



UrsaNav

Leaders in what's now. Innovators of what's next.



Providing a Resilient Timing and UTC Service Using eLoran in the United States

Motivation For a Resilient Timing and UTC Service

GPS/GNSS Vulnerabilities

- Performance degradation
 - Ionosphere & solar activities (natural)
 - Unintentional & intentional (human factors)
- Signal blockage
- Spectrum competition
- Common signal use across GNSS
- Radio frequency interference
- System anomalies & failures
- Jamming
- Spoofing & Counterfeit Signals
- *Proliferation of satellite systems*
- *Escalating costs*
- *Program funding delays*
- *Satellite launch problems*
- *Ground segment problems*

*Of the 16 Critical Infrastructure / Key Resource sectors in the U.S., 15 use GPS for **timing**.*

*GPS **timing** is deemed **essential** for 11 of the sectors.*

[Source: U.S. DHS]

Can we have complementary (PN)T via eLoran?

Table 4-14 Timing User Requirements

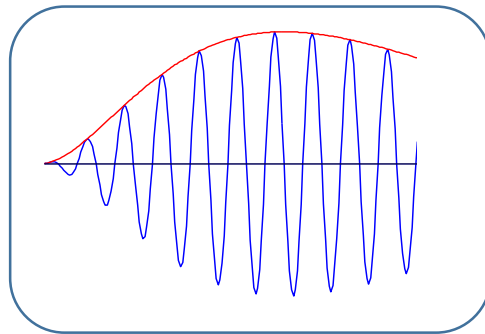
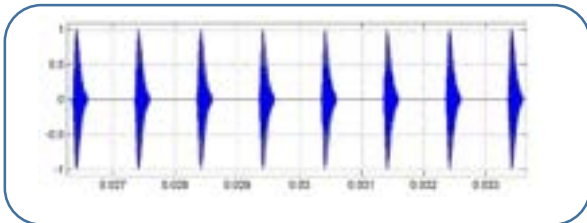
REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (Time with respect to UTC)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Financial transaction timestamp	1 s	TBD	TBD	TBD	TBD	Worldwide
Electric power transmission	1 μ s	TBD	TBD	TBD	TBD	North America
Cellular telephony	1 μ s	Outages not to exceed 8 hr	TBD	TBD	TBD	North America
Inter-carrier telephone and data networks	1 μ s	TBD	TBD	TBD	TBD	North America
Scientific community	nanoseconds	TBD	TBD	TBD	TBD	Worldwide
Traffic Signal Timing	TBD	TBD	TBD	TBD	TBD	Nation Wide/Intersections

Source: 2014 Federal Radionavigation Plan

- CRADA Partners: DHS S&T; USCG; Harris; UrsaNav
- **Evaluate eLoran as a stable, wide area source of precise time** for redundancy and resiliency in critical infrastructure.
 - Determine coverage area and accuracy
 - Test in areas where GPS is unavailable or significantly degraded
 - Evaluate UTC TWSTT time synchronization with USNO

Loran-C:

- Radio Frequency (RF) system
- 90 – 110 kHz
- **Ground wave** signal
- Very high power
- Pulsed
- Stratum 1 frequency standard
- Positioning, Navigation, Timing



Enhanced Loran:

All the good stuff from Loran, plus:

- Time-of-Transmission control
- Differential corrections (dLoran or DGPS)
- Receivers can use all-in-view signals
- **Loran Data Channel (LDC)**
- Additional integrity
- Transmissions synchronized to UTC
- New infrastructure & technology
 - 21st century solid state transmitters
 - Three cesium PRS per station
 - Precision time & frequency equipment
 - Whole-station UPS
 - Secure telecommunications
- New Operations Paradigms
 - Unmanned and/or autonomous operation
 - Sites v. Stations
 - Time-of-Emission v. System Area Monitor
 - ASF modeling and/or measurement

User Receivers



Transmitting Site



- Remote Time Scale
 - GNSS (GPS)
 - TWSTT
 - TWLFTT
 - Microwave
 - Dedicated fiber
 - "Hot Clock"
-
- Local Time Scale
 - 5071A Cesium PRS
 - 5071A Cesium PRS
 - 5071A Cesium PRS

Differential Reference Site



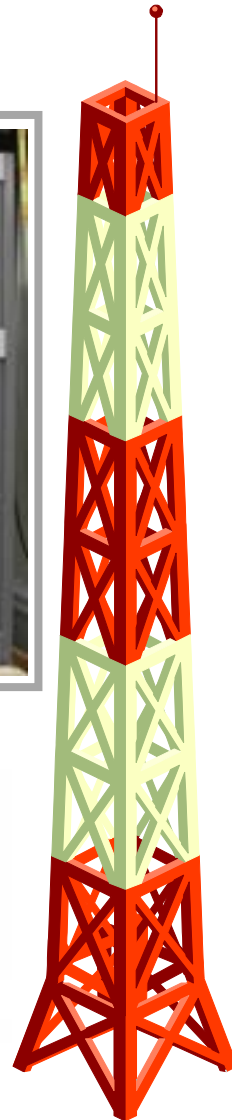
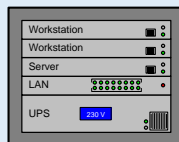
Can operate 70-90 days without remote reference.

LCD, keyboard and mouse set per MCS Workstation

Primary Workstation
Secondary Workstation
MCS Server
Network switch with VPN support

Uninterruptible Power Supply - provided by GLAS

"Control" & Monitor Site

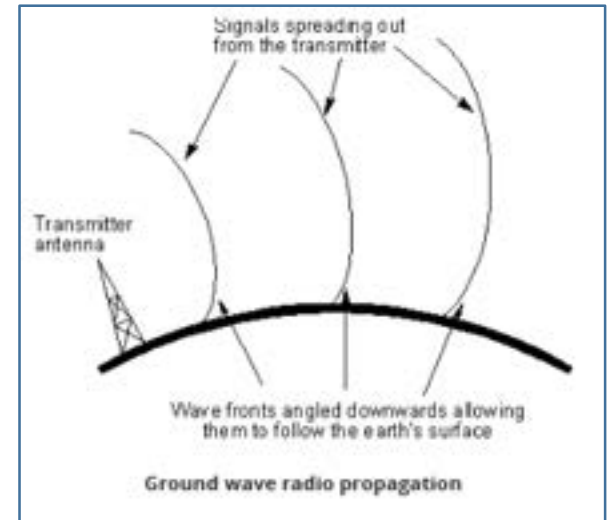


Ground Wave: We Must Compensate for Propagation Delays

An eLoran receiver measures the Time-of-Arrival (TOA) of the signal.

$$\text{TOA} = \text{TTOR} - \text{TTOT} = \text{PF} + \text{SF} + \text{ASF} + \Delta R_x$$

- TOR - Time of Reception,
- TOT - Time of Transmission,
- PF - Primary Factor,
- SF - Secondary Factor,
- ASF - Additional Secondary Factor, and
- ΔR_x - Receiver and cable delays.



Source: electronics-radio.com

PF accounts for propagation through **air**.

SF accounts for propagation over **sea water**.

ASF accounts for propagation over **land and elevated terrain**.

PF and **SF** are **well defined delays** and can be **calculated** as a function of distance.

ASF delays are typically unknown at the time of installation, but may be **modeled and/or measured**, or may be pre-loaded in a **receiver database**.

Correcting for Wide Area Delays

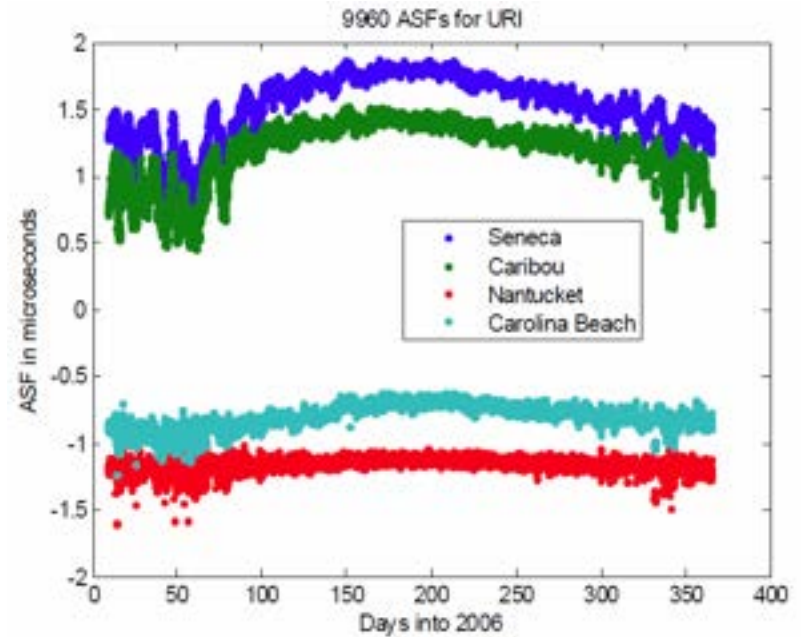
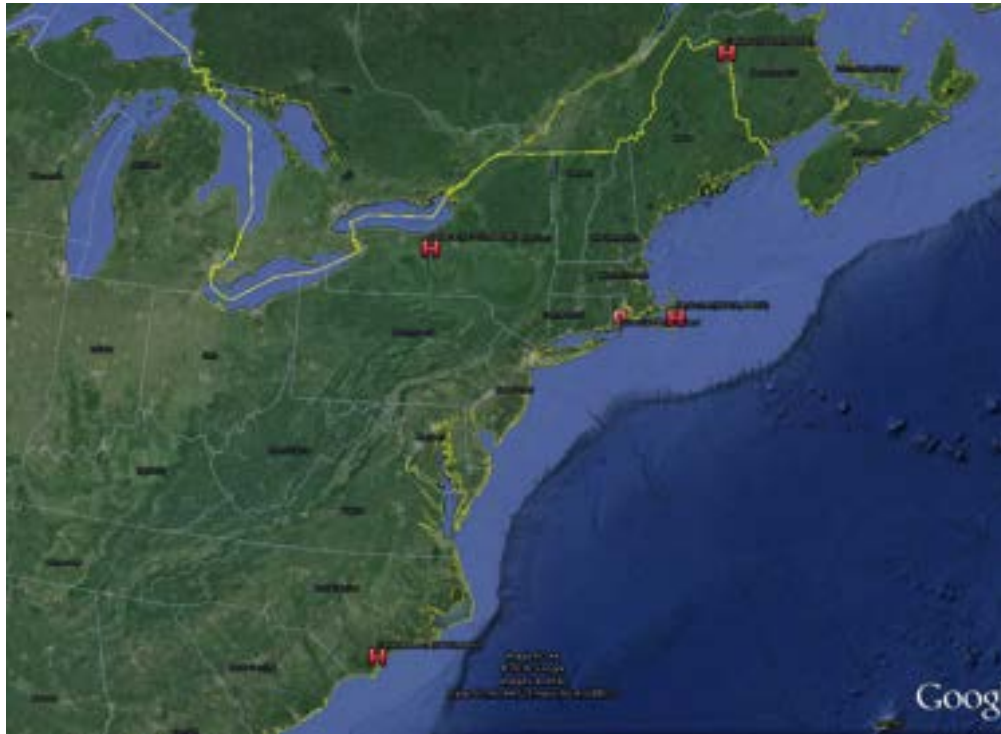


Figure 3: Typical data collected at a monitor site.

