eLoran for Time and Frequency Applications

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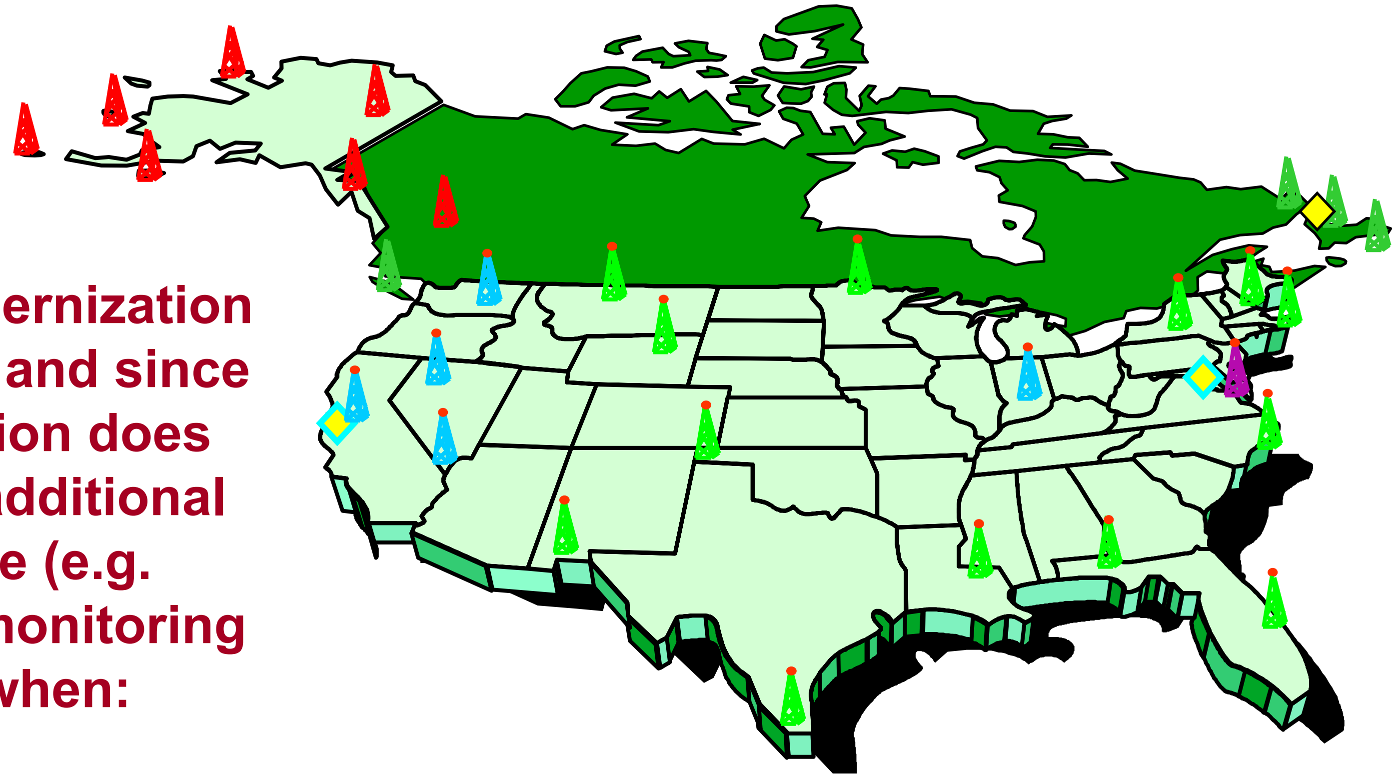
Outline

- The US is closer to using eLoran for time and frequency than for navigation
- eLoran properties that complement GNSS in time/frequency applications
- Recent test results using indoor and outdoor antennas
- Conclusions

The US is closer to using eLoran for time and frequency than for navigation



CONUS modernization is complete, and since this application does not require additional infrastructure (e.g. differential monitoring sites), then when:

9th pulse begins → eLoran becomes an alternate, infinite, and traceable high precision time <u>and</u> frequency source that does not share GPS vulnerabilities.

TOT begins → LPAs and secondaries are eliminated, so each station equivalent for phase locking and many stations available at receiver sites for redundancy.

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eLoran Properties that Complement GNSS in Time/Frequency Applications:

- A single device provides time and frequency capabilities fully redundant to GPS (e.g. unlike Rb, Loran is a primary reference system and can supply UTC)
- Since many signals are available at each receiver site, the system provides multiple time/frequency sources and excellent reliability
- It can be an infinite backup to GPS, enabling scheduled maintenance rather than immediate response (i.e. substantial operator savings)
- Signal levels can enable equipment location in sites where difficult with GPS (i.e. minicells will become more prevalent and difficult to establish site)
- H-field doesn't require ground, so installation and maintenance costs are reduced, and antenna can be collocated with GPS if desired
- H-field antenna provides opportunity for indoor operation, which would result in huge savings for installation costs and annual antenna space rental fees.

