How Industry Utilizes GPS for Traceable Frequency Measurements and Calibrations

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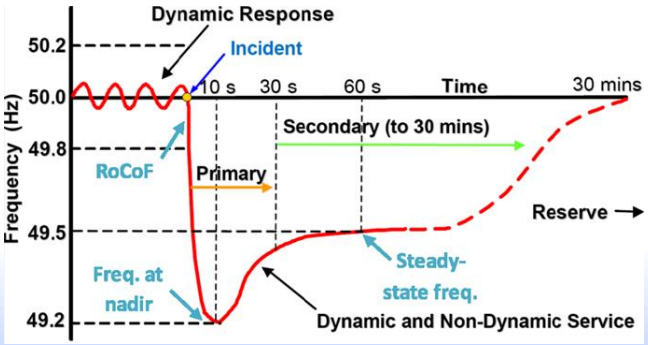
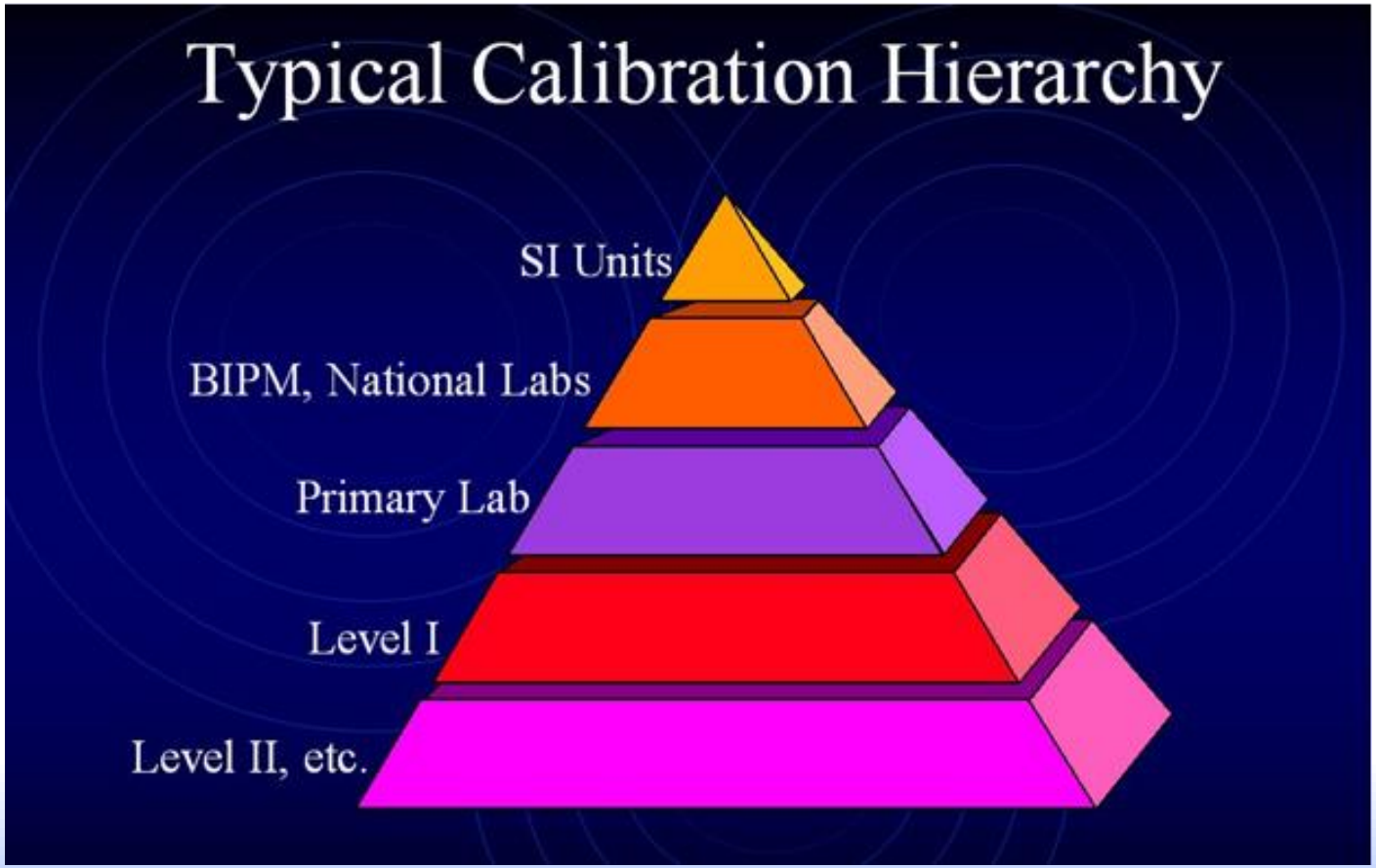
Where Frequency Measurements Are Needed

