# GNSS-Independent Sources of Coordinated Universal Time

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National Institute of Standards and Technology

WSTS
April 1, 2021

# GNSS-Independent Sources of UTC

**A 2019 study estimated the economic consequences of 30-day GPS outages:**

- Overall, combined loss to the U. S. economy > $1 billion per day, with up to half of that in the telecommunications sector.

  A. O'Connor et al., "Economic Benefits of the Global Positioning System (GPS)," RTI International, 306 p., June 2019.

**Lots of Activity in the government to reduce risk from dependence on GNSS:**

- Executive Order 13905
- Space Policy Directive 7 (SPD-7)

# Executive Order 13905

Federal Register
Vol. 85, No. 32
Tuesday, February 18, 2020

## Presidential Documents

Title 3—

The President

Executive Order 13905 of February 12, 2020

Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services


**Calls on NIST to do two things:**

1. *Within 1 year … develop and make available… **PNT profiles** that will enable users to identify systems, networks, and assets dependent on PNT services, … detect the disruption and manipulation of PNT services, and manage the associated risks ….*

**www.nist.gov/pnt**

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1. *Within 1 year … develop and make available… PNT profiles that will enable users to identify systems, networks, and assets dependent on PNT services, … detect the disruption and manipulation of PNT services, and manage the associated risks ….*

2. ***Within 180 days … make available a GNSS-independent source of UTC, to support the needs of critical infrastructure owners and operators, for the public and private sectors to access.***

# SPD-7 calls on NIST to:

- Develop quantum technologies applicable to PNT,
- Improve long-distance time transfer technologies,
- Standardize for the integration of multiple PNT sources for resilience and anomaly detection.

The implementation plan for SPD-7 is currently being written.

## Memorandum on Space Policy Directive 7

INFRASTRUCTURE & TECHNOLOGY | Issued on: January 15, 2021

January 15, 2021

MEMORANDUM FOR THE VICE PRESIDENT
THE SECRETARY OF STATE
THE SECRETARY OF DEFENSE
THE ATTORNEY GENERAL
THE SECRETARY OF THE INTERIOR
THE SECRETARY OF COMMERCE
THE SECRETARY OF TRANSPORTATION
THE SECRETARY OF ENERGY
THE SECRETARY OF HOMELAND SECURITY
THE DIRECTOR OF THE OFFICE OF MANAGEMENT AND BUDGET
THE DIRECTOR OF NATIONAL INTELLIGENCE
THE ASSISTANT TO THE PRESIDENT FOR NATIONAL SECURITY AFFAIRS
THE ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
THE CHAIRMAN OF THE JOINT CHIEFS OF STAFF
THE CHAIRMAN OF THE FEDERAL COMMUNICATIONS COMMISSION

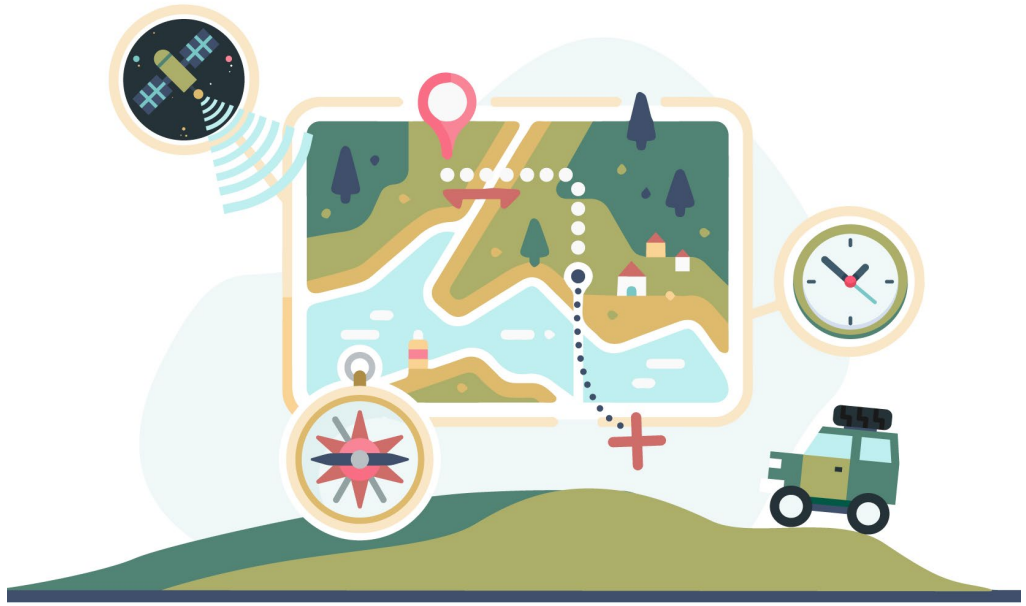
SUBJECT: Space Policy Directive 7, The United States Space-Based Positioning, Navigation, and Timing Policy

# Working with NIST

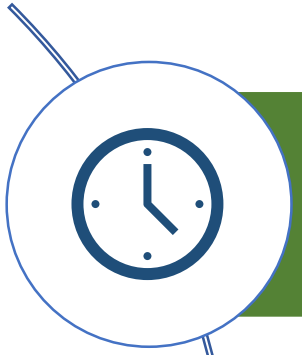
## We Welcome:

- New ideas on how to improve our systems and methods to make them more accessible, usable, and valuable to users.