Recent Tests Using Indoor and Outdoor Antennas

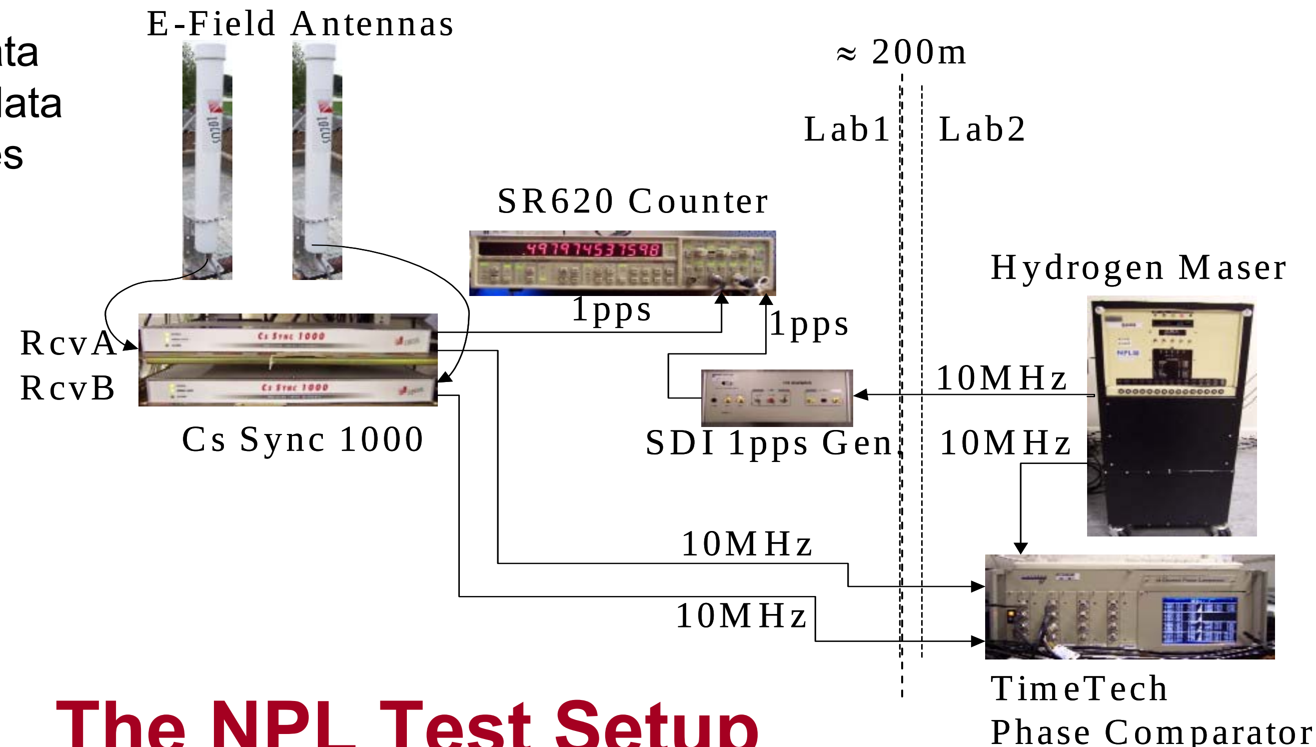
1. 2004 tests at National Physical Laboratory (NPL) using CsSync 1000 with outdoor e-field antennas
   - similar tests and results to those performed by NIST/TSC/USCG

2. 2004 - 2005 tests at Locus validating indoor reception using H-field
   - 2004 tests compared e and H-field reception indoors
   - 2005 tests compared Loran tracking parameters using indoor H-field and roof-mounted e-field

3. 2005 tests in Texas
   - compared indoor Loran (H-field) with outdoor GPS performance
   - used performance metrics common in telecommunication world, i.e. maximum time interval error (MTIE) and time deviation (TDEV)

Outdoor eLoran Performance

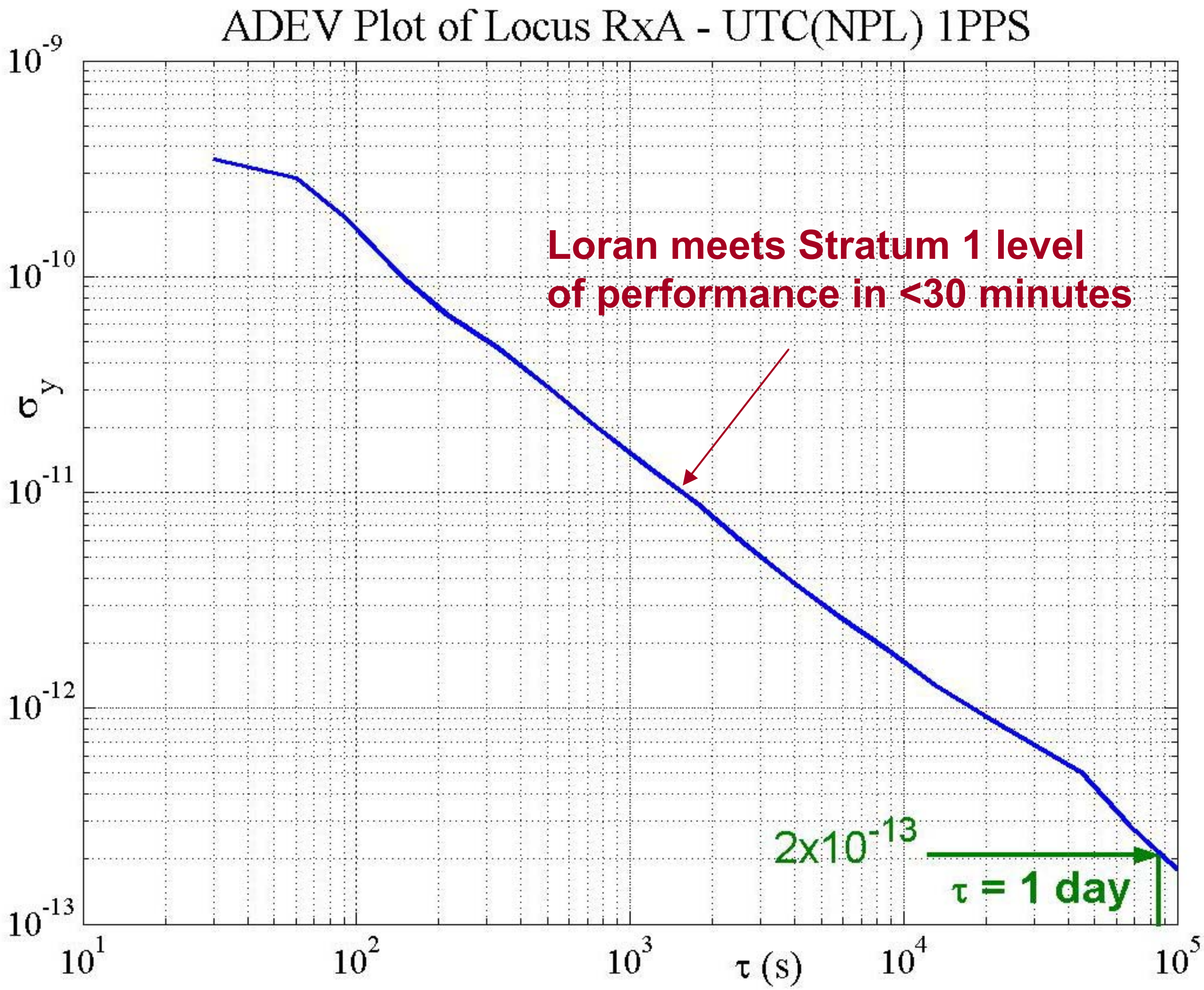
- eLoran receiver (Eurofix now)
- NPL tests 9thJune – 6th September 2004
- **Receivers locked to Loran-C station in Lessay, France**
  - Rcvrs 10MHz output (derived from Lessay)
  - Rcvrs 1pps output not aligned to UTC
- Sampling rate
  - 30s for 1pps data
  - 10s for phase data
- Common-view studies shortly



