GPS Activities at the National Measurement Institute, Australia

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Abstract—**The National Measurement Institute, Australia, (NMIA) is continuing the development of reliable, high-integrity and remotely-operable GPS-based systems for precise time and frequency transfer. These systems combine an OEM receiver with a PC and support a variety of applications, of which we describe three: the intercomparison of receiver internal delays among laboratories in the Asia-Pacific, using a portable time-transfer system; a geodetic monitoring station, contributing data to Australian and international geodetic reference networks; and delivery of traceable time and frequency to a distant location, or equivalently continuous remote calibration of a frequency standard at a client's premises.**

I. Introduction

Time and frequency transfer using GPS signals is particularly important for Australia, owing to its large size and geographic isolation. There is consequently a key requirement for GPS time-transfer systems to support dissemination of national standards and to provide traceability to secondary calibration laboratories.

Australia's new National Measurement Institute (NMIA) was formed on 1 July 2004 and maintains standards of physical, chemical and biological measurement [1]. The Physical Metrology Branch of NMIA, formerly the National Measurement Laboratory (NML) of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), is continuing a long-running program to develop systems for high-reliability and high-integrity GPS time and frequency transfer, and to use these systems for a variety of research and metrology applications [2]. Here we describe three such applications: a portable system, for intercomparison of receiver delays; a geodetic GPS/GLONASS monitoring station; and remote calibration of a frequency standard in a client laboratory.

II. The NMIA GPS time-transfer system

The NMIA time-transfer system in its basic form consists of an Intel PC running the Linux operating system, a GPS receiver board and antenna, and a counter-timer (Fig. 1 (a)). Data from the receiver and the counter-timer is processed by NMIA software to generate CGGTTS-format data files [3] following standard algorithms. The generated data can therefore be used both for strict common-view and all-in-view GPS time transfer. Because all the raw data is stored on the system PC, it can be reprocessed for custom applications, for example using precise ephemerides available from the International GNSS Service (IGS) or different tracking schedules.

The design philosophy is to use commercial and relatively generic hardware throughout, and to make the software as hardware-independent as possible. This provides significant flexibility for future upgrades as customer requirements and available technology evolve. For example, we have commissioned a number of systems based on the Javad/Topcon Euro-80 GPS receiver, where the full functionality of the receiver hardware is selectively enabled with a software key. This provides a very simple upgrade path from single-frequency to dual-frequency operation just by changing the key. Updates to the receiver firmware or to data processing and reporting software are similarly straightforward, and all of these can be applied remotely. In a second example, we have conducted some preliminary investigations of the use of the Trimble Resolution T GPS receiver. Results to date indicate that for time-transfer systems where lower cost is more important than highest precision, this new single-frequency receiver should be a suitable replacement for the now-discontinued Motorola Oncore receiver family. Modular software design means that modifications to use the Trimble receiver instead of a Motorola Oncore VP are comparatively straightforward, with the bulk of the data processing remaining unchanged.

Although its core function is time and frequency transfer, the form of the system allows ready extension to other applications by adding additional software and hardware as necessary. Fig. 1 (b) shows a variant system with an integrated Rb atomic frequency reference. This reference can be controlled over a serial connection to the PC, for example to apply occasional adjustments to frequency or the phase of

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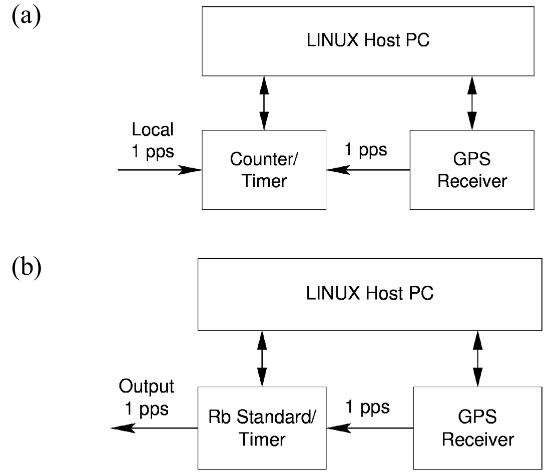

Figure 1. Sample configurations of the NMIA time-transfer system: (a) GPS common-view time transfer of a local reference; (b) using a Rb reference with integral timer for a remote Network Time Protocol server.

