A TWSTFT Experiment Using the Telstar-5 Satellite

13th Annual Meeting of the CCTF Working Group on Two-Way Satellite Time and Frequency Transfer

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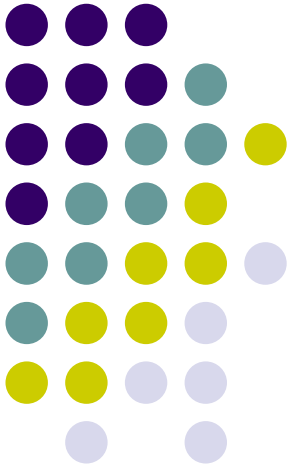
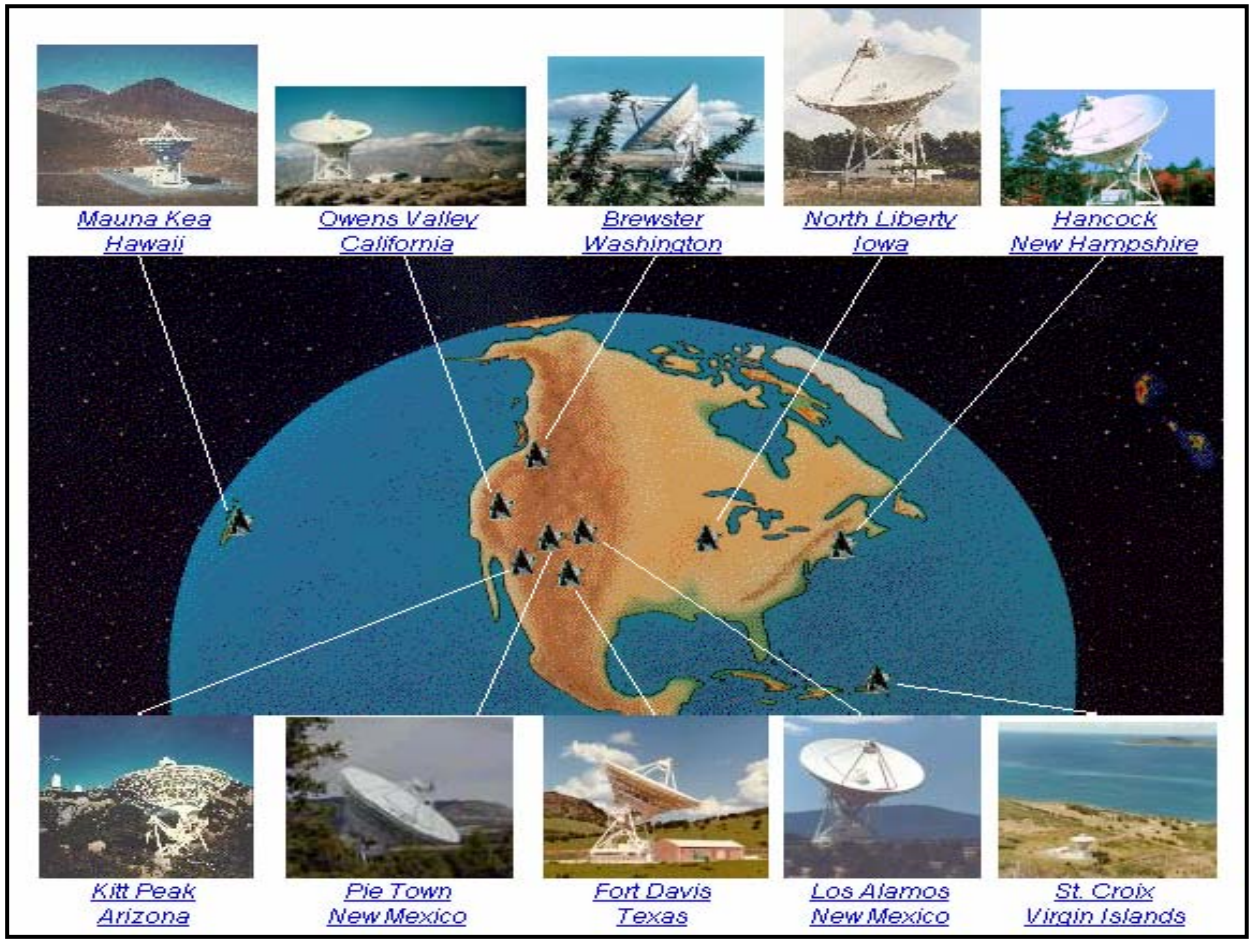


Outline

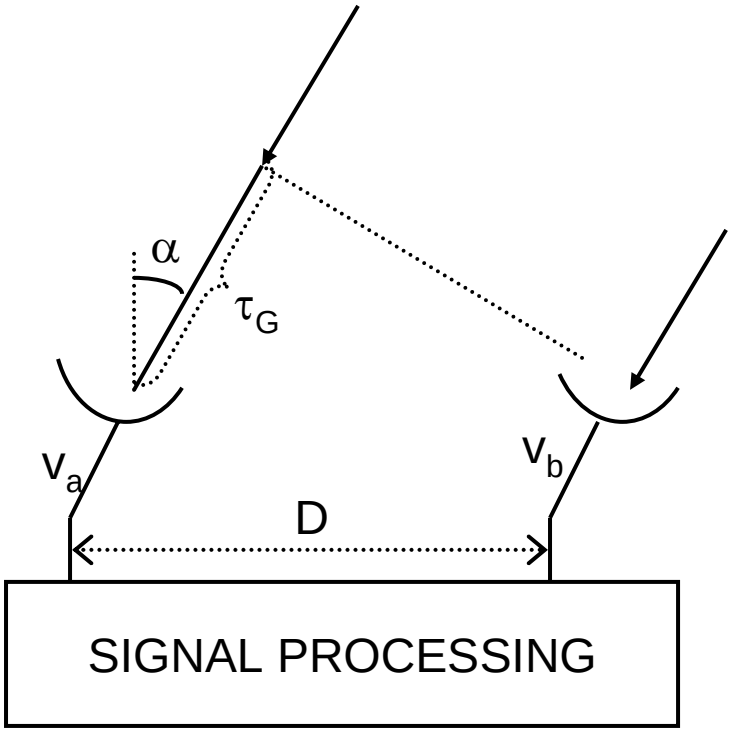
- Background and Motivation
  - Radio Astronomy and VLBI
- TWSTFT System
  - System Description
  - Hardware
- Experimental Results
- Conclusions

