Status Report: Time and Frequency Activities at the National Measurement Institute, Australia

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Abstract

The Australian National Measurement Act requires NMI to maintain Australia's standards for measurement of physical quantities. This paper presents an update on some of the activities of the Time and Frequency Section of NMI since the most recent ATF meeting at KRISS in 2002.

1. Introduction

The Time and Frequency Section of the National Measurement Institute (NMI), presently six staff, is responsible for maintaining Australia's national standards for time of day and for frequency, disseminating time and frequency information nationally and internationally by a variety of methods, and carrying out research in the field of time and frequency standards**.** These activities have been described previously [1]; this paper will present a short summary, together with recent developments since the time of the last ATF meeting at KRISS in 2002.

2. Formation of a new National Measurement Institute

On the 1st July 2004, the National Measurement Laboratory (NML) separated from the Australian scientific organization CSIRO and became part of the new National Measurement Institute of Australia. The NMI is constituted as a Division of the Commonwealth Department of Industry, Tourism and Resources. It amalgamates and replaces the former CSIRO NML, the Australian Government Analytical Laboratories (AGAL) and the National Standards Commission (NSC). Dr Barry Inglis, formerly the Director of NML, heads the NMI as both Chief Executive Officer and Australia's first Chief Metrologist.

The NMI comprises three Branches: Physical Metrology, incorporating the physical standards work of the former NML and the pattern approval activities of the NSC; Chemical and Biological Metrology, incorporating the former AGAL and the gas mixture standards activities of NML; and Legal Metrology.

3. Standards for time and frequency

3.1. Australia's national standards

NMI presently maintains four commercial cesium beam standards and two hydrogen masers on site in Lindfield, Sydney. The 1 pulse-per-second (pps) output of one of the HP5071A cesium standards is designated as UTC(AUS), the official Australian realization of Coordinated Universal Time (UTC). The rate of this cesium standard is adjusted from time to time in order to maintain UTC(AUS) within 1µs of UTC. A 10 MHz output from the same standard is designated as the National Frequency Standard.

3.2. Australia's contribution to UTC

Australia contributes to UTC by NMI reporting GPS time receiver and clock data to BIPM. NMI collects and transmits this data to BIPM following BIPM's standard protocols and data formats. Clock data (values of UTC(AUS) – clock) are currently submitted from clocks located at NMI Sydney, at the Tidbinbilla deep space tracking station near Canberra and at the Telstra laboratories in Melbourne.

UTC(AUS) is thus linked via continuous GPS common-view (GPSCV) time transfer to the international network of clocks from which UTC is derived. Reporting of clock data to BIPM is essential for maintaining international traceability of Australian time and frequency. The history of UTC(AUS) since August 2002 is shown in Figure 1.

4. Time and frequency dissemination in Australia

NMI monitors a variety of signals at the Sydney site and around Australia to support dissemination of UTC(AUS) by comparison of remote clocks with the national standard [1]. These signals include GPS (with monitoring of integrity of GPS signals as received at several locations) and the synchronization pulse in television broadcasts. Monitoring of Radio VNG, a high-frequency broadcast radio time service operated by NSC, ceased when this service was shut down at the end of 2002. Clients from around Australia submit devices for calibration at NMI, providing legal traceability to the national standards by direct comparison. NMI also maintains Network Time Protocol servers for distributing time through the Internet, a direct telephone dial-up service and has recently constructed a speaking clock.

4.1. Network Time Protocol (NTP)

At the last ATF meeting [1] we reported a sudden, exponential growth in traffic to our public NTP servers. The projected network charges quickly became of concern and it was necessary to investigate the source and any means of halting the growth. Most of the traffic was eventually traced to an inexpensive broadband router/firewall sold for home use in the US. How this was done, and the potential hazards of operating a public-access NTP service, may be of some interest.

Traffic on our NTP servers is monitored continuously with daily logs summarized and emailed automatically for perusal. One day, a particular IP address started sending more than 200 queries per second to each of our three NTP servers. This sort of problem is relatively common, usually disappearing within 24 hours, but on this occasion it persisted. We were fortunately able to contact the owner of that address in Washington, using contact details from the ARIN database, and trace the traffic to a router. The owner was unaware of the NTP function of the router, and said that there was no mention of this in the manual and no way to reconfigure it. It seemed that there could be many of these routers using our NTP servers.