- Testing Laboratories (Biomedical, Chemical)
- Calibration Laboratories
- Legal Metrology
- Communications
- Industrial Process Control
- Electrical
- Police Radar
- Power/Energy



Measurement Quality Needs

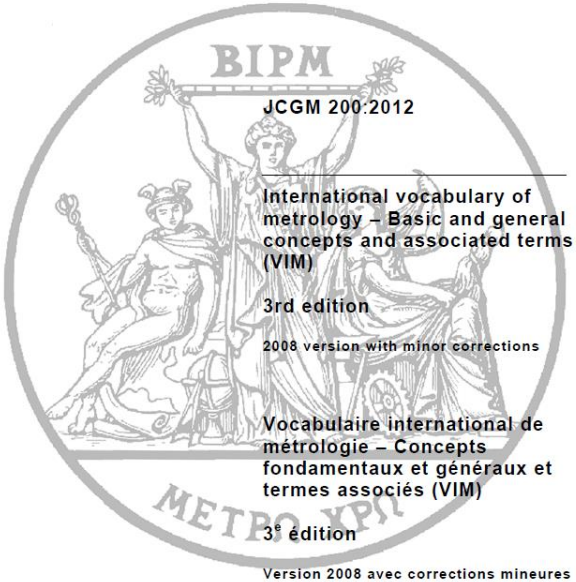
- Metrological Traceability to the SI (International System of Units)



Metrological Traceability Defined

- International Vocabulary of Metrology (VIM)

Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty



SI (BIPM) to NIST

- Circular T report available at BIPM Website
- http://www.bipm.org/en/bipm-services/timescales/time-ftp/cirt.html#nohref
- NIST uncertainty ≈ 1 x 10^{-14}

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The contents of the sections of BIPM *Circular T* are fully described in the document " Explanatory supplement to BIPM Circular T " available at ftp://ftp2.bipm.org/pub/tai/publication/notes/explanatory_supplement_v0.1.pdf

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties. From 2015 July 1, 0h UTC, to 2017 January 1, 0h UTC, *TAI-UTC* = 36 s. From 2017 January 1, 0h UTC, *TAI-UTC* = 37 s.

Date 2016 0h UTC		JUL 30	AUG 4	AUG 9	AUG 14	AUG 19	AUG 24	AUG 29	Uncertainty/ns		
	MJD	57599	57604	57609	57614	57619	57624	57629	u_A	u_B	u

NIST to GPS

- GPS Data Archive maintained by NIST
- https://www.nist.gov/pml/time-and-frequency-division/services/gps-data-archive
- NIST Uncertainty ≈ 1 x 10^{-14}

GPS monitoring data for the 30 day period ending 2016-08-31
(as received at NIST in Boulder, Colorado)

Archive Home | 1 Day Averages | 1 Hour Averages | 10 Minute Averages | Next Date | Last Date

GPS - UTC(NIST)
(one-hour averages using all satellites in view)

Hours	Mean Time Offset (ns)	Range (ns)	Frequency Offset	Confidence (r)
720	-8.20	19.98	<1.0 x 10^{-15}	+0.17