Source: Swaszek, Lo, et al, ILA 2007

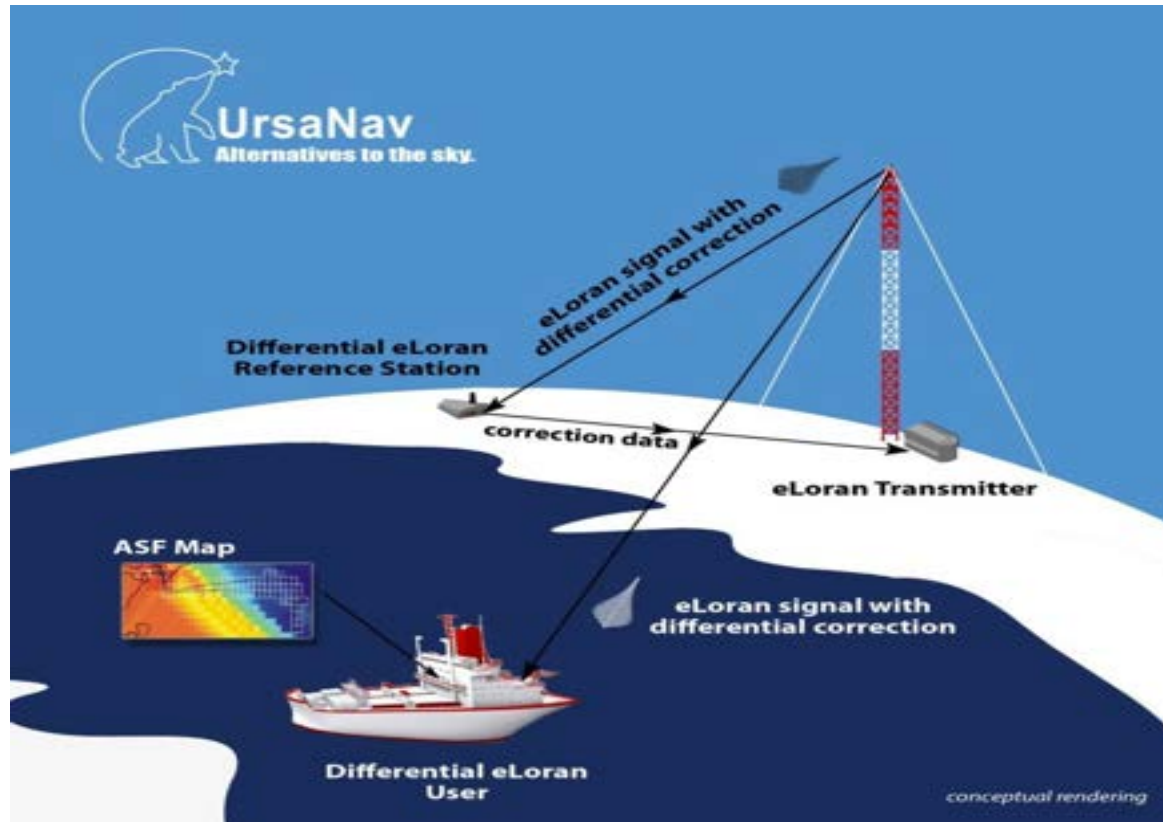
Distances (miles)

Caribou, ME to URI:	430
Seneca, NY to URI:	300
Nantucket, MA to URI:	85
Carolina Beach, NC to URI:	600

ASFs are virtually constant over long periods!

Correcting for Local Variations

Differential eLoran RefSta: weather, seasonal conductivity changes, diurnal influences



- User is equipped with a receiver that has a stored ASF map
- Corrections for the area of operation calculated at a fixed site
- Correction info sent to transmitter for broadcast via data channel
- Corrections can be applied by receiver and are monitored for integrity
- Note that multiple data channels are available to support various applications, including differential corrections, signal integrity, encrypted messaging, etc.

Positioning or **Timing** User

Evaluate: eLoran as a Wide Area Timing Source

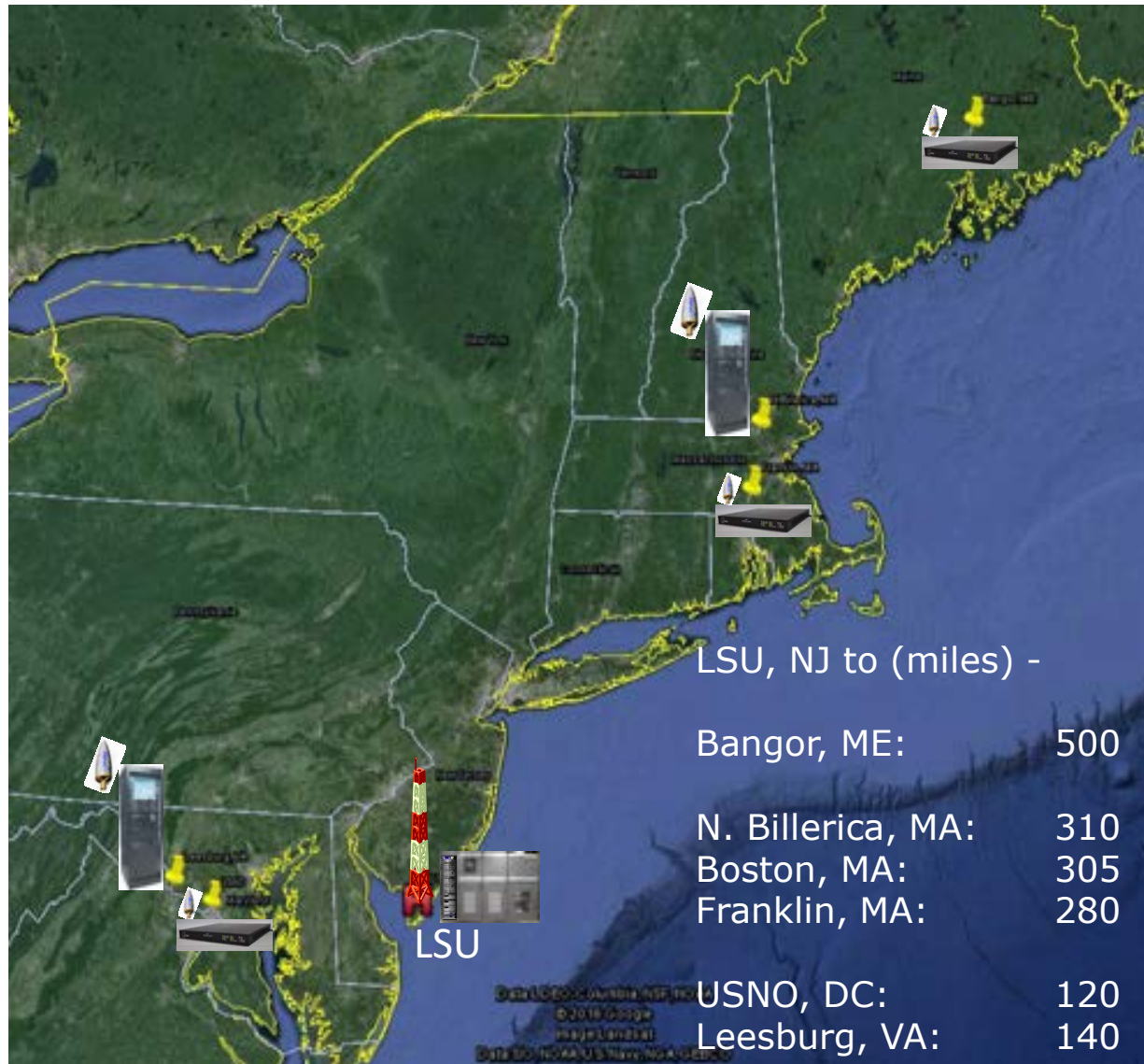
- Transmissions from former USCG Loran Support Unit site at Wildwood, NJ
 - 360 KW Effective Radiated Power
 - TWSTT UTC reference from the USNO

- Receivers
 - Bangor, ME
 - N. Billerica, MA
 - Franklin, MA
 - Washington, DC (USNO)
 - Leesburg, VA

- Technology
 - Outdoor E-Field antenna
 - Loran Data Channel (LDC) demodulation available
 - GPS and/or 5071A PRS used as timing comparison
 - Without** differential corrections