The router was known to poll all three of our NTP servers, and the traffic logs confirmed that nearly all of our clients did this. Analysis of the polling frequency identified one group of about 70,000 addresses polling every two hours, and another large group polling every thirty seconds. (We also identified another large group of about 100,000 addresses, largely in Japan, polling once per day; subsequent enquiries indicated that this low-level traffic was probably from another router type manufactured there.) A combination of careful analysis of request traffic, experiments blocking response to particular addresses, and tests with a unit we purchased confirmed that requests from both groups of addresses were originating from this model of router. These units normally polled our servers every two hours, but increased this to every 30 seconds if no reply was received. Unfortunately, the default configuration of the router blocked replies to its own NTP requests, generating a group of devices polling every 30 seconds and a significant load on our NTP servers. If our servers blocked all responses, these routers generated over 2000 NTP requests per second per server, causing operational problems for our network operators. Our server addresses had been coded into the router firmware and could not be reconfigured.

After persistent effort, we were eventually able to establish contact with the manufacturer, who agreed to remove references to our servers from the firmware. This stopped new traffic, but existing traffic could still grow substantially if our server responses were blocked (for example, by another firewall or by a change to the router security settings). Users of these devices were unlikely to upgrade the firmware, so a solution for existing traffic was still required. Our network operator decided to 'blackhole' the NTP traffic by propagating a null route for the NTP servers. This does not stop the traffic; it just blocks it closer to its origin, so that it is not concentrated at a few points. Unfortunately, it is likely that this traffic will persist for years to come.

Any open, public service will always be vulnerable to this kind of unintentional abuse. We have therefore moved our NTP servers to new addresses and restricted access. Prospective users must first register their details and give the IP addresses of their NTP clients. Unregistered clients do not receive a response from our servers. After 18 months of operation, we have about 280 registered users. The users are diverse, including banks, large companies, government departments, universities, Internet service providers and individuals. The requirement for a static IP address bars many home users from accessing the service.

Our experiences mirror those of several other NTP service operators in the past two years, including at least one other national laboratory. As a result of these problems, an Internet Engineering Task Force working document was produced by Dave Plonka at the University of Wisconsin, with recommendations pertinent to NTP service operators [2]. However, there continue to be reports of new devices with embedded, non-configurable NTP clients on the comp.protocols.time.ntp newsgroup, so the process of educating network device manufacturers is likely to be long.

4.2. Computer dialup service

The computer dialup time service uses the ACTS protocol as designed by Judah Levine at NIST. Demand for this service is relatively low at present. It is mainly used by organizations which are unable to use NTP because of their network security policy.

4.3. Speaking clock

Existing speaking clock services in Australia have been measured to have relatively low accuracy, exhibiting variations of several hundred milliseconds or larger over the course of a day. For some purposes, such as spot checks on the operation of stop watches, improved accuracy is desirable, and traceability to UTC(AUS) is important for a number of applications. NMI has constructed and tested a speaking clock in the past year to address this need.

The speaking clock design separates the tasks of generating voice announcements and marker tones (Figure 2). The marker tones are produced by dedicated hardware and their epoch is directly traceable to UTC(AUS). Since there are no hard timing requirements on the voice announcement, this function is performed by a PC, with the voice announcement generated by audio cards in the PC. The voice announcement and pips are combined and then pass to the telephone system. The PC, which is synchronized to a 1 pps signal from UTC(AUS) and local time-of-day sources, also checks the synchronization of the marker tones and adjusts the position of the marker tones during leap seconds. The software runs under the Linux operating system, providing high integrity and reliability and allowing the system to be remotely controlled and monitored.

Australia nominally has three time zones, but this can increase up to six because of variations in adherence to Summer Time. Rather than providing a separate telephone number for each Australian state, the NMI speaking clock system asks callers to select the desired time announcement from a menu. This requires the use of computer telephony boards with digital signal processing capabilities. The system as presently operating can handle 30 simultaneous calls; this can be easily expanded to many hundreds, making the system a suitable platform for a national service.

5. Research activities

Research undertaken at NML includes the development of microwave frequency standards based on trapped $^{171}Yb^{+}$ ions, development of reliable and remotely operable single- and dual-frequency GPS time-transfer systems [3], and evaluation of two-way satellite time transfer (TWSTT) links. These activities are briefly summarized here.