The Very Long Baseline Array

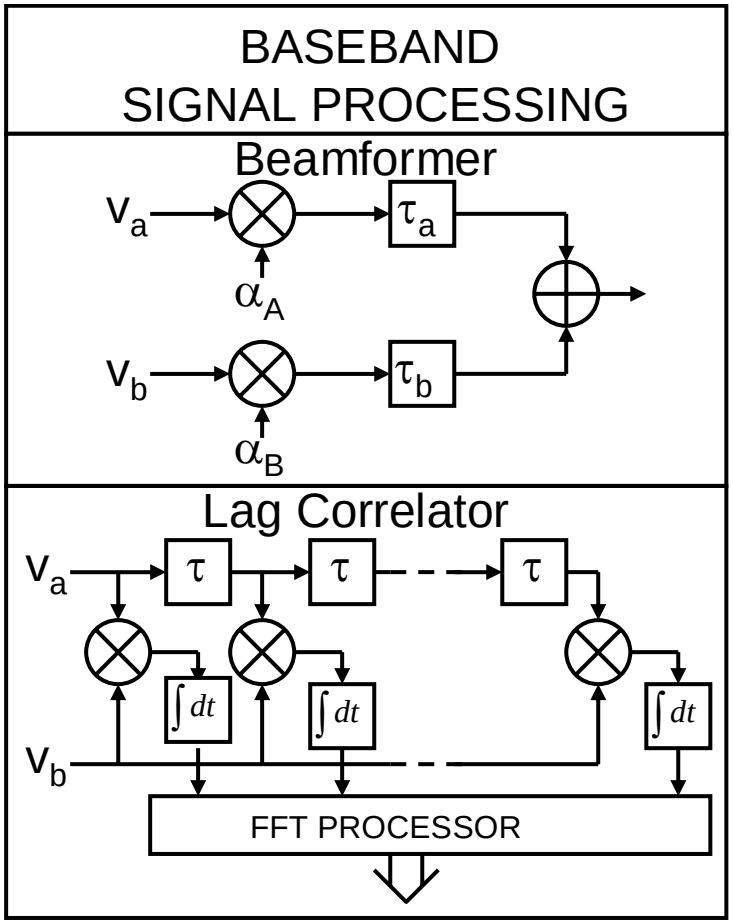


REF: "The Very Long Baseline Array Antenna Sites," http://www.aoc.nrao.edu/vlba/html/vlbahome/thesites.html