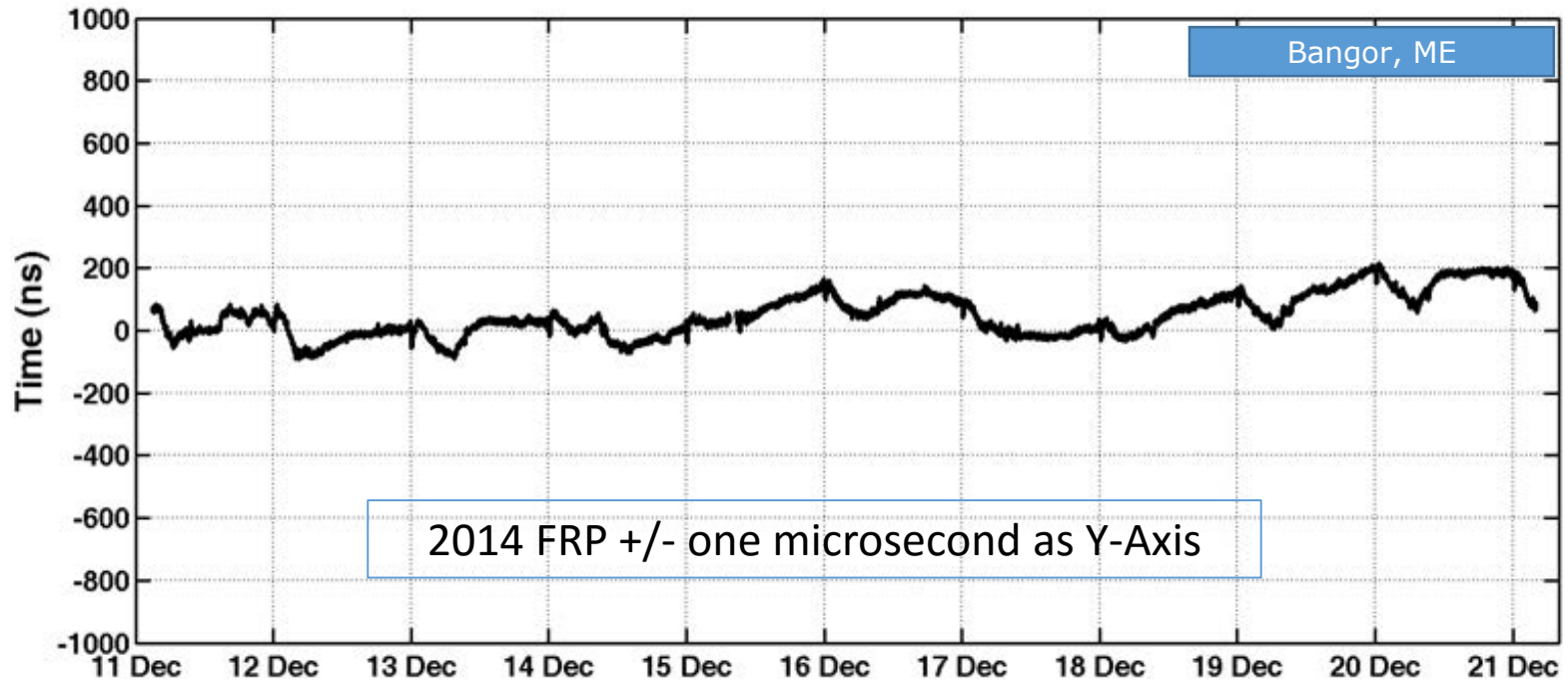
- Criteria
 - Meet one microsecond 2014 FRP Timing User Requirement

eLoran Timing Evaluation Technology Laydown



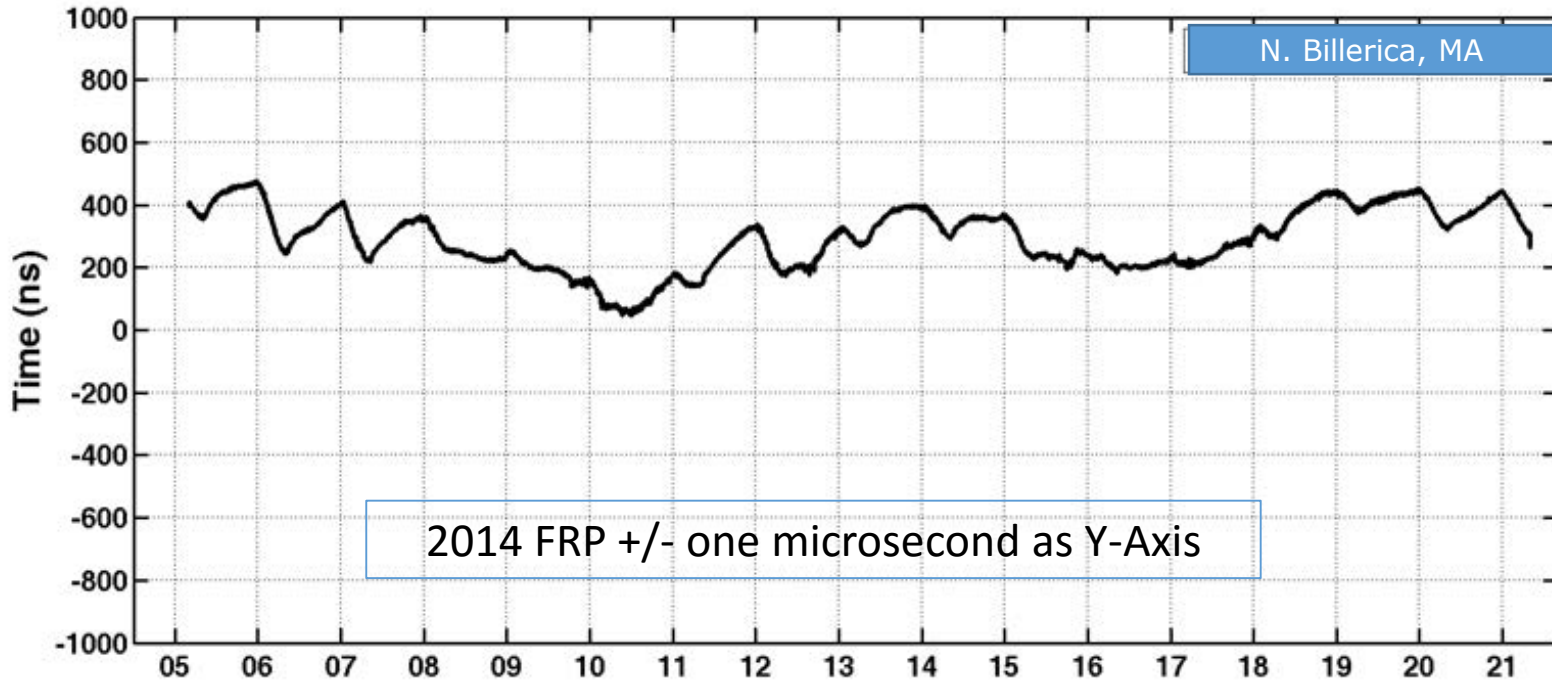
- eLoran transmitter at Wildwood, NJ
 - Synchronized to UTC via Two Way Satellite Time Transfer (TWSTT) provided by US Naval Observatory
 - 360KW of Effective Radiated Power
 - Broadcasting dual rated as 8970 Master and Secondary
 - Data sent via LDC only on Secondary rate at raw data rate of 56 bps and effective data rate of 21 bps
- Differential eLoran Reference sites at:
 - North Billerica, MA
 - Leesburg, VA

Wildwood, NJ to Bangor, ME User Receiver



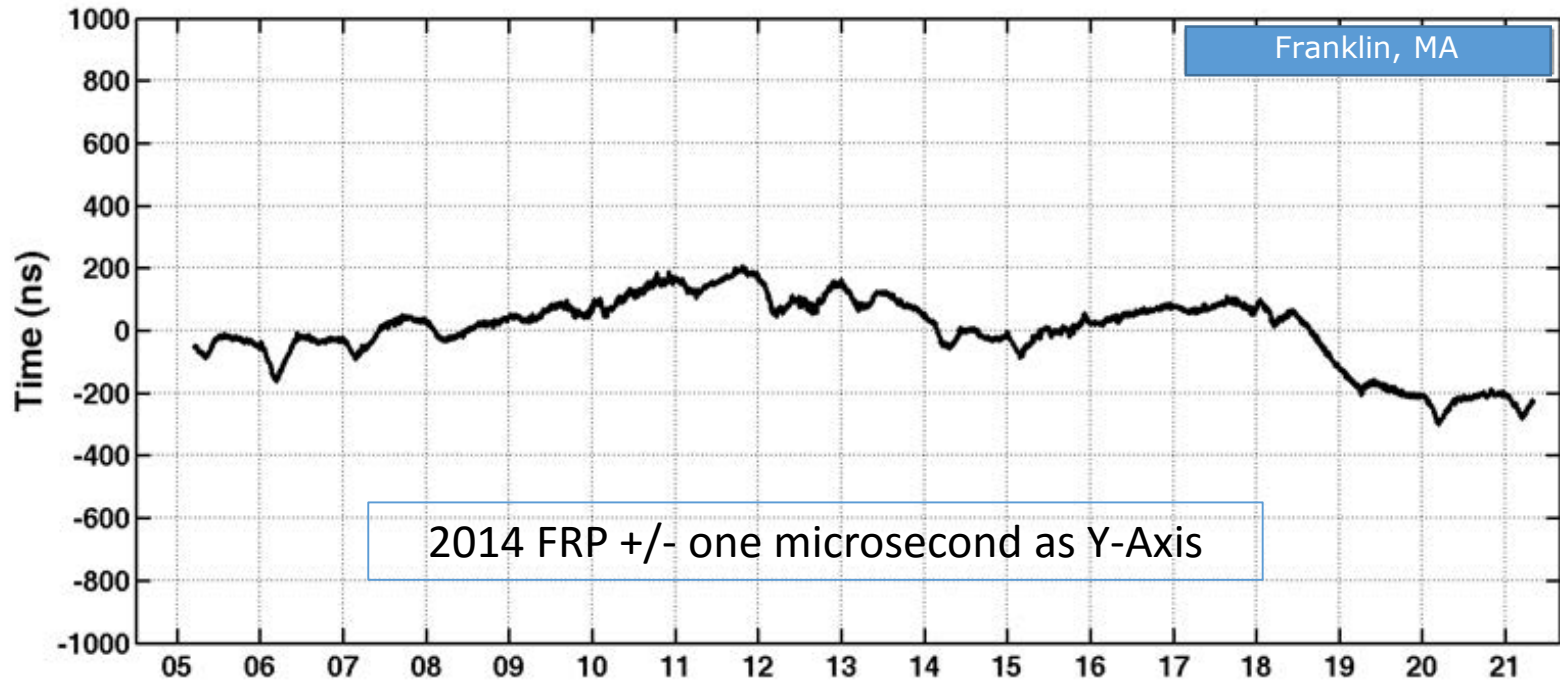
December 2015
Distance to XMTR: 500 miles
Mean: 49.7 ns
STD: 68.6 ns
Max: 216.0 ns
Min: -91.0 ns

