Modernized LORAN-C Timing Test Bed Status and Results

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LORAN-C Timing Test Bed

- Loran-C system being modernized to meet modern PNT requirements
  - Significant focus of modernization is changing traditional Loran-C into a differential service
  - Enhanced performance, reliability and integrity are expected improvements of modernized service
- As part of the modernization, a coordinated effort is underway to evaluate modernized Loran-C's potential as a precise time and time interval (PTTI) source
  - Modernized LORAN has emerged as the best option to backup GPS timing service
    - » Addressed in Lombardi paper later in this session
- LSU leading an effort with multiple agencies to collect and analyze Loran-C time/frequency data over an east coast evaluation network
  - This paper presents the current status of the test bed and related activities

LORAN-C Timing Program Status

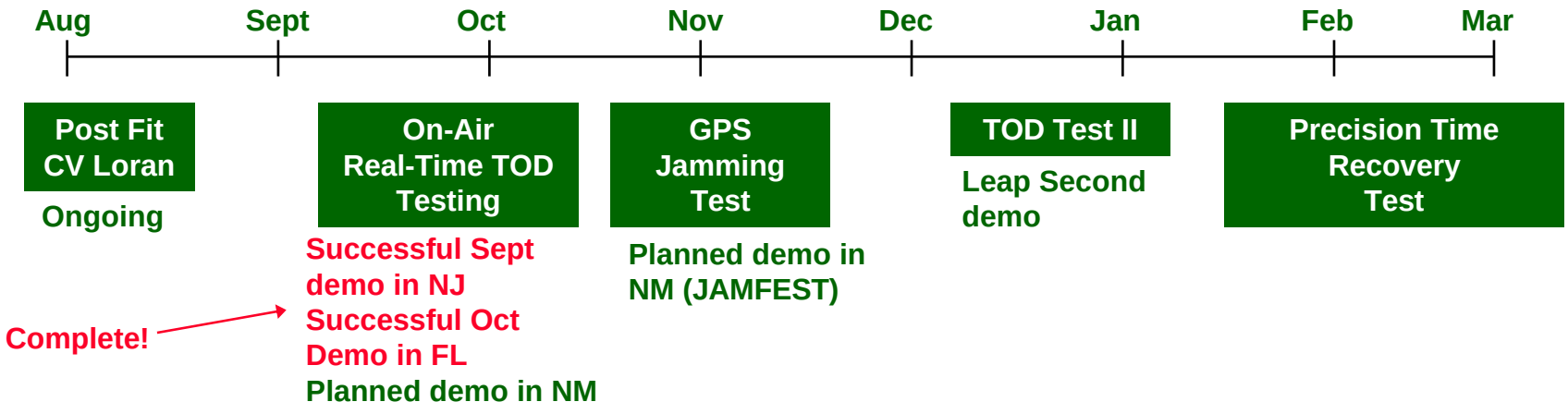
- Significant progress in all components of LORAN-C timing program has been made over the last 12 months
  - — Planned work included development and testing in all aspects of LORAN-C precision time recovery
    - » Data Analysis: Post-processing of standard LORAN-C data using the LORAN-C test bed on the east coast
    - » Broadcasting LORAN Data Channel (LDC): Changes made to Time and Frequency Equipment (TFE) to create a ninth pulse in LORAN signal that is modulated to transmit data to the users
    - » LORAN-C timing receiver: User receiver developed to process LDC and produce IRIG-B and NTP, as well as, 10 MHz and 1 PPS
    - » LORAN-C monitor receiver: Receiver designed to process LORAN-C signal and produce corrections for transmission in LDC
    - » Two-Way Time Transfer: GPS independent front end has been demonstrated at LSU with the plans for a small network implementation in 2006

Focus of ILA 2005 Paper

- Development period is beginning to transition to a test and verification period where new LORAN-C functionality will be incrementally demonstrated and documented via technical publications