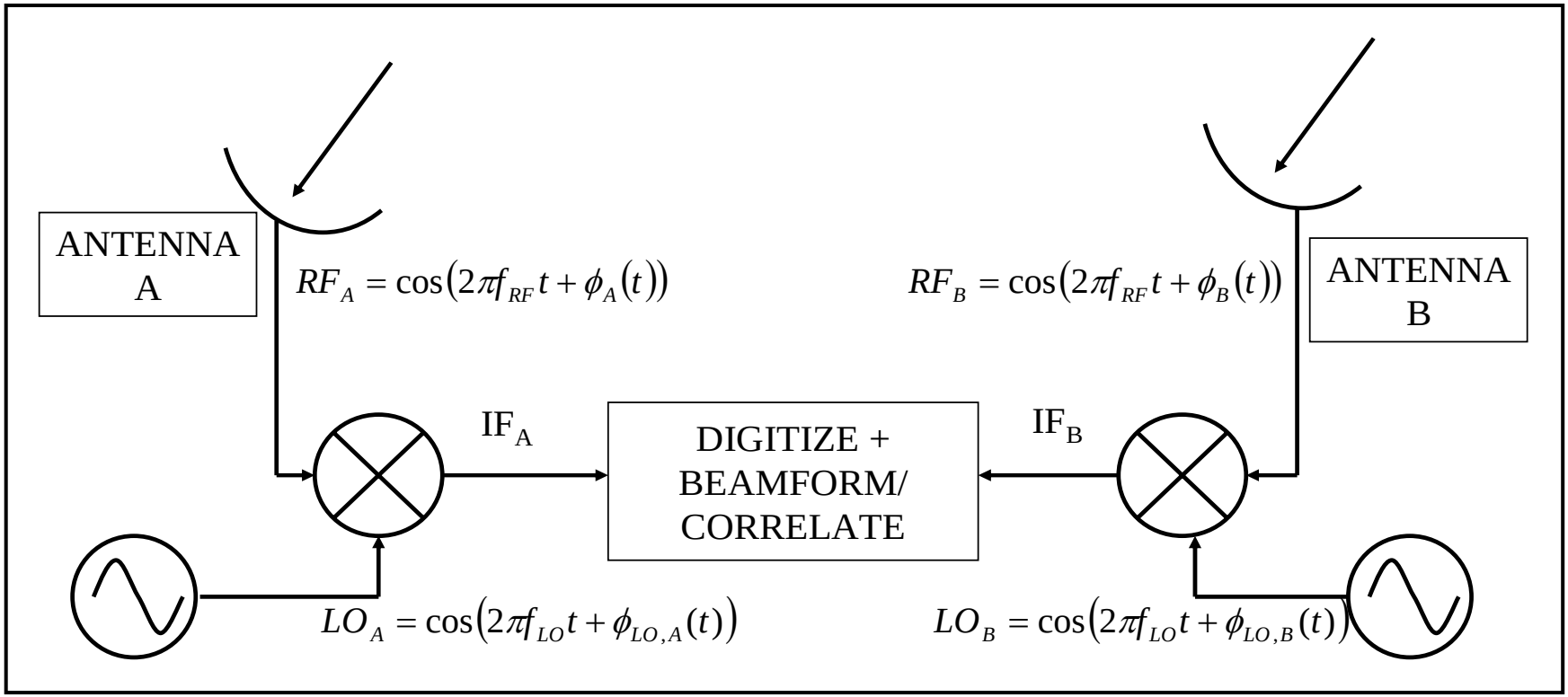
Array Signal Processing



$$\tau_G = \frac{D}{c}\sin(\alpha)$$



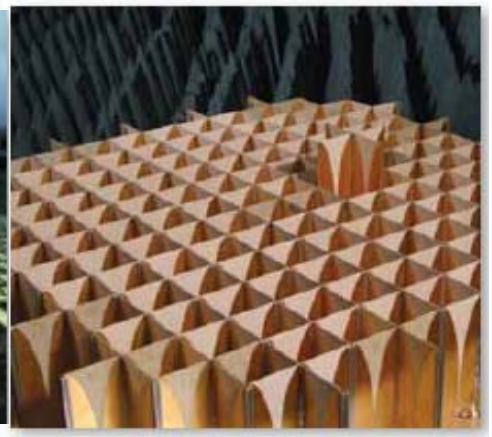
Coherence Requirement



Square Kilometre Array

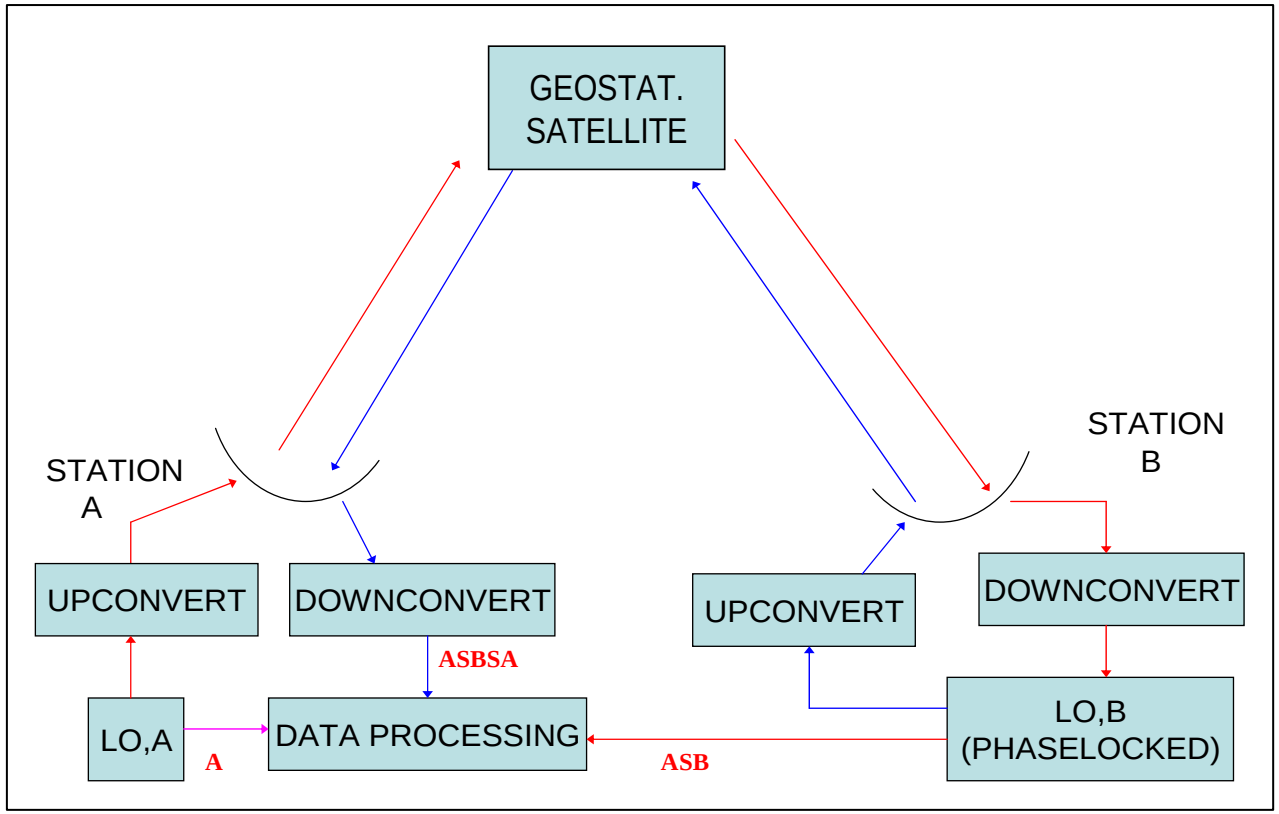
- International collaboration in which a 1km^2 aperture will be synthesized over the 0.1-25GHz band
- Topology not yet determined, several different approaches are now in the proof of concept stage.