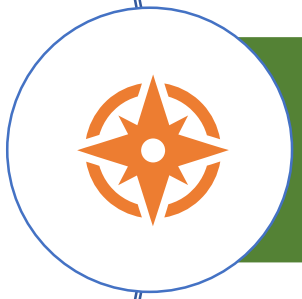
- New collaborations that will strengthen timing for critical infrastructure:
  - CRADAs, SBIRs, MoUs, Calibration Services, …



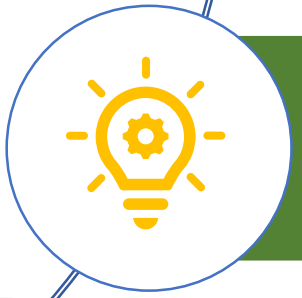
# Outline of the Rest of this Talk



What the NIST Time and Frequency Division does



How we have responded to EO 13905 so far



Things that are planning or just beginning

# UTC(NIST) Time Scale

Judah Levine, Jeff Sherman, Biju Patla, Roger Brown, Ladan Arissian

- Located in Boulder, CO
  - 10 to 15 atomic clocks are typically included
  - 2/3 Hydrogen Masers, 1/3 Cs clocks
- A weighted average of the clocks provides the U. S. national standards for frequency and time
- A secondary UTC(NIST) time scale with 5 cesium clocks is in Fort Collins at WWV. We also have 2 cesium clocks in Gaithersburg


**Satellite comparisons for time realization**

**Outputs to customers for time distribution**

# A Few Time Signals Distributed by NIST

NIST serves the private and public sectors through the continuous distribution of UTC(NIST).

| Service | Best Case Uncertainty (microseconds) | Customer Cost | Estimated Average Users Per Day |
|---|---|---|---|
| Two-way satellite T&F Transfer | 0.002 | ~$100k per year plus ground station | 12 (USNO, PTB, and other national labs) |
| Time Measurement & Analysis Service | 0.01 | $945 to $1890 per month | 36 |
| Time Over Fiber (New!) | 0.05 | >$5000/month, depending on route | 2 |
| WWVB | 100 | Free | 100 000 000 |

**All of these services can play a role in improving resilient timing.**

# New NIST Service


Time over Fiber Special Test

SKU 78100S
Availability:

Add to Cart for Price Quote

**Primary NIST Technical Contact:**
Name: Judah Levine
Phone: (303) 497-3903
Email: Email NIST Technical Contact

Provide a signal traceable to UTC(NIST) from NIST Gaithersburg through a third-party optical fiber to a customer's outside user facility.

- Customers subscribe to the service at cost.
- Initial goal : 1 μs in a remote location – eventual improvement to < 100 ns

