Instituto Nacional de Tecnología Industrial, INTI, ARGENTINA

Report on Research and Development Activities in Electricity and Magnetism 2014-2016

CCEM Meeting, March 2017

1. Quantum Standards

1.1. Transport Phenomena of Quantum Hall Effect Systems

(Contact: Mariano Real, mreal@inti.gob.ar and Alejandra Tonina, atonina@inti.gob.ar)

This project is aimed to achieve experimental developments of transport and thermal transport properties of the quantum Hall effect (QHE), to have greater comprehension and manipulation of edge states in these systems with applications in metrology. The Quantum Standard Laboratory is adapting and expanding existing equipment and capabilities. The theoretical support for these developments is carried out in the quantum transport group of ICAS-UNSAM (International Center for Advanced Studies placed at University of San Martín). We have started with studies on fractional quantum Hall effect on GaAs/AlGaAs devices. A set of samples were grown and provided by PTB and afterwards processed at INTI. During a research stay at PTB an initial set of samples were tested.
With the aim to observe thermal transport we started to process Corbino structures too, with a central NiCr heater, which should produce a temperature gradient between the center and the outer edges. This device could be suitable for thermoelectricity measurements.

1.2. Design and study of feasibility of a cryo-free system

(Contact: Mariano Real, mreal@inti.gob.ar and Alejandra Tonina, atonina@inti.gob.ar)

Given the increase of cost and use of Helium in recent years it is a goal of many institutes and universities to switch to cryo-free systems. Particularly PTB under the direction of Dr. F. Ahlers is pursuing such type of systems, to be used in combination with graphene based QHE devices. Collaboration was established to perform a design and a study of feasibility of a cryo-free system capable to be use at 3 K and 7 T or better. Given the already existing experience at PTB a staff from INTI made a research travel to PTB.

1.3. Robust control of cryogenic current comparators

(Contact Marcos Bierzychudek, marcosb@inti.gob.ar)

Modern control theory is a powerful tool to improve the performance of dynamic systems and we are devoted to research the impacts of this theory in metrology systems. For this purpose, the open loop and closed loop dynamic behavior of measurement bridges is analyzed using control theory techniques, in order to reduce the measurement uncertainty. In the last years, we have studied two bridges based on cryogenic current comparators (CCC). In both cases a robust controller designed according to the H_∞ theory improved the bridge balance with respect to the conventional integral controller.
The first studied CCC system was designed to calibrate two-terminal resistors with nominal values between 100 kΩ and 1 GΩ. Its behavior was described with an equivalent electrical circuit obtaining a 70% of agreement between measurements and simulations. Next, a family of models was constructed to represent all the possible configurations of the system. Closed-loop simulations were performed to compare the balance achieved with the integral controller

and with the controller designed by H∞. This second reduced the effects of distortions in the SQUID output by 20 dB up to 30 Hz and by a lower difference up to 5 kHz.
The second CCC bridge was designed and build by PTB. It can measure four-terminal resistors from 1 Ω up to 100 MΩ and is more complex than our two-terminal bridge. Hence four working configurations were selected and for each setup a model was identified and a robust controller was implemented. Experimental data showed that the new controllers were suitable for regular use in resistance calibration. It was also noted that the controllers designed with H∞ reduced the effect of distortions in the SQUID output by ten times from 0,1 Hz up to 700 Hz.
Our next step is to build a new four-terminal CCC to measure from 1 Ω up to 10 kΩ resistors with a multiple input – multiple output feedback loop, which will allow testing modern control theory techniques.

