Time and Frequency Activities at the National Measurement Laboratory, CSIRO Australia

Peter Fisk, Bruce Warrington, Michael Wouters and Malcolm Lawn

National Measurement Laboratory
CSIRO Division of Telecommunications and Industrial Physics
PO Box 218, Lindfield NSW
Sydney, Australia
Email: peter.fisk@tip.csiro.au

Abstract

The Australian National Measurement Act requires CSIRO to maintain, or cause to be maintained, Australia's standards for measurement of physical quantities. The CSIRO National Measurement Laboratory (NML) discharges CSIRO's responsibilities under the Act. This paper outlines some of the activities of the Time and Frequency Section of NML.

1. Introduction

The NML Time and Frequency group consists of six people, and is located in the suburb of Lindfield, in Sydney, Australia. The ongoing responsibilities of the group include:

- Maintenance and dissemination of the National Time Scale, UTC(AUS).
- Coordination of the input from clocks in Australia to the International Atomic Time Scale (TAI) maintained by BIPM.
- Maintenance and dissemination of the National Frequency Standard (NFS).
- Maintenance of the National Atomic Time Scale, TA(AUS).
- In-house frequency and time interval calibration service.
- Maintenance of frequency and time references used by other organisations, within Australia and overseas.
- Maintenance of the primary Network Time Protocol (NTP) server network for Australia.
- Monitoring, for timing purposes, of TV-Sync signals with respect to UTC(AUS) in the metropolitan areas of Sydney, Melbourne and Perth.
- Monitoring, for timing and system integrity verification purposes, signals from the Global Positioning System (GPS) satellite navigation system in Sydney, Melbourne and Perth.
- Monitoring, for timing and system integrity purposes, signals from the Radio VNG time signal service, with respect to UTC(AUS).
- Processing of GPS timing data for Australian and international external customers for the purpose of time and frequency transfer.

In addition, the NML Time and Frequency group is presently involved in several research and facility development projects, including:

- Development and installation of a nationwide Network Time Protocol time dissemination service.
- Development of GPS common-view time transfer systems, and the installation of a network of ten such systems in client laboratories in Australia and the Asia-Pacific

region.

- Development of GPS integrity monitoring software.
- Organisation of a round-robin intercomparison of GPS common-view receiver delays in APMP timing laboratories.
- Two-Way Satellite Time Transfer measurements with NIST (USA) and CRL (Japan).
- Development of software for the automation of frequency calibrations.
- Development and implementation of an accredited Quality Management System for a national timing laboratory.
- Development of a new frequency standard based on trapped ytterbium ions.

After describing the general structure of Time and Frequency dissemination, this paper will present an outline of a selection of the above ongoing and development activities. The NML Time and Frequency Group's activities in the areas of GPS, Trapped Ion Clock development and Quality System implementation will be discussed in detail in separate papers to be presented at ATF2000.

2. Time and Frequency Dissemination Within Australia: The Present System

2.1 UTC Australia

The system for dissemination of precise time and frequency within Australia is shown, from a technical point of view, in Figure 1. Traceability of Australian time and frequency to the basic unit of time interval, the Système Internationale (SI or metric) second, is maintained by continuous international time transfer by NML in Sydney. The SI second is realised at NML with an uncertainty smaller than 2 parts in 10^{13}.

Coordinated Universal Time (UTC) is realised at NML with an accuracy of better than 200 ns. NML maintains a 1 pulse per second timing outputs within ± 1 μs of UTC, and this signal is designated UTC(AUS), the official Australian realisation of UTC.

Dissemination of time traceable to UTC(AUS) and hence UTC throughout Australia has to-date been provided principally by Telstra, via the speaking clock and landline services. Traceability of the Telstra time and frequency signals to the SI second and UTC(AUS) is presently maintained by GPS common view and domestic satellite common view links with NML.

The Australian standard for frequency and time interval, the National Frequency Standard (a caesium atomic clock), is also maintained by NML. Precise frequency and time interval are disseminated by NML by several methods, to suit the requirements and budgets of users. The techniques for legally traceable frequency and time interval dissemination currently in use within Australia are compared on a number of criteria in Table 1.