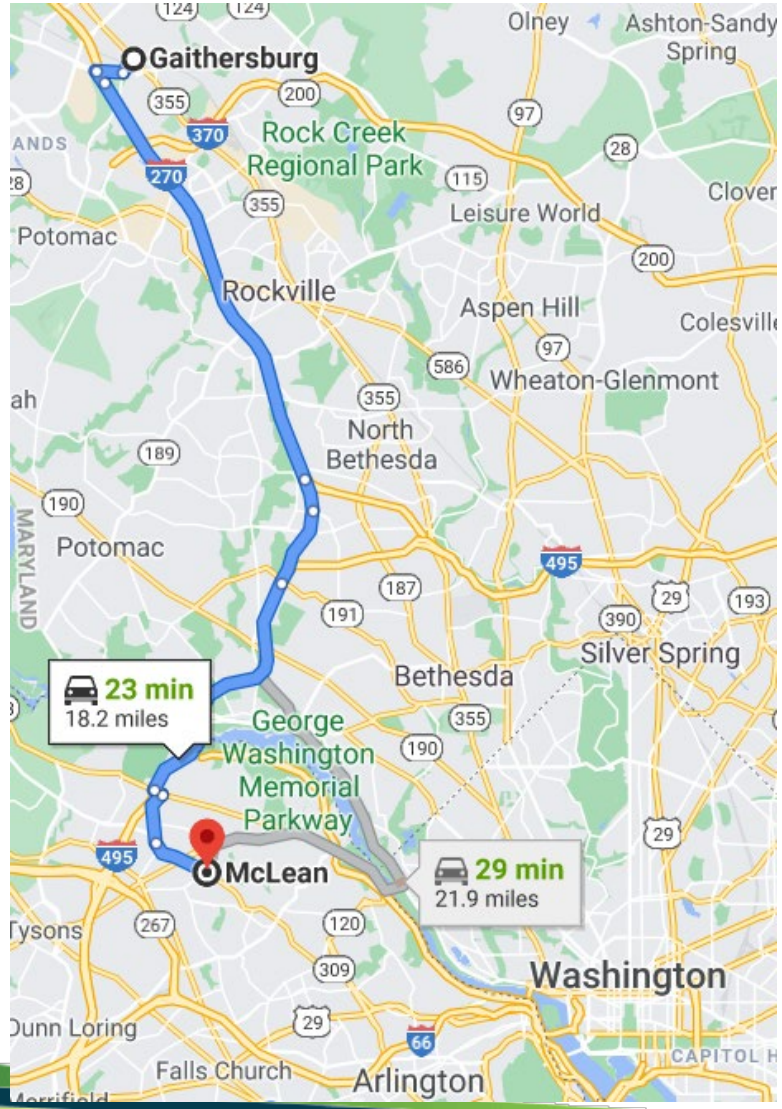
# Time Over Optical Fiber

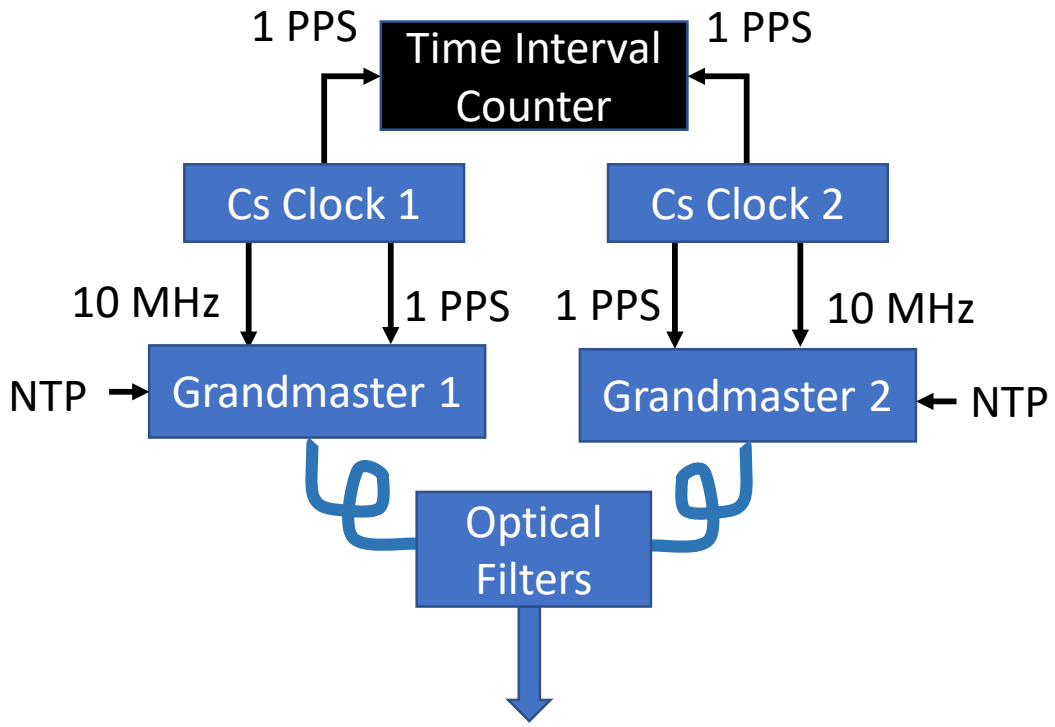
- Time distribution over optical fiber can utilize PTP, White Rabbit, or other protocols over long-distances.
- Can provide a level of security that wireless signals cannot
  - Immune from RF interference, free from reliance on satellite signals.
- Challenges with wide adoption are logistical and financial, but not technical.