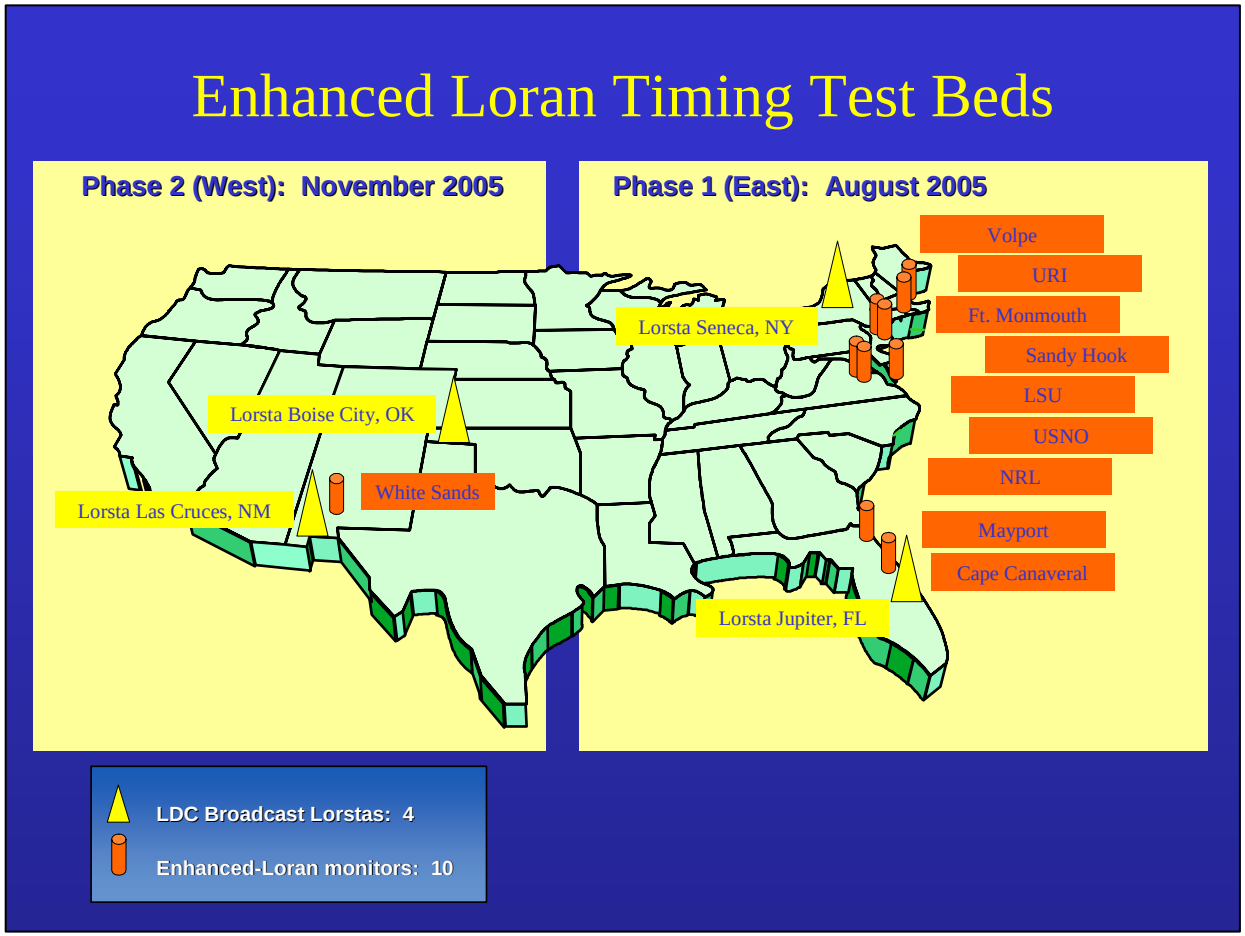
Planned Testing

- LSU is collaborating with US Govt agencies to monitor and analyze timing performance with LORAN
  - — USNO, NIST, NRL, RCC have provided facilities, signals and programmatic support
- Network of sites will be used over the next 6 months for tests and demonstrations of LORAN's ability to meet the critical requirements to serve as a backup to GPS for precise time users
  - — Time of day testing, GPS Jamming testing, Real-time precision (<50ns RMS) time recovery
- LSU also reaching out to academia for support to the algorithm development for application of monitor data as corrections to the transmitted signal
  - — USCG Academy and University of Rhode Island to support studies in the processing of monitor data for real-time corrections



LORAN On-Air Tests

- Network of sites have been prepared for LORAN-C on air tests
- Proposed transmit sites
  - LorSta Jupiter, FL
  - LorSta Las Cruces, NM
  - LorSta Boise City, ID
  - LorSta Seneca, NY
- Monitor sites
  - USNO
  - NRL
  - Eastern Range
  - LSU
  - Sandy Hook
  - Volpe
  - White Sands



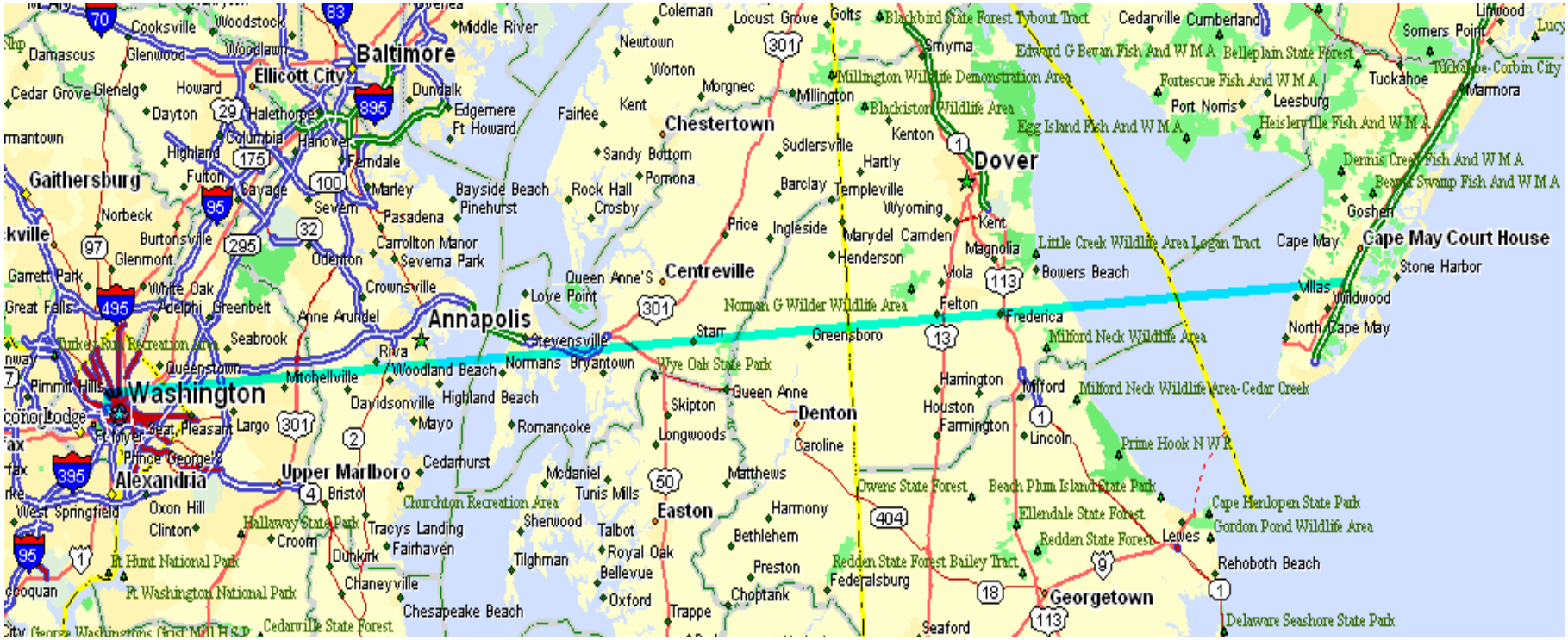
Results from on-going LORAN-C timing data collection

