



Australian Government
Department of Industry,
Innovation and Science

**National
Measurement
Institute**

Traceability of the NMI WebTimer service

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Summary

This document describes how the NMI WebTimer is traceable to the Australian national standard for time, UTC(AUS). It explains the role of NMI in providing Australia's standards for time and frequency, how the WebTimer works, details the uncertainty budget for the WebTimer, and provides examples of how the time interval measurement reported by the WebTimer is calculated and then used in practice.

Time in Australia

The National Measurement Institute (NMI) maintains the Australian primary standard for measurement of frequency and time interval and is the legal reference for time of day in Australia. These roles are defined in the *National Measurement Act (1960)*.

The Australian primary standard for time of day is realized at the NMI Lindfield site using atomic clocks and is denoted UTC(AUS). This nomenclature indicates that UTC(AUS) is a realization of Coordinated Universal Time (UTC), the international time standard, and is traceable to UTC. This traceability is maintained through continuous participation in CCTF-K001.UTC, the Key Comparison in time and frequency. The results of this Key Comparison are reported in *BIPM Circular T*.¹

How the WebTimer works

The WebTimer operates like a stopwatch. When a user presses the 'Start' button, the user's computer requests the time from the remote WebTimer server. Similarly, when the 'Stop' button is pressed, another time request is made. The difference between these two times is then calculated and reported to the user. The uncertainty in each measurement is mainly determined by the time taken for each time request to travel to the server and back and this is also reported to the user.

Traceability and auditability of the WebTimer

The server running the WebTimer software takes its timing reference directly from the Australian primary standard UTC(AUS) as a continuous, one pulse-per-second electrical signal (Figure 1). This keeps the server synchronized with respect to UTC(AUS) to better than 10 microseconds.

Time-of-day is obtained from NMI's network of Network Time Protocol servers which are themselves fully traceable to UTC(AUS).

Continuous records of the synchronization of the WebTimer and its offset from UTC(AUS) are kept and available to users of the service.

NMI Time and Frequency is fully accredited for time and frequency measurements by NATA, the National Association of Test Authorities. Our current NATA accreditation includes measurement of time interval with a least uncertainty of 2 ns, and UTC(AUS) with a least uncertainty of 50 ns.

¹ <https://www.bipm.org/en/bipm-services/timescales/time-ftp/Circular-T.html>

Uncertainty budget for the WebTimer

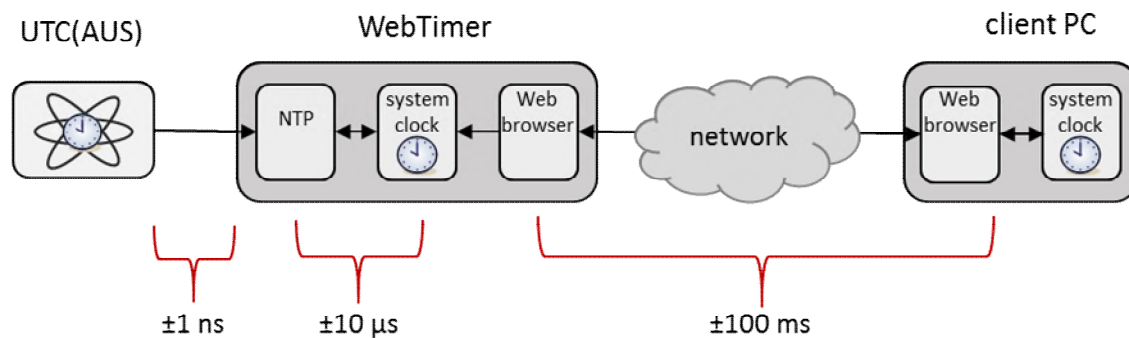


Figure 1 Measurement chain for the WebTimer and some typical uncertainties. The overall uncertainty is dominated by the network delay.

A complete measurement requires the time stamps T_{start} for the start time and T_{stop} for the stop time, each with its own uncertainty. Here we will describe an uncertainty estimate for a single time stamp.

Uncertainty budget for the WebTimer server time

A one pulse-per-second (pps) signal from UTC(AUS) is used to synchronize the WebTimer server (Figure 1). The uncertainty in the delay of the cable providing this 1 pps is the principal uncertainty in the distribution chain. Other factors such as the effect of temperature variations are negligible in comparison. More detailed information about this can be obtained from NMI if required.