**Could be a long-term solution to provide timing resilience**

# White Rabbit Link to McLean, VA

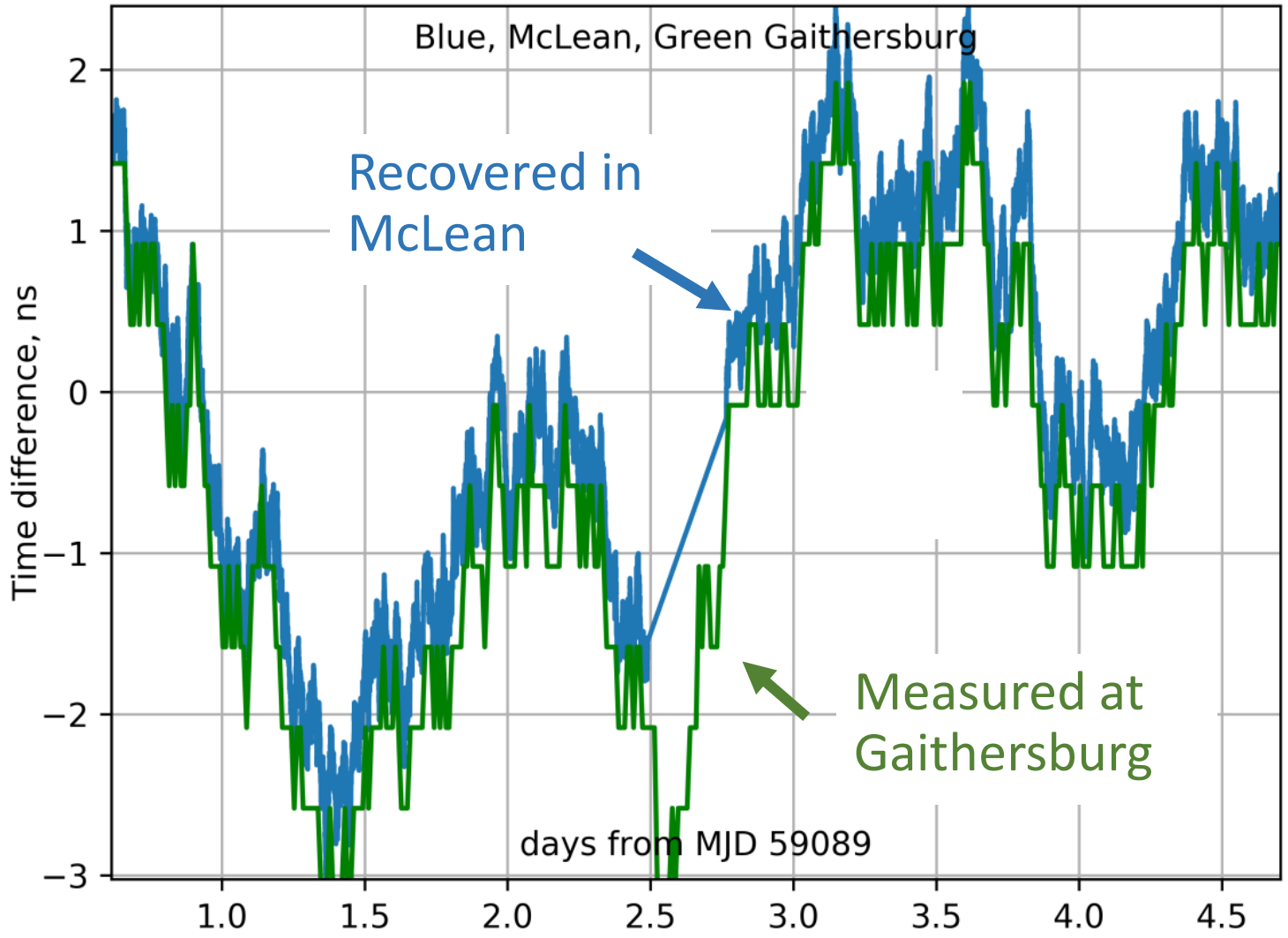
Judah Levine & Jonathan Hardis, NIST, Monty Johnson, OPNT