2.2 Australia's contribution to UTC

Australia contributes to UTC by NML reporting GPS time receiver and clock data to BIPM. The GPS time receiver data links UTC(AUS) via GPS common-view (GPSCV) time transfer to the international network of clocks from which UTC is derived. Clock data (values of UTC(AUS) – clock) are currently submitted from five clocks located at NML in Sydney, one at NML's Melbourne Branch, two at the Tidbinbilla deep space tracking station near Canberra and one at the Telstra laboratories in Melbourne. Australia's local atomic time scale TA(AUS) is also reported to BIPM for inclusion in the calculation of UTC. Reporting of clock data to BIPM is essential for maintaining international traceability of Australian time and frequency. NML assembles and transmits this clock data to BIPM following BIPM's standard protocols and data formats.

2.3. UTC(AUS) and TA(AUS)

The history of Australia's local atomic time scale TA(AUS) and UTC(AUS) over approximately the last 850 days is shown in Figure 2. UTC(AUS) is currently defined to be the epoch of the 1 pps timing output at the rear panel of a high-performance HP5071A Cs frequency standard. NML steers the frequency of this standard to maintain UTC(AUS) within approximately 1 μs of UTC.

3. Modes of Dissemination for Time and Frequency Presently in Use in Australia

3.1 Timing facilities

Table 1 lists the methods, with approximate accuracies, of dissemination of legally traceable (or potentially legally traceable) Time and Frequency information presently in use within Australia. To support the dissemination methods listed in Table 1, NML maintains timing facilities in Melbourne and Perth, in addition to its primary facility in Sydney.

The Melbourne and Perth remote facilities consist of a clock (Cs in Melbourne, and Rb in Perth) maintained on-time with respect to UTC(AUS) using the same GPS common-view time transfer technique as used by BIPM for the maintenance of UTC. The remote systems are controlled by a computer running the Linux operating system, and are maintained from Sydney via an Internet connection. The remote facilities provide GPS monitoring, NTP and TV-Sync monitoring services, and are discussed in more detail in another paper to be presented at the ATF2000 meeting.

3.2 Network Time Protocol (NTP)

NTP is rapidly increasing in importance as a means of disseminating time information. The primary application of NTP in Australia is to keep computer clocks on time. Accurate computer timing will be essential for a wide range of purposes, including banking, electronic commerce and computer-based document exchange.

As mentioned in section 3.1, NML maintains three NTP servers, located in Sydney, Melbourne and Perth (Figure 3). Installation of further servers is planned in other state capital cities to provide improved accuracy and redundancy for clients across Australia. NML has developed software which continuously monitors and records the performance of the NTP servers. Such records are essential for legally traceable time dissemination, since it must be possible to demonstrate beyond reasonable doubt that, at any time in the past, the servers were disseminating time information within known accuracy limits.

Figure 4 shows traffic on our main NTP server in Sydney and indicates a steady increase in the number of users over time. Note that "No. of Hosts" means the number of individual computers logged as having requested time information from the server during a daily two-hour sampling period. It is likely that many of these hosts in turn provide NTP services to their own clients, so that the dissemination of UTC(AUS) by this means may be much wider than is indicated by the data.

3.3 Two Way Satellite Time Transfer (TWSTT)

NML presently maintains two Two-Way Satellite Time Transfer (TWSTT) links. The details of these links are shown in Table 2.The primary purpose of the TWSTT experiments is to compare the performance of GPS and TWSTT over very long (NML-NIST) and trans-equatorial (NML-CRL) baselines, over a period of several years. Results of the NML-CRL experiment are presented in a separate paper at the ATF-2000 conference.

NIST's Boulder laboratories are located at the base of the Rocky Mountains and do not have a view of any satellites that can be used for a TWSTT link with NML. However, NIST maintains the WWV timing broadcast station at Ft Collins, about 60 km north of Boulder. From Ft Collins, line of sight to Intelsat 701 is possible (although it is only three degrees above the horizon) and for this reason the NIST TWSTT C-Band Earth station used for the link to NML is located here. The short timing link to UTC(NIST, Boulder) is maintained by conventional GPS common view.

Data from the TWSTT link is presented in Figure 5 where its difference from UTC(AUS)-UTC(NIST, Boulder) as given by Circular T has been plotted. The delays at both stations have not yet been calibrated and the offset indicated in Figure 5 reflects this. The spike around MJD 51600 is due to an anomaly in the UTC(AUS) data given in Circular T and is not real. There is the suggestion of an oscillation with a period of about a year in the data but further data is required to verify this. In Figure 6, UTC(AUS)-UTC(NIST) is plotted for both Circular T and the TWSTT link. The TWSTT exhibits more noise than the GPS link over time scales of several days, which may not be surprising since the TWSTT data is averaged over less than 30 minutes of transmission time per week, whereas the GPS Common-view data is quasi-continuous. The stability of the TWSTT link may also be affected by factors associated with the very low elevation of Intelsat 701 as viewed from Ft Collins.