1.4. Waveform metrology based on spectrally pure Josephson voltage. EMPIR-EURAMET 2016

(contact Ricardo Iuzzolino, ricardo.iuzzolino@inti.gob.ar)

This Joint Research Project (JRP) will develop measurement systems centered on true AC-voltage quantum devices which will both operate at the highest level of accuracy and be simple enough for exploitation outside the national metrology institutes. The term 'true quantum devices' refers to the recently achieved breakthrough which provided spectrally pure quantized Josephson AC-voltages exceeding for the first time the usability threshold of 1 V RMS. In this JRP, innovative use of Josephson junctions is proposed for measurements of arbitrary signals in terms of fundamental constants referenced to the volt in the new SI. The need for this development is clearly driven by development in the application fields: Sensing and measurement are increasingly dependent on fast analogue-to-digital conversion. Recent R&D in precision integrated circuits and measurement equipment has brought about a step change in the sampling rates and accuracies available. Whereas direct traceability of DC electrical metrology to quantum standards is well established, emerging measurement applications in high end equipment are placing new demands on the traceability for dynamic quantities, which cannot be satisfied by the existing approaches. Fluke e.g. has written "One of the barriers to reducing the uncertainty of these multifunction calibrators for AC voltage is the magnitude of uncertainty inherited in the traceability chain."
The overall objective of this JRP is to provide for all end-users direct, efficient, and highly accurate traceability of AC-voltages to the SI volt for dynamic measurements in the most relevant range of DC to 1 MHz, up to levels of 1 kV.

INTI is participating as founded partner in Working Package no.1. The aim of this work package is to design and build a quantum voltage digitizer. Delta sigma electronics, a pulse generation system and a feedback loop will be developed.

The components developed in WP1, together with the quantum-accurate system developed in WP2 will form a quantum voltage digitizer, which will be tested and characterized in WP1. Together with the voltage dividers (WP3) the system will be used in WP4 to develop the methodology for characterization of industrial devices. It will also be used to calibrate some industrial instruments in WP4.

The quantum voltage digitizer will operate over DC to 1 MHz frequency range with a target uncertainty of 10 nV/V level for frequencies up to 5 kHz and better than 10 µV/V for frequencies up to 1 MHz. The sampling rate will be 100 MHz and the input will be +/-1 V maximum. The spectral purity (SINAD) will be better than 110 dB. At lower frequencies distortion levels of better than -140 dB are expected.

EMRP project Q-WAVE is developing a quantum voltage digitizer using a prototyping approach (based on off-the-shelf commercial evaluation boards) to provide proof of concept. A first order delta sigma loop has been demonstrated (as yet without quantum-accurate feedback). This EMPIR project will build on the knowledge gained within the Q-WAVE project.

The practical realization will use specially designed circuitry rather than off-the-shelve hardware. Further expertise will be drawn from international experts (APPLICOS, INTI and Signal Conversion) to result in a robust, flexible and optimized design providing a state-of-the-art system. Building on the EMRP project, the frequency range will be extended by a factor of ten, the uncertainty lowered by a factor of ten and the sampling rate increased by a factor of 10. This quantum voltage digitizer will be key in Europe's future provision of quantum-accurate AC voltage metrology to NMIs and industrial users.

1.5. Infrastructure for direct traceability to the unit volt of novel digital sampling

algorithms with quantum voltage standards. Joint Project INTI-PTB under bilateral Argentine-Germany cooperation program MINCyT- BMBF.

(contact Ricardo Iuzzolino, ricardo.iuzzolino@inti.gob.ar)

The main goal of this Project is to join the volt unit directly to sampling algorithms at INTI. To accomplish the objective INTI is upgrading its Josephson system to a programmable system in cooperation with PTB. And, INTI is improving its sampling system based on sigma-delta ADC techniques to measure ac signal in the amplitude range up to 1 V with frequency up to 100 kHz.
The MINCyT and its counterpart, BMBF, are given financial support for scientist exchange from both institutions.