The NPL Test Setup

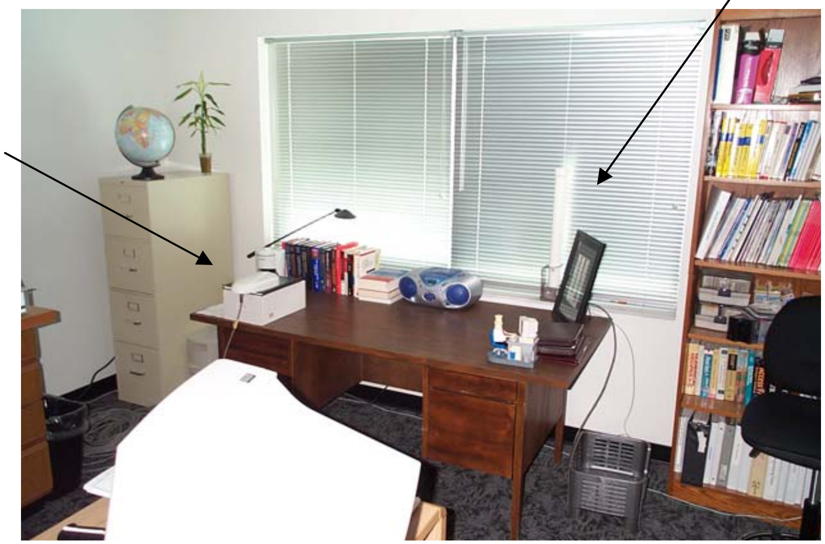
Outdoor eLoran Performance

- Fractional frequency
  fr= (f-f0)/f0 [-]
- Frequency stability
  (Allan deviation)
  2x10 -13 (τ= 1 day)
- Comparable to Cs clock
- Better than MSF
- Similar results to
  TSC/USCG/NIST tests



From Hlavac and Stacey, RIN NAV 04

Evaluating Indoor Performance with e-field and H-field Antennas - 2004



- Locus office used for recording, with aluminum window frame and shades. E-field on window ledge and H-field on desk.

- Locus building is primarily wood/stucco/brick with steel frame

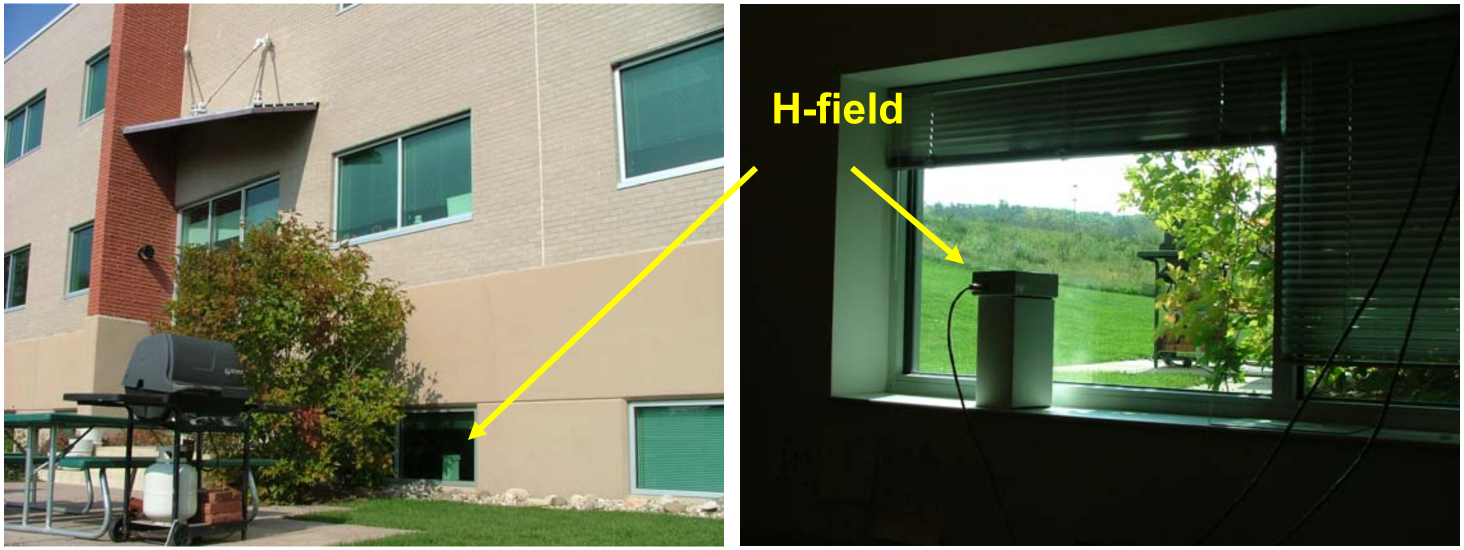
Evaluating Indoor Performance with e-field and H-field Antennas - 2004

- **Preliminary conclusions:**
  - Can track 30 stations, but many on skywave; use criterion of <900 mi for groundwave
  - Indoor H-field SNR ~ 5-10 lower than outdoor, and primarily due to increased interference
  - Indoor E-field SNR ~ 10-15 lower than outdoor, and primarily seems to be due to signal attenuation by building