Starting Points

- Common-View LORAN-C is a differential timing technique where corrections from a monitor site are applied to the user's received signal
  - Correlated measurements between monitor and user site are subtracted to remove the temporal propagation changes that limit time recovery performance
- Results from CO-WY common-view LORAN-C baseline presented in previous papers (PTTI, ILA and FCS)
  - Synchronization performance over short baseline that was comparable to GPS (< 10 ns RMS)
  - Performance over longer baseline met timing specifications (< 50 ns RMS) to provide precise time recovery
- Timing community response to CO-WY results was lukewarm due to lack of "challenge" in baseline
  - Conducting test in mid-west US did not impress users of legacy LORAN-C that had seen microsecond+ performance on east coast of US

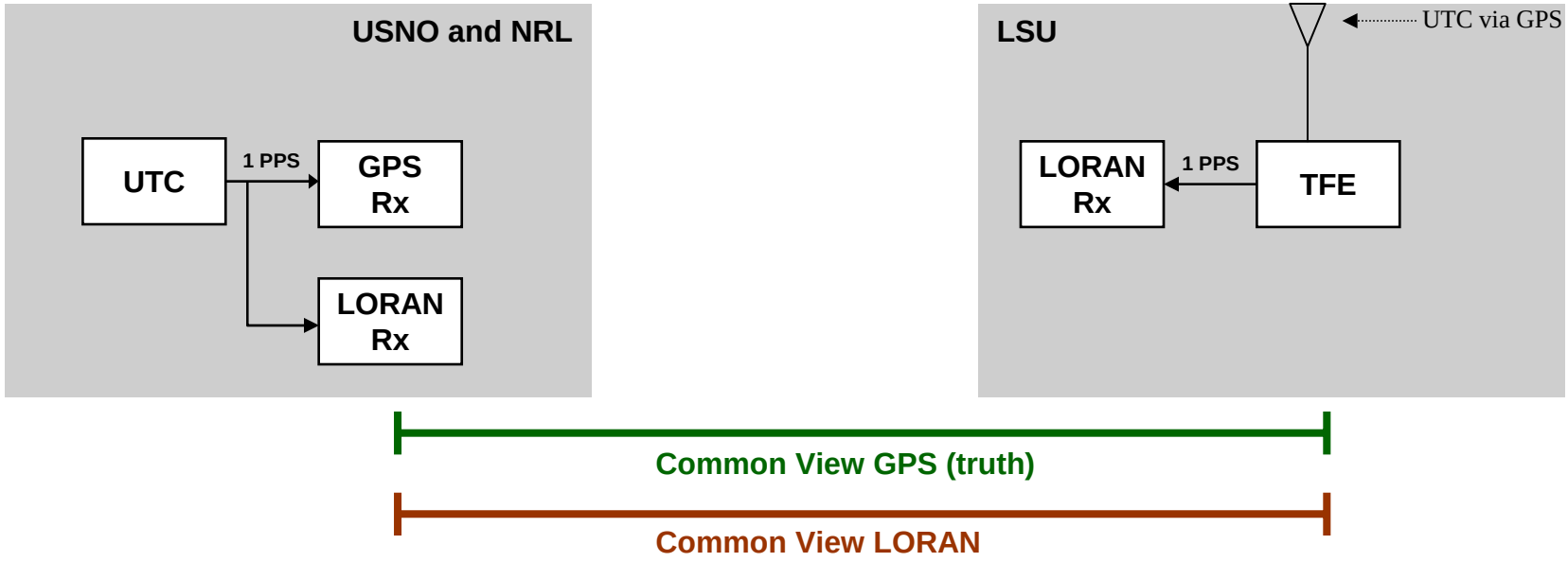
Enhanced LORAN Results (Long Baseline)

- Data collected between LSU (Wildwood, NJ) and USNO (Washington DC) to determine the effectiveness of a monitor on long east coast common-view baselines
  - — Collection baseline chosen where weather conditions and geography make LORAN time recovery challenging
    - » 120 miles with land and water propagation between the two sites



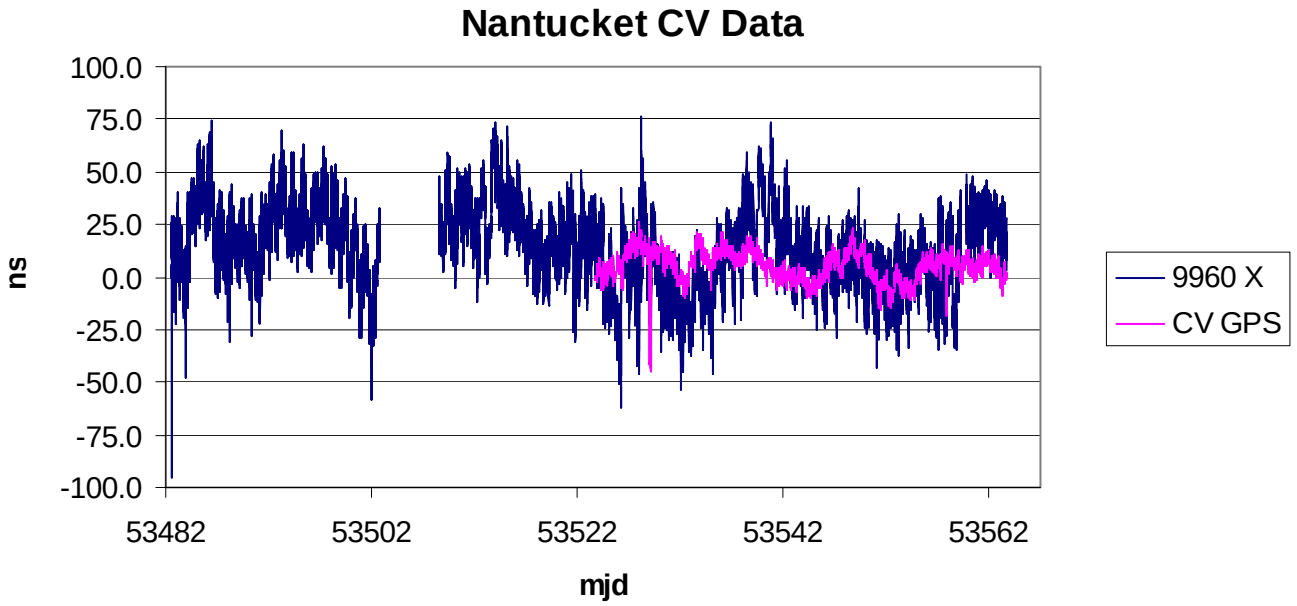
Data Collection

- USNO provides the optimal monitor site as there is no error to UTC
  - GPS data logging is also available for “truth” common view measurement to compare to CV LORAN
- Timing system at LSU provides the timing signal to measure with CV LORAN
  - When system is calibrated, it provides a 1 PPS that is within 10 ns (RMS) of UTC(USNO)
    - » System was calibrated prior to data collection
  - GPS data not available for initial portion of test