- Angular resolution specification of 0.2/f_{GHz} arcsec requires baselines out to 3000km
- Total budget of ~$1B USD does not permit the purchase and upkeep of hundreds of Hydrogen Masers—LO signals must be distributed some other way!

Large N-Small D Approach (USA)



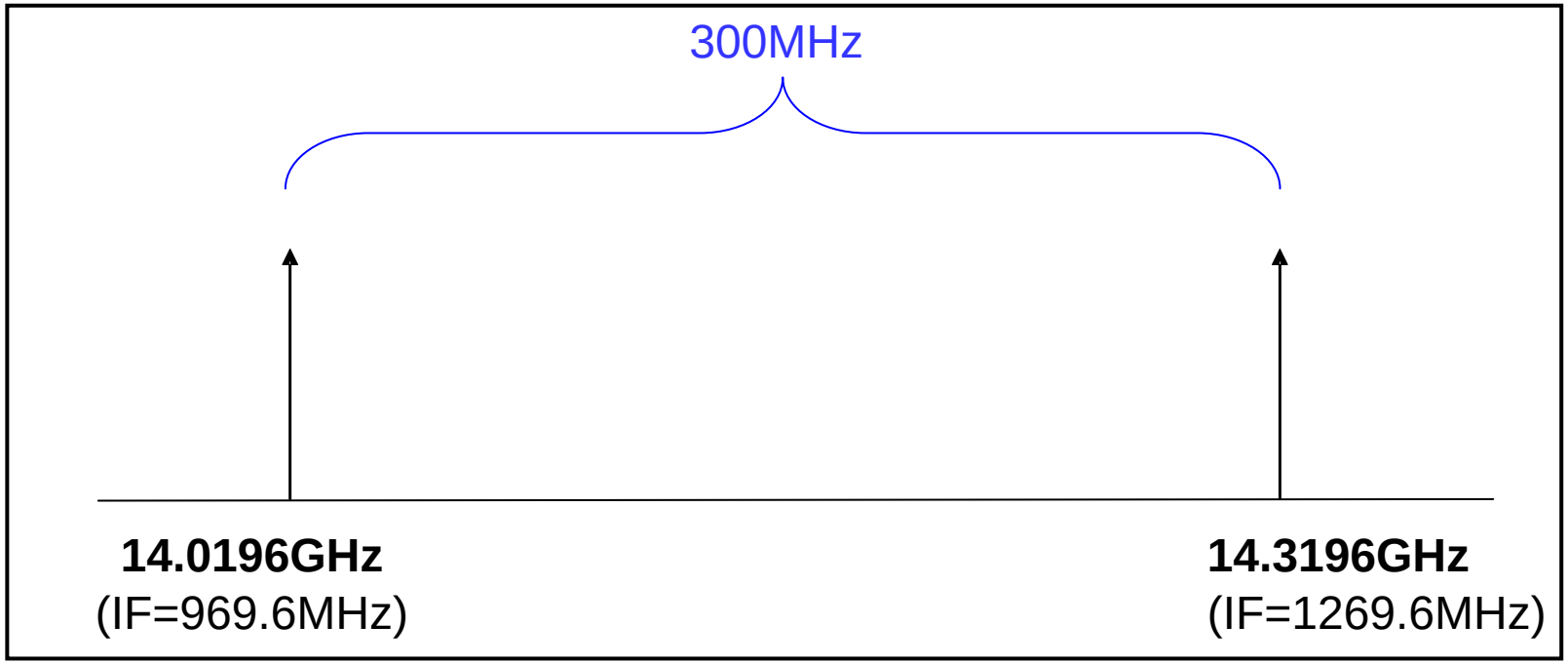
Phased Array Approach (Europe)

