NIST Global Positioning System (GPS) Data Archive

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http://tf.nist.gov/service/gpstrace.htm

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NIST Global Positioning System (GPS) Data Archive

The Global Positioning System (GPS) is a radionavigation system that is available worldwide. GPS signals are broadcast from a constellation of 24 or more earth orbiting satellites. Because the GPS signals are derived from the atomic frequency standards on board each satellite, they are widely used as a reference for time synchronization and frequency calibration.

NIST continuously monitors the GPS signals from Boulder, Colorado and the frequency standard on each satellite to the NIST frequency standard. Commercially available GPS receivers often provide a 1 pulse per second (pps) timing output, and standard frequencies such as 1, 5, and 10 MHz. Properly designed GPS receivers can provide traceability to the national frequency standard maintained by NIST (read more about using GPS for NIST traceability).

The archived data available here can be used to support claims of frequency traceability to NIST through the use of GPS, since the frequency uncertainty of each satellite is listed. You can use the archive to quickly check the status of the GPS constellation on any given date.

To view archived GPS data select the month, day, and year, and then click the "Get Data" button. New data (from the previous day) are added daily at about 1600 UTC. By default, yesterday's date should be selected.

Month	Day	Year	Days
05 ▼	12 ▼	2003 ▼	__1 ▼

Get data

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GPS monitoring data for 2003-05-12 (as received at NIST in Boulder, Colorado)

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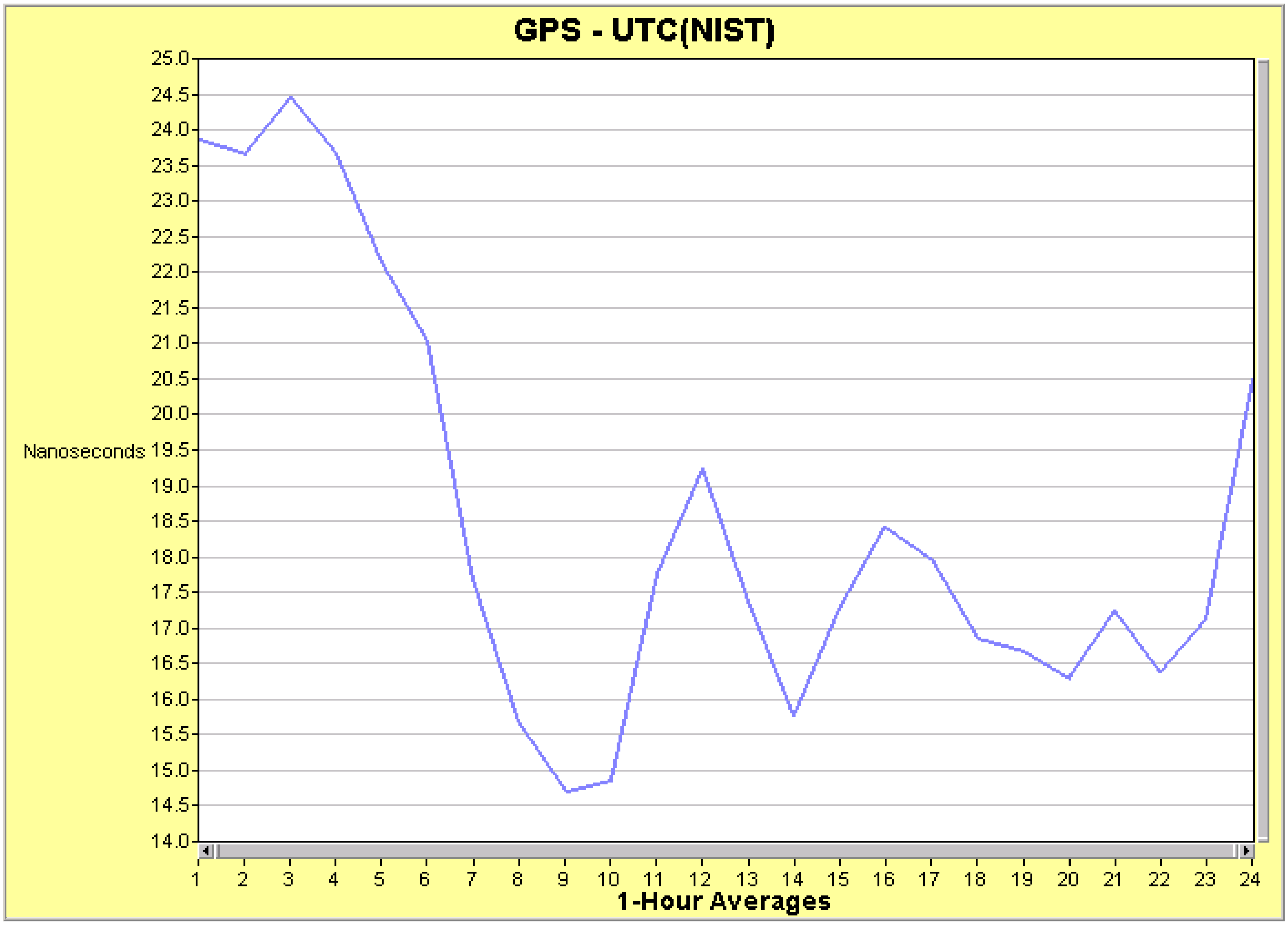
GPS - UTC(NIST)
(one-hour averages using all satellites in view)