4. Conclusion

Like many National Measurement Institutes, NML is currently facing a rapidly increasing client demand for accurate, legally traceable time and frequency information, *realised at the client's premises*. This is driving the development of remotely operable, low cost software-based solutions such as NML's GPSCV timing systems and NTP servers. The advantage of these systems is that the infrastructure used for the transfer of time information from NML (the GPS system and the Internet) already exists and can be used at minimal cost.

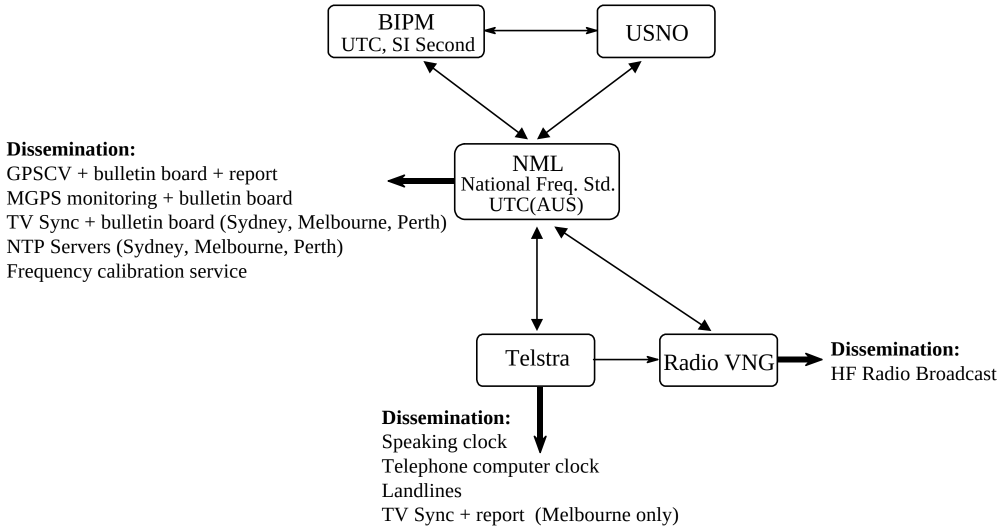

Figure 1: The present system for dissemination of precise time and frequency within Australia. Telstra is the principal telephone/telecommunications company in Australia