Long Baseline Data – LORSTA Nantucket

- Common-View LORAN data collected between LSU and USNO meets 100 ns (RMS) performance goal
  - Standard Deviation of six best rates is < 30 ns
- Common-View LORAN data is consistent with common-view GPS data
  - LORAN data has been arbitrarily scaled (not calibrated in absolute sense)
- Performance is a function of distance from transmitter and from monitor
  - Data collected from LORSTA Jupiter is considerably worse than Nantucket or Carolina Beach



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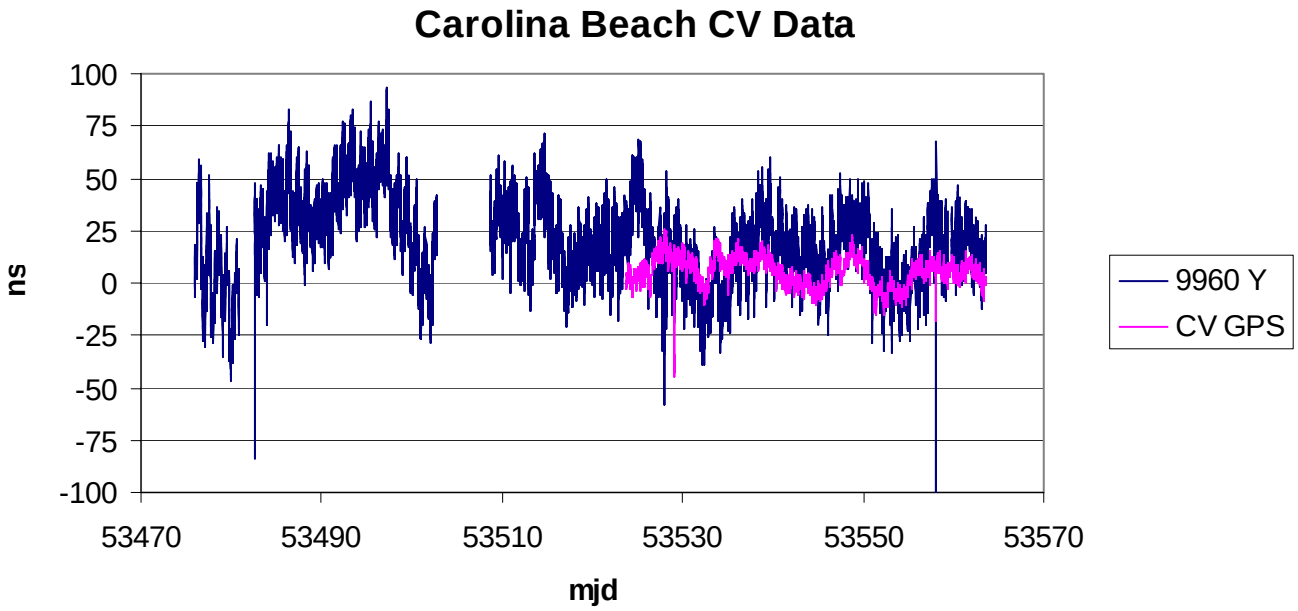