Hours	Mean Time Offset (ns)	Range (ns)	Frequency Offset	Confidence (r)
24	18.6	9.7	-7.01×10^{-14}	-0.59



Allan Deviation

Averaging Time (τ) (hours, minutes)	Samples	Frequency Stability
0 h, 10 min	142	2.84 x 10^{-12}
0 h, 20 min	140	1.46 x 10^{-12}
0 h, 40 min	136	9.15 x 10^{-13}
1 h, 20 min	128	5.20 x 10^{-13}
2 h, 40 min	112	3.45 x 10^{-13}
5 h, 20 min	80	1.78 x 10^{-13}

Time Deviation

Averaging Time (τ) (hours, minutes)	Samples	Time Stability (ns)
0 h, 10 min	142	0.99
0 h, 20 min	139	0.77
0 h, 40 min	133	0.81
1 h, 20 min	121	0.94
2 h, 40 min	97	1.42
5 h, 20 min	49	1.72

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

GPS PRN	Minutes (In-View)	Mean Time Offset	Range (ns)	Time Deviation	Frequency Offset	Confidence (r)	View Track
1	370	+21.38	19.40	1.24	-5.5 x 10^{-13}	-0.74	View
2	350	+21.55	21.80	1.85	-5.3 x 10^{-13}	-0.61	View
3	450	+15.36	15.65	1.62	+5.3 x 10^{-14}	+0.37	View
4	330	+17.20	13.40	0.91	-1.6 x 10^{-14}	-0.03	View
5	380	+13.79	25.30	2.54	-2.2 x 10^{-13}	-0.68	View
6	330	+19.34	29.80	1.10	-6.4 x 10^{-13}	-0.46	View
7	380	+13.20	9.55	1.11	-2.5 x 10^{-13}	-0.66	View
8	350	+16.42	13.25	1.14	+2.5 x 10^{-13}	+0.48	View
9	420	+21.67	13.55	1.25	+1.0 x 10^{-13}	+0.59	View
10	370	+19.12	16.95	1.26	-5.9 x 10^{-14}	-0.21	View
11	460	+23.42	14.70	1.64	-4.1 x 10^{-14}	-0.21	View
12	---	---	----------	-------	--------------	------	----
13	340	+19.26	18.60	1.05	-5.6 x 10^{-13}	-0.86	View
14	370	+20.30	14.75	0.94	-7.6 x 10^{-14}	-0.74	View
15	310	+10.14	30.55	2.24	-8.4 x 10^{-14}	-0.22	View
16	370	+23.42	68.00	7.91	-5.2 x 10^{-15}	-0.01	View
17	400	+17.98	17.30	2.87	+2.0 x 10^{-13}	+0.48	View
18	340	+18.52	13.35	1.54	-6.0 x 10^{-14}	-0.58	View
19	---	---	----------	-------	--------------	------	----
20	390	+22.95	13.00	1.12	-8.0 x 10^{-14}	-0.39	View
21	300	+16.30	11.10	0.89	+3.7 x 10^{-13}	+0.81	View
22	---	---	----------	-------	--------------	------	----
23	350	+15.61	23.35	1.33	-1.7 x 10^{-13}	-0.91	View
24	370	+21.69	15.35	1.12	+2.5 x 10^{-13}	+0.42	View