5.1. A microwave frequency standard based on trapped ytterbium ions

Work continues to achieve the 4 parts in 10^{15} projected uncertainty of the laser-cooled, trapped $^{171}Yb^{+}$ frequency reference. Recent progress since ATF 2002 has included the design and commissioning of a non-magnetic UHV vacuum chamber, and preliminary investigations of trap loading by photoionization.

In the most recent absolute frequency measurement [4], the dominant systematic uncertainty was due to inhomogeneity of the magnetic field across the cloud of trapped ions, which causes a variation in the correction for the quadratic Zeeman shift. The uncertainty in this correction was approximately 5×10^{-14} for this measurement. The inhomogeneity was largely due to the stainless-steel vacuum chamber itself, so we have developed a new vacuum chamber in the novel alloy CrCu.

CrCu was selected because it is non-magnetic (susceptibility $\mu - 1 \sim 10^{-5}$, from measurements made at NMI) and compatible with UHV: a pre-bake *in vacuo* promotes diffusion of Cr to the material surface, which when oxidized forms a good barrier to interstitial hydrogen and reduces outgassing [5]. The material is hard enough that the conventional Conflat flange design can be used with metal gasket seals. We also require large-area viewports for fluorescence collection and high-quality fused-silica windows for laser access; custom glass-to-metal seal solutions for these components were developed with the manufacturer [6].

The new chamber was commissioned in mid-2004, and has a base pressure below 10^{-10} Torr with our current pumping configuration. The homogeneity of the magnetic field, as measured by the width of the field-sensitive $F=0 \rightarrow F=1$, $M_F=1$ hyperfine component of the reference transition, has been improved by almost two orders of magnitude. The corresponding uncertainty in the second-order Zeeman shift correction has been reduced by the same factor, to below 1 part in 10^{15}.

We have also made some preliminary investigations of loading the trap using photoionization [7], rather than electron impact. Light is required at 399 nm, the resonance transition of the neutral Yb atom, and at any wavelength shorter than 394 nm, to promote an excited Yb atom above the ionization threshold; the latter can in principle be provided by a UV LED. The two principal advantages of this technique are that DC fields from stray charge are greatly reduced, and that it eliminates the need for special samples isotopically-enriched for ^{171}Yb. We have demonstrated isotope-selective loading using a collimated Yb oven and a frequency-doubled Ti:sapphire laser to generate 399 nm.

5.2. Development of GPS common-view time transfer systems

For a number of years, NMI has been developing CCTF-compatible, dual-frequency GPS common-view time transfer software and hardware, based on the Javad/Topcon Euro-80 GPS engine. Over the last two years we have installed a number of these systems in laboratories around the Asia-Pacific region. In a joint project with Geoscience Australia, Australia's national mapping agency, we have also recently commissioned a new geodetic reference station in Sydney. The station is based on a variant of the NMI-developed time-transfer system, and will provide high-quality time-transfer between the NMI and other sites. This station contributes geodetic monitoring data to the Australian Regional GPS Network, and is intended to provide data of suitable quality for inclusion in the wider network of the International GPS Service.

5.3. Intercomparison of GPS common-view receiver delays in APMP laboratories

We have constructed a portable version of the NMI/Topcon GPSCV system under contract to the Telecommunications Laboratory of Taiwan, which can be circulated among APMP member laboratories for round-robin intercomparison of GPS receiver internal delays. This portable receiver has recently finished its first campaign. NMI is coordinating the intercomparison and processing the data.

5.4. Two-Way Satellite Time Transfer activities

The Telecommunications Laboratories (TL) in Taiwan and NMI have been performing bi-weekly TWSTT sessions using a Ku-band link since November 2002, using satellite time generously made available by the National Institute of Information and Communications Technology (NICT) in Japan. A C-band TWSTT link was also trialled between TL and NMI as part of a three-way comparison also involving NIST in the United States, beginning in September 2002 and ending in April 2003. We are currently participating in a collaboration to explore the use of dual-frequency GPS data recorded at both the TL and NMI earth stations to calculate corrections for ionospheric delay, which can be significant at C-band frequencies.