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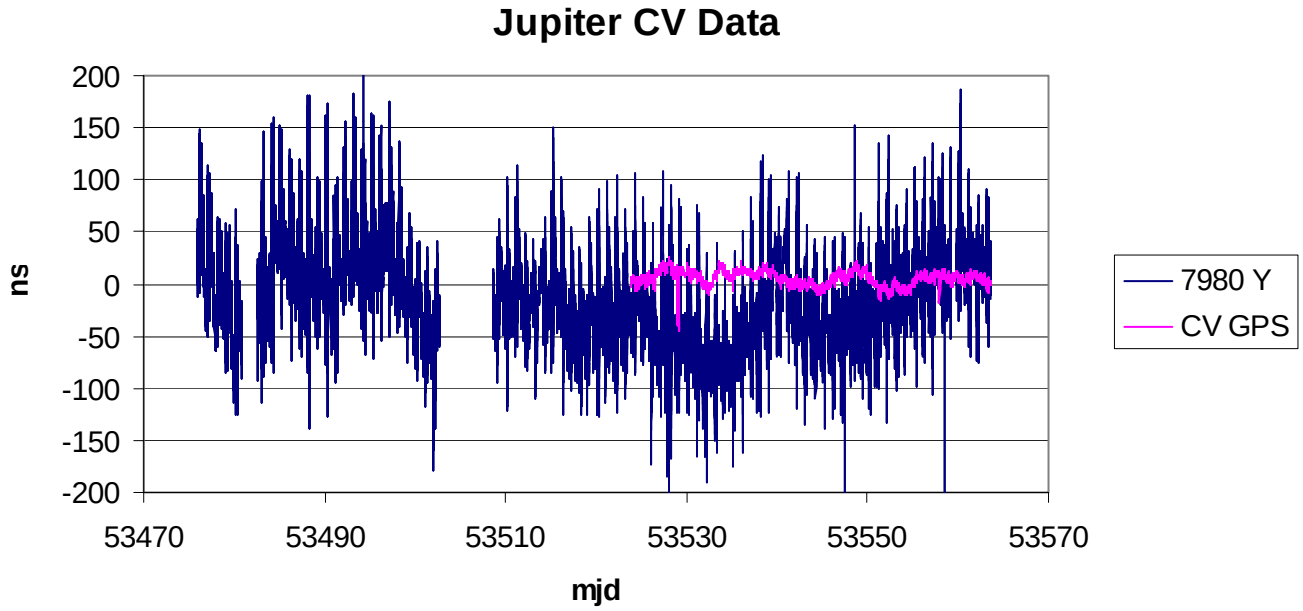
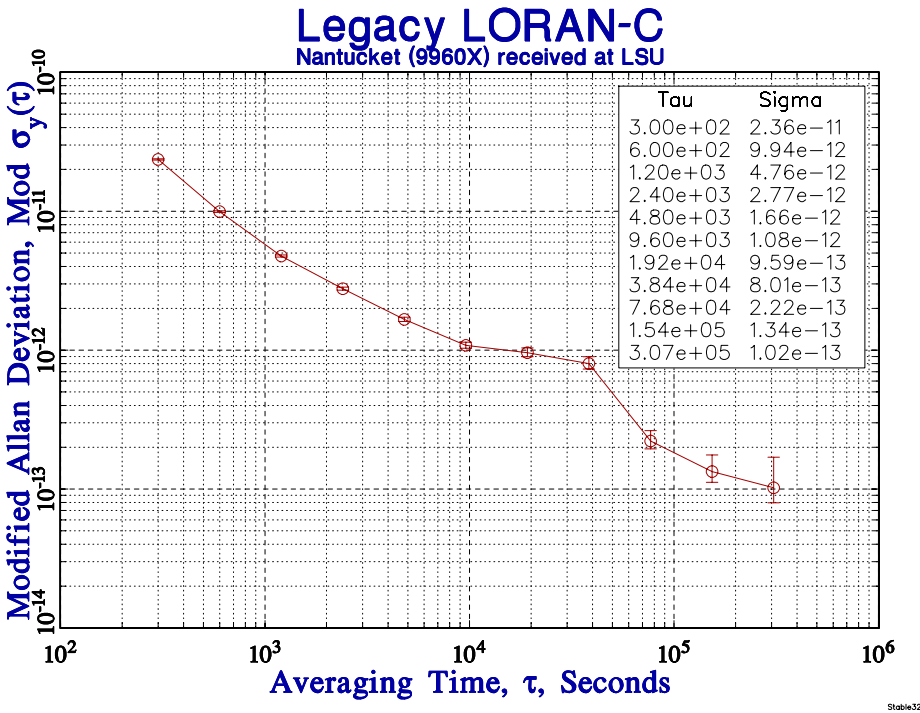
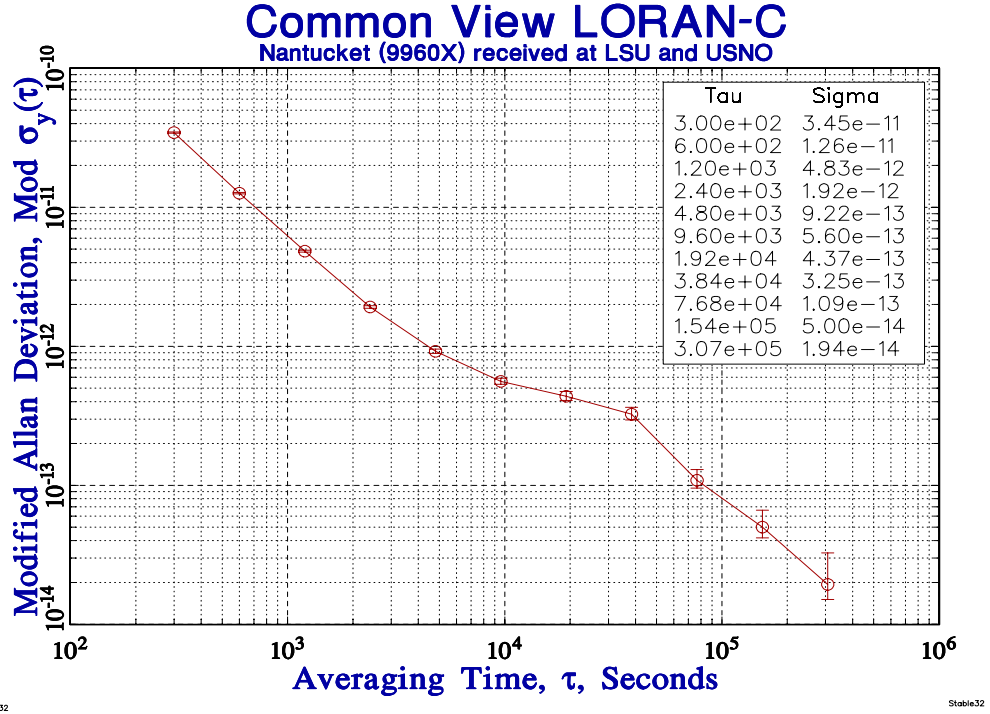


LORAN-C Frequency Data

- Long baseline common view LORAN-C frequency recovery data shows Stratum I performance with less than 1 hour of averaging time
  - No significant difference from the single-ended case over the short term
- Common view technique not as beneficial for frequency recovery in short term
  - Benefit of common-view for frequency users beginning to show up in East Coast data at averaging times of 1 day and beyond (more data required)





