TIME AND FREQUENCY ACTIVITIES AT THE CSIR NATIONAL METROLOGY LABORATORY

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Abstract

The CSIR – National Metrology Laboratory (CSIR-NML) is the custodian of the South African national measurement standards. The Time and Frequency (TF) Laboratory is responsible for the maintenance of the SI second, which is the most accurate standard currently maintained. In addition to the maintenance of the national timescale, the TF Laboratory is also responsible for a number of other parameters, including fast electrical pulse characterization, phase angle, phase noise, and a number of fiber-optic parameters. A project in which the TF Laboratory plans to take a leading role is establishing a frequency comb based on a femtosecond laser at the CSIR-NML.

INTRODUCTION

The CSIR is the custodian of the national measurement standards of South Africa. The Measuring Units and National Measuring Standards Act, Act 76 of 1973, as amended by Act 24 of 1998, gives this authority to the CSIR. The CSIR delegates the authority to the National Metrology Laboratory (CSIR-NML). The primary responsibility of the Time and Frequency (TF) Laboratory of the CSIR-NML is the maintenance of the national standard for time.

In addition to the maintenance of the national time scale, the TF Laboratory also maintains standards for frequency, electrical pulse characterization, phase angle, phase noise, and optical time delay, wavelength, attenuation, and power in fiber optics. The TF Laboratory produces a monthly bulletin **[1]** that is distributed to local users free of charge. The bulletin is e-mailed to a number of recipients in text format and published on the Internet **[2]**. Time services, in the form of a Telephone Time Service and an Internet time service, are also provided.

The South African National Accreditation Service (SANAS) **[3]** assessed the TF Laboratory of the CSIR-NML in September 2002 and accreditation for most of the calibration services offered by the Laboratory was granted in June 2003. The TF Laboratory is also involved in knowledge transfer activities. Metrology courses in the field are designed by staff members and lectured on behalf of the Center for Skills Coordination **[4]**.

TIME AND FREQUENCY ACTIVITIES

In order to provide an overview of the activities of the TF Laboratory at the CSIR-NML, each of the parameters and services provided in the Laboratory will be discussed briefly.

TIME AND FREQUENCY

As mentioned in the Introduction, the primary activity of the CSIR-NML TF Laboratory is the maintenance of the national timescale of South Africa. A local representation of Coordinated Universal Time (UTC) is maintained at the CSIR and designated UTC (CSIR). UTC (CSIR) is based on the output of a commercial cesium beam atomic clock. Time transfer data generated by a multi-channel Global Positioning System (GPS) / Global Navigation Satellite System (GLONASS) satellite timing receiver is submitted to the International Bureau of Weights and Measures (Bureau International des Poids et Mesures – BIPM) on a weekly basis.

In addition to the clock generating the national timescale, the Laboratory also owns two other commercial cesium clocks. These clocks and a clock residing in a commercial laboratory located about 20 kilometers from the CSIR are also monitored on a weekly basis. In order to monitor these clocks independently, a Motorola-based common-view GPS receiver was developed in the Laboratory a few years ago **[5]**. A geodetic-quality GPS / GLONASS receiver was installed in the Laboratory to provide additional data and hopefully improve the performance of the time transfer links of the Laboratory.

Frequency is the reciprocal of time and is the parameter most often measured in the TF Laboratory. A number of frequency counters and generators make up the bulk of the equipment available in the Laboratory. Frequencies from 1 mHz to 40 GHz can be generated and measured in the Laboratory. Equipment calibrated includes crystal and rubidium oscillators, signal generators, and frequency counters.

Time interval is another parameter that is maintained in the TF Laboratory. The Laboratory has capabilities covering time interval from 1 ns to 100,000 seconds and beyond. Equipment calibrated includes time interval counters, delay generators, and stopwatches.

FAST ELECTRIC PULSE CHARACTERIZATION

A 50 GHz digital sampling oscilloscope forms the basis of the fast electrical pulse characterization facility of the TF Laboratory. A commercial rise time source with a certified fall time of 15 ps provides traceability to the services offered. Equipment calibrated includes fast rise sources and digital sampling oscilloscopes. Traceability for this service is obtained through the calibration services of the National Physical Laboratory of the United Kingdom.

PHASE ANGLE

The phase angle standard at the CSIR is based on a commercial phase angle standard. The accuracy of the phase angle standard is verified using passive phase bridges. The National Institute of Standards and Technology (NIST) of the United States of America periodically calibrates these phase bridges.