TWSTFT Block Diagram

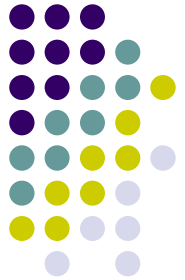


$$\phi_{RESIDUAL} = \phi_{ONE-WAY} - \frac{\phi_{ROUND-TRIP}}{2}$$

Modulation Scheme

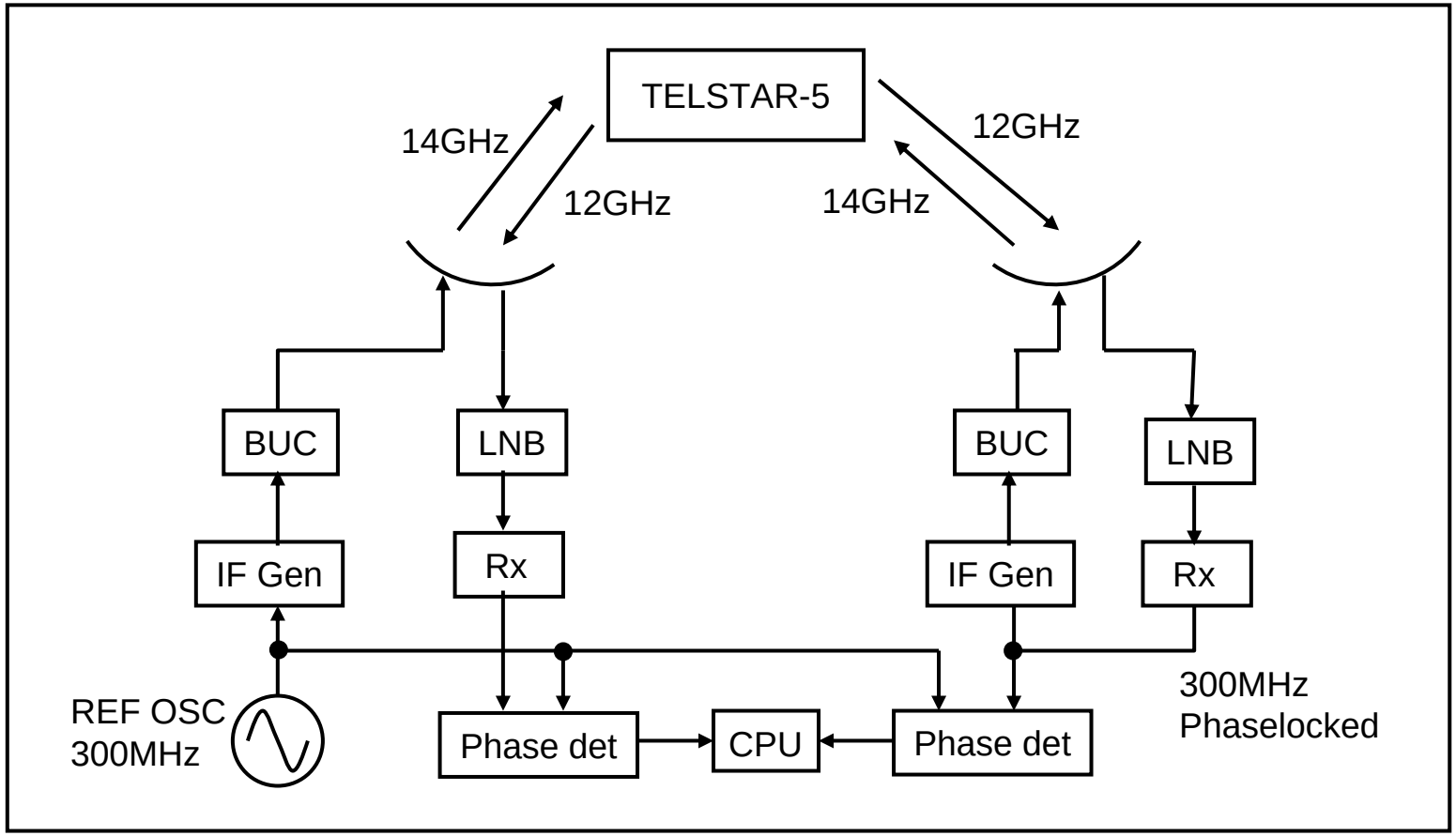


Two-Tone Modulation Technique



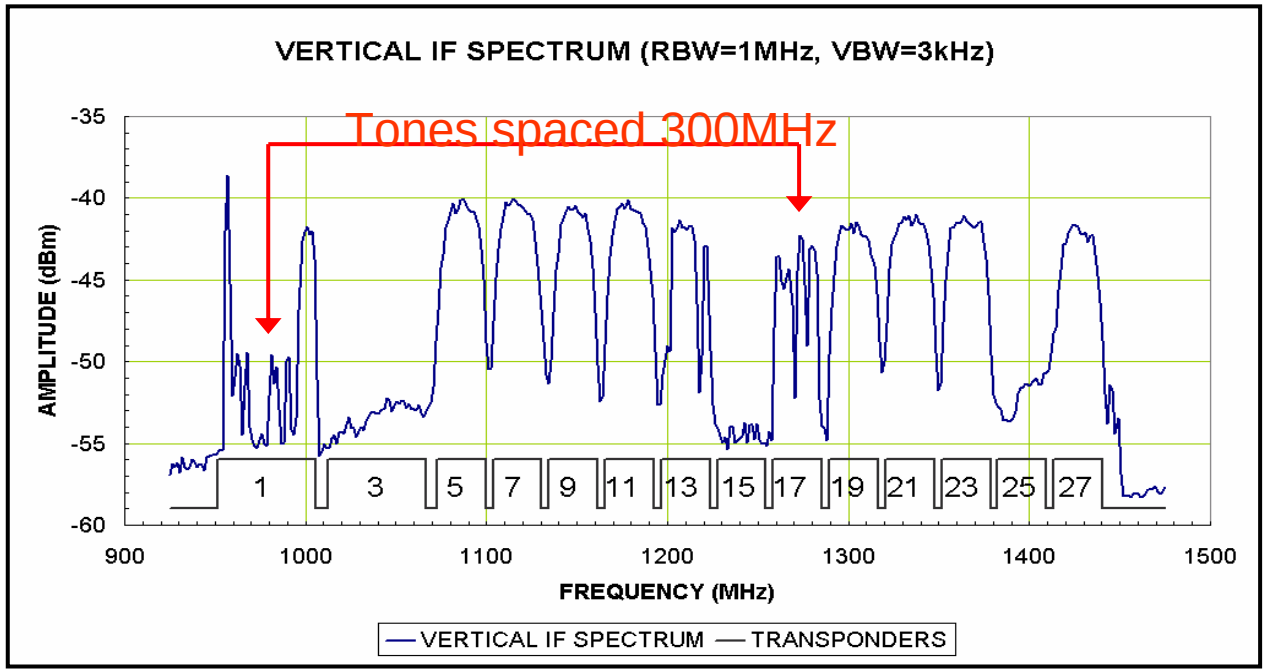
- Insensitive to translation oscillator onboard satellite
- Very small bandwidth requirements: theoretically ~1Hz/carrier.
- With 300MHz carrier, ambiguity interval is 3.3ns.
- Ambiguity interval can be made much larger by transmitting an additional set of tones with a much smaller separation. Ex: 1MHz -> 1us

Block Diagram

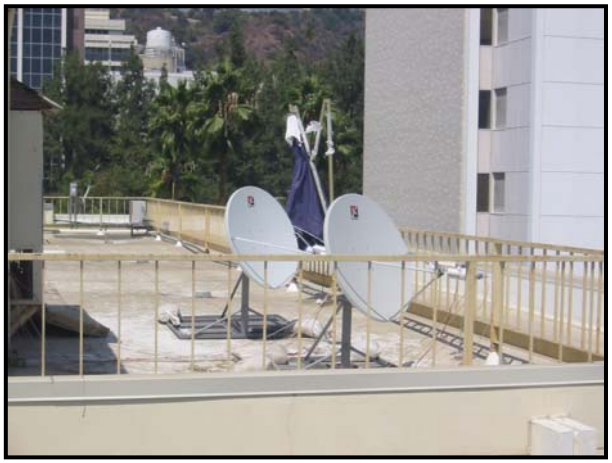


Telstar-5

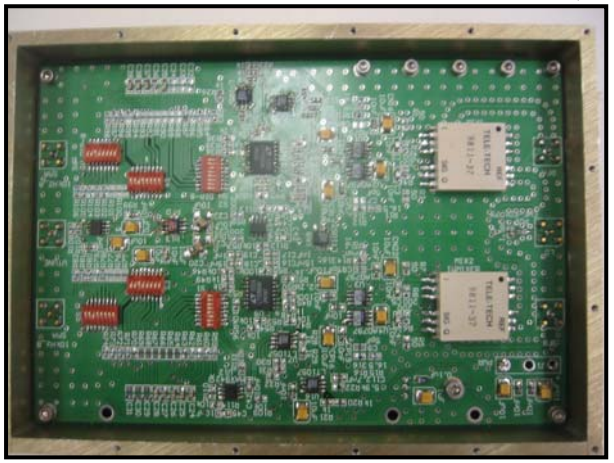
- Telstar 5 is a commercial communications satellite with four 54MHz wide and twenty four 27MHz wide 100W transponders in the 12/14GHz band.
- Caltech leased three 100kHz wide bands in transponders 1 and 17 for $1600 USD per month