Wildwood, NJ to N. Billerica, MA User Receiver



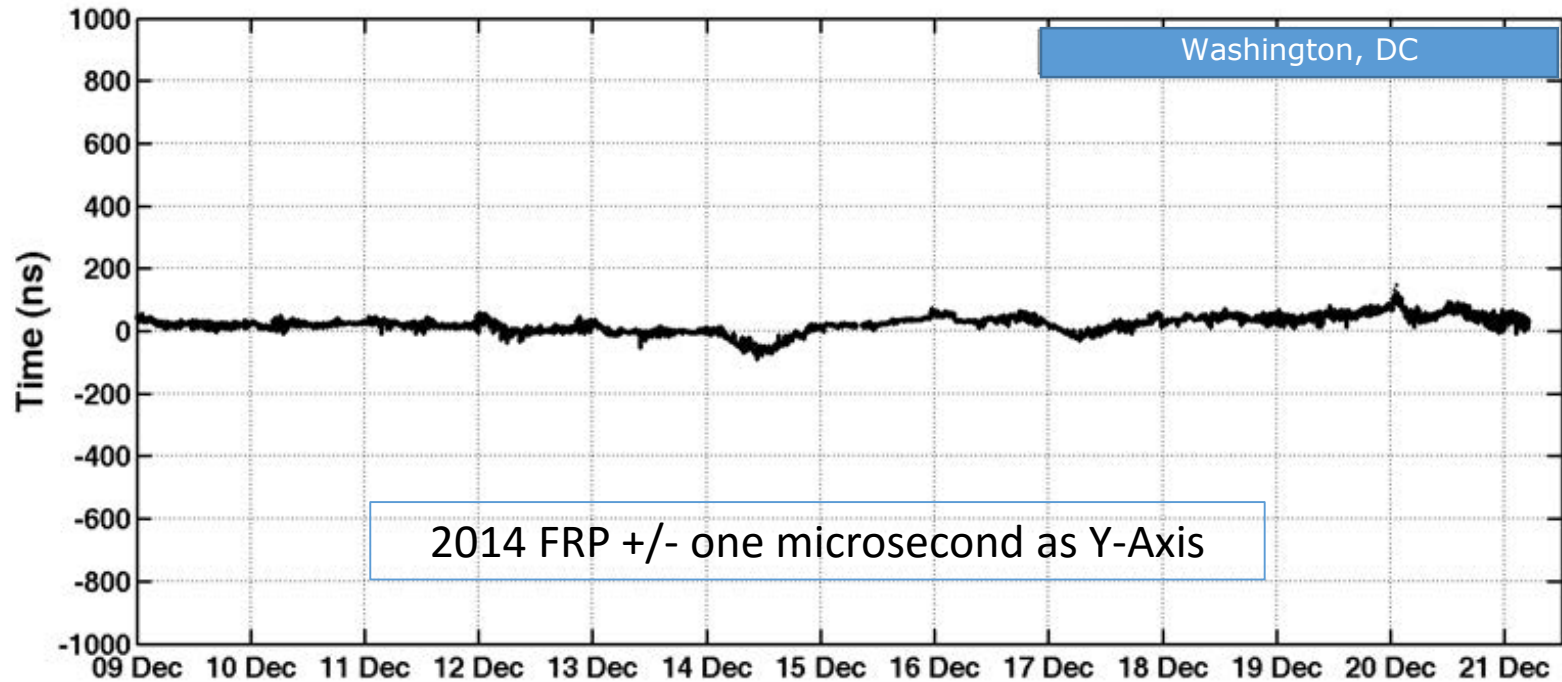
January 2016
Distance to XMTR: 310 miles
Mean: 291.7 ns
STD: 96.3 ns
Max: 474.0 ns
Min: 47.0 ns

Wildwood, NJ to Franklin, MA User Receiver



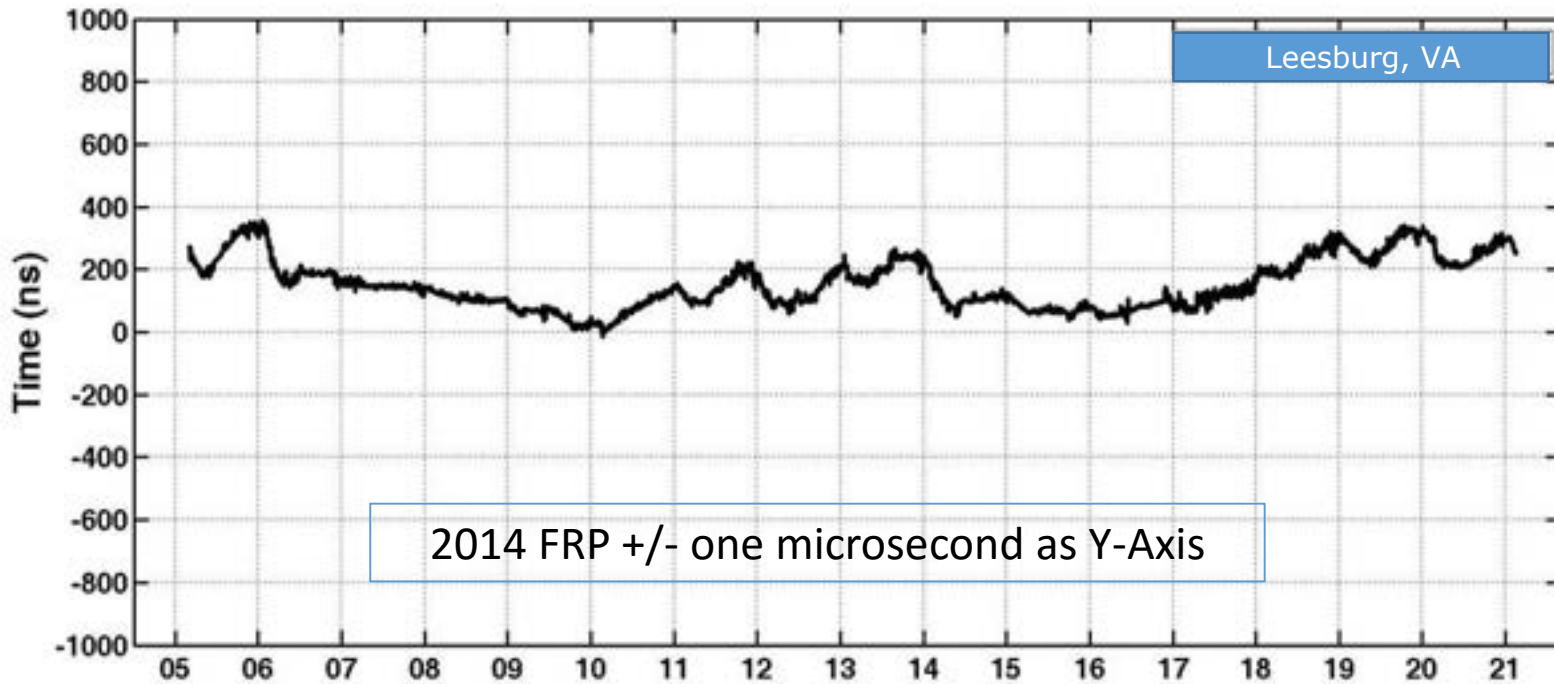
January 2016
Distance to XMTR: 280 miles
Mean: 4.2 ns
STD: 109.3 ns
Max: 205.8 ns
Min: -301.3 ns

Wildwood, NJ to Washington, DC (USNO) User Receiver



December 2015
Distance to XMTR: 120 miles
Mean: 22.9 ns
STD: 26.1 ns
Max: 147.0 ns
Min: -90.0 ns