25	350	+19.38	19.40	1.45	-3.7×10^{-14}	-0.22	View
26	320	+19.12	19.90	1.87	-7.1×10^{-14}	-0.25	View
27	390	+21.18	12.20	1.48	-1.6×10^{-13}	-0.29	View
28	410	+8.59	10.35	1.13	$+1.0 \times 10^{-13}$	+0.31	View
29	400	+19.08	18.70	1.75	$+2.6 \times 10^{-14}$	+0.13	View
30	400	+24.77	18.80	1.25	-1.3×10^{-13}	-0.58	View
31	310	+14.09	24.00	1.43	$+2.8 \times 10^{-13}$	+0.96	View
32	---	---	----------	-------	--------------	------	----

Legend	
GPS PRN	The unique pseudo random noise (PRN) code (1 to 32) used to identify each satellite. If no satellite is assigned to a given PRN code, then no data are shown.
Minutes (In-View)	The number of minutes when the satellite was visible at NIST in Boulder, Colorado. During this period, the time difference between the satellite clock and UTC(NIST) is measured every second, and 10 minute averages are stored. Since data is recorded in 10 minute segments, the values are even multiples of 10 minutes.
Mean Time Offset	The mean time offset (nanoseconds) of the 10-minute averages recorded from each satellite.
Range	The difference between the maximum and minimum time offset values (nanoseconds).
Time Deviation	The time deviation (TDEV) of the 10-minute averages (nanoseconds).
Frequency Offset	The estimated frequency offset of the satellite clock with respect to UTC(NIST). This estimate is obtained by fitting a least squares line to all of the recorded data.
Confidence Level (r)	The confidence level of the estimated frequency offset. The confidence level is the correlation coefficient (r) of the least squares line fitted to the data.
View Track	Clicking on the View link displays a plot of data from the selected satellite. The number of previous days shown equals the number of previous days shown on this page, up to a maximum of 30 days.

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Using a Global Positioning System (GPS) receiver as a NIST traceable frequency reference

GPS receivers often provide a 1 pulse per second (pps) timing output, as well as standard output frequencies such as 5 and 10 MHz. If properly designed and used, a GPS receiver can provide traceability to the NIST frequency standard. The NIST GPS data archive shows the frequency of the signals broadcast from each GPS satellite with respect to NIST. However, before claiming NIST traceability using GPS, please read the following sections.

The Importance of Traceability

What is traceability? According to ISO's *International Vocabulary of Basic and General Terms in Metrology (VIM)* [1], traceability is defined as:

> *The property of a result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.*

Since many companies now seek registration or compliance with ISO-9000 quality standards, more and more importance is being placed on traceability. ISO Guide 17025 [2] is the internationally recognized document that lists the requirements for competence of calibration and testing laboratories. Section 5.6.21 of Guide 17025 states:

> *For calibration laboratories, the program for calibration of equipment shall be designed and operated so as to ensure that calibrations and measurements made by the laboratory are traceable to the SI (Systeme International) units of measurement. Traceability of measurement shall be assured by the use of calibration services from laboratories that can demonstrate competence, measurement capability, and traceability. The calibration certificates issued by these laboratories shall show there is a link to a primary standard or to a natural constant realizing the SI unit by an unbroken chain of calibrations.*

In short, in order to meet Guide 17025 requirements, calibration and testing laboratories must demonstrate that their calibrations are traceable to national standards. In many cases, United States laboratories must show traceability to NIST. Since many laboratories use GPS receivers as a frequency reference and since GPS is not a NIST generated service, this raises the following questions: "Is GPS a NIST-traceable frequency reference? If so, what is the uncertainty?" The answers to these questions are discussed below.

The Traceability Chain

The definition of traceability tells us that a traceable measurement requires an "unbroken chain of comparisons all having stated uncertainties." In order to show traceability to NIST through the use of GPS, the unbroken chain must stretch from the measurement made with GPS back to NIST.