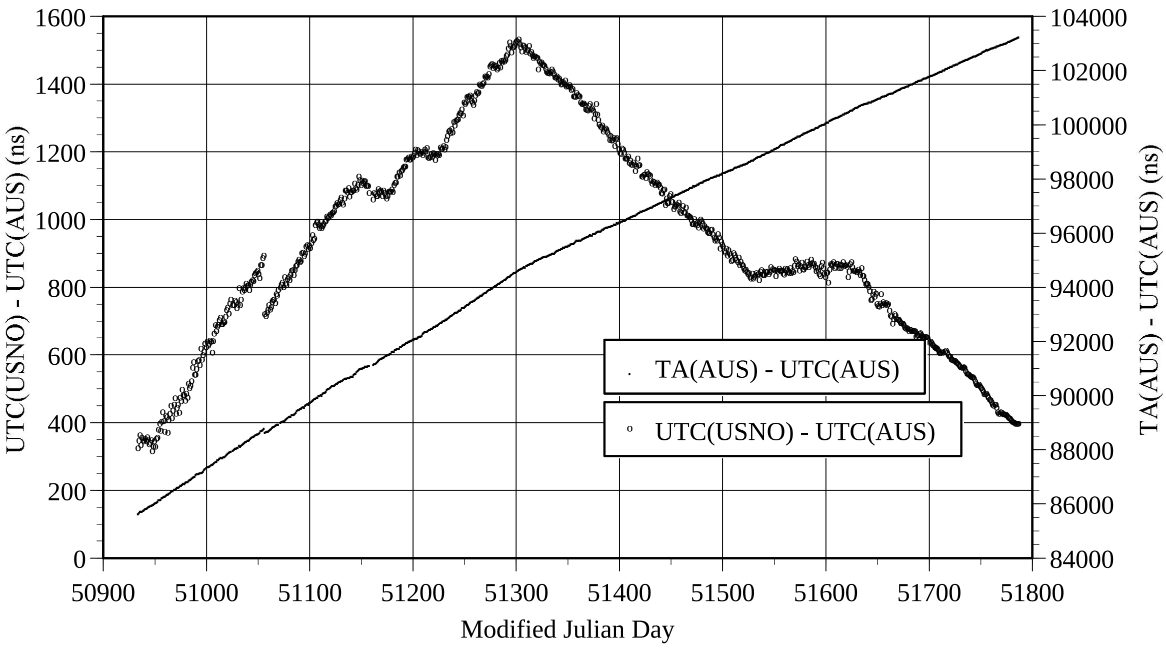

Figure 2: History of UTC(AUS) and TA(AUS) from 1 May 1998 to 31 August 2000. Leap seconds have been accounted for in the calculation of TA(AUS) - UTC(AUS).
(MJD 51800 = September 13, 2000).

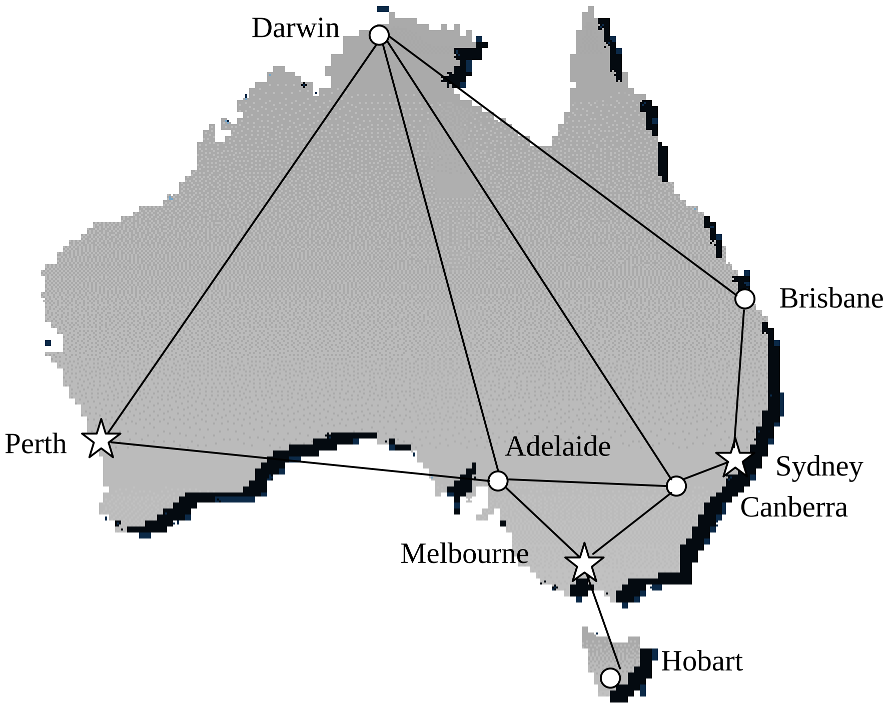

Figure 3: NTP servers in Australia – existing (☆) and planned (❍)