Wildwood, NJ to Leesburg, VA User Receiver

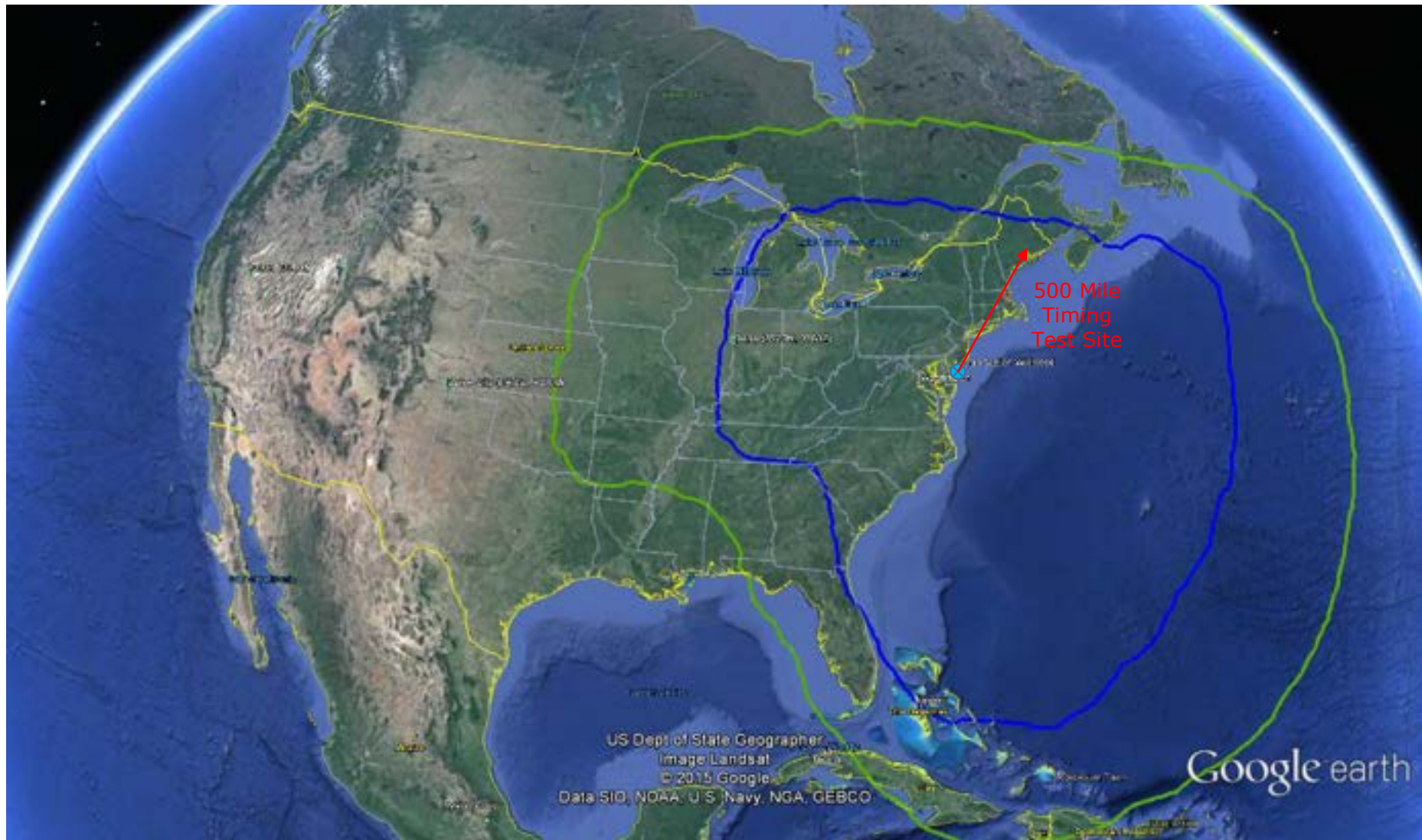


January 2016
Distance to XMTR: 140 miles
Mean: 153.6 ns
STD: 79.9 ns
Max: 358.0 ns
Min: -16.0 ns

Postulate: Wide Area *Basic eLoran Timing Service (BeTS)*

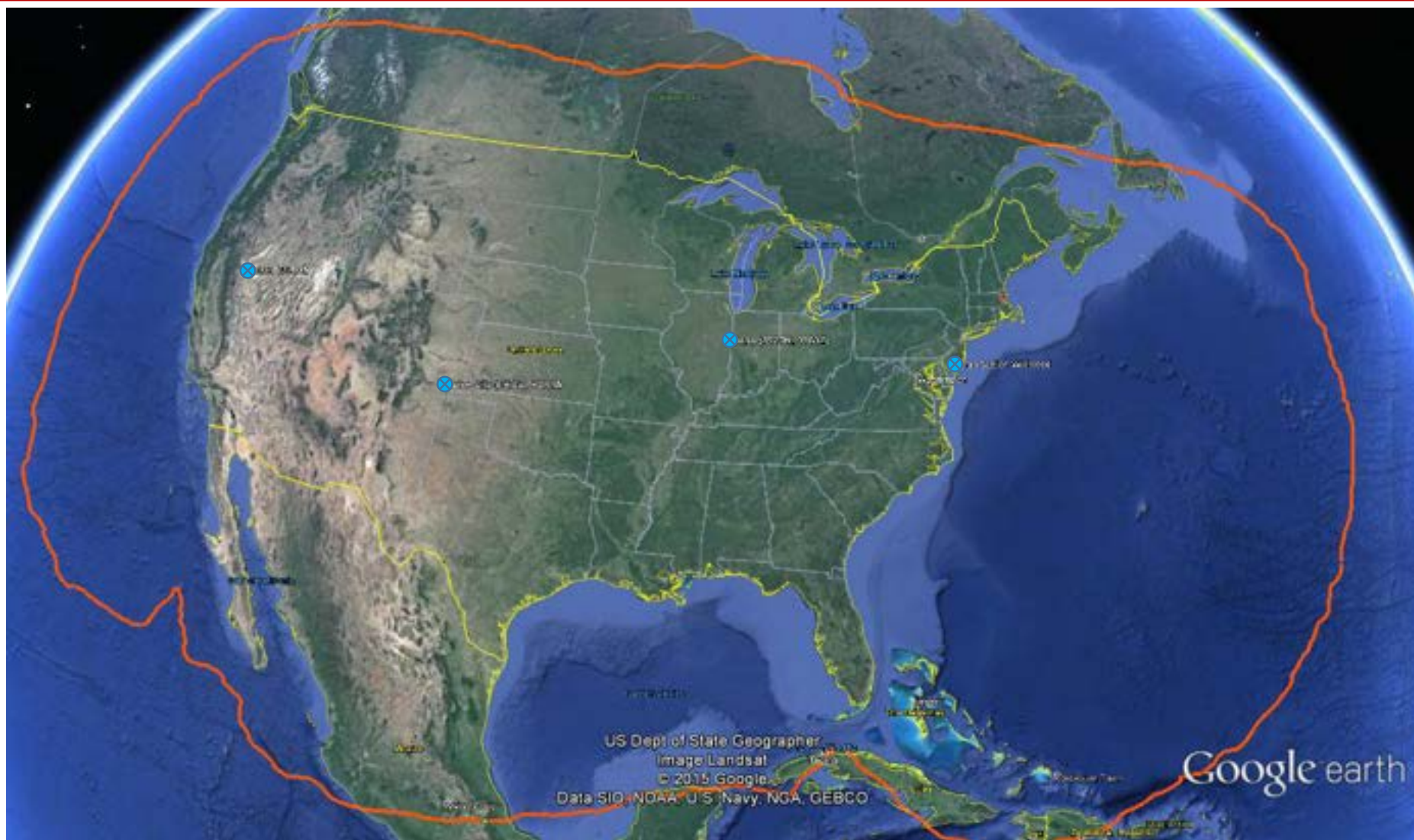
- ❑ CONUS
- ❑ 4 transmitting stations
 - ❑ Former Loran Support Unit site at Wildwood, NJ
 - ❑ Former Loran-C transmitting station sites: Dana, IN; Boise City, OK; Fallon, NV
- ❑ 1 MW ERP
- ❑ Loran Data Channel demodulation coverage
- ❑ No differential reference stations
- ❑ Meets, or exceeds, 2014 FRP one microsecond timing accuracy requirement

BeTS Coverage From Former Wildwood, NJ Transmitting Site



2014 FRP Coverage Area. — 360 KW transmissions. — 1 MW transmissions.

BeTS Coverage From Initial Four CONUS eLoran Transmitting Sites



— 2014 FRP Coverage Area With 1 MW Transmitting Stations

Evaluate: eLoran as a Higher Accuracy Timing Source

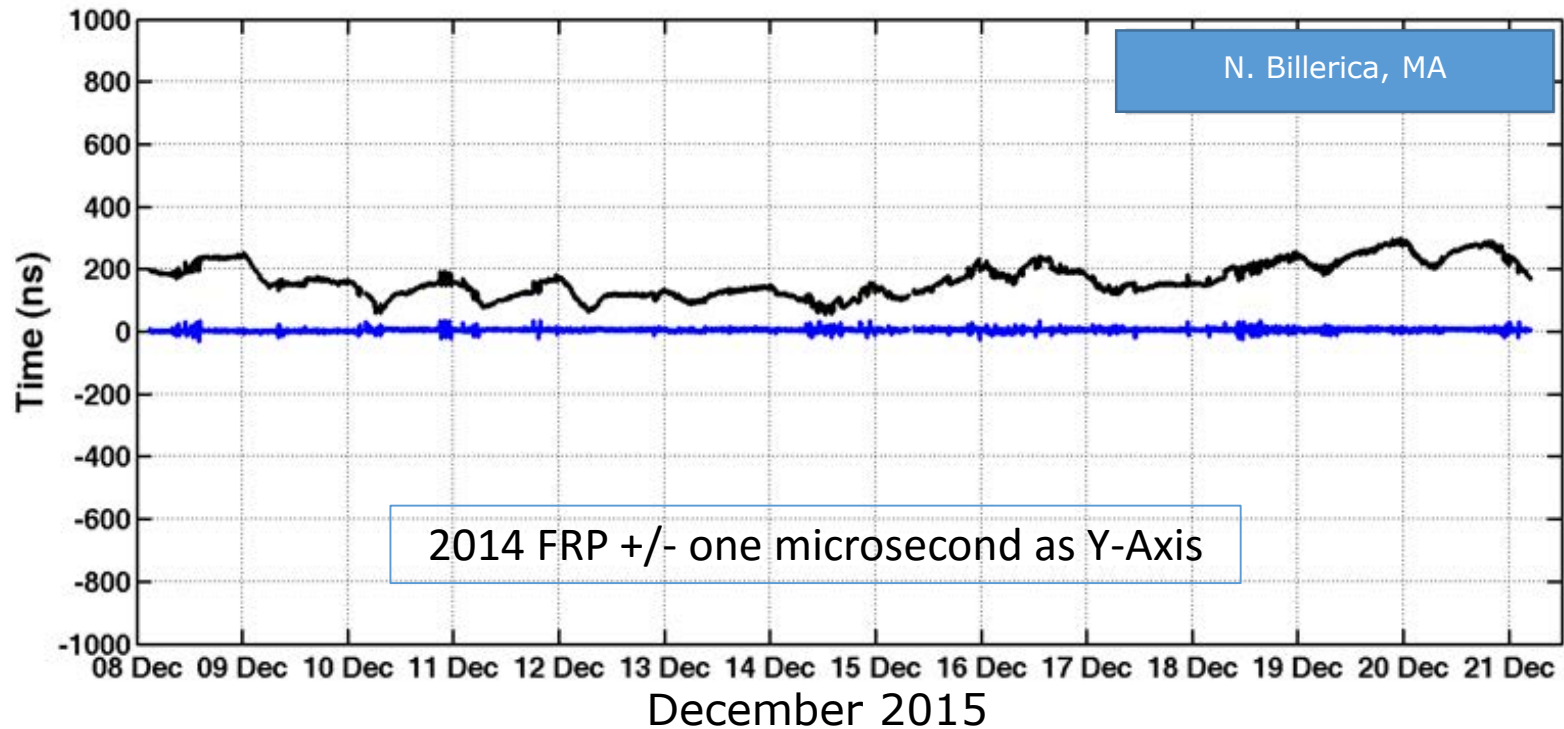
- ❑ Transmissions from former USCG Loran Support Unit site at Wildwood, NJ
 - ❑ 360 KW Effective Radiated Power
 - ❑ TWSTT UTC reference from the USNO