The time and frequency reference for GPS is provided by the United States Naval Observatory (USNO). The NIST and USNO frequency standards are regularly compared and equivalent at their point of origin to 1×10^{-13} or less. [3] One way to establish the traceability chain is to show the uncertainty of the GPS constellation relative to the USNO frequency standard, and then show the uncertainty of the USNO frequency standard relative to the NIST frequency standard. Raw data from the following sites can be used to compute the uncertainty:

- GPS Time vs. UTC via USNO Master Clock
- BIPM Circular T (Shows NIST, USNO and other national laboratories relative to UTC)

A second, more convenient way to establish the traceability chain is through a direct comparison of GPS to the NIST frequency standard. This comparison is made through NIST monitoring of the GPS satellites as discussed in the next section.

NIST Monitoring of GPS Broadcasts

In order for continuous traceability to be established, continuous comparisons must be made. In a presentation at the 5th U. S.-Italy Bilateral Seminar, the Acting Deputy Directory of NIST expanded on the definition of traceability:

> *It is noted that traceability only exists when scientifically rigorous evidence is collected on a continuing basis showing that the measurement is producing documented results for which the total measurement uncertainty is quantified.*

Using these comments as a guideline, Ehrlich and Rasberry [4] of NIST state that:

> *A single measurement result is sufficient to establish uncertainty relationships only over a limited time interval, and that direct periodic comparisons are otherwise required.*

For this reason, NIST compares the frequency recovered from GPS to the national frequency standard 24 hours per day to establish continuous traceability. The signal broadcast from each satellite is monitored for the entire time that the satellite is visible from the NIST laboratories in Boulder, Colorado. The results of these comparisons are published (updated daily) in the NIST GPS data archive.

The data archive lists daily time and frequency offsets for each GPS satellite. These data for the previous UTC day are made available each morning at about 1600 UTC. The archived data are obtained by comparing a "typical" GPS receiver to the NIST frequency standard. These data can be used to support claims of frequency traceability to NIST through the use of GPS signals.

Keep in mind that NIST monitors the satellites only while they are visible from Boulder, Colorado. Data broadcast by the satellites when they are not visible to NIST are not published in the data archive. Using more than one monitoring station is a future possibility.

Are all GPS Receivers Traceable Frequency Standards?

Even though the GPS broadcasts are continuously monitored by NIST, not all GPS receivers are suitable for use as traceable frequency standards. Remember that the definition of traceability states that traceability is the property of "the result of a measurement." The uncertainty relative to NIST can vary widely depending upon the GPS receiver used to perform the measurement. The uncertainty is also dependent upon the method or procedure used to perform the measurement.

To explain why different GPS receivers behave differently requires discussing the similarities and differences of the commercially available models. Hundreds of companies sell GPS products, and at least a dozen manufacturers advertise their units as time and frequency standards. Most receivers are designed using an OEM GPS "engine." These engines are small circuit boards or chipsets that require a power supply, antenna, and control software to use. They typically have a computer interface and provide a 1 pps output.

Commercial GPS receivers share several characteristics:

- Most GPS receivers automatically select the satellites used in the timing solution. This makes them easy to use. Often, you simply turn the receiver on and wait for a signal to be acquired. However, different algorithms are used to select satellites, and each receiver has its own thresholds at which it decides to keep, drop, or acquire a satellite. Some algorithms choose the satellites that provide the best geometric dilution of precision (GDOP). Others choose the highest in the sky after a fixed position has been entered. Some algorithms limit the timing solution to just one, or just a few satellites. Others can use as many as 12 satellites in the solution. For this reason, two GPS receivers can obtain very different results even when connected to the same antenna in the same location.

- Most GPS receivers have poor short term stability. The models with the best short term stability typically discipline an oven controlled quartz oscillator (OCXO) or a rubidium oscillator to the GPS signal. However, many receivers do not discipline an oscillator at all. Instead, they divide the output of a small temperature controlled crystal oscillator (TCXO) to 1 pps, and then synchronize the 1 pps to the GPS signal. The TCXO free runs and the receiver accumulates time errors until the total time error approaches a threshold (a multiple of the half period of the oscillator), and then generates a phase step that reduces the time error to a minimum. Some receivers step phase in increments of 100 ns or less, but some use increments of 1 μs or larger. If the TCXO is offset in frequency by 1×10^{-7} (typical), a 100 ns phase correction is needed every second. As a result, the short term stability of these models is very poor, but their long term performance may be equivalent to models that discipline a quartz or rubidium.