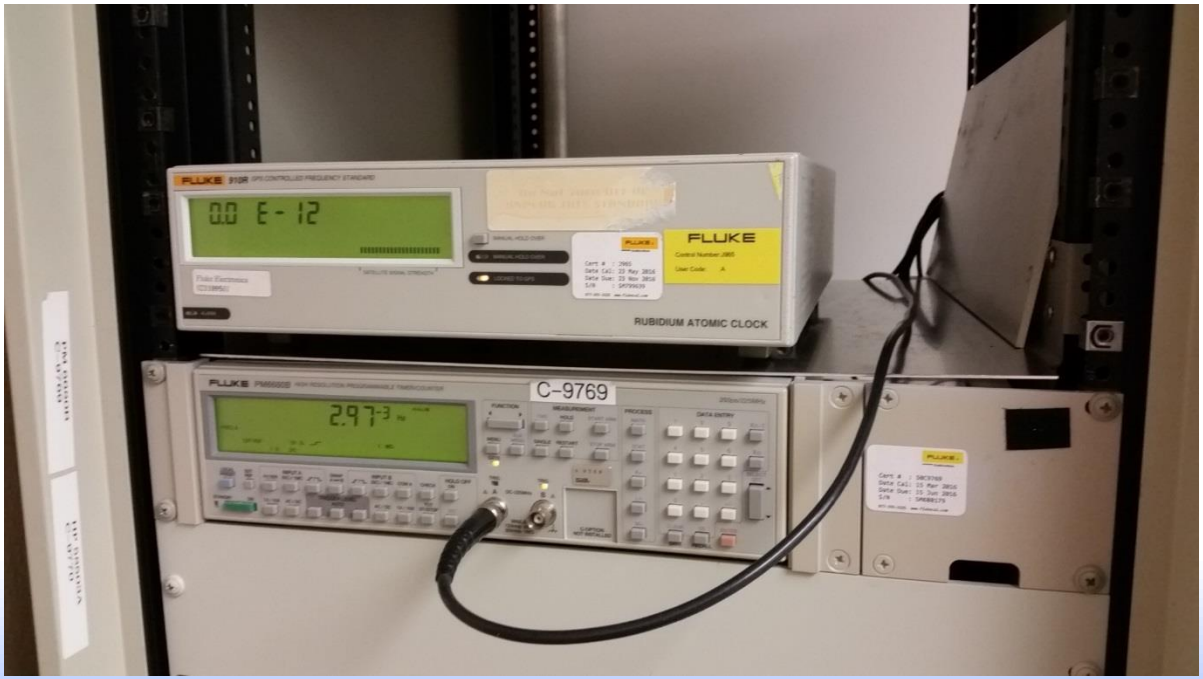
GPS Data Archive

GPS PRN - UTC(NIST)
(data from individual GPS satellites)

GPS PRN	Minutes (In-View)	Mean Time Offset	Range (ns)	Time Deviation	Frequency Offset
1	12180	-6.31	33.95	2.38	$<1.0 \times 10^{-15}$
2	10920	-12.62	36.00	1.56	$<1.0 \times 10^{-15}$
3	11060	-5.62	47.05	2.77	$<1.0 \times 10^{-15}$
4	---	---	----------	-------	----------
5	9340	-8.49	39.45	1.94	$<1.0 \times 10^{-15}$
6	9860	-7.22	35.35	1.90	$<1.0 \times 10^{-15}$
7	11420	-6.54	33.60	1.78	$+1.0 \times 10^{-15}$
8	11040	-7.26	32.80	2.52	$+1.3 \times 10^{-15}$
9	9650	-4.74	38.95	1.67	$+2.6 \times 10^{-15}$
10	11110	-6.99	141.60	3.23	$+1.7 \times 10^{-15}$
11	11140	-9.80	103.10	3.49	$<1.0 \times 10^{-15}$
12	9940	-8.28	40.30	1.67	$<1.0 \times 10^{-15}$
13	12730	-7.46	39.85	2.46	$<1.0 \times 10^{-15}$
14	11230	-9.63	34.45	1.79	$<1.0 \times 10^{-15}$
15	10020	-8.54	58.30	2.70	$<1.0 \times 10^{-15}$
16	10150	-8.42	34.05	2.41	$+1.6 \times 10^{-15}$
17	8540	-7.72	28.55	1.62	$<1.0 \times 10^{-15}$
18	12000	-11.08	140.60	2.19	$+1.3 \times 10^{-15}$
19	10430	-12.32	33.60	1.91	$<1.0 \times 10^{-15}$
20	9050	-12.24	48.35	1.81	$<1.0 \times 10^{-15}$
21	11850	-12.23	32.30	1.61	$<1.0 \times 10^{-15}$
22	8000	-9.95	23.55	1.36	$+1.2 \times 10^{-15}$
23	10590	-7.61	38.00	1.69	$+1.8 \times 10^{-15}$
24	13070	-6.51	40.40	2.32	$<1.0 \times 10^{-15}$
25	10310	-6.69	28.25	1.92	$<1.0 \times 10^{-15}$
26	11110	-5.35	47.15	2.22	$+1.8 \times 10^{-15}$
27	12150	-6.14	45.15	2.36	$+1.7 \times 10^{-15}$
28	12350	-10.42	37.50	1.69	$<1.0 \times 10^{-15}$
29	9750	-8.99	34.15	1.67	$<1.0 \times 10^{-15}$
30	9790	-7.43	33.35	1.76	$+1.4 \times 10^{-15}$
31	9720	-5.21	33.55	2.30	$+1.2 \times 10^{-15}$
32	8780	-6.23	37.30	1.54	$+1.3 \times 10^{-15}$