The server's operating system must time stamp each incoming 1 pps to measure the difference between the server time and the 1 pps and the server does not respond instantly to each incoming 1 pps. The typical delay is known from measurements to be between 10 and 20 μ s and is accounted for as a systematic correction of 15 ± 5 μ s.

It also takes a measurable time to make a call to the server operating system to retrieve the current time. This systematic delay is measured to be between 17 and 25 ns and is accounted for as a systematic correction of 21 ± 4 ns.

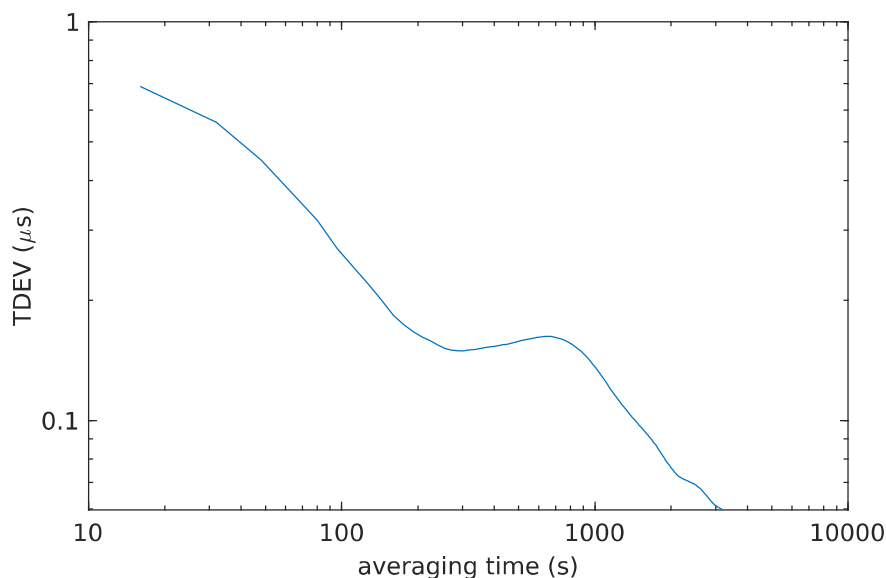


Figure 2 Time deviation (TDEV) of offsets applied to the server system time.

Finally, a contribution for the instability of the system time is added. The log files of time offsets applied to the system time by ntpd, the NTP software, are used to estimate the time deviation TDEV. ntpd also adjusts the frequency of the system clock, but this adjustment is very small, typically a few parts in 10^8 , so the contribution from this is neglected. Figure 2 shows the time deviation TDEV during typical operation. TDEV at 16 s, the interval between updates to the system time, is used to characterize the instability and is approximately 0.6 μ s.

Uncertainties in the server system are summarized in Table 1 below. The main source of uncertainty is the 1 pps time stamping delay.

Table 1 Uncertainty budget for the server system time

Uncertainty component	Raw estimate U_i (μ s)	Distribution	Reducing factor k_i	Standard uncertainty (μ s)
Cable delay	0.001	normal	1	0.001
1 pps time stamping delay	5	normal	1	5
System time stamp latency	0.004	normal	1	0.004
System time stability	0.6	normal	1	0.6
Combined standard uncertainty				5
Expanded uncertainty (k=2)				10

Uncertainty in the WebTimer client time stamp

Model of the measurement

The WebTimer client (i.e. the software running on the user's computer) requests a time stamp from the WebTimer server over the Internet (Figure 1). The time taken for the time stamp to be transmitted to the server and then returned to the client (network delay) is unpredictable and the major source of measurement uncertainty.

To estimate the delay and its uncertainty, the WebTimer uses the same method as is used in the Network Time Protocol to synchronize computers over a network. Four time stamps are recorded:

- T_1 The client records the time at which it sends a request (i.e. when the user presses the 'Start' or 'Stop' button)
- T_2 The server records the time when it receives the request
- T_3 The server records the time when it replies to the request
- T_4 The client records when it receives the reply

The time stamp T_1 is the time stamp associated with pressing the button. It is made using the client computer as the time reference and is not traceable. However, it can be corrected and made traceable. In particular

$$T_1(\text{corrected}) = T_2 - \text{forward network delay}$$

The round trip network delay Δ is estimated as:

$$\Delta = (T_4 - T_1) - (T_3 - T_2)$$

The term $T_3 - T_2$ is an estimate of the processing delay on the server. This is typically much less than 1 ms.