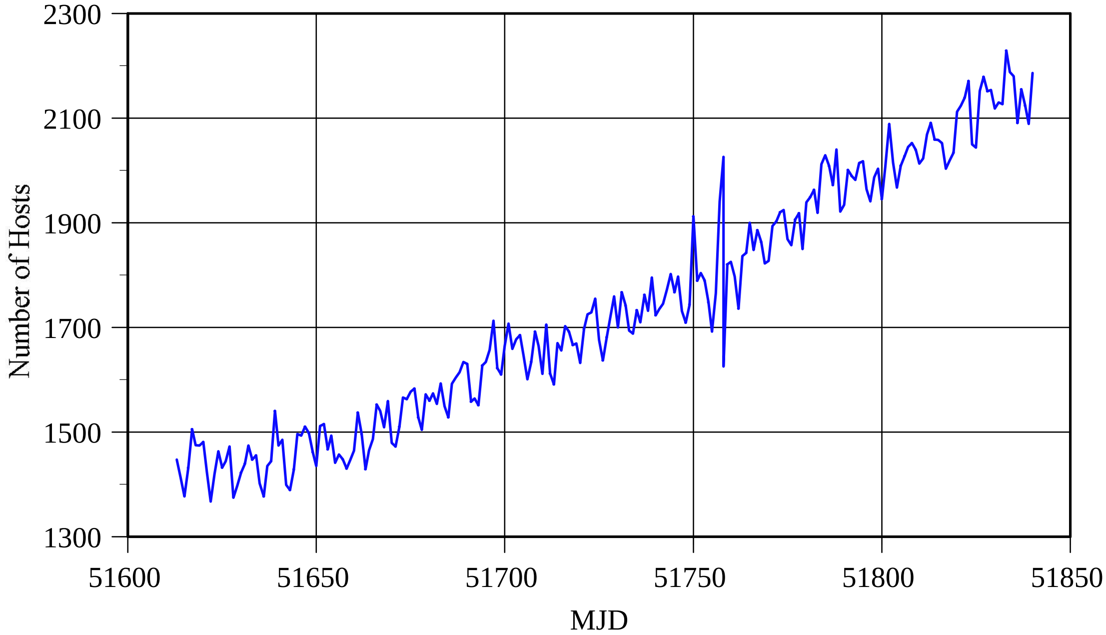

Figure 4: Number of hosts accessing the NTP server at NML Lindfield in a sample two hour period each day. (MJD 51810 = September 23, 2000)

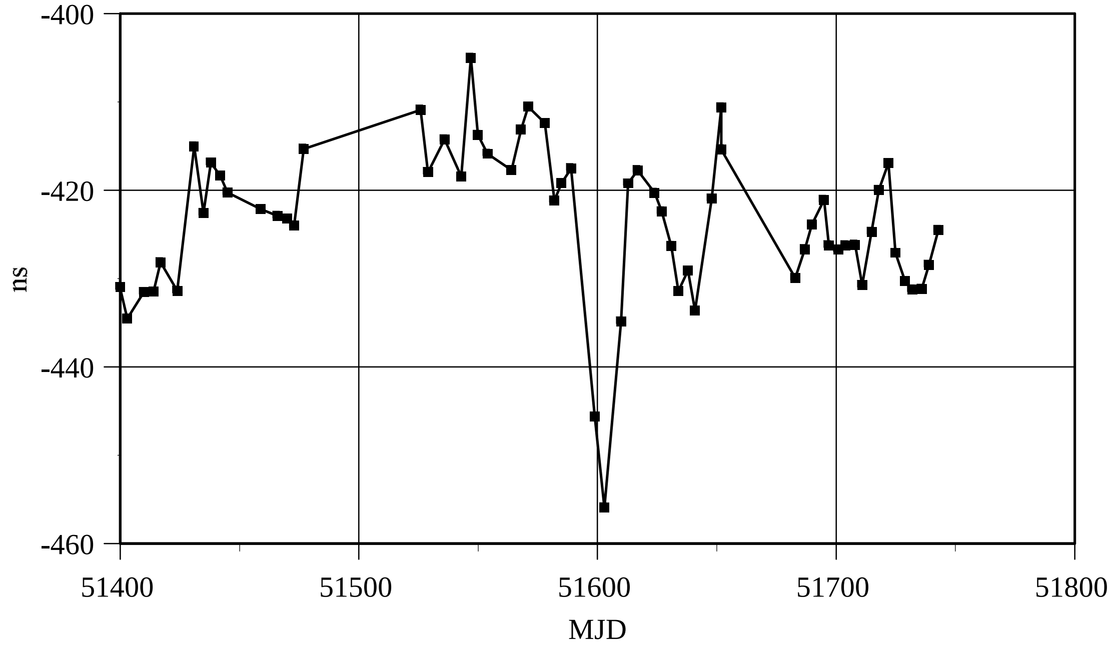

Figure 5: Difference between UTC(AUS) – UTC(NIST) as calculated from BIPM Circular T and UTC(AUS) – UTC(NIST) as determined from a TWSTT link between NML and NIST, Fort Collins.