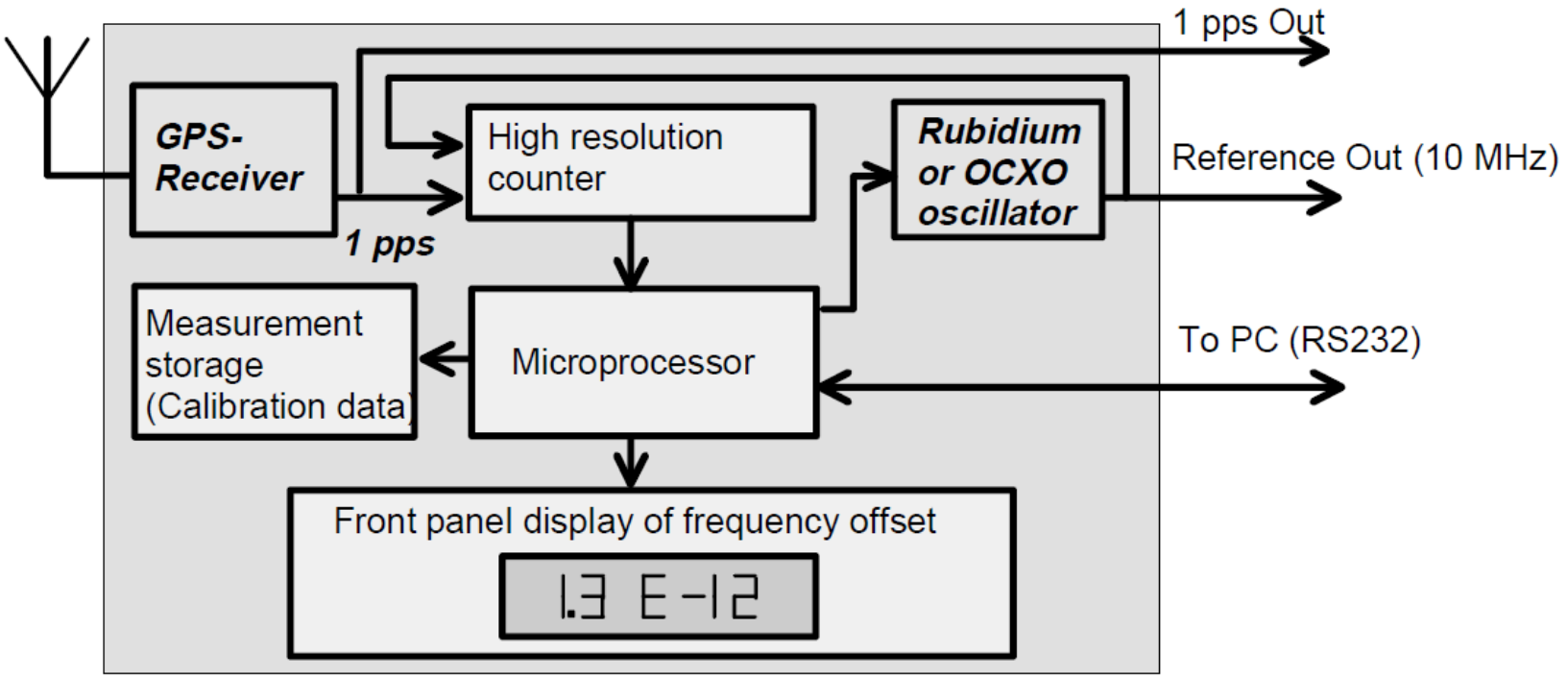
GPS to Industry

- GPS Disciplined Oscillator
- Fluke 910R
- Freq. offset (24 hour mean) < 1 x 10^{-12}
- Alan Deviation < 1 x 10^{-12} (t = 100 s)