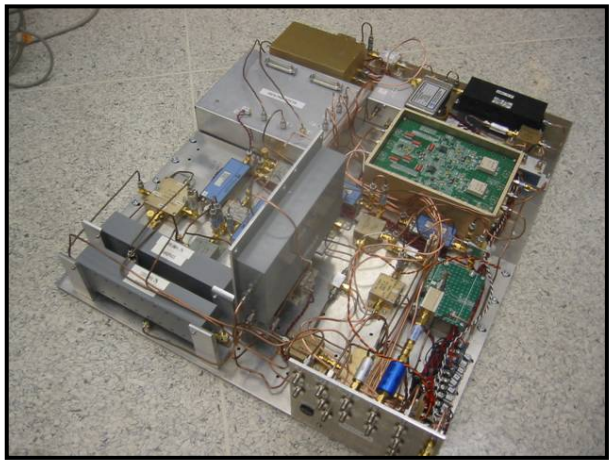
Hardware



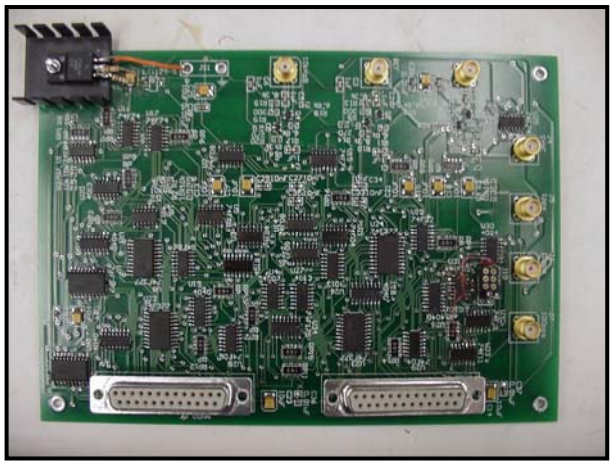
ANTENNAS



PLL DOWNCONVERTER

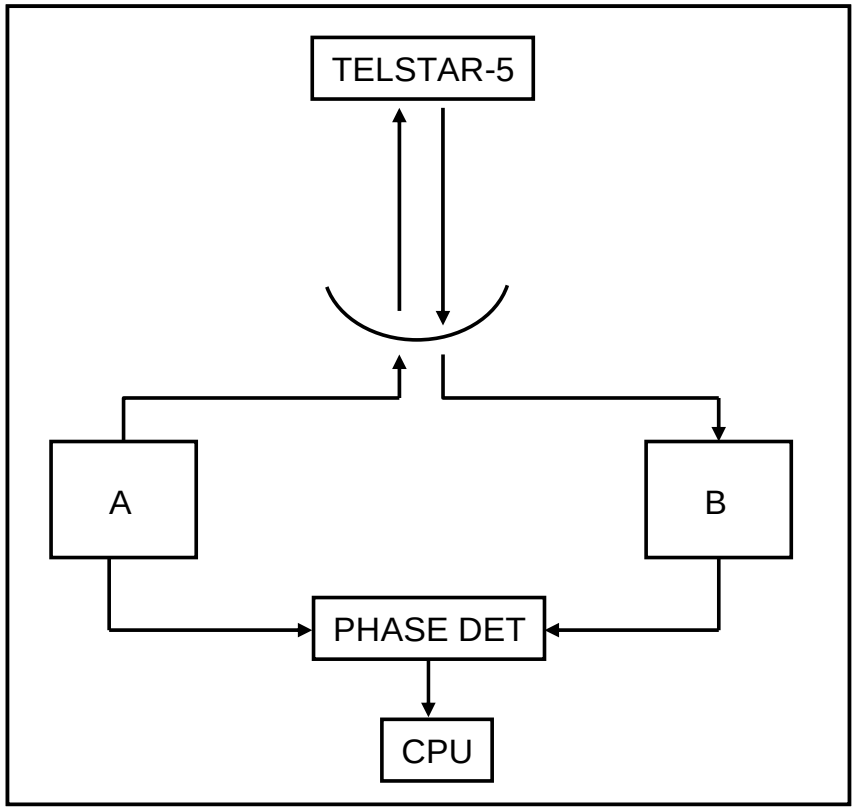


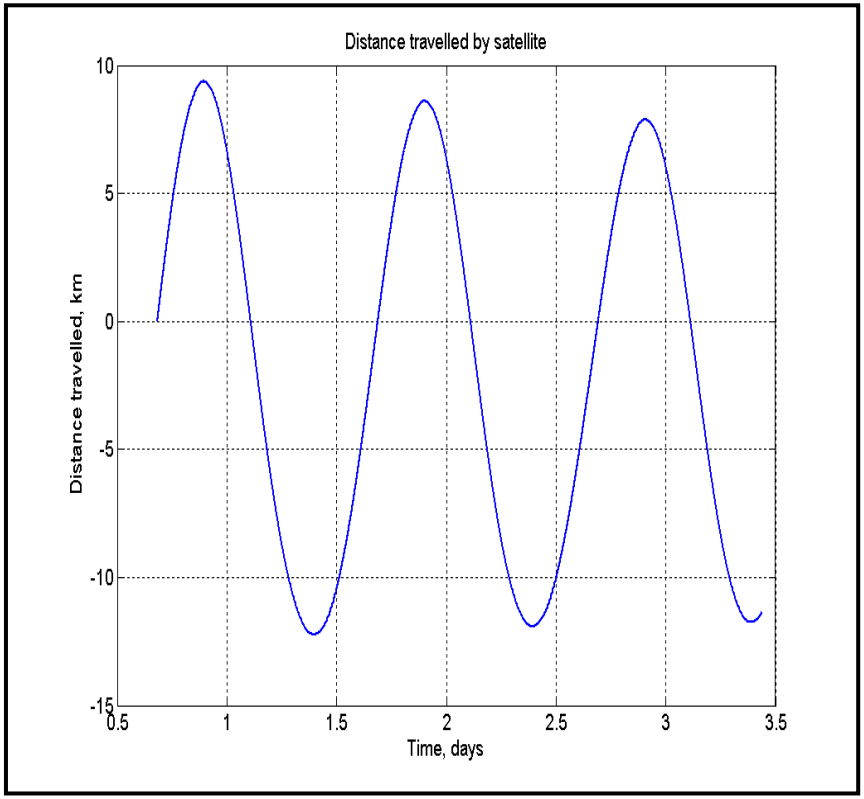
STATION A HARDWARE