Example data from 16 stations within 900 miles

			E-field			H-field	
Station	Power	Distance	Signal Level	SNR		Signal Level	SNR
7980 M	800 kW	860 mi	51 dB uV/M	-3		61 dB uV/M	0
7980 W	800 kW	850 mi	53 dB uV/M	-4		63 dB uV/M	5
7980 Z	600 kW	875 mi	48 dB uV/M	-3		56 dB uV/M	-3
8290 W	800 kW	460 mi	70 dB uV/M	8		78 dB uV/M	17
8290 X	540 kW	815 mi	56 dB uV/M	2		59 dB uV/M	4
8970 M	400 kW	240 mi	76 dB uV/M	14		86 dB uV/M	26
8970 W	800 kW	860 mi	51 dB uV/M	-4		61 dB uV/M	2
8970 X	800 kW	640 mi	63 dB uV/M	3		64 dB uV/M	3
8970 Y	800 kW	460 mi	70 dB uV/M	9		78 dB uV/M	19
8970 Z	900 kW	844 mi	56 dB uV/M	-4		57 dB uV/M	-3
9610 M	900 kW	844 mi	57 dB uV/M	-3		57 dB uV/M	-4
9610 V	540 kW	815 mi	56 dB uV/M	0		59 dB uV/M	3
9610 Z	800 kW	850 mi	54 dB uV/M	-5		63 dB uV/M	2
9960 M	800 kW	640 mi	61 dB uV/M	2		64 dB uV/M	2
9960 Y	600 kW	875 mi	47 dB uV/M	-4		57 dB uV/M	0
9960 Z	400 kW	240 mi	75 dB uV/M	14		86 dB uV/M	24

Comparing Indoor H-field and Outdoor e-field Performance - 2005



H-field in south (towards Dana) basement window facing open area

e-field in standard roof-mount site

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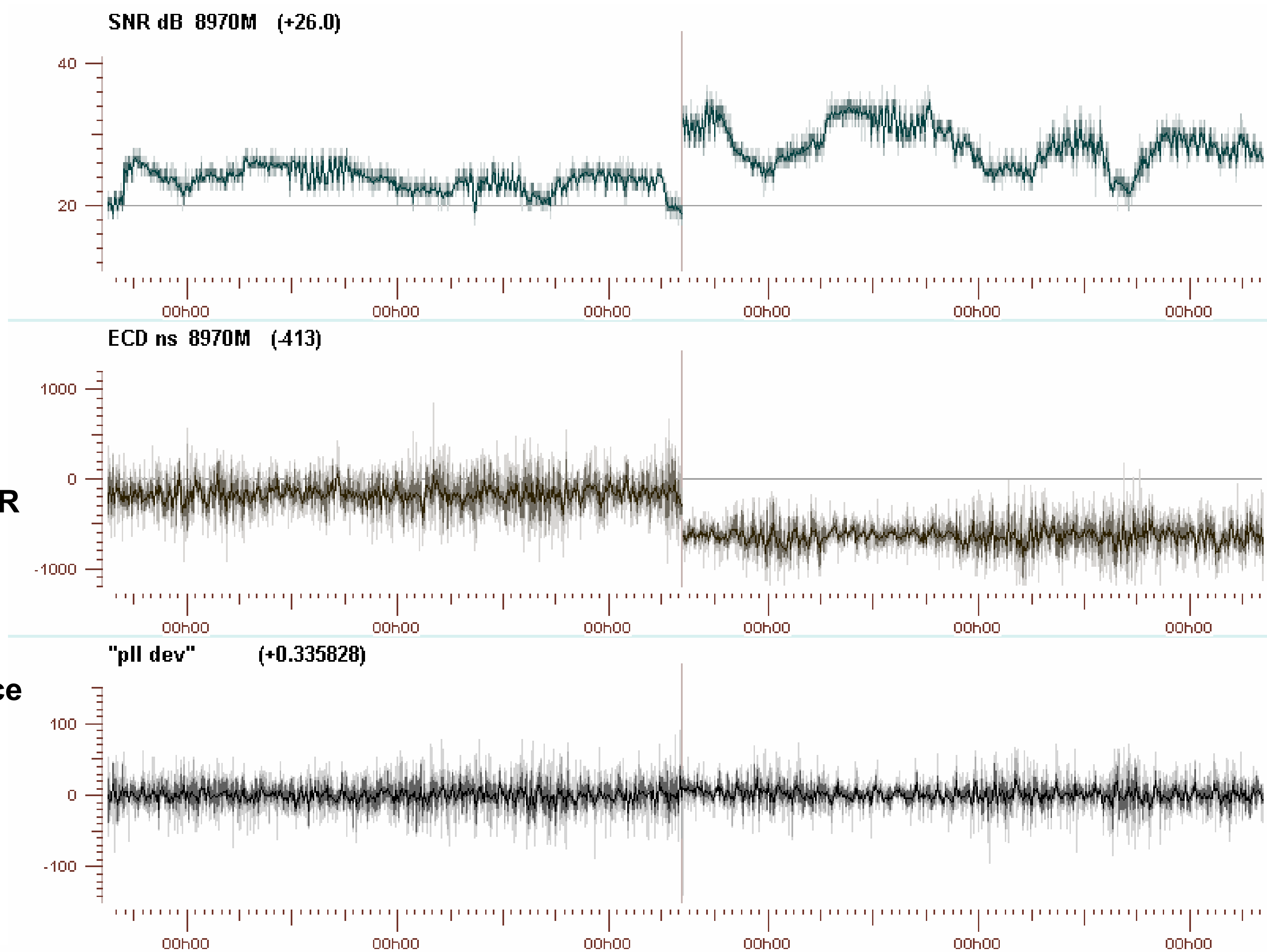
Indoor H-field   Outdoor e-field



Tests from September 30 – October 3, 2005

Each receiver locked to Dana, 8970M

Very similar performance, except lower SNR indoors

ECD offset attributed to antenna tolerance

Comparing Indoor H-field and Outdoor GPS Using Telecommunication Metrics

Overview of Common Metrics and Definitions related to Telecom Interfaces:

Digital Signal level 1 (DS1) runs at 1.544 Mbits/sec and interface synchronization is derived from the pulse and/or framing pattern (192 bits/frame). A slip is a repetition or deletion of a frame caused by a discrepancy of read/write rates at received buffer.