**Bidirectional Dark Fiber Link**

# Time Difference Measurements

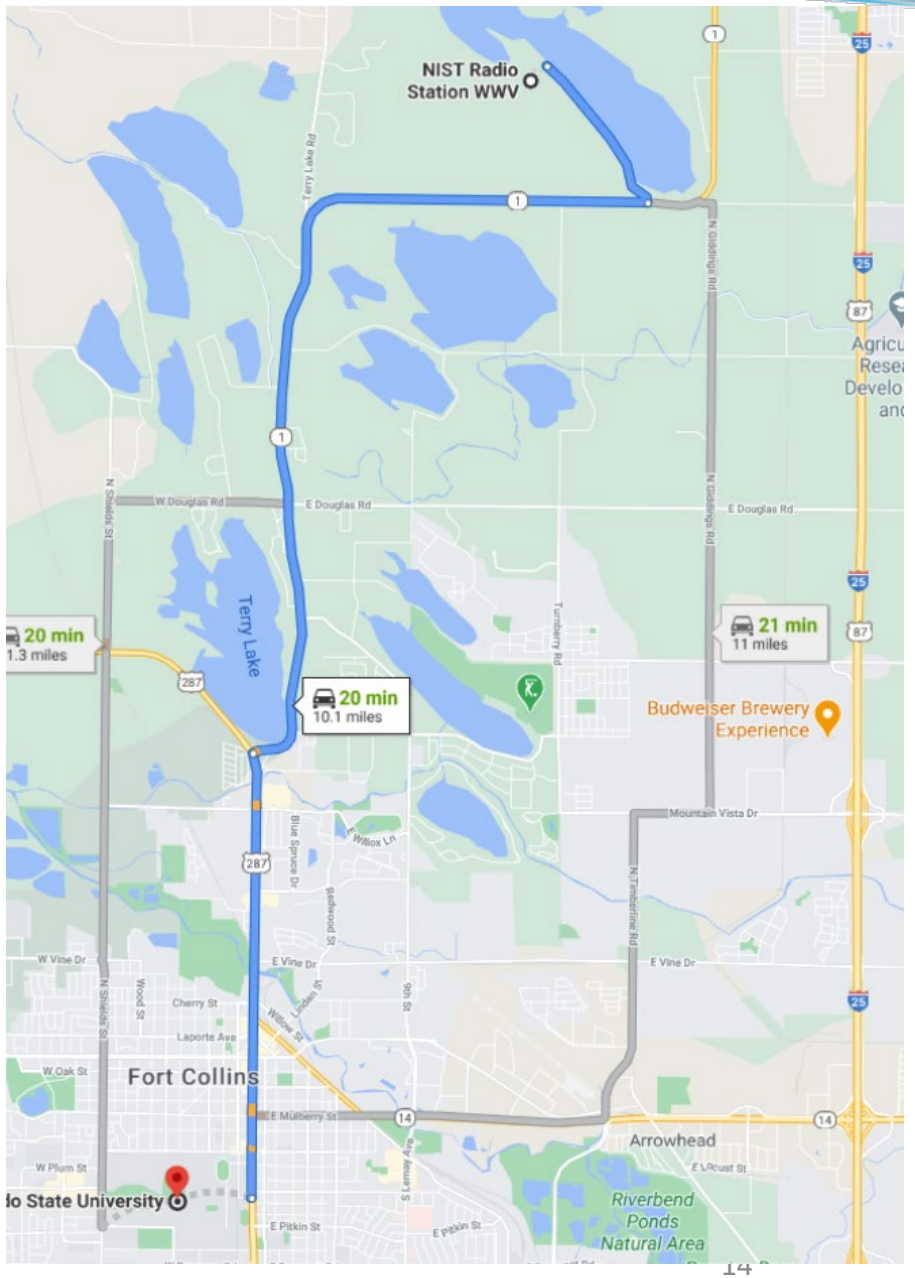



- Comparison between time differences measured in Gaithersburg and recovered in McLean
- Preliminary results suggest that ±100 ns uncertainty has been realized.

# WWV to Colorado State University Link

Michael Lombardi and Jeff Sherman (NIST)
Sam Brewer and Dylan Yost (CSU)

- NIST has a new CRADA with CSU to deliver time over fiber from the NIST Radio Station WWV to CSU.
  - < 20 km route
- Goal to eventually extend link to Boulder