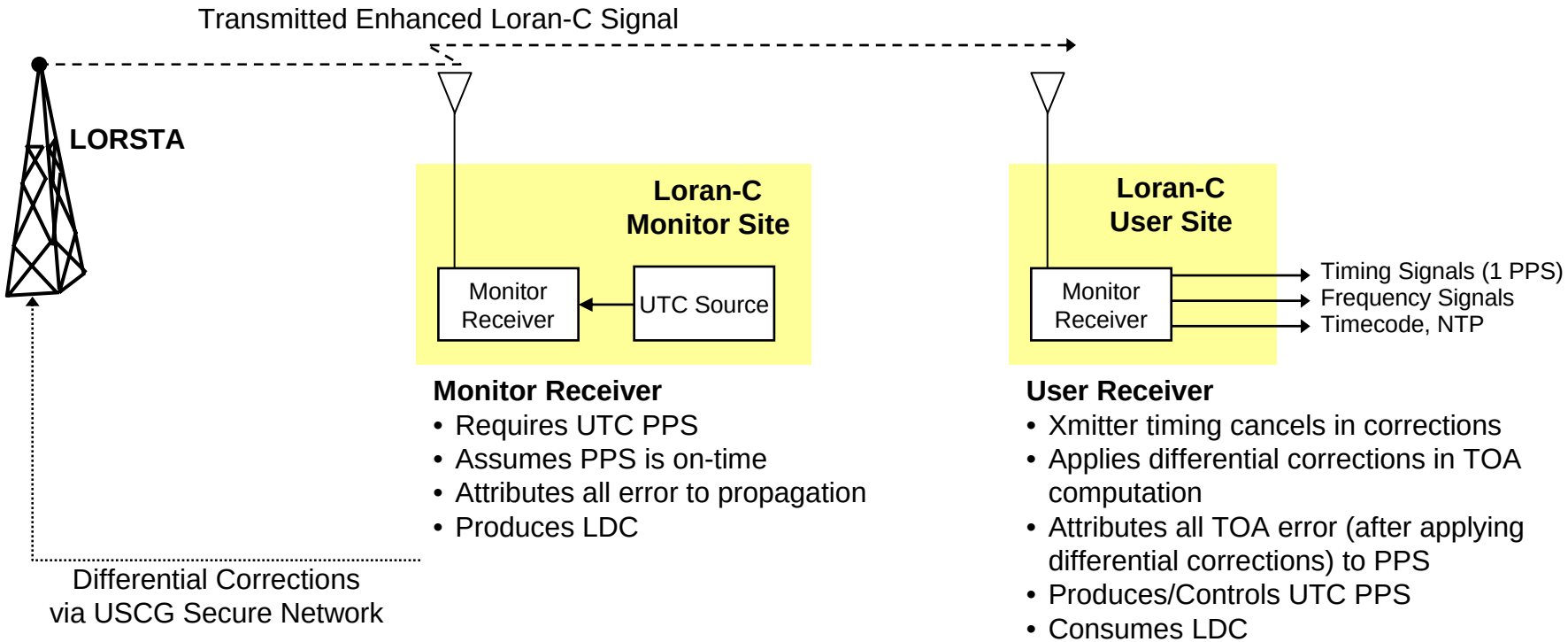
Modernized LORAN-C User Receiver Results

LORAN Timing Receiver

- LSU developing two receivers to address the technology gap between legacy LORAN-C and modernized LORAN-C performance goals
  - Enhanced LORAN Research Receiver (ELRR) is a platform to develop algorithms for monitoring LORAN-C reception and determining corrections to be transmitted to and applied by user equipment
  - LORAN Timing User Receiver provides enhanced LORAN user equipment that applies corrections and produces IRIG-B, NTP and precision 1 PPS and 10 MHz signals
- Receivers will be used to demonstrate new LORAN-C functionality and to provide data that will be processed to refine and optimize the modernized LORAN service
  - Two devices enable collection of real world data to complement the studies performed by the LORIPP and LORAPP

Monitor Receiver vs User Receiver

- Monitor receiver and user receiver have the same LORAN engine with different constraints
  - — Monitor receiver receives UTC and produces corrections, User receiver produces UTC and applies corrections



Monitor Receiver
- Requires UTC PPS
- Assumes PPS is on-time
- Attributes all error to propagation
- Produces LDC

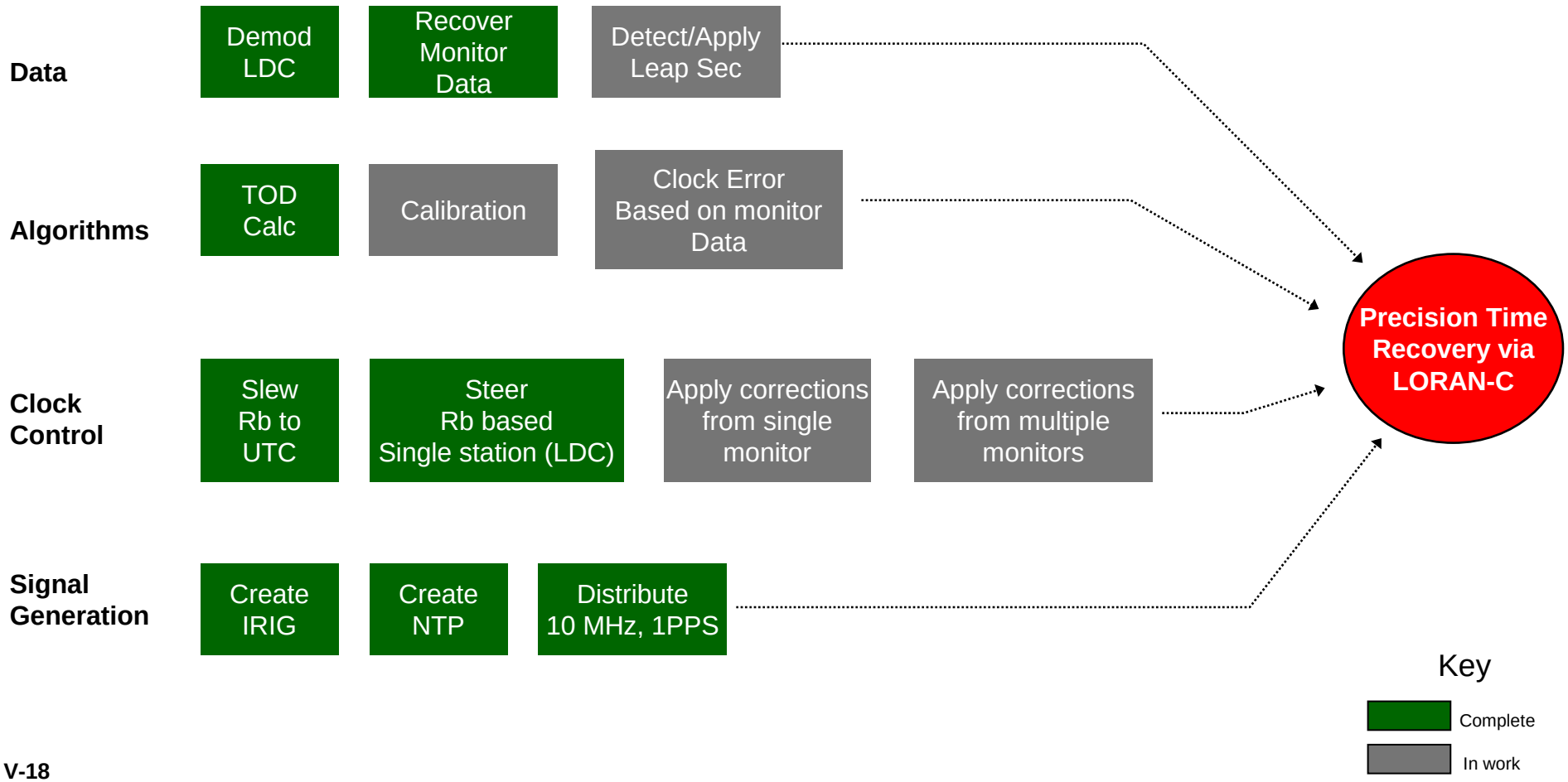
User Receiver
- Xmitter timing cancels in corrections
- Applies differential corrections in TOA computation
- Attributes all TOA error (after applying differential corrections) to PPS
- Produces/Controls UTC PPS
- Consumes LDC