Maximum Time Interval Error (MTIE) is the maximum TIE for a sequence of TIEs that occur for a given different observation time. MTIE is a measure of timing instability which is related to slip performance.

Time Deviation (TDEV) is the RMS value of filtered TIE over a range of integration times (tau) and is used to characterize phase instability at synchronization reference interfaces.

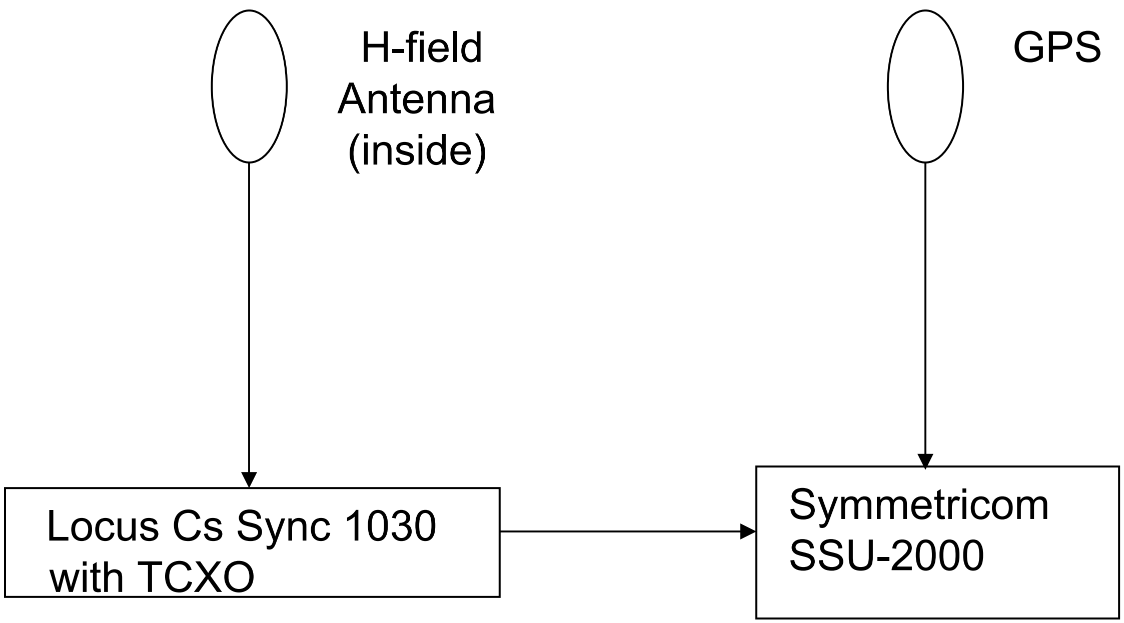
Primary Reference Sources (PRS) provide long term frequency accuracy of 1 part in 10^{-11} or better and here are synonymous with Stratum 1 devices. In telecom, Cs, GPS, and Loran can act as Stratum 1 devices (Hydrogen masers are too expensive).

Above taken from ANSI and NIST sources

Comparing Indoor H-field and Outdoor GPS Using Telecommunication Metrics

Test Setup:

SSU-2000 with Rb referred to GPS signal with 9000 second Tau
Loran 10 MHz output to SSU to determine TI (phase), MTIE, and TDEV over 24 hours
Loran receiver with TCXO phase locked to: Raymondville, 7980X, 273 miles, June 2005
Boise City, 9610M, 506 miles, August 2005



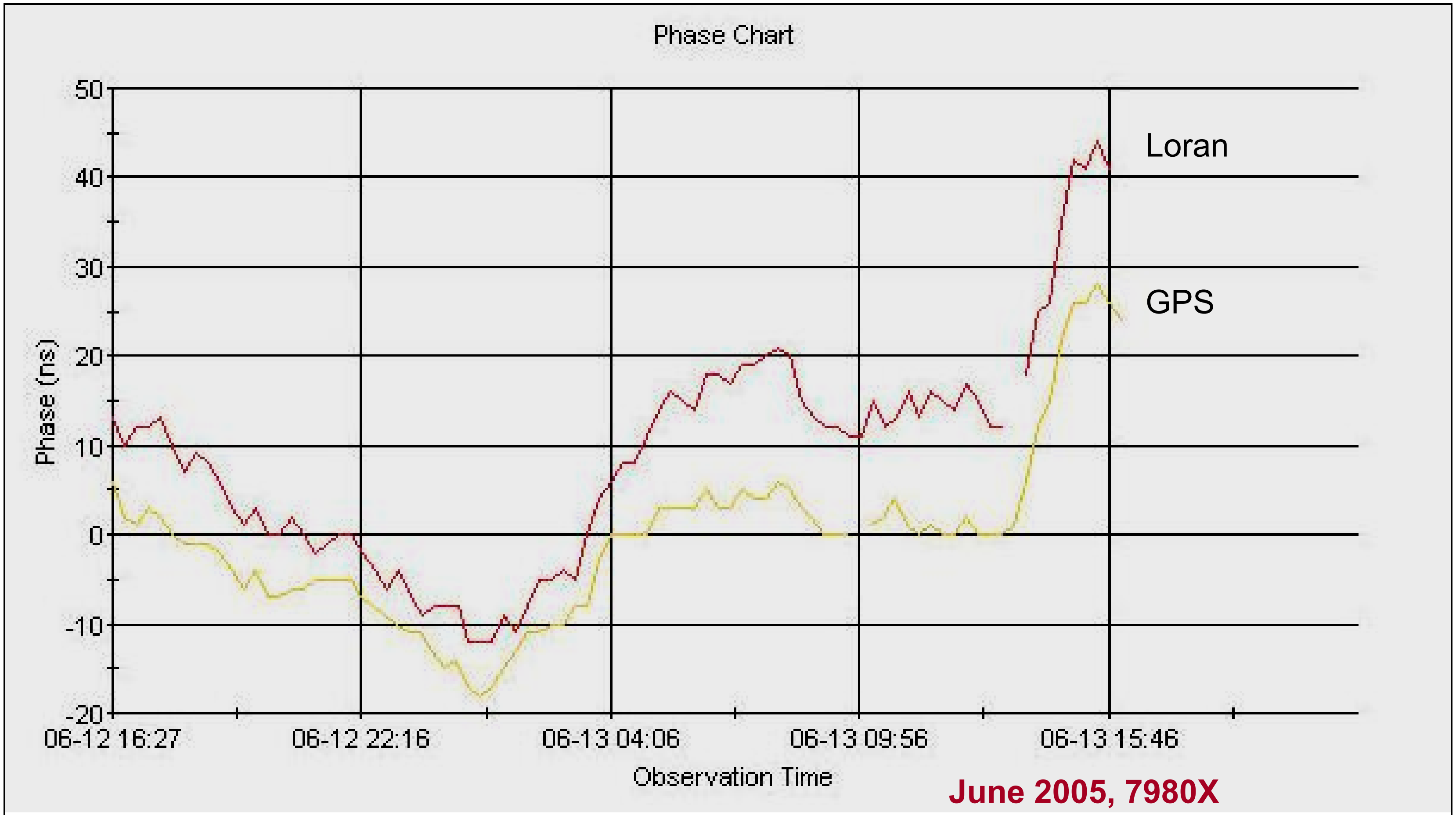
Comparing Indoor H-field and Outdoor GPS Using Telecommunication Metrics