PHASE NOISE

A phase noise measurement system was acquired in 2002. A certified secondary noise standard capable of generating noise over a 10 MHz bandwidth with carrier frequencies of 5 MHz to 640 MHz was acquired in 2003 to provide traceability to the phase noise measurements performed in the TF Laboratory, through calibration of the secondary noise standard at NIST.

FIBER-OPTIC PARAMETERS

The fiber-optic facility was moved to the TF Laboratory in 1999. The TF and Radio Frequency (RF) laboratories are located in the same wing of one of the buildings of the CSIR-NML. The reason for the move was the similarity of the measurements made in fiber optics to those made in the TF and RF Laboratories, for example the calibration of optical delay lines is a time-interval measurement and the measurement of optical powers and attenuation is similar in nature to the equivalent measurements performed in the RF Laboratory.

FIBER OPTIC TIME DELAY

The TF Laboratory calibrates optical delay lines and the time delay / distance scale of Optical Time Domain Reflectometers (OTDRs).

OPTICAL WAVELENGTH

Optical wavelengths measured in the TF Laboratory are primarily those associated with the telecommunications industry, these being 850 nm, 1310 nm, and 1550 nm, including the associated Wavelength Division Multiplexing (WDM) and Dense Wavelength Division Multiplexing (DWDM) wavelength bands. Fiber-optic sources (lasers and LEDs) can be calibrated for wavelength, including sources that form part of fiber-optic instruments such as OTDRs. Optical Spectrum Analyzers (OSA) and optical wavelength meters can also be calibrated.

An acetylene-stabilized laser, developed at the CSIR-NML, and the acquisition of an OSA has improved the calibration of wavelengths in the 1520 to 1540 nm band. Helium neon lasers were previously used to calibrate a monochromator that was used in turn to perform wavelength calibrations throughout the communication band. Development of frequency-stabilized standards for other spectral regions is in progress.

OPTICAL POWER AND ATTENUATION

Fiber-optic power meters are the most common fiber-optic instrument calibrated by the TF Laboratory. Fiber-optic power meters can be calibrated for power and spectral response. These calibrations are traceable to the absolute radiometer. When calibrated against the absolute radiometer, uncertainties can approach 0.1 dB.

The linearity with power of fiber-optic power meters and detectors can also be calibrated. The traceability of the attenuation scale is obtained through detector linearity. Instruments and artifacts that can be calibrated for attenuation include fiber-optic attenuators, fiber-optic delay lines, and OTDRs.

ACCREDITED PARAMETERS

The TF Laboratory was assessed by SANAS in September 2002 to ascertain compliance of the Laboratory systems with ISO 17025. In addition to the TF parameters assessed, fiber-optic time delay was also assessed, with the rest of the fiber-optic parameters scheduled for assessment in May 2004. Accreditation was granted to the Laboratory in June 2003. The assessment team consisted of four people, an international technical expert, a local technical assessor, a local management system assessor, and a local technical observer. The schedule of accreditation is shown in Table I below. Note that “f” under item 1 in the table refers to the frequency of the unit under test and “t” under items 2 and 6 to the time interval being measured. Under item 3, the “t” refers to the rise or fall time under consideration.

Table I. Accredited parameters in the TF Laboratory of the CSIR-NML.

Item	Function	Nominal range	Best measurement capabilities expressed as an uncertainty (±)
1	Frequency	Specific values: 1 MHz, 5 MHz and 10 MHz Other values: 1mHz to 1,3GHz 1,3GHz to 40GHz	$1 \cdot 10^{-13} \cdot f$ $2 \cdot 10^{-10} \cdot f$ + 10μHz 3Hz
2	Time Interval	1ns to 100 000s	$2 \cdot 10^{-11} \cdot t$ + 2ns
3	Rise and fall time	15ps to 1μs	0,006·t + 6ps
4	Waveform aberration	0% to 50%	0,5%
5	Phase angle	0 to 360°, 5V equal amplitude: 1Hz to 6,25kHz 6,25kHz to 50kHz 50kHz to 100kHz 0 to 360°, 50mV to 100V: 1Hz to 100kHz	 0,005° 0,01° 0,02° 0,05°
6	Optical length	5ns to 300μs	$2 \cdot 10^{-5} \cdot t$ + 200ps

SERVICES

The TF Laboratory offers a number of time services. These include the Telephone Time Service (TTS) and Internet time services, and the publication of a monthly Time and Frequency Bulletin. All these services are available free of charge.