# NIST Remote Time Services

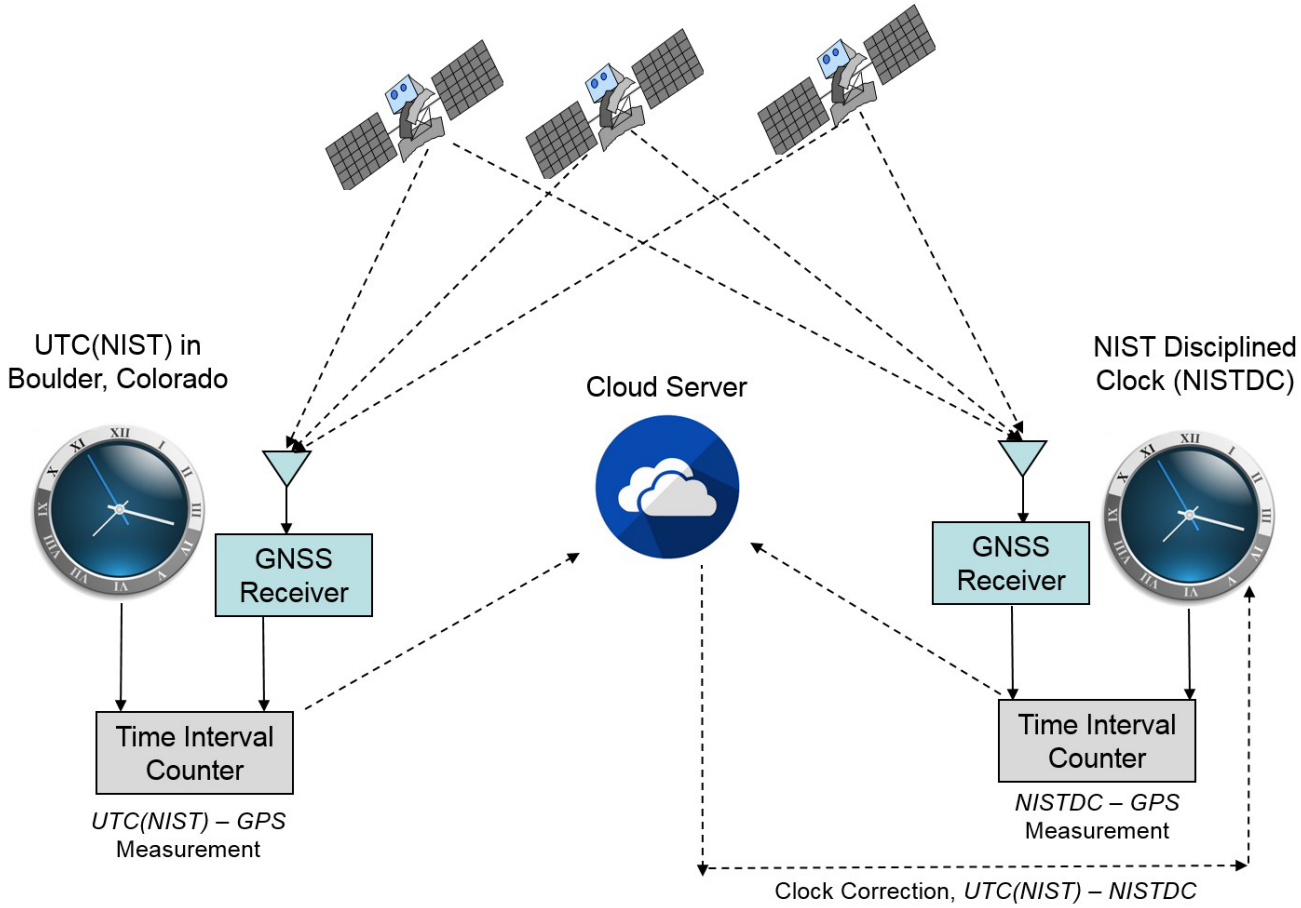
Michael Lombardi and Andrew Novick

**TMAS, FMAS, and NISTDC services**

- Use GPS Common View

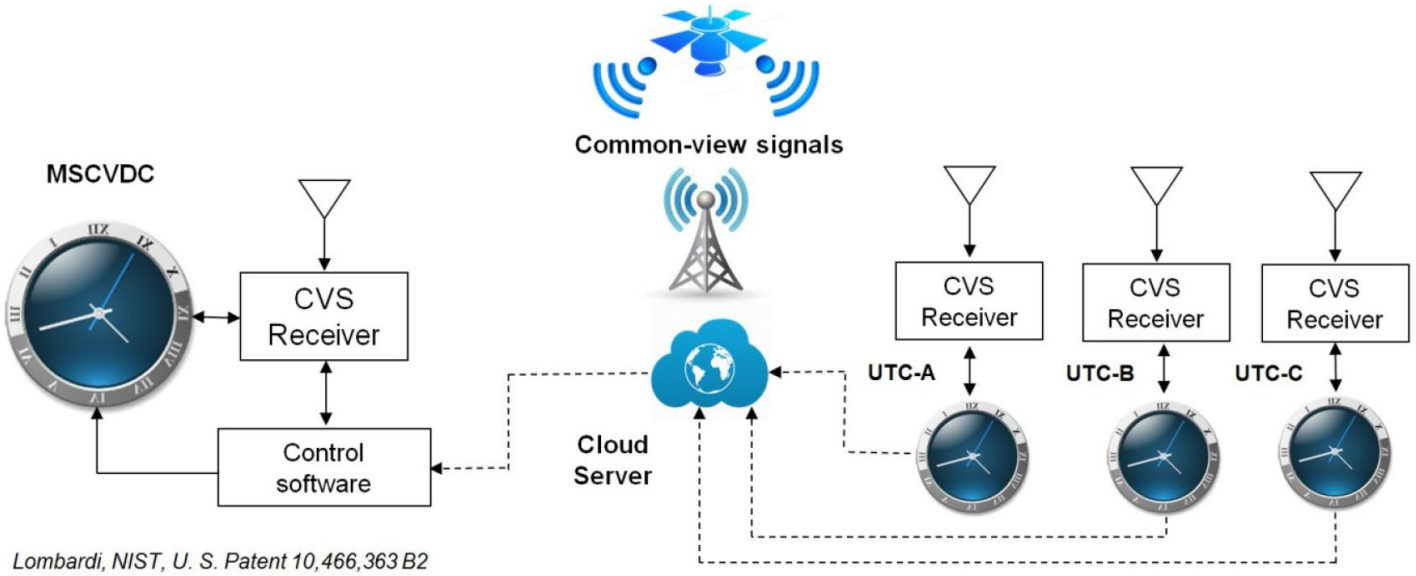
**Frequency to within parts in $10^{14}$**

**Time to within 10 ns of UTC(NIST)**




**The GPSDC models can provide holdover from days to months.**

# Multi-Source Common-View Disciplined Clock (MSCVDC)




Lombardi, U.S. Patent 10,466,363 B2 (2019)

- Multiple common sources are observed simultaneously at both sites
  - GNSS, communications satellites, terrestrial sources, …

**More attention to the method could lead to the development of commercially available products that use multiple, diverse signals.**

# Two-way satellite time and frequency transfer (TWSTFT)

Jeff Sherman and Roger Brown

- Point-to-point sync through communications relay satellites
  - ~ 2 ns timing uncertainty typical
- Equipment commercially available but requires investment in a ground station and satellite time.