Preliminary Indoor Testing in Texas – June and August 2005

Test Building

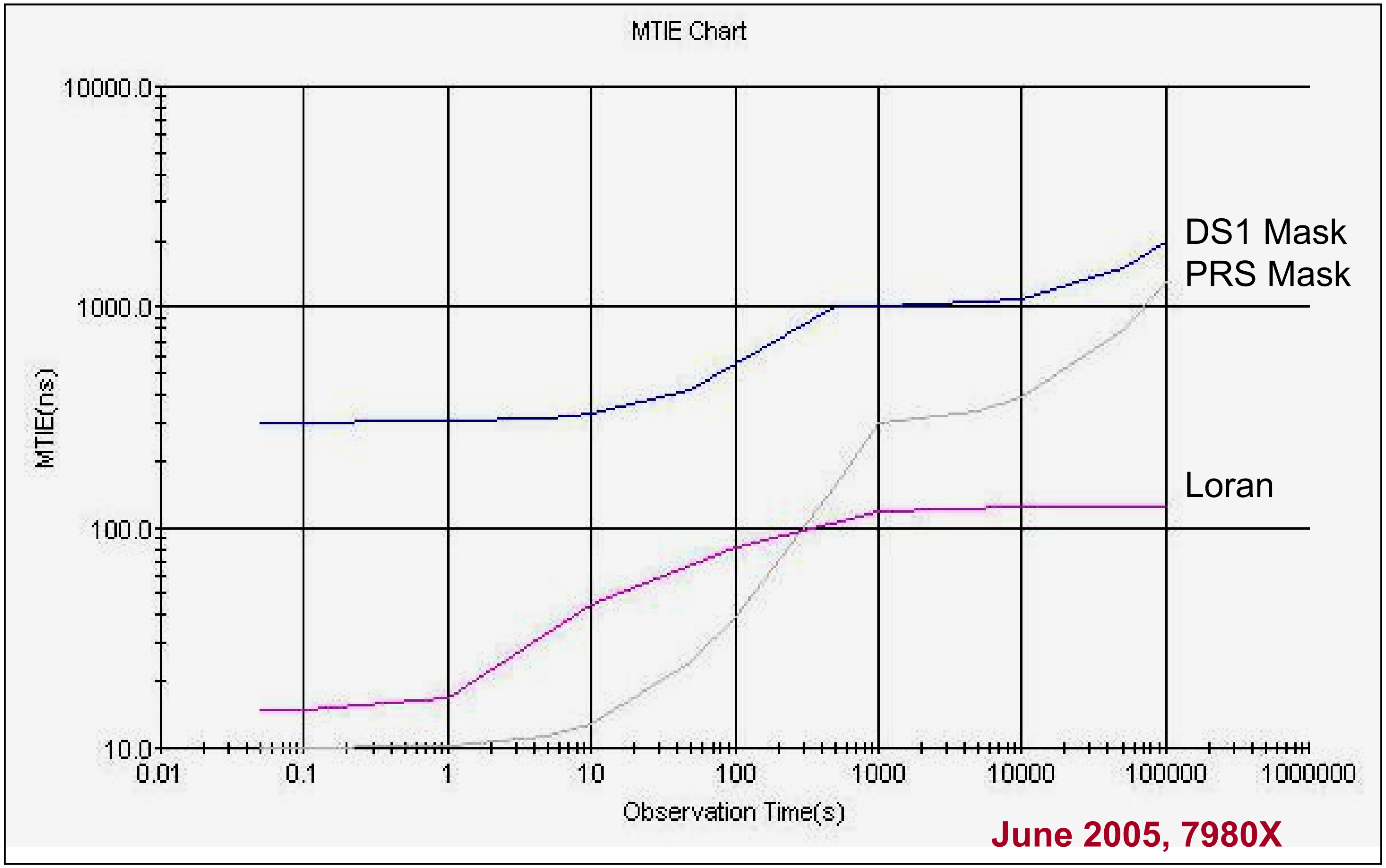
H-field Location

Comparing Indoor H-field and Outdoor GPS Using Telecommunication Metrics – Phase (TI)