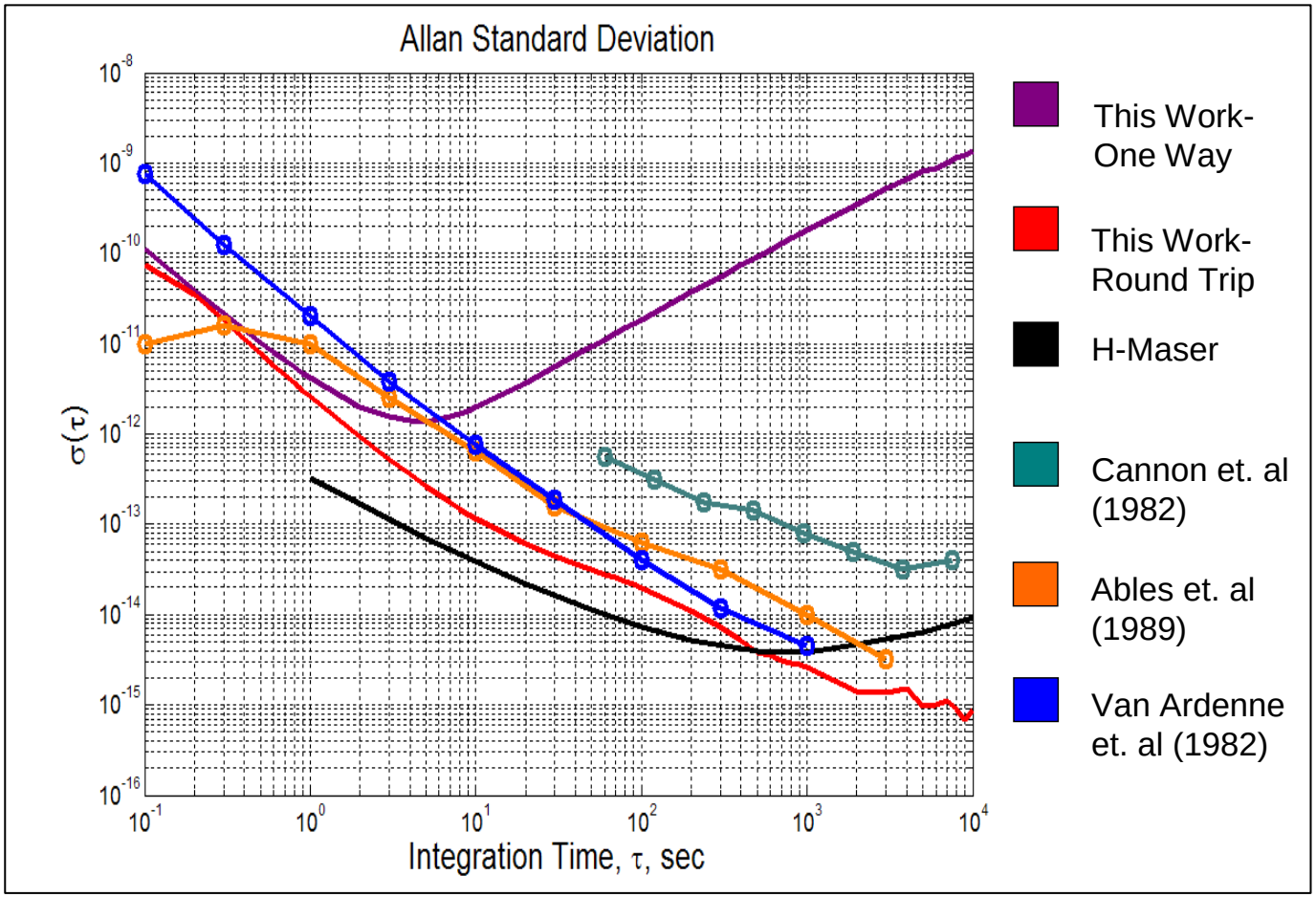
DIGITAL PHASE DETECTOR

One-Way Test

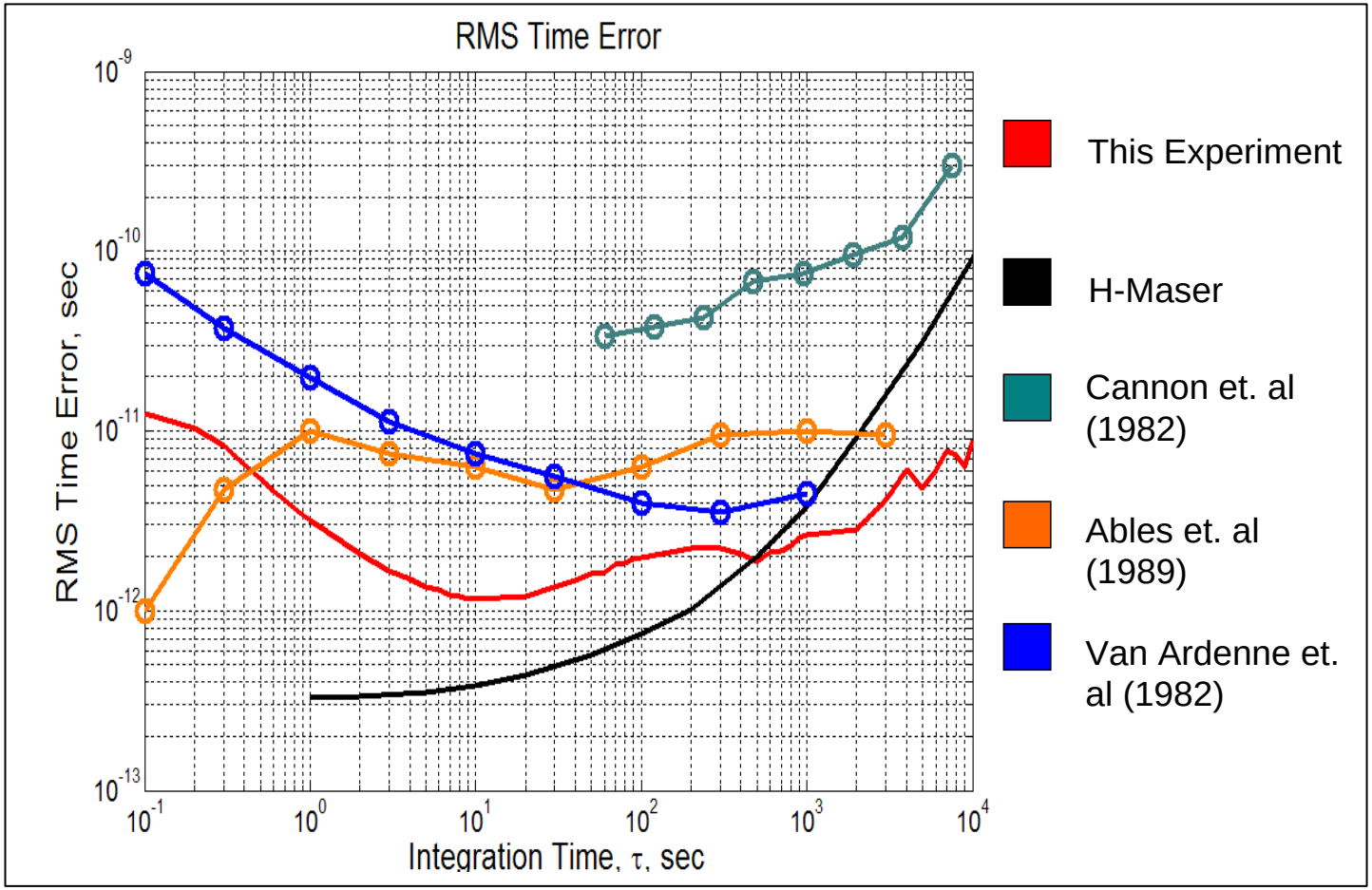

TELSTAR-5
A
B
PHASE DET
CPU


Distance travelled by satellite
Distance travelled, km
Time, days
10
5
0
-5
-10
-15
0.5
1
1.5
2
2.5
3
3.5