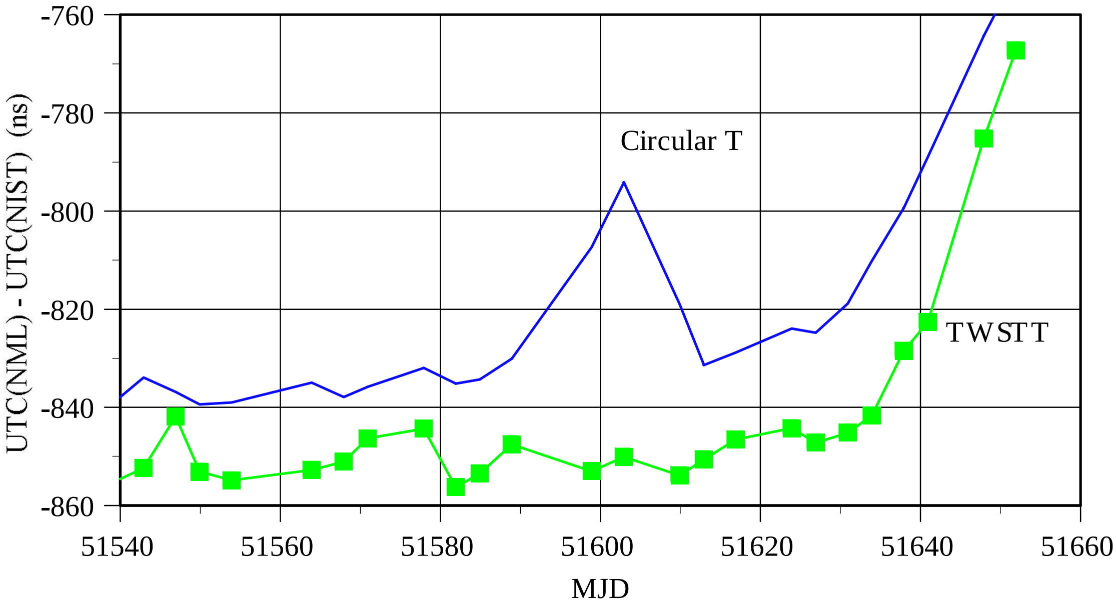

Figure 6: Comparison of UTC(AUS) – UTC(NIST) as calculated from BIPM Circular T and as determined from a TWSTT link between NML and NIST, Fort Collins. The TWSTT data has been offset to make the comparison clearer.

Method	*Accuracy (Time) (single reading)*	*Accuracy (Freq) (1 day average)*	*Receiver cost (Approx)*	*Present coverage*	*Future coverage*
GPS Common View (GPSCV)	< ± 100 ns	< 1 part in 10^{12}	$30k	Australia-wide	Australia-wide
Multichannel GPS (MGPS)	< ± 1 µs	< 1 part in 10^{11}	$5k	Eastern Australia	Australia-wide
Network Time Protocol	< ± 1 s or better, depending on location	Not recommended	Public domain software	Australia-wide	Australia-wide
Radio VNG	< ± 5 ms	< 1 part in 10^{10}	$1k	Usually Australia-wide, subject to ionospheric conditions	No change planned, but subject to funding
TV Synchronisation pulse (TV Sync)	< ± 10 µs	< 1 part in 10^{10}	$1k	Syd/Melb/Perth Metropolitan areas	No change planned[Note 1]
Telstra speaking clock	< ± 100 ms	< 1 part in 10^{8}	Domestic telephone	Australia-wide	Australia-wide
Telstra landline	< ± 1 ms [Note 2]	< 1 part in 10^{9}	Line rental	Capital cities	Availability decreasing

Note 1: Outside present coverage areas the use of MGPS is now recommended
Note 2: In and near capital cities

Table 1: Methods of disseminating time and frequency in Australia

Link 1:
Tx/Rx Band____________________ C-Band
Earth stations ________ NML, Sydney, Australia and NIST, Ft. Collins, USA
Satellite ________________ INTELSAT 701, 180°E
Tx power____________________10 W
Antenna____________________4.6 m
Modem ____________________ MITREX
Timing reference________H Maser (NML), High Perf. Cs (Ft. Collins)
Schedule ______________ 2 x 15 minute sessions per week
Regular operation began______________ July 1999

Link 2:
Tx/Rx Band____________________Ku-Band
Earth stations ________ NML, Sydney, Australia and CRL, Tokyo, Japan
Satellite ________________ INTELSAT 702, 177°E
Tx power____________________4 W
Antenna____________________2.2 m
Modem ____________________ATLANTIS
Timing reference________ High Perf. Cs (NML), High Perf. Cs (CRL)
Schedule ______________ 2 x 30 minute sessions per week
Regular operation began______________ March 1998

Table 2: TWSTT links between NML and NIST, Fort Collins, USA and NML and Communications Research Laboratory (CRL), Tokyo, Japan.