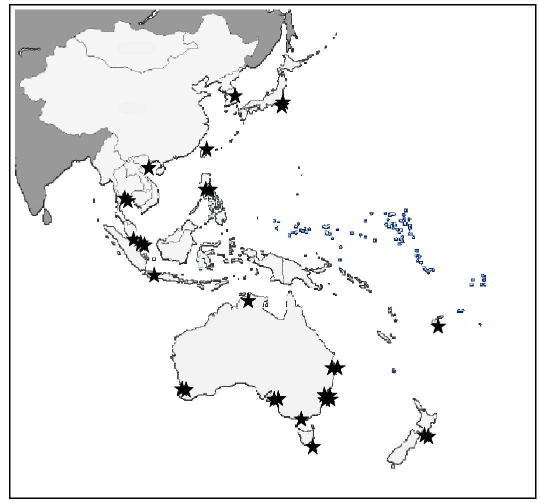

Figure 2. NMIA-developed GPS common-view time transfer systems installed in the Asia-Pacific region. In many cases these provide the primary link between the reference timescale of the host nation and UTC.

an output 1 pulse per-second (pps) signal. References such as the Stanford Research Systems PRS10 also include an integral time-interval counter, removing the need for a separate counter. With some additional software the PC can use the Rb reference as an external timing reference, and can function as a Network Time Protocol (NTP) server to disseminate this reference over a computer network.

NMIA uses this configuration to operate NTP servers at a number of sites around Australia including Adelaide, Brisbane, Hobart, Melbourne and Perth. Using common-view GPS time- and frequency-transfer, each of these servers is compared to UTC(AUS), Australia's realisation of Coordinated Universal Time (UTC), which is maintained at NMIA Lindfield in Sydney. Each server can be maintained within a specified tolerance of UTC(AUS) by remotely applying appropriate corrections to the Rb reference. NMIA also uses the raw data reported by the receiver to monitor the integrity of timing information as received from the GPS system at each location. A daily processed data summary is made available to the public, and the raw data is archived so that is available for detailed post-processing and verification on request.

NMIA and its predecessor NML have supplied a number of these time-transfer systems to calibration laboratories within Australia and to national measurement institutes around the Asia-Pacific region (Fig. 2). At the time of writing there are 36 such systems currently in operation in thirteen countries, with an accumulated total of over a hundred system-years of operation. This represents a significant body of experience, but also an important data resource. NMIA and other Asia-Pacific laboratories maintain extensive data archives which can be used to quantify the performance of time-transfer links generally and of several receivers specifically. It is worth noting here that there are two features of time-transfer links in this region which do not apply in (for example) Europe or North America, namely trans-equatorial links over long baselines and laboratories at mid-latitudes where ionospheric activity is particularly high.

III. COMPARING GPS RECEIVER DELAYS

A portable version of the time transfer system was developed at NMIA in 2002, under contract to the Telecommunications Laboratories (TL) in Taiwan. The main application of the portable system is calibration of the internal delay of other receivers: the portable system acts as a transfer standard when operated together with a host receiver using a common local reference, allowing a known value for the internal delay of one such host system to be readily transferred to the others in a calibration campaign. The portable system includes several additional features designed for this application, in particular a very rugged shock-mount case to protect the system during shipping and stabilisation of the receiver temperature for best performance. A dual-frequency receiver allows accurate self-survey of the antenna coordinates of the portable system to centimetre level, so that these need not be known in advance.

In 2004 and 2005 NMIA has been coordinating an extended series of comparisons within the framework of the Asia Pacific Metrology Programme (APMP), the network of national measurement institutes in the Asia-Pacific region. At the time of writing the system has visited twelve laboratories (some more than once) in ten countries, and is scheduled to visit a further five laboratories in the current round. This represents essentially all the APMP laboratories active in the field of time and frequency. The delay of the portable system has been determined by comparison to receivers of the International Bureau of Weights and Measures (BIPM) at the Observatoire de Paris, and of the National Institute of Standards and Technology (NIST) in Colorado. This calibrated delay can then be transferred to the primary receiver at each APMP national institute. The intercomparison provides important support for developing economies in the Asia-Pacific, and also establishes a formal comparison between the APMP and the equivalent regional organisations in Europe (EUROMET) and North America (SIM).