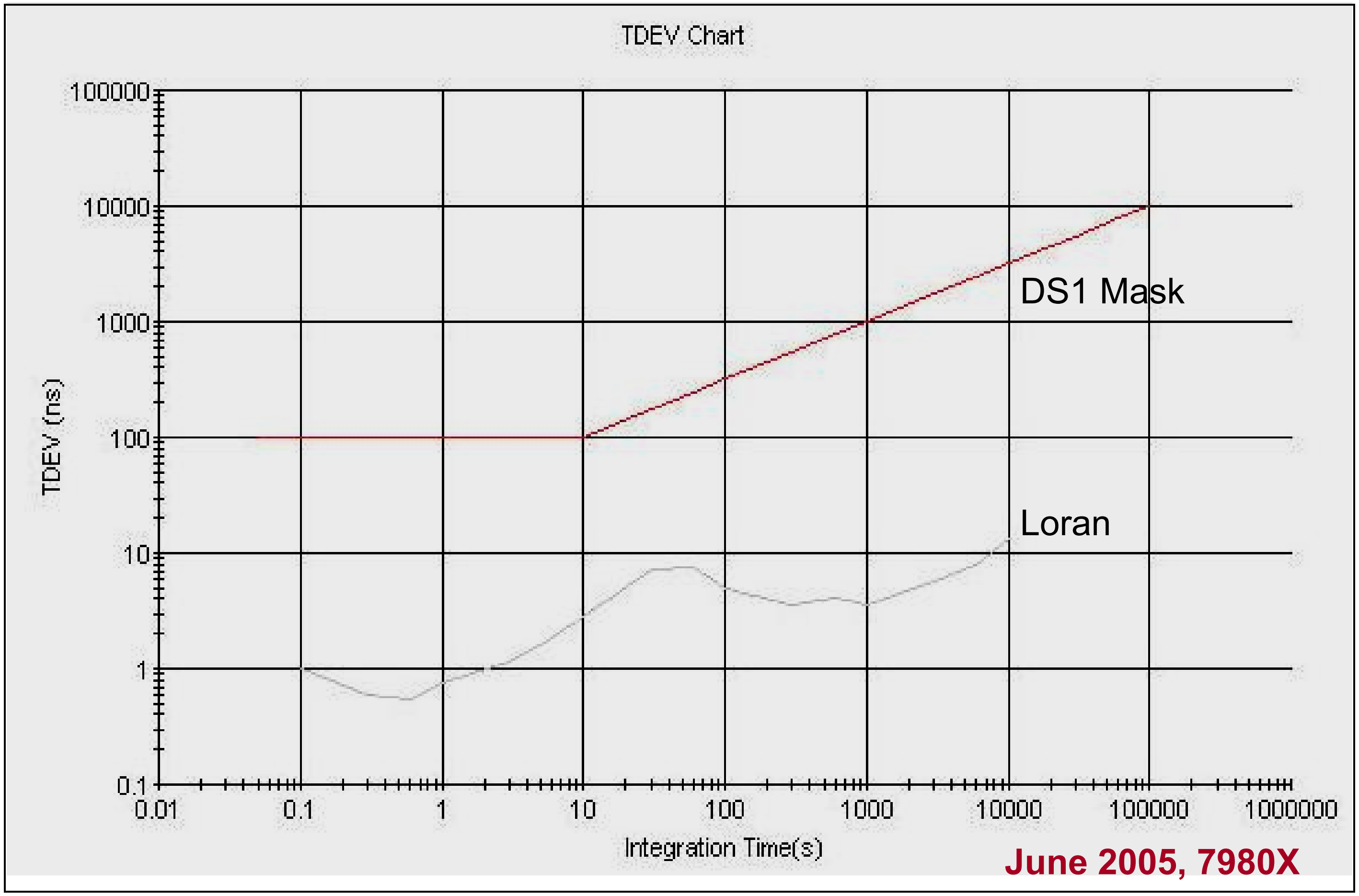


June 2005, 7980X
1000 sec averages

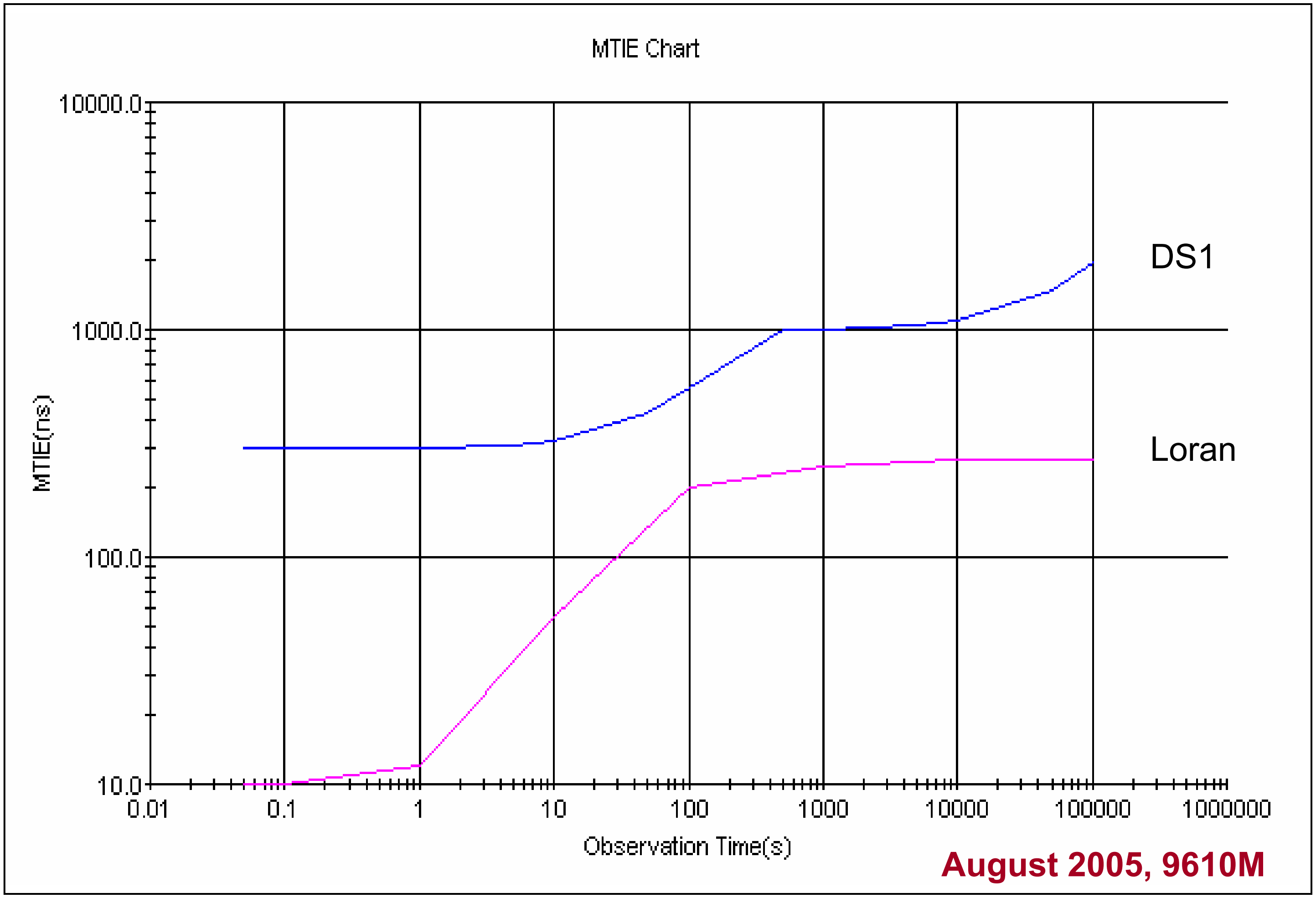
Comparing Indoor H-field and Outdoor GPS Using Telecommunication Metrics – MTIE