- Some GPS receivers are suitable for timing applications, but are not suitable as a frequency reference. For example, a receiver that produces a 1 pps output for timing applications, might do a poor job of producing standard frequencies like 5 and 10 MHz. In some cases, the 1 pps output is not in phase with the standard frequency outputs. You might find receivers with a specification for frequency uncertainty (5 and/or 10 MHz) of about 1×10^{-9}, even if the specification for their 1 pps output is 100 ns.

- Most receivers allow the use of a fixed position, after which no further positions are computed. However, some receivers cannot turn off position fixes, which makes them a poor choice for a frequency standard. Even though the receiver is stationary, it will appear to be moving, and the position errors will contribute large fluctuations to the frequency.

- Since each GPS satellite is visible at a given location for a limited time, all GPS receivers must add and remove satellites from the group used to obtain time and frequency information. Often, adding and/or removing a satellite from the timing solution causes an instantaneous frequency change. Some receivers have much better "handoff" algorithms than others.

- Different receivers handle GPS broadcast errors differently. For example, if a satellite is broadcasting bad data (such as PRN 5 on March 18, 1997), some receivers fail, and others do not. Some receivers have built-in software designed to remove "bad" data, but even these receivers might fail under certain conditions.

If requested by a manufacturer or end user, NIST can evaluate a particular GPS receiver for its suitability as a frequency standard. For a predetermined fee, NIST will issue a report stating the frequency uncertainty of the receiver under test relative to NIST. The uncertainty will be stated for each output frequency over a given measurement interval. The results of this evaluation are kept confidential and not published by NIST.

Typical GPS Performance

Since the deactivation of the Selective Availability program on May 2, 2000, most GPS receivers now produce a 1 pps output with a standard deviation of 10 ns or less. Many receivers produce frequency with an uncertainty of $< 1 \times 10^{-12}$ when averaged for one day. Two key factors that contribute to receiver performance are the quality of the receiver's internal oscillator, and the quality of the software algorithms that process data acquired from the satellites.

Summary and Conclusion

A properly designed and maintained GPS receiver can be used to show frequency traceability to NIST at an uncertainty of $< 1 \times 10^{-12}$ when averaged for one day. There are at least 2 ways to establish traceability to NIST through the use of GPS:

- By subscribing to the NIST Frequency Measurement and Analysis Service. This service provides everything needed to establish traceability to NIST at an uncertainty of 2×10^{-13}, including a complete GPS-based measurement system that can calibrate 5 oscillators at once. The measurement results are reviewed by NIST personnel and a monthly traceability report and uncertainty statement is sent to each subscriber.

- By using a commercial GPS receiver designed to work as a traceable frequency standard, operating the receiver properly, and establishing a traceability chain through the use of the NIST GPS data archive, or the use of NIST-USNO comparison data. The uncertainty of a specific receiver can be estimated by using the manufacturer's specification, or by having NIST or another national measurement laboratory perform an evaluation.

References

1. *International Vocabulary of Basic and General Terms in Metrology*, second edition, International Organization for Standardization (ISO), 1993.
2. ISO/IEC Guide 17025, *General Requirements for the Competence of Calibration and Testing Laboratories*, International Organization for Standardization (ISO), 1999.
3. Dennis Bodson, Robert T. Adair, and Michael D. Meister, "Time and Frequency Information in Telecommunication Systems Standardized by Federal Standard 1002A", *Proc. of the IEEE*, Volume 79, Number 7, July 1991.
4. Charles D. Ehrlich and Stanley D. Rasberry, Metrological Timelines in Traceability (PDF file), *Journal of Research*, Volume 103, Number 1, January-February 1998.

For more detailed information about GPS measurements and GPS traceability chains, please see the following papers:

Traceability in Time and Frequency Metrology
(Cal Lab Int. Jour. of Metrology, September-October 1999, pp. 33-40)

Time and Frequency Measurements using the Global Positioning System
(Cal Lab Int. Jour. of Metrology, July-September 2001, pp. 26-33)

For questions or comments regarding GPS traceability to NIST, contact Michael Lombardi: (lombardi@boulder.nist.gov).

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