To estimate the one-way network delay δ , it is necessary to assume that the network path is symmetric i.e. that the forward and return delays are equal so that $\delta = \Delta/2$. Under normal conditions this is a good approximation but to recognize that this may not always hold, δ is assigned an uncertainty of $\Delta/2$. This encompasses the two limits, where the forward network delay is zero, and where the forward network delay is all of the measured delay (equivalently, the return network delay is zero).

Other error sources

The time stamps T_1 and T_4 are obtained using a Javascript function which has a resolution of 1 ms. The time stamps T_2 and T_3 are obtained from the server and have a resolution of 1 μ s.

The delay δ is not strictly traceable because it is estimated using the client PC time. However, the uncertainty in δ arising from this can be readily bounded. The clock in a computer is a crystal oscillator which at worst will have a frequency error of a few parts in 10^4 . Assuming that $\delta = 1$ s and a crystal frequency error of 1 part in 10^3 , the additional error in δ is just 1 ms. Typically, δ will be much less than 1 s, so this estimate is conservative.

The use of a mouse to trigger recording of time stamps introduces a time delay and uncertainty. USB human interface devices like mice and keyboards are polled devices so there is a delay between, for example, the mouse being clicked and the event registering with the operating system. This delay is typically 8 ms so an uncertainty of ± 4 ms is assigned.

Uncertainty budget

The *fixed* components of the uncertainty budget for a single time stamp, including the server time as estimated in Table 1, are summarized in Table 2. The main contribution to the uncertainty is the mouse click latency.

Table 2 Fixed components of the uncertainty budget

Uncertainty component	Raw estimate U_i (ms)	Distribution	Reducing factor k_i	Standard uncertainty (ms)
WebTimer server time	0.005	normal	1	0.01
Client PC time stamp resolution	1.4	rectangular	1.73	0.8
Server time stamp resolution	0.0014	rectangular	1.73	0.0008
Client PC frequency error	1	normal	1	1
Mouse click latency	4	rectangular	1.73	2.3
Combined standard uncertainty				2.6
Expanded uncertainty (k=2)				5.2

The uncertainties displayed by the WebTimer do not include the total fixed component of 5.2 ms estimated here because it is not applicable to all client platforms. For example, it is not applicable to touchscreen devices. It is left to the user to include this uncertainty, noting however that it will typically be negligible in comparison with the network delay.

Example of a time interval measurement reported by the WebTimer

Suppose the WebTimer records the following four UNIX² time stamps for 'Start':

$$T_1 = 1489361716.056$$

$$T_2 = 1489361716.2738$$

$$T_3 = 1489361716.274$$

$$T_4 = 1489361716.297$$

and the following four time stamps for 'Stop':

$$T_1 = 1489361766.054$$

$$T_2 = 1489361766.245$$

$$T_3 = 1489361766.2452$$

$$T_4 = 1489361766.268$$

For 'Start', the one-way network delay is

$$\begin{aligned}\delta &= [(1489361716.297 - 1489361716.056) - (1489361716.274 - 1489361716.2738)]/2 \\ &= 0.1204 \text{ s}\end{aligned}$$

and the start time is

$$T_{\text{start}} = T_2 - \delta = 1489361716.1534$$

The uncertainty δ in the start time has a rectangular distribution so the standard uncertainty is 0.07 s.

Similarly, for the stop time

$$\delta = 0.1069 \text{ s}$$

$$T_{\text{stop}} = 1489361766.1381$$

The reported time interval is then

$$1489361766.1381 - 1489361716.1534 = 49.9847 \text{ s}$$

Combining the two uncertainties in quadrature, the uncertainty in the time interval measurement is 0.161 s, which expands to 0.322 s using a coverage factor of 2.

Example calculation of time interval uncertainty for a stopwatch verification

Suppose that a stopwatch is being verified using the WebTimer running on a PC.

Using the data from the previous example, the WebTimer reports to the user:

$$\text{time interval} = 49.9847 \text{ s}$$

$$u = 0.161 \text{ s } (k=1)$$

² UNIX time is counted as the number of seconds since the beginning of Jan 1st, 1970 UTC.

From Table 2, the fixed components of the uncertainty budget error component contribute an extra 0.0026 s which must be included twice (once for each time stamp).

The uncertainty estimated here also needs to make an allowance for the stopwatch and mouse not being started or clicked at the same time. This is taken to be 0.2 s and it must be included twice.

Summing in quadrature, the total unexpanded uncertainty is thus

$$\sqrt{0.161^2 + 2 \times 0.0026^2 + 2 \times 0.2^2} = 0.32 \text{ s.}$$