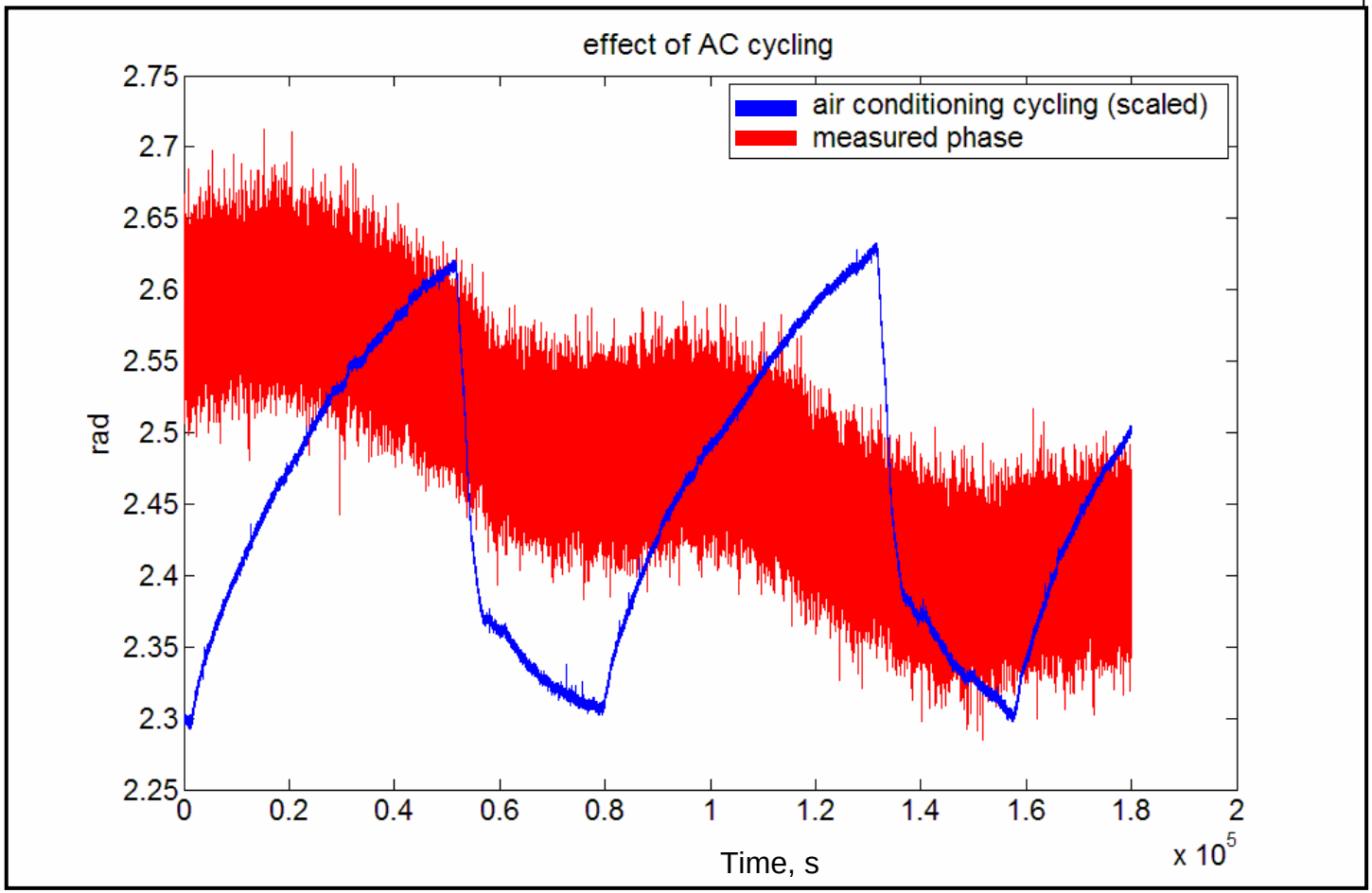
Allan Standard Deviation



RMS Time Error



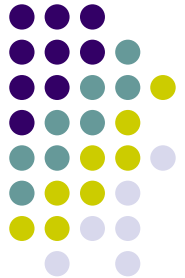
Thermal Effects



Future Work

- Add thermal stabilization hardware
- Perform test in which terminals are separated.

Acknowledgements



- This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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[1] J. Bardin, “Local Oscillator Distribution Using a Commercial Geostationary Satellite,” M.S. Thesis, Electrical Engineering Department, University of California, Los Angeles, 2005.

[2] J. Bardin, S. Weinreb, D. Bagri, “Local Oscillator Distribution Using a Geostationary Satellite,” *The Square Kilometre Array: an Engineering Perspective*, Peter Hall, ed., The Netherlands: Springer Press, pp193-195.

[3] Cannon, et. al, “Phase Stable Long Baseline Interferometry via A Satellite Link,” Very Long Baseline Interferometry Techniques, 1982, Cepadues Press, Toulouse (443-458).

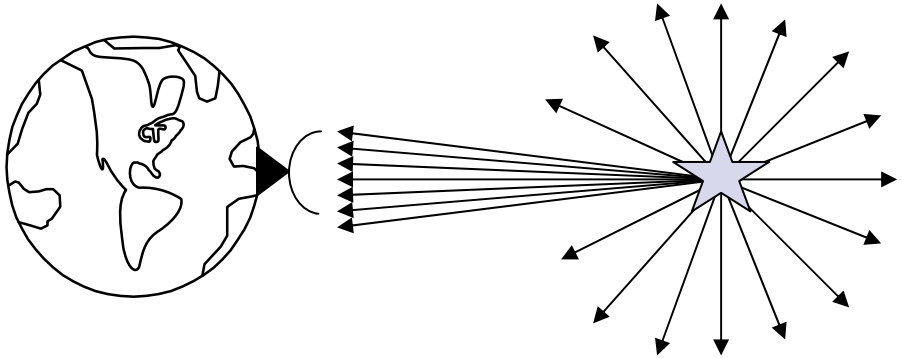
[4] Van Ardenne, et al, “VLBI Clock Phase Comparison Using a Geostationary Satellite,” Very Long Baseline Interferometry Techniques, 1982, Cepadues Press, Toulouse (459-466).

[5] S. T. Ables, “A Report on the Phase Stability of the Aussat Phase Transfer System (draft),” July 1989

[6] F. Gardner, *Phaselock Techniques*, John Wiley and Sons, New York, 1979.

[7] A. Van Ardenne et al, “A High-Precision Phase-Comparison Experiment Using a Geostationary Satellite,” *IEEE Transactions On Instrumentation and Measurement*, Vol IM-32, NO. 2, June 1983, 370-376.

Radio Astronomy



- Study of the universe by electromagnetic radiation measurements.
- Two main classes of telescopes: single dish telescopes and aperture synthesis (array) telescopes.
- Dynamic range of images limited by signal to noise ratio (SNR) of the system. SNR is proportional to the system noise temperature and the total collecting area.
- Aperture synthesis telescopes have the advantage of being able to form beams in the sky by phasing the outputs of the individual elements.
- Size of beam in sky, or angular resolution of aperture synthesis telescope, is generally limited by separation of elements: zoom lens type effect.
- In order to take advantage of the zoom lens effect, the antennas can be separated by very large distances resulting in images with incredible resolution. Such arrays are referred to as very long baseline arrays.