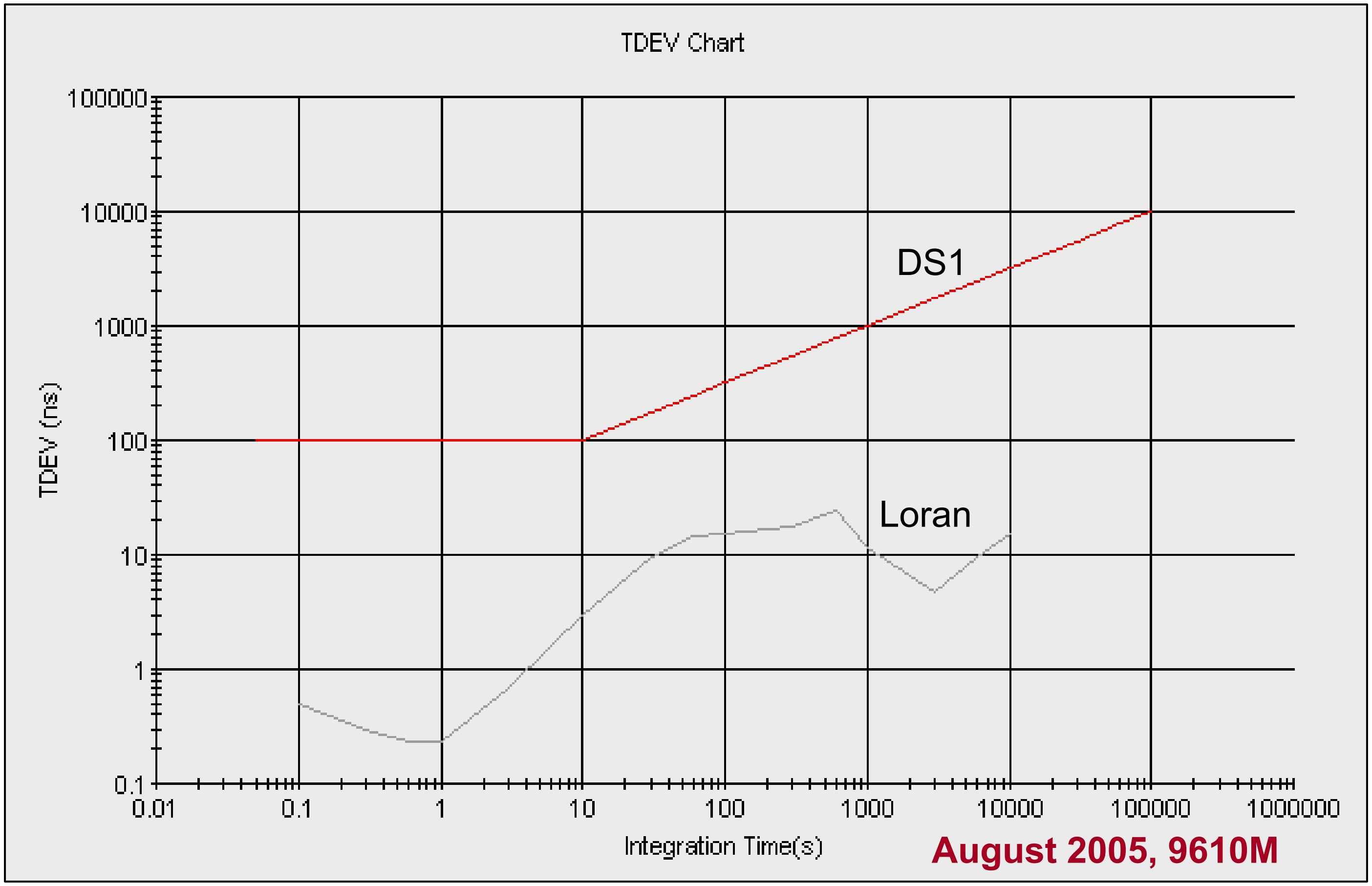
Comparing Indoor H-field and Outdoor GPS Using Telecommunication Metrics – TDEV



Comparing Indoor H-field and Outdoor GPS Using Telecommunication Metrics – MTIE



Comparing Indoor H-field and Outdoor GPS Using Telecommunication Metrics – TDEV



Conclusions

- Completion of the CONUS infrastructure modernization means implementation of 9^{th} pulse and TOT control will immediately enable greatly enhanced time and frequency performance using Loran (i.e. time/frequency users will likely enjoy benefits of eLoran before navigation users).

- Since tracking a single station will provide frequency and time, and since many signals (typically 10-15) are available, the system will be extremely robust.

- In addition to being able to backup GPS, Loran has many practical properties that make it extremely useful in time/frequency applications.

Conclusions

- Frequency studies with eLoran receiver (OCXO equipped) using outdoor e-field antenna document Stratum 1 performance in < 30 minutes and 2×10^{-13} in 24 hours.

- Preliminary studies with eLoran receiver (only TCXO equipped) using indoor H-field antenna suggest:
  - indoor Loran can meet MTIE and TDEV standards for DS1
  - a better oscillator is required to meet PRS standards
  - additional studies required with different antenna placements and indoor conditions and in different areas of country

- For the vast majority of time and frequency users, eLoran can provide important complementary and backup capabilities to support GPS and provide systems with more robust time and frequency performance.