In our experience, the principal challenge with conducting these TWSTT experiments is not the weekly operation of the link itself, despite a wide variety of technical challenges, but rather careful analysis of performance. It is the nature of this research that both operation and analysis must be sustained over a longer term to complete a detailed evaluation and to extract full value from the potential of this technique.

6. Conclusion

The formation of the new NMI offers great opportunities for closer collaboration among related areas of research and development, and establishes a single point of contact providing services across all areas of metrology to government, industry and the community. Our continuing challenge is to use our technical expertise in measurement to foster innovation in our national economy, provide training both nationally and internationally, and collaborate effectively with our colleagues around the Asia-Pacific region.

As we have previously observed [1], demand continues to increase within Australia for accurate, legally traceable time and frequency information realised at the client's premises. This continues to drive the development of remotely operable, software-based solutions such as NMI's GPSCV timing systems, NTP servers and the new speaking clock. On a wider scale, the development of high-accuracy and high-stability frequency standards in many laboratories around the world will test the ability to compare these standards across large distances, and time-transfer research remains an important challenge for our region.

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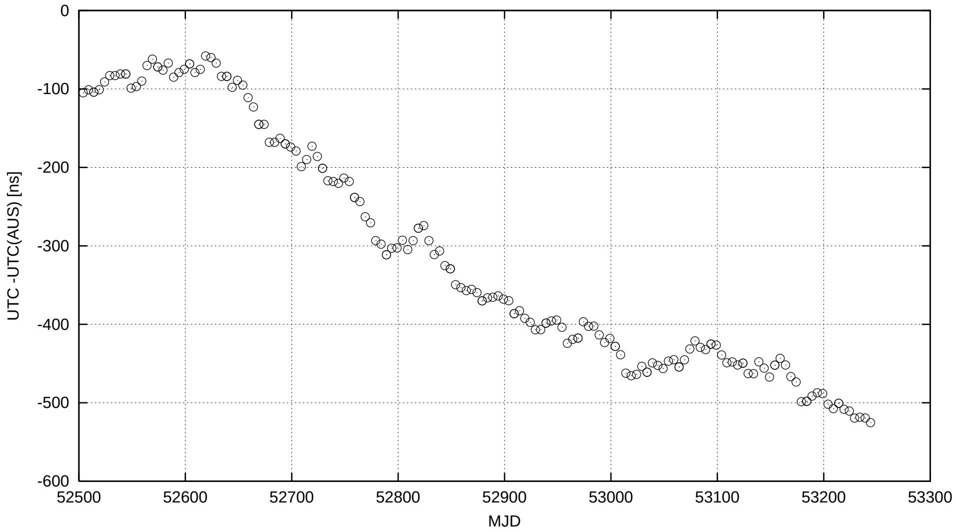

Figure 1: History of UTC(AUS) since August 2002.

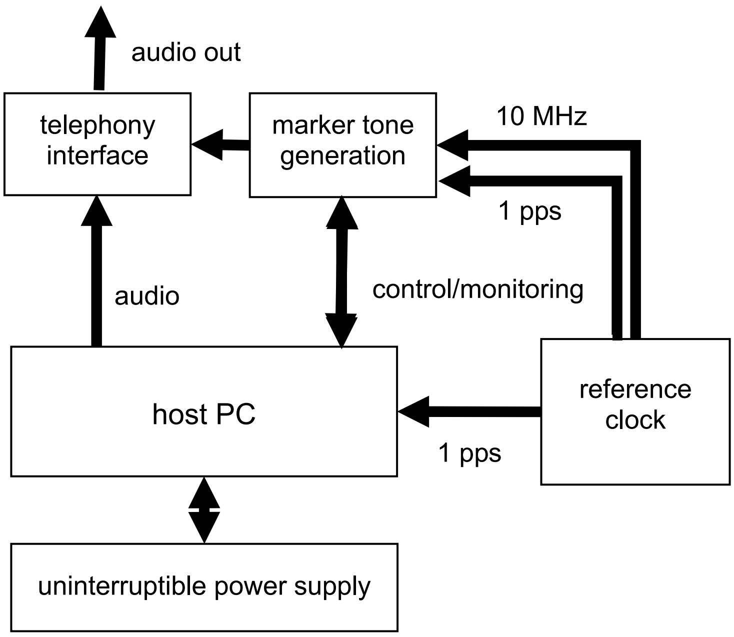

Figure 2: The NMI speaking clock system.