IV. Geodetic Monitoring Stations

The basic time-transfer system developed at NMIA can also be extended to provide high-quality positioning data for geodetic applications. The two primary requirements in this case are a very stable antenna mount with good reception conditions, and additional software to process raw GPS observation data into the standard RINEX format used in geodesy [4]. A new geodetic monitoring station was commissioned at NMIA Lindfield in September 2004, in collaboration with Geoscience Australia. The new station forms a key linkage between geodesy and timing, and is one of only relatively few such stations sited at institutes hosting national time and frequency standards.

The station antenna is mounted in the grounds of the NMIA site at Lindfield, Sydney, on a concrete pillar extending approximately 10 m below ground level. The antenna site was selected for optimal GPS signal reception, in particular to minimise multipath reflections. A geodetic quality dual-frequency GPS receiver, the Javad/Topcon Euro-160, is sited in the time and frequency laboratory some distance away; this provides good access to reference clock signals and also stabilises the receiver temperature. The GPS signal is relayed from the antenna to the receiver over 520 m of optical fibre (Fig. 3), to avoid signal attenuation and to minimise variation of delays with temperature. The delay of the optical fibre can be measured by optical time-domain reflectometry or calibrated by transfer in several ways.

Software developed at NMIA processes the same raw GPS observations for both geodesy and time transfer. The geodetic data is automatically uploaded to Geoscience Australia; data is currently sent every hour, but in the near future data will be provided every fifteen minutes and the data can in principle be sent in real-time. The station forms one node of the Australian Reference GPS Network maintained by Geoscience Australia, with data processed for precise positioning and national mapping applications. It also forms the SYDN node of the IGS global network of monitoring stations, and contributes observations used by the IGS to calculate a range of data products including ionospheric maps and precise GPS ephemerides.

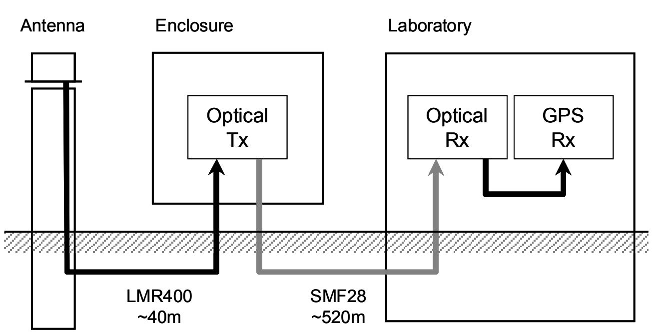

Figure 3. Design of the SYDN geodetic monitoring station (not to scale). The GPS signal is carried from the Ashtech choke-ring antenna over copper cable to an optical transmitter in a weatherproof enclosure, then by optical fibre to an optical receiver, and finally by a short copper cable to the GPS receiver. The horizontal line represents ground level.

A. *Tests of temperature dependence*

We have conducted a series of tests to determine the variation of signal delays with temperature. These are important because the signal path includes additional components over a standard geodetic station, in particular the optical transceivers and fibre. The temperature tests compared CGGTTS-format GPS data files recorded for two dual-frequency Euro-160 receivers with a common antenna (zero baseline), with the component under test in one signal path placed in an environmental chamber and varied over a range from 0 to 40 °C.

The results indicate no measurable temperature dependence for the optical transmitter. This is an important result, because this transmitter is in an outdoor environment and therefore subject to significant temperature variation. The variation of internal delay for the GPS receiver (Fig. 4) was approximately 160 ps/°C, and therefore not significant as the receiver is in a temperature-controlled laboratory (typically ±0.25 °C ambient). Finally the variation of optical fibre delay is similarly negligible, especially since it is buried underground for much of its length and therefore subject to reduced temperature fluctuations.

