have more than one solution in the proposed architecture, with different approaches for the center of the array vs. the extents.

Rural Electric Cooperatives



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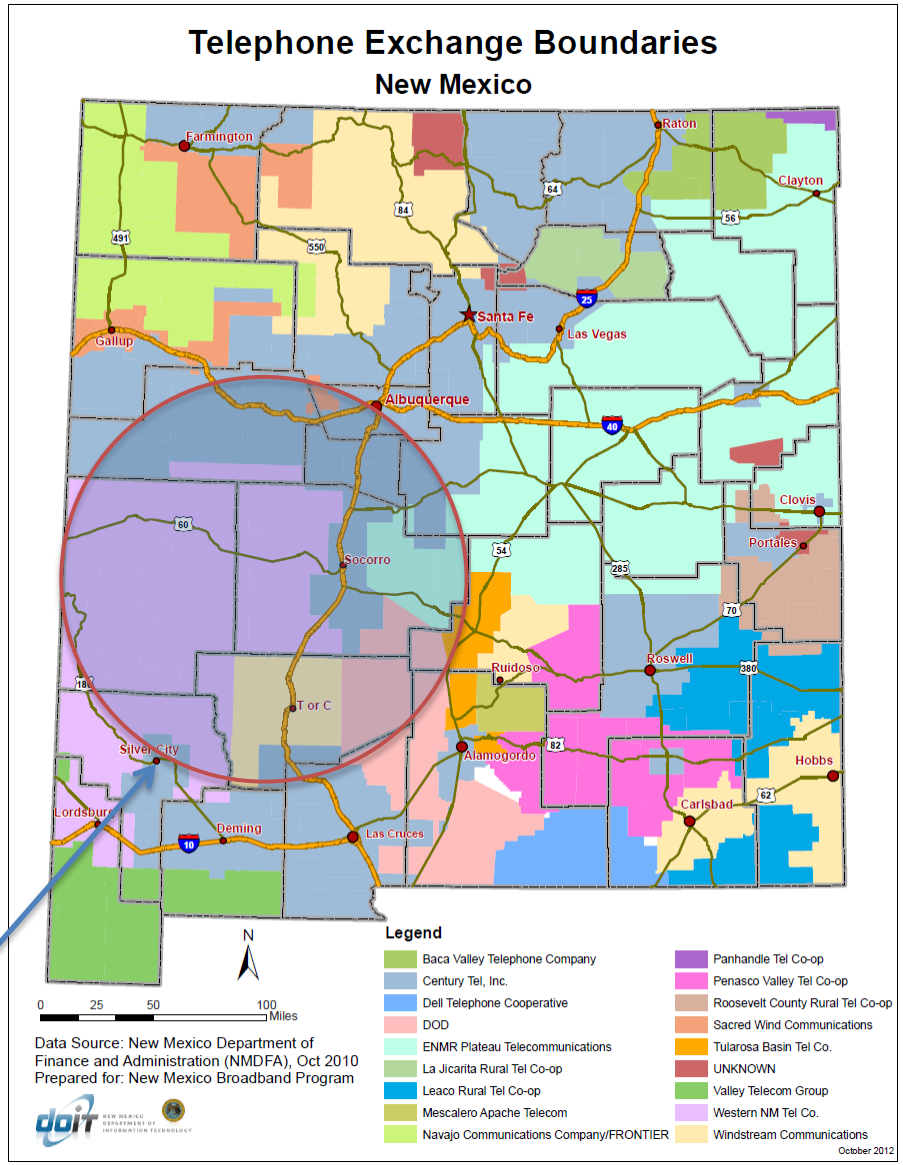

Known Issues

- Issues vary with the fiber topology:
  - NRAO owned, buried fiber: The 'easy' case. Model on prior experience, scale by a factor of 10x. New part is the need for SOAs/EDFAs or active repeaters.
  - Leased fiber: Access to telecom closets, standards and lab certification of equipment, possible overhead lines…
  - Leased bandwidth: Impractical to do distribution of references. Suggests a need for local references (such as hydrogen masers), with perhaps short-haul distribution (station model).

Trends & Opportunities

- Wireless transmission of references
  - With GPS-III, can a GPS disciplined oscillator be made good enough?
- Synchronization with National Laboratories
  - NIST, USNO facilities close to boundaries of the array.
- New lower cost, high-stability secondary frequency references
  - Photonic oscillators
  - new Rubidium standards

Trends & Opportunities

- Integration
  - Full timecode distribution on frequency reference carrier
  - May eliminate a signal reconciliation risk

- Full RF bandwidth over fiber, eliminating the need for reference distribution to the antenna.
  - Transceivers are approaching bandwidths of 100GHz.
  - Unclear if there is sufficient total power to remain linear while preserving SNR and providing adequate dynamic range.
  - Creates new concerns, such as the dispersion in velocity, jitter in the transmitter, etc.
  - Still need to monitor the optical length of the fiber system to maintain phase coherence.

Desirable Outcomes from this Session:

- A better understanding of:
  - The requirements and parameter space for time and frequency distribution systems.
  - Limitations and scalability of current approaches to reference distribution.
  - Technical risks and issues to be addressed.
  - Emerging technologies that may provide construction and/or operations cost savings, while meeting performance specifications.
  - Possible architectures for ngVLA reference distribution.

Session Schedule

Time	Topic	Presenter
1:00-1:20	Time and Frequency Distribution: Overview and Issues	Rob Selina
1:20-1:40	ALMA Approach	Bill Shillue
1:40-2:20	Oscillators and Phase Noise from Low RF to Microwave Photonics	Enrico Rubiola
2:20-3:00	Long-haul Implementation of White Rabbit Ethernet for Fiber-optic Synchronization of VLBI Stations	Jeroen Koelemeij
3:00-3:20	Discussion	
3:20-3:40	Break	

Discussion and/or Questions?