Fluke 910R

- The only GPSDSO that provides cal data of the oscillator from GPS
- Data is stored and available to the user



Verification of Performance

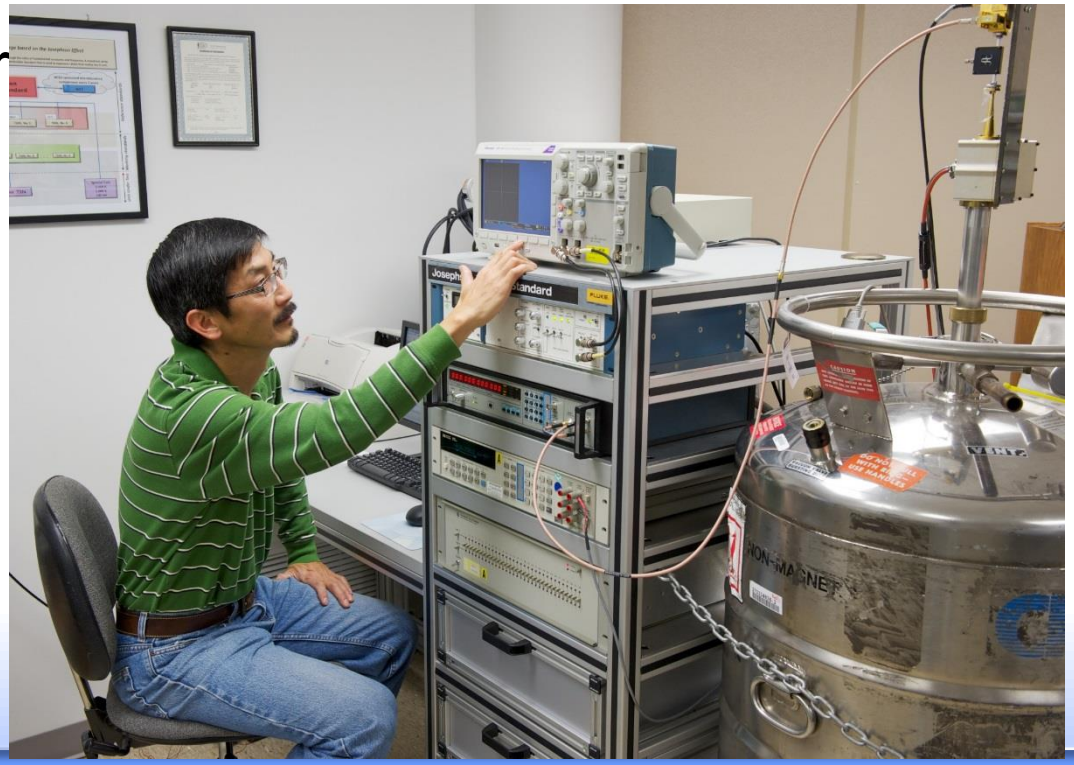
- Fluke has a reference 910R that is continuously compared using the NIST FMAS
- Uncertainty ≈ 3×10^{-13}
- Frequency offset is measured by FMAS and data is compared to the 910R internal data for agreement to 1×10^{-12}
- 910R owners can send in their units for calibrations
- Certificates issued are under laboratory scope of accreditation to ISO/IEC 17025

GPSDSO to Counters and Sources

- Time Base oscillators for Frequency Counters and Signal Generators calibrated via frequency comparison to GPSDSO
- Uncertainty ≈ 1 x 10^{-11}

GPSDSO as House Frequency Std

- Josephson Voltage Standard, primary standard for DC volt
- $K_{J\text{-}90}$ is assigned as 483 597.9 GHz/V
- Key contributor to uncertainty is frequency standard that drives Gunn diode at ≈ 75 GHz
- Uncertainty r



Down the Traceability Chain

- Frequency Counter calibrates lower accuracy Signal Generators
- Signal Generators calibrate lower accuracy Frequency measurement devices
- Timometer (stop watch calibrator)
- Specified accuracy 0.05 s/day (≈ 5.8 x 10^{-7})

Conclusion

- GPSDO’s are used in nearly every frequency calibration laboratory around the world
- Industrial measurement traceability depends on GPS