- ❑ Reference Stations / User Receivers
 - ❑ N. Billerica, MA RefSta
 - ❑ Franklin, MA
 - ❑ Leesburg, VA RefSta
 - ❑ Washington, DC (USNO)

- ❑ Technology
 - ❑ Outdoor E-Field antenna
 - ❑ Loran Data Channel (LDC) demodulation available
 - ❑ GPS and/or 5071A PRS used as timing comparison
 - ❑ **With** differential corrections

- ❑ Goal
 - ❑ Timing accuracy of +/- 100 nanoseconds WRT UTC (USNO)
 - ❑ Initial differential coverage of 35 miles radius

Wildwood, NJ to N. Billerica, MA RefSta



Black – Basic

Distance to XMTR: 310 miles

Mean: 166.7 ns

STD: 53.6 ns

Max: 299.0 ns

Min: 56.0 ns

Blue – Precision

Distance to XMTR: 310 miles

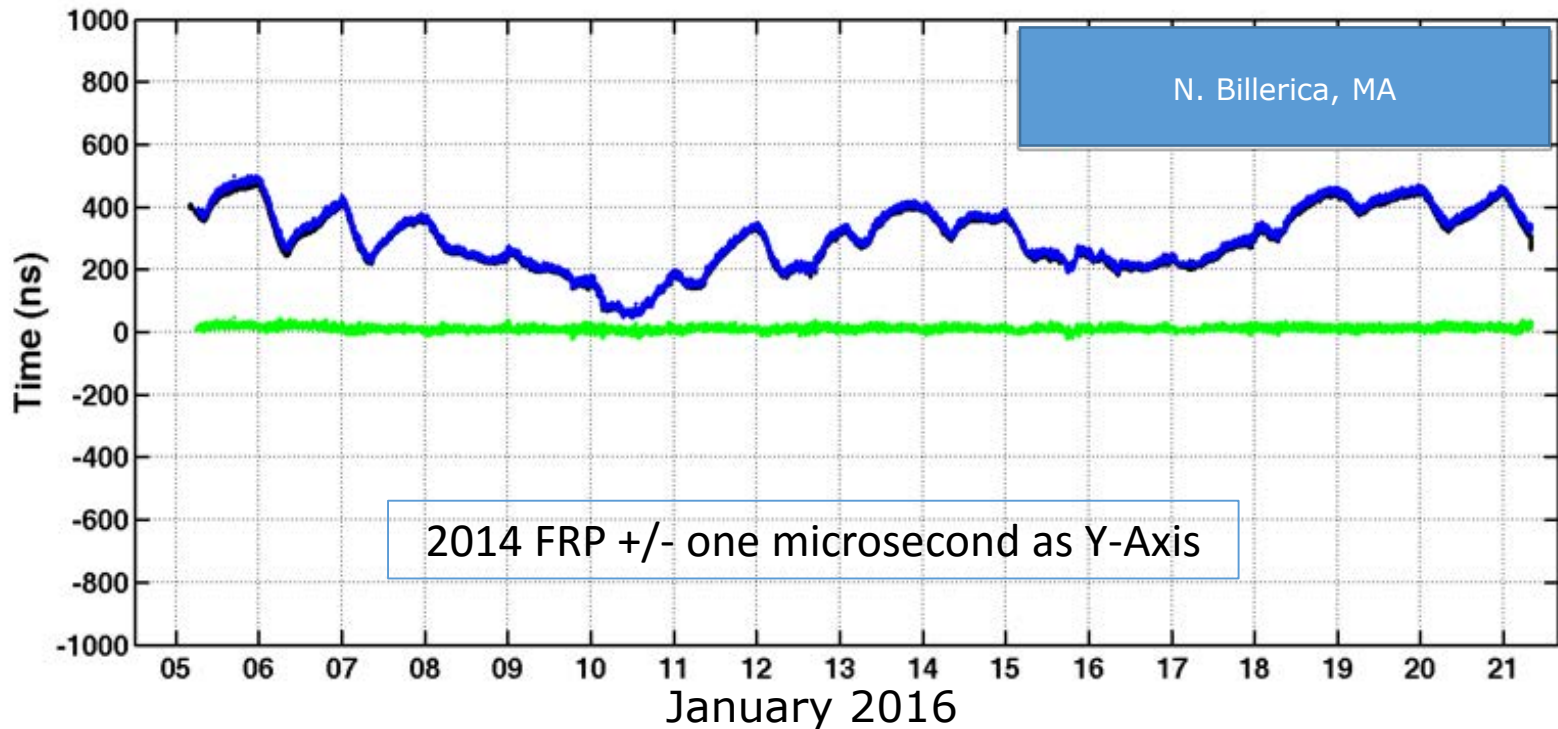
Mean: 5.0 ns

STD: 4.4 ns

Max: 36.0 ns

Min: -31.0 ns

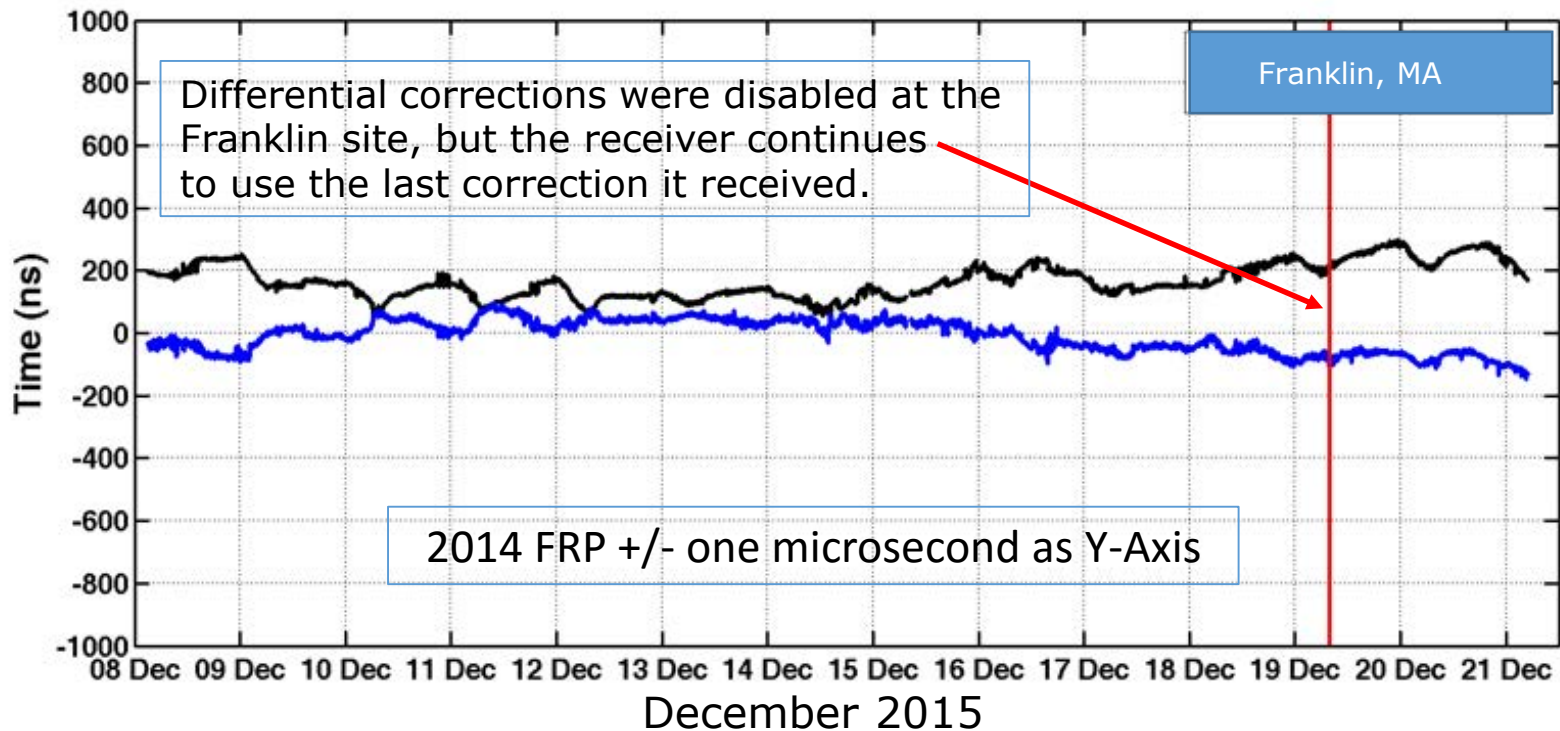
Wildwood, NJ to N. Billerica, MA RefSta



Black/Blue – Basic
Distance to XMTR: 310 miles
Mean: 303.0 ns
STD: 98.5 ns
Max: 500.0 ns
Min: 46.0 ns

Green – Precision
Distance to XMTR: 310 miles
Mean: 11.8 ns
STD: 6.8 ns
Max: 48.3 ns
Min: -20.9 ns