**Due to its nanosecond-level accuracy TWSTFT could be applied to demanding applications.**

# Time by Low Frequency Radio: WWVB

WWVB continuously broadcasts a digital time code from Fort Collins, CO that synchronizes many millions of clocks and watches daily.

**100 microsecond uncertainty achievable with careful calibrations for propagation delays.**

# Radio Station WWVB

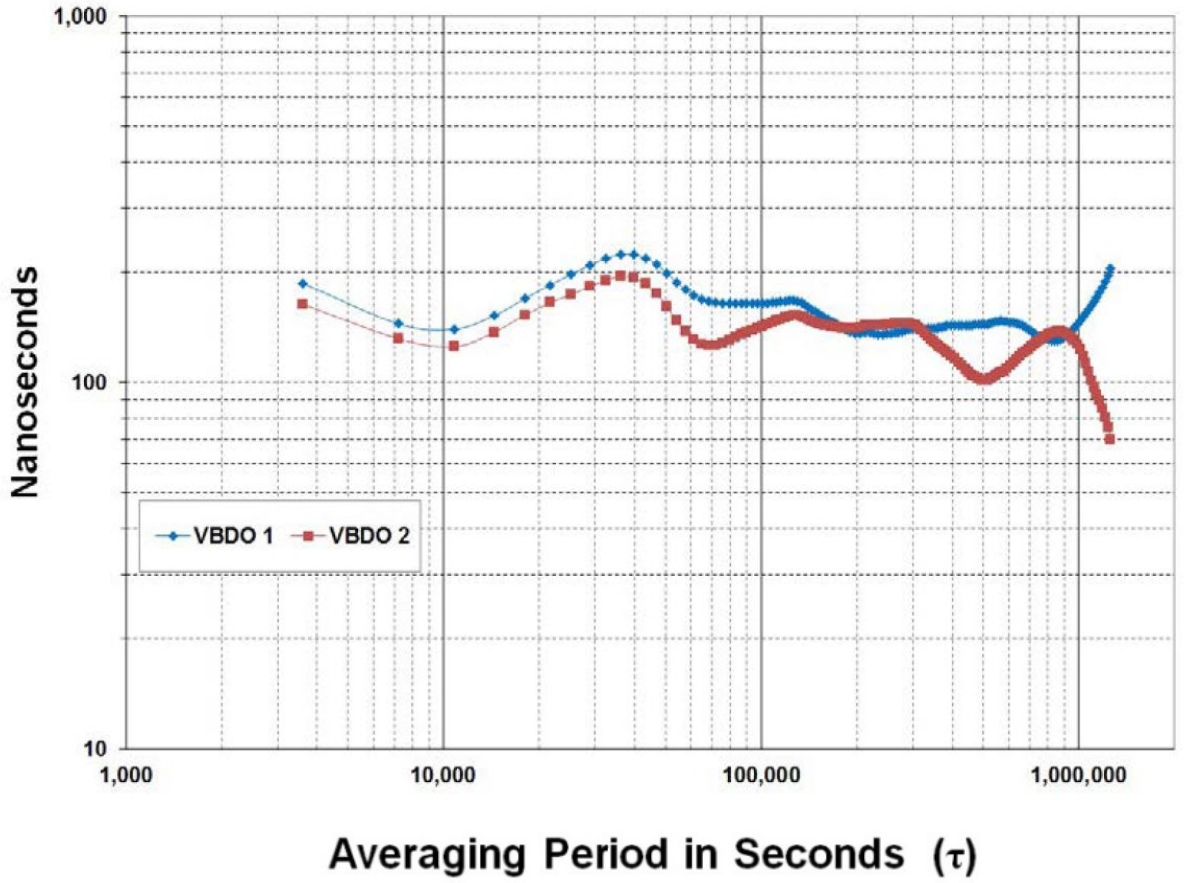
Matt Deutch, Glenn Nelson, Bill Yates, Douglas Sutton, Jim Spicer

## Holdover Frequency for GPS Disciplined Clocks

- Could provide holdover frequency for GNSS clocks through GPS signal outages.
- GPSDCs modified to accept a VBDO could maintain < 200 ns sync for clocks previously synced with GPS.

## Validation

- Can be used for internal health monitoring and detection and rejection of spoofed GNSS signals.
- GNSS clock manufacturers can consider the use of WWVB as verification sources for GNSS time-of-day information.