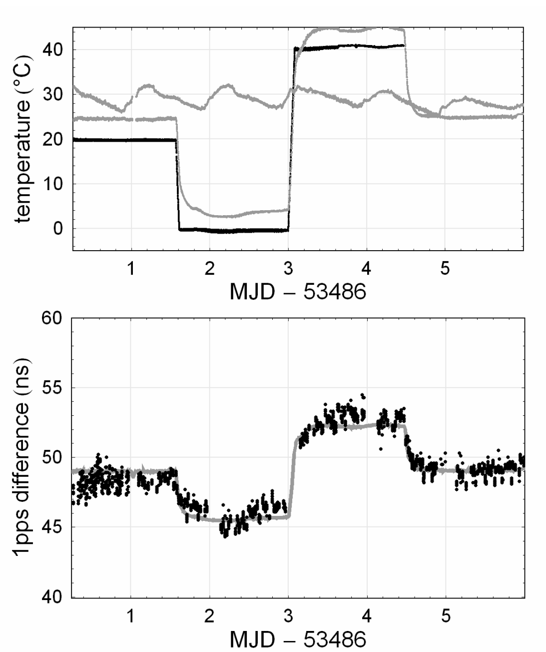

Figure 4. Testing the temperature dependence of GPS receiver internal delays (see text). The upper plot shows temperature of an environmental chamber (black) and of two receivers inside and outside the chamber (gray). The lower plot shows time differences between data tracks (points) from the two receivers; the fit (line) gives a coefficient of 160 ps/°C.

B. Geodetic station at ATNF Parkes

The Australia Telescope National Facility (ATNF) operates a major radio-observatory at Parkes in NSW, including an active research program observing millisecond pulsars. An NMIA time-transfer system has been in operation at Parkes for several years, linking the millisecond pulsar timing observations to UTC(AUS) and thus to Coordinated Universal Time (UTC). This system has recently been upgraded to a full geodetic station in a three-way collaboration between ATNF, Geoscience Australia and NMIA. The station is of similar design to that at NMIA Lindfield, but the software developed at NMIA has been extended to support observations of the GLONASS satellite navigation system. This increases the utility of the station to the geodesy community. We anticipate upgrading the SYDN station to include GLONASS observations in the near future.

C. Time transfer using the phase of the GPS carrier

NMIA plans to establish a new carrier-phase time- and frequency-transfer link between NMIA and the University of Western Australia (UWA) in Perth, upgrading an existing GPS common-view link which has been in operation for several years. The Frequency Standards and Metrology group at UWA develop some of the world's most stable oscillators, and linking these to the standards at NMIA significantly enhances Australia's national timing infrastructure. The new link is part of a wider project to link UWA and NMIA [1], but also establishes an opportunity for NMIA to contribute to research in this field and to develop new systems for high-precision time and frequency transfer.

V. Remote Calibration

From the point of view of a national measurement institute, a time-transfer system essentially delivers continuous remote calibration of a secondary time and frequency standard at the premises of a client calibration laboratory. Such a system provides continuous monitoring, whereas conventional calibration of the secondary standard at the national institute only provides assurance of correct operation at periodic intervals.

NMIA currently provides such a remote calibration service for a number of client laboratories in Australia and the South Pacific, and has therefore expended significant effort to automate the calibration process as far as possible. This includes the retrieval of CGGTTS-format data from remote sites, the processing of these data to compare remote standards to UTC(AUS), and the generation and dissemination of reports with the results. At present, calibration data are automatically emailed to a number of customers once per week, with paper reports typically following monthly. This provides written documentation to support third-party accreditation of the remote laboratory calibration services, but also delivers more frequent electronic data to assist customers to maintain both synchronization and syntonization to national standards as required.

A natural extension to remote calibration of a frequency standard in a client laboratory is the calibration of a device under test (DUT) submitted to the same laboratory. If laboratory staff are available to connect the DUT to the standard initially, a remote connection from NMIA to the time-transfer system PC can subsequently be used to control the entire calibration of the DUT, including data acquisition, data processing and the generation of a calibration report. This kind of 'remote calibration' is at one further remove from NMIA.

If the DUT is to be compared only with the frequency standard in the client laboratory, there is little advantage to this method beyond providing additional scheduling flexibility between the client laboratory and NMIA. However, since the client standard is already compared back to UTC(AUS), it is trivial to apply this additional correction and thereby to calibrate the DUT against the national standard. This effectively projects a complete NMIA calibration service into the remote laboratory, which may have significant advantages for customers submitting devices for calibration by removing shipping requirements and increasing operational flexibility.

Development of methods to conduct this kind of remote calibration of a DUT in a remote laboratory is currently in progress at NMIA, including associated verification and quality control procedures.

VI. Summary

The use of GPS signals for time transfer is an active research and development area with particular relevance for NMIA, owing to Australia's geographical isolation and the need to provide traceability to UTC(AUS) from calibration laboratories widely distributed around the country. This continues to drive the development of high-integrity, high-reliability, and remotely operable time-transfer systems, and the use of these systems in a wide variety of applications.

Acknowledgments

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