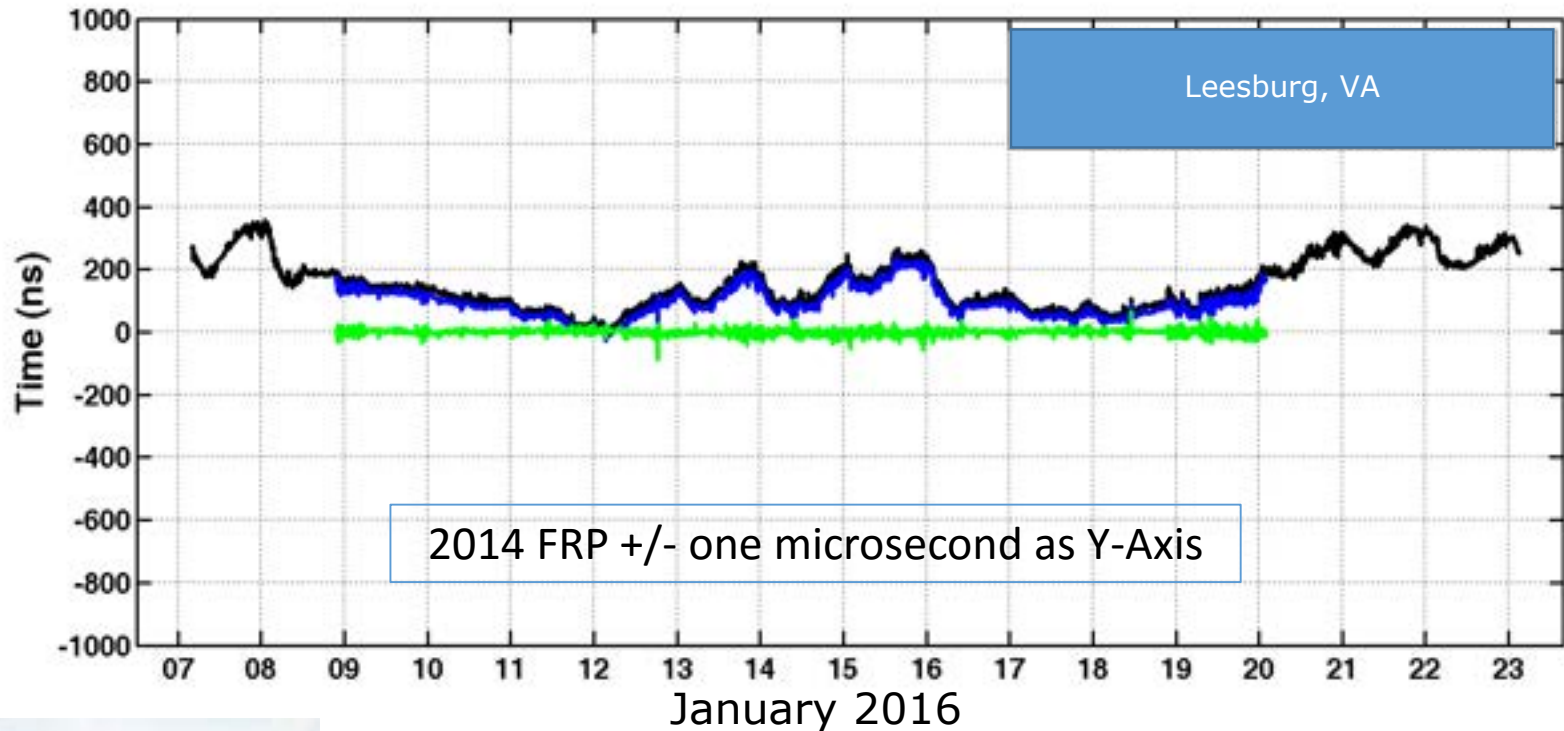
N. Billerica, MA RefSta to Franklin, MA User Receiver



Black – Basic
Distance to XMTR: 280 miles
Distance to REFSTA: 35 miles
Mean: 166.9 ns
STD: 53.6 ns
Max: 299.0 ns
Min: 56.0 ns

Blue – Precision
Distance to XMTR: 280 miles
Distance to REFSTA: 35 miles
Mean: 1.2 ns
STD: 45.2 ns
Max: 96.1 ns
Min: -106.4 ns

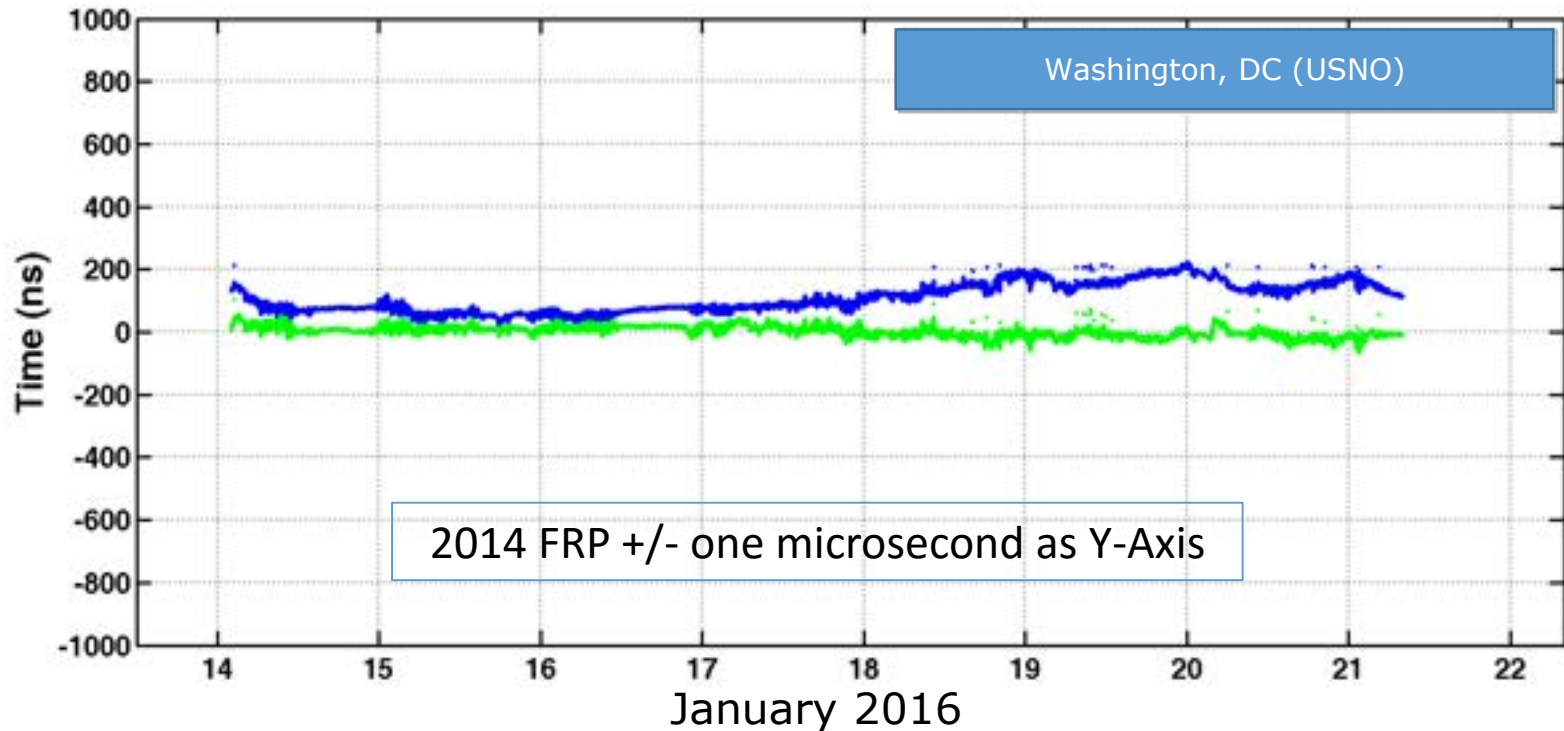
Wildwood, NJ to Leesburg, VA RefSta



Black/Blue – Basic
Distance to XMTR: 140 miles
Mean: 153.6 ns
STD: 79.9 ns
Max: 358.0 ns
Min: -16.0 ns

Green – Precision
Distance to XMTR: 140 miles
Mean: 0.0 ns
STD: 7.8 ns
Max: 66.2 ns
Min: -88.8 ns

Leesburg, VA RefSta to Washington, DC (USNO) User Receiver



Blue – Basic

Distance to XMTR: 120 miles

Distance to REFSTA: 25 miles

Mean: 110.0 ns

STD: 46.2 ns

Max: 224.0 ns

Min: 23.0 ns

Green – Precision

Distance to XMTR: 120 miles

Distance to REFSTA: 25 miles

Mean: 2.5 ns

STD: 16.8 ns

Max: 103.3 ns

Min: -66.2 ns

Postulate: Local Area *Precision eLoran Timing Service (PeTS)*

- ❑ CONUS metropolitan or other high priority locations
- ❑ Coverage and accuracy
 - ❑ Expected differential timing coverage of 35 miles radius
 - ❑ Expected accuracy of +/- 100 nanoseconds WRT UTC (USNO)
- ❑ Representative Differential Reference Station laydown consists of 71 locations
 - ❑ Covers top 50 major metropolitan areas
 - ❑ Covers top 50 ports/harbors
 - ❑ Covers top 50 airports