LORAN Timing User Receiver

- The LORAN-C Timing User Receiver is based on an existing TSC GPS disciplined Rb
  - — LORAN engine replaces GPS engine and leverages off existing infrastructure (recurring theme)
  - — LORAN engine includes a digital board where Peterson Integrated Positioning (PIG) code is implemented on a DSP
  - — Unit is a development platform that will be used to demonstrate many “firsts” for LORAN over the next 6 months
    - » TOD via ntp, IRIG-B, Leap second, Precision PPS

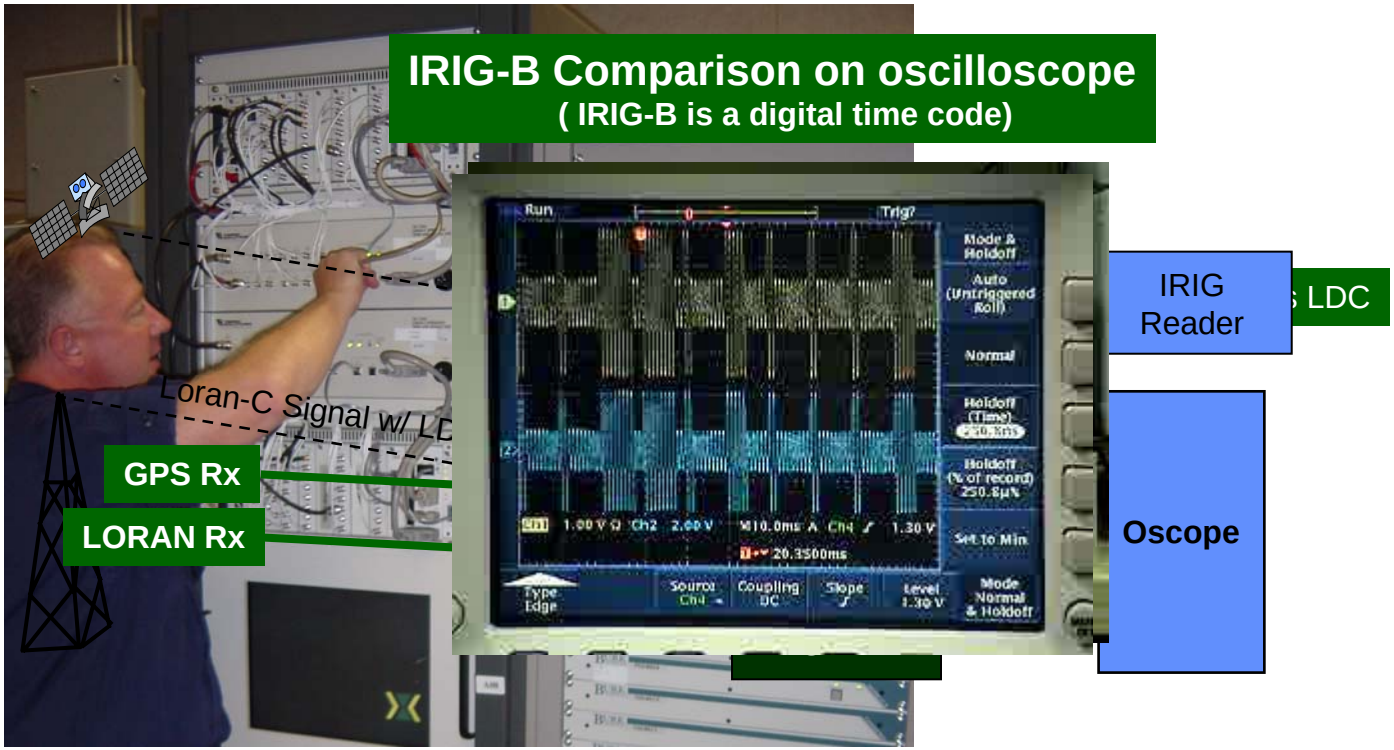
Roadmap to LORAN-C Time Recovery

- Precision, Real-Time LORAN-C Time Recovery is the combination of data demod, timing and propagation algorithms, clock control and signal generation
  - — Initial work is complete with final components to mature with analysis of field data



Speaking of Firsts…

- As of 1400Z on DOY 291, LDC is on air in Jupiter with the continuous time message transmission
- LSU verified transmission with comparison of recovered time via LORAN with "truth" from GPS
- Producing IRIG-B and NTP from a LORAN receiver is a huge step forward that enables new user groups (RCC is first in line…)