TIME AND FREQUENCY BULLETIN

The TF bulletin gives information on the status of the national standard master clock in relation to the GPS and GLONASS satellite systems, the average drift of the master clock, and the relation of UTC (CSIR) to UTC. Additional information include the status of the GPS satellite system, extracted from the GPS Notice Advisory to Navstar Users (NANU) list on the US Coast Guard Web site **[6]**; the current common view GPS tracking schedule; TF announcements; and information on the introduction of leap seconds. The TF Bulletin is available online **[2]**, or in printed format (on request) **[1]**.

TIME SERVICES

TELEPHONE TIME SERVICE

The TTS offers a machine-readable code to enable synchronization of computer systems. Special software, downloadable from the CSIR-NML Web site **[7]**, is required to access the service. The service can be accessed at 9600, 1200, and 300 baud. The best attainable accuracy of the synchronizing pulse is 1 ms, at 300 baud. The number of users for this service has declined over the last few years, with most users opting for the Internet time service. Users requiring secure access and users without access to the Internet still make use of the TTS.

INTERNET TIME SERVICE

The Internet time service offered by the CSIR-NML can serve the Time protocol and the Network Time Protocol (NTP) **[7]**. Two servers are available, *tick.nml.csir.co.za*, a Stratum 1 server using the master clock as it's synchronization source, and *tock.nml.csir.co.za*, a Stratum 2 server using the Stratum 1 machine as it's time reference. These two NTP machines are the only servers in South Africa that supply legal traceability in terms of the South African national measurement standard for time. The Stratum 1 server is access-restricted, while the Stratum 2 server has an open access policy. The use of this service has grown steadily over the past two years, with many TTS users switching to the Internet time service.

OTHER ACTIVITIES

In addition to the activities described above, the personnel in the TF Laboratory are SANAS technical assessors that perform assessments in the TF and fiber-optic fields on behalf of SANAS. Laboratory staff members also lecture a number of metrology courses.

KNOWLEDGE TRANSFER

The Time and Frequency course is presented on an annual basis depending on requirements. This course deals with the theory of clocks and oscillators; measurement techniques in time and frequency; an introduction to time transfer, including the use of GPS; and an introduction to oscilloscopes.

Several courses dealing with measurement uncertainty was developed in the past 2 years in the TF Laboratory. This included an internal course presented to all the technical staff members of the CSIR-NML, and two external courses – one presented to the technical assessors of SANAS (only some modules of this course were developed by the TF Laboratory), and one presented to technical staff of SANAS accredited laboratories.

FUTURE PLANS

The TF Laboratory plans to further expand its activities into optical frequency standards in the near future. It plans to establish a femtosecond (fs) frequency comb in the TF Laboratory that will replace a number of wavelength standards in the CSIR-NML. The fs comb is based on the frequency multiplication that takes place when very short pulses of light are launched into a nonlinear fiber, producing a comb of wavelengths. When this comb of wavelengths span more than an octave, it is possible to lock the comb directly to the radio frequency domain, making the frequency of every element in the comb known absolutely **[8]**.

REFERENCES

[1] Standard Time and Frequency Bulletin, National Metrology Laboratory, CSIR, Pretoria, South Africa, ISSN 1024-1612.

[2] Bulletins from 1996 available at *http://www.nml.csir.co.za/tfbulletin/*

[3] SANAS Web site at *http://www.sanas.co.za/*

[4] NLA Web site incorporating the Center for Skills Coordination at *http://www.nla.org.za/*

[5] E. L. Marais, 2000, "*The Development of Multi-channel GPS Receivers at the CSIR National Metrology Laboratory,*" in Proceedings of the 32nd Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 28-30 November 2000, Reston, Virginia, USA (U.S. Naval Observatory, Washington, DC), pp. 129-136.

[6] NANU page at *http://www.navcen.uscg.gov/gps/nanu.htm*

[7] Time Service page at *http://www.nml.csir.co.za/time.htm*

[8] R. Holzwarth, J. Reichert, T. Udem, and T. W. Hänsch, 2001, "*A New Type of Frequency Chain and Its Application to Optical Frequency Metrology,*" **Laser Physics, Vol. 11**, No. 10, pp. 1100-1109.