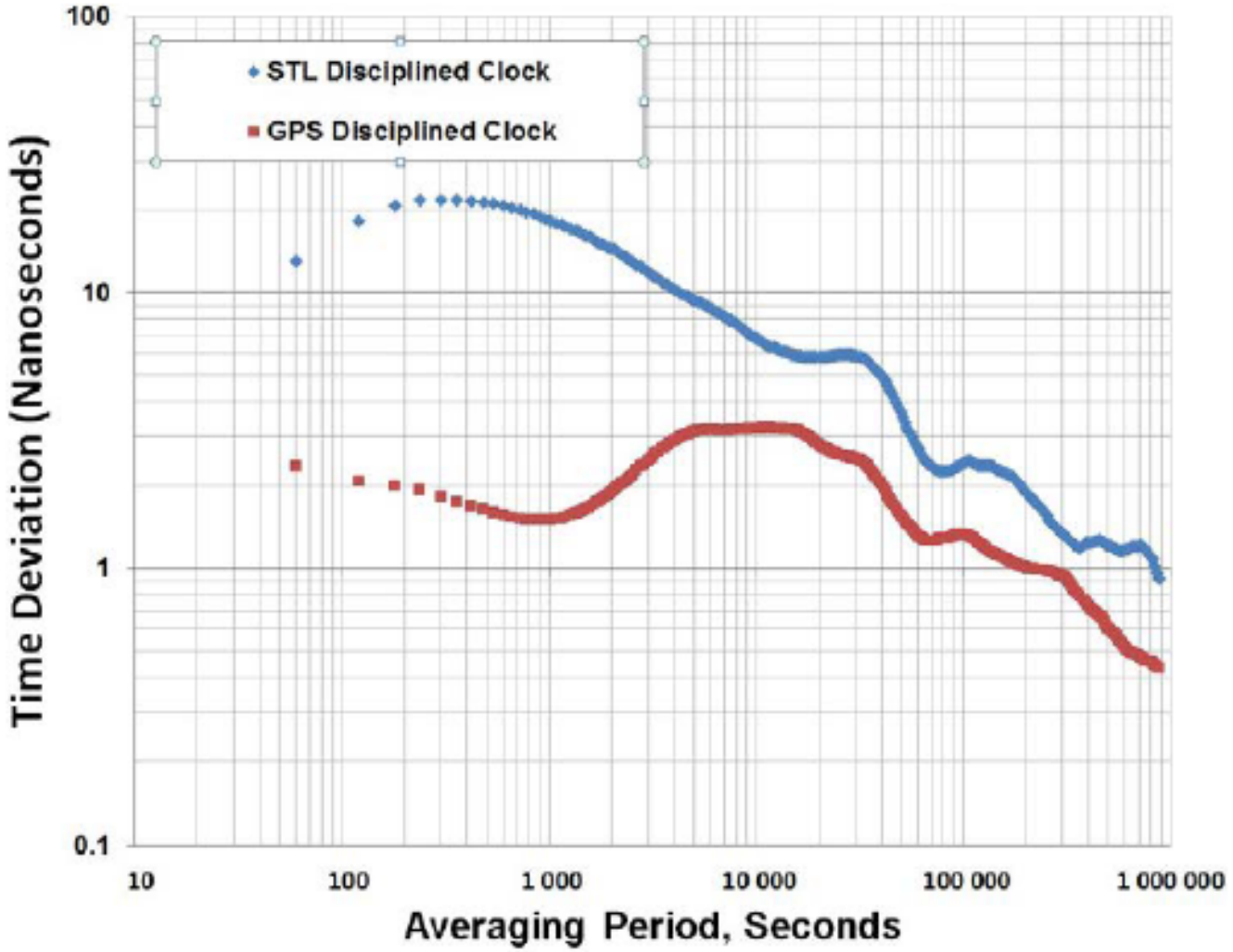


# Indirect Distribution of UTC(NIST) via non-GNSS, non-NIST Signals

Michael Lombardi

Many public and private time distribution systems offer the potential of GNSS independence. One example: The Satellite Time and Location (STL) service.

- For 50 days in 2020, NIST compared the 1 PPS output from an STL clock with an indoor antenna to the UTC(NIST).



# NIST STL Measurements

Michael Lombardi and Andrew Novick

NIST is in an agreement with Satelles to measure offsets between STL time and UTC(NIST) to provide validation, verification, and redundancy.

We installed a STL ground station in February of 2021.


**We aim to become more involved in monitoring systems like this, perhaps leading to UTC(NIST) corrections being included in some broadcasts.**

# Other Ongoing NIST Efforts

## Things we are already working on

- Develop high performance, portable, advanced optical clocks for holdover
- Expand customer base for our time-over fiber calibration service.

## Things we want to do

- Connect NIST Gaithersburg and USNO through government fiber networks.
- Install a TWSTFT link between NIST Gaithersburg and Boulder
- Upgrade our secondary time scales in Fort Collins and Gaithersburg with masers
- Build a longer white-rabbit connection in response to SPD-7

Thank you!

# NIST

Time & Frequency Division