Representative Higher Accuracy Locations Within CONUS



◆ Location of Differential eLoran Reference Station Site

Indoor H-Field Test: Metropolitan Boston, MA

Westin Hotel
36th (top) floor

Copley Square

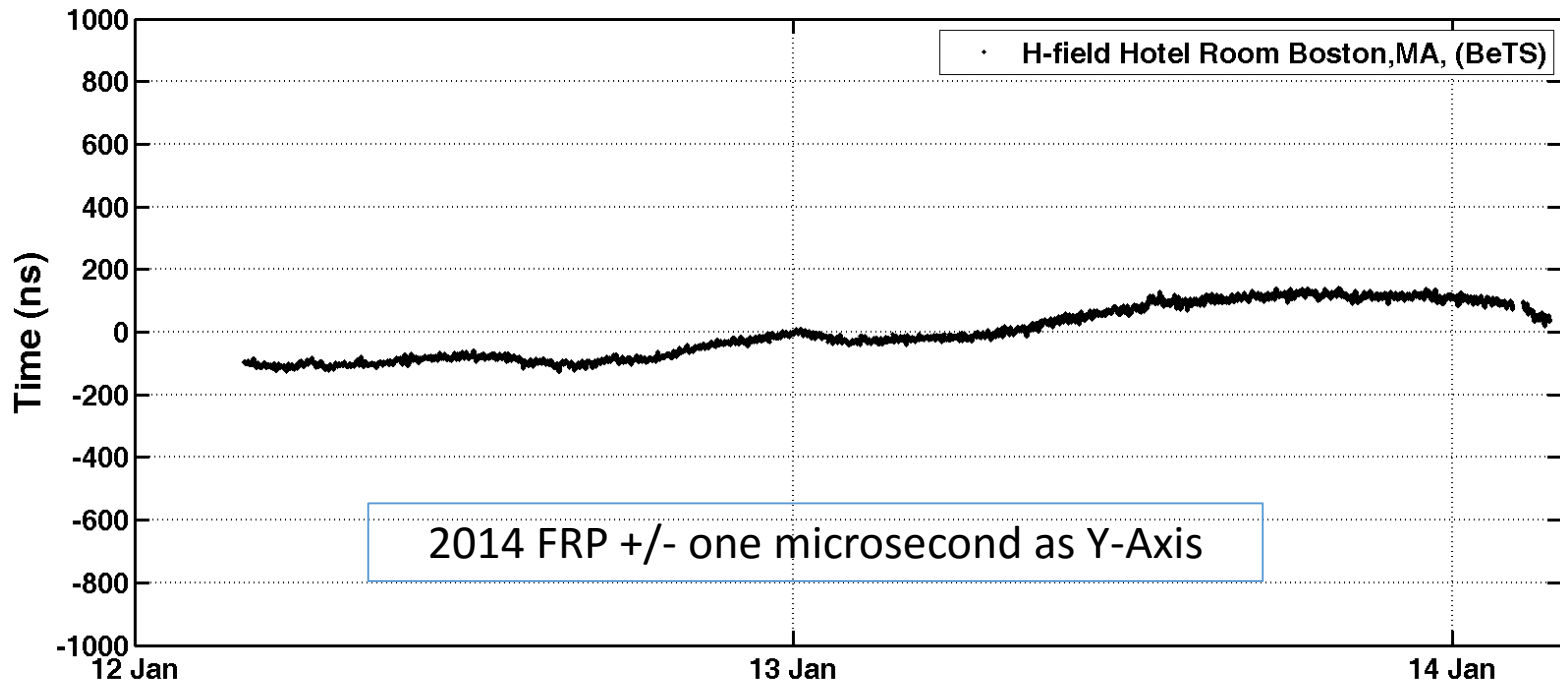
305 miles NE of transmitter



Prototype H-Field
Antenna



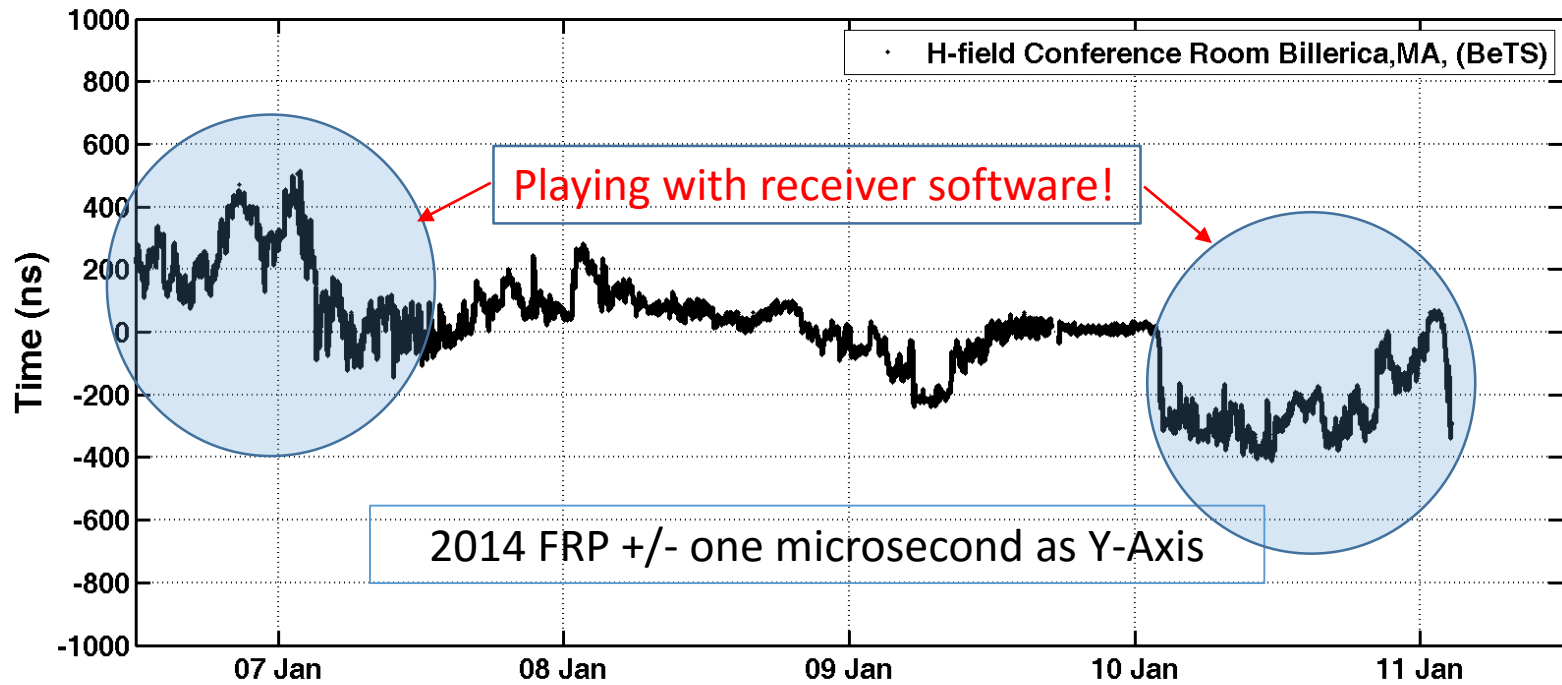
Metropolitan Area Indoor H-Field Test: Boston, MA



January 2016
Distance to XMTR: 305 miles
Without differential corrections.

Mean: 0.0 ns
STD: 83.2 ns
Max: 139.9 ns
Min: -126.1 ns

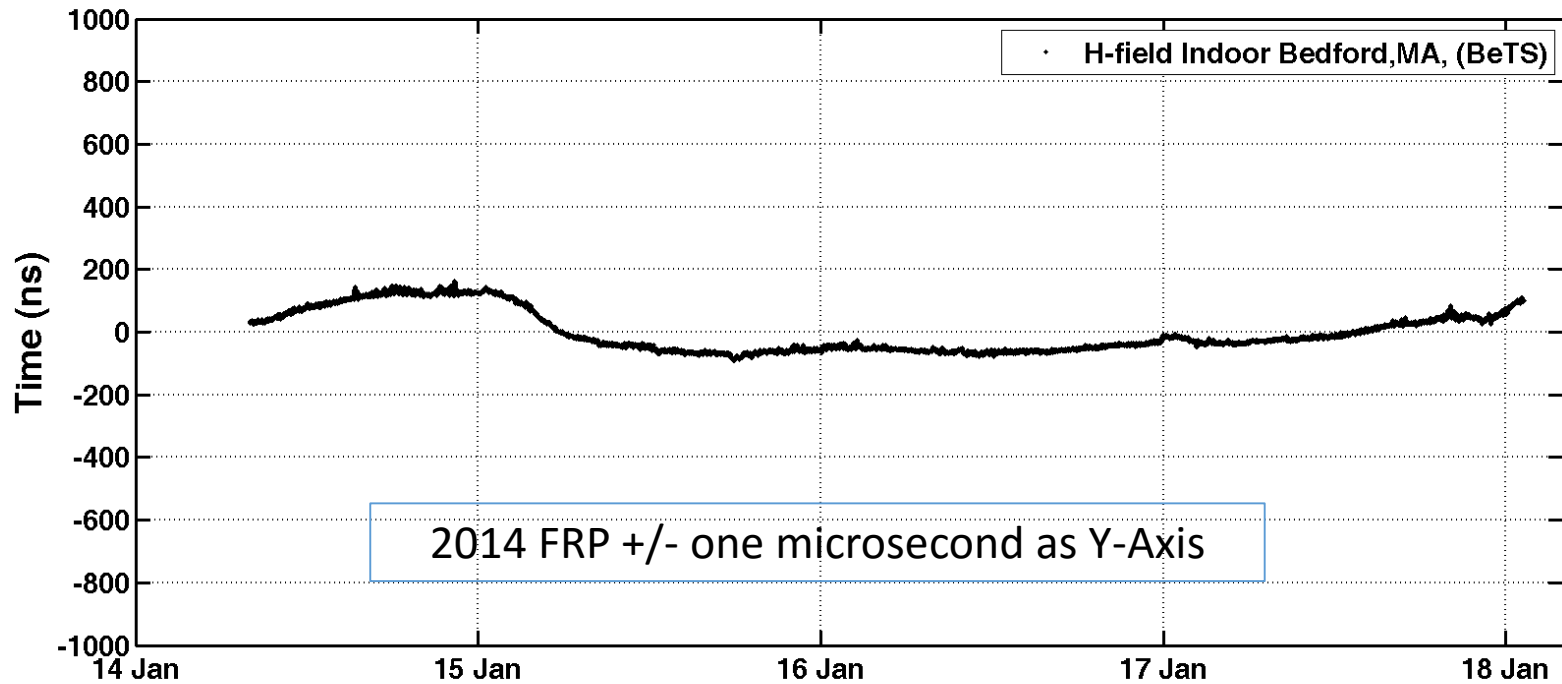
Commercial Area Indoor H-Field Test: N. Billerica, MA



January 2016
Distance to XMTR: 310 miles
Without differential corrections.

Mean: 0.0 ns
STD: 178.6 ns
Max: 514.4 ns
Min: -412.6 ns

Residential Area Indoor H-Field Test: Bedford, MA



January 2016
Distance to XMTR: 303 miles
Without differential corrections.

Mean: 0.0 ns
STD: 66.5 ns
Max: 162.6 ns
Min: -91.4 ns

Take Aways

1. eLoran **is** a stable, wide area source of PNT for redundancy and resiliency in critical infrastructure and key resource sectors
- B. **Without** differential corrections, eLoran is capable of meeting 2014 FRP timing user requirements over very wide areas
- III. **With** the application of differential corrections, eLoran is capable of meeting the needs of higher accuracy timing users over a local area
- Δ. With an initial four transmitting stations, eLoran can provide resilient and complimentary timing, frequency, and data over the CONUS
5. With additional transmitting stations, eLoran can provide additional resilience and complimentary positioning over the CONUS

Contact Us for Collaborative Efforts

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