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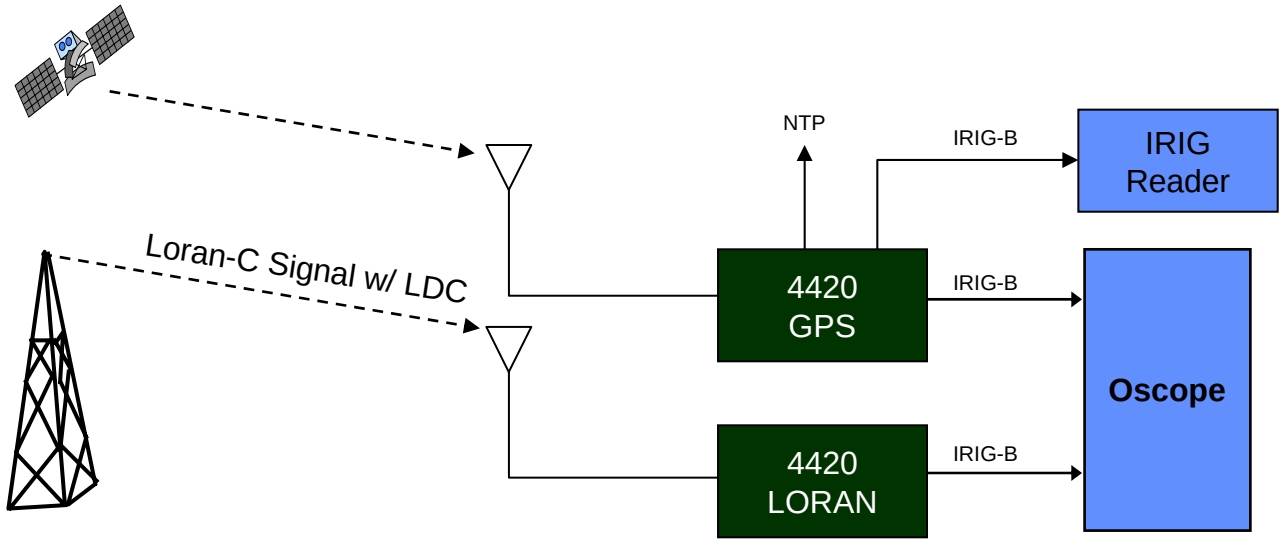

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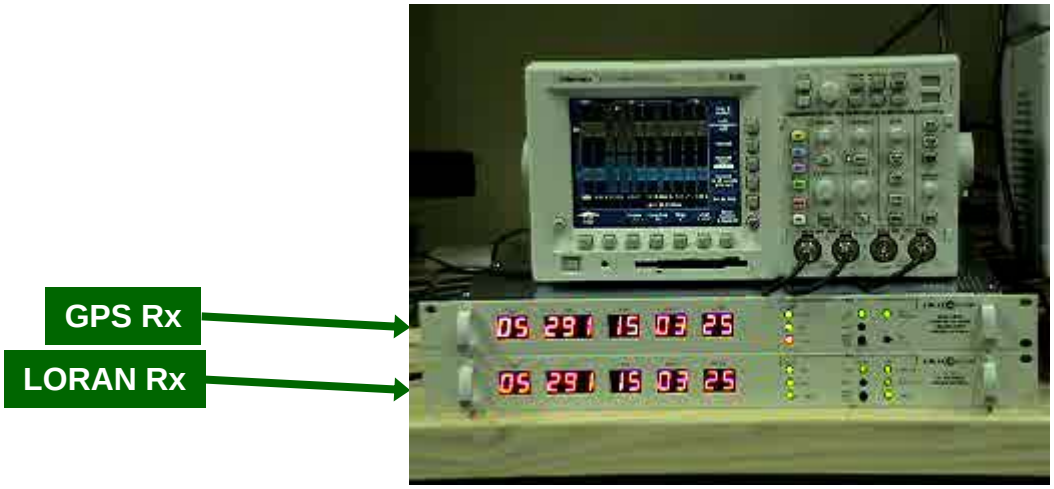

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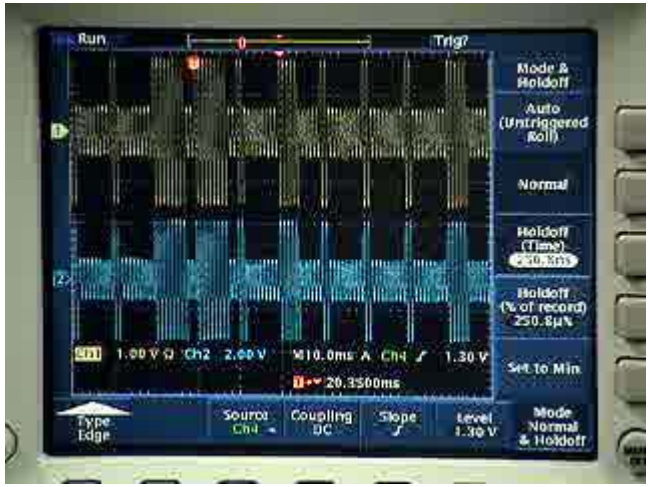
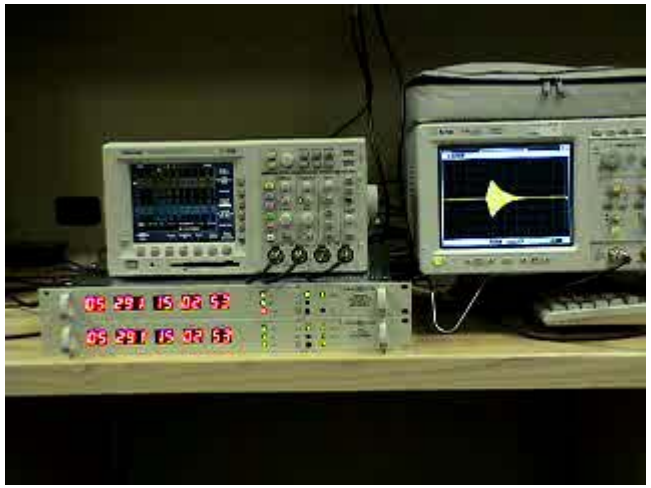
IRIG-B Comparison on oscilloscope
(IRIG-B is a digital time code)



Summary

- Work continues on the LORAN-C Timing Test Bed with new functions to be demonstrated over the next 6 months
- Major milestones will be reached in the near future
  - Time of day via LORAN-C (demonstrated today)
  - Leap second via LORAN-C
  - Real-time, precision time recovery via LORAN-C
  - GPS independent front-end for LORAN-C via two-way time transfer (next year's paper)



Stay tuned…