2. Power and Energy

2.1. Phasor measurement system for the development of smart grids

(Contact Lucas Di Lillo, ldili@inti.gob.ar)

The present work is a joint development between the INTI (National Institute of Industrial Technology), the Center for Computational Simulation of CONICET (CSC), Institute of Technological Research for Networks and Electrical Equipment (IITREE) of the Faculty of Engineering of National University of La Plata and COMPUTEC SRL with the aim of design, development and construction of a phasor measurement unit (PMU) that fulfils the requirements of the IEEE Standard C37.118.1-2011
This project involves I&D activities in various disciplines: electrical metrology, signal analysis, embedded software, electronic design, power system analysis and electromagnetic compatibility. The experience of the different groups is complemented to cover all the necessary expertise. The project consist of three working package

WP 1. Development of a commercial PMU that fulfils the requirements of the IEEE standard C37.118.1-2011

The aim of this subproject is base on testing and selection of the appropriate spectral estimation algorithms for synchrophasor estimation, development of current and voltage transducers to adapt the input signals to the levels required for the internal electronics, development of the PMU communication module and the implementation of PMU electronics and embedded software.

WP 2. Development of PMU test platform

The aim of this subproject is the development of a reference system for the calibration of PMUs and the implementation of the Electromagnetic Compatibility and Electrical Safety Tests.

WP 3. Development of software tools for the processing and analysis of synchrophasors.

The aim of this subproject is the development and implementation of synchrophasor processing and analysis software as well as the optimization of the sensor network.

Concerning the activities of WP 1 and WP 2, an algorithm for the calculation of the synchrophasors that fulfils the requirements IEEE Std. C37.118.1 was designed. Also, a synchronous generation and sampling system was designed to compare the synchrophasors measured by the PMU under test with the reference synchrophasors generated by the reference system. The reference synchrophasors are estimated by polynomial approximations that are solved by the least square method. For the validation of these approximations a comparison was made between the synchrophasors obtained by the synchrophasor laboratory the METAS for stationary test and the frequency ramp, obtaining satisfactory results. One of the activities of WP 3 is and the implementation of synchrophasor processing and analysis software. The objective is focused on the processing of data collected from a number of PMUs that may be installed on the network. To achieve this goal, an online processing module is being worked out in which phasor diagrams and trend diagrams are displayed in graphic form, allowing a real-time view of the behavior of the power system. On the other side, a second offline module which is capable of processing the data and it will can show and analyze events such as decomposition into sequence components and analysis of system oscillation modes.

2.2. High frequency wattmeter

(Contact Lucas Di Lillo, ldili@inti.gob.ar)

The Instituto Nacional de Metrologia, Qualidade e Tecnologia (INMETRO), in Brazil, the Instituto Nacional de Tecnología Industrial (INTI), in Argentina, and the Administración Nacional de Usinas e Transmisiones Eléctricas (UTE), in Uruguay, are jointly developing a reference system for measuring electric power up to 100 kHz. The objective is the construction of three similar measuring systems, one for each institute.
This project will contribute to provide calibration services in measuring ranges still not covered by the three institutes. The project will also contribute to improve the traceability not only of electric power but also of related quantities like ac-dc transfer, voltage ratio, phase angle, ac voltage and ac current. The project is coordinated by INMETRO, who is responsible for the purchase and transportation of the components and parts needed to the construction of the modules, and for the transportation of the modules needed to the assembly of the measuring systems, in each partner country.
INMETRO is also responsible for the development of the wideband power and transconductance amplifiers and of new digital sampling algorithms. INTI is responsible for the development of the arbitrary waveform function generator, the dual-channel digitizer and the current shunts (and their calibration). UTE is responsible for the development of the resistive voltage dividers (and their calibration).
The project activities include the design, layout and documentation of the printed circuit boards of the modules, the design and documentation of the electronic packaging of the modules, the calibration of resistive voltage dividers and current shunts, the design and documentation of the software and firmware, and the measuring system integration, testing and documentation.
The project is supported in part by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), in Brazil.

3. High Voltage

3.1. New voltage transformer calibration set-up.

(Contact José Luis Casais, jcasais@inti.gob.ar)
The indirect method in use for the calibration of high voltage transformers (up to 500 kV) has a typical uncertainty of $200 \cdot 10^{-6}$. A new self calibration method that uses a capacitive divider and a current comparator with reduced uncertainty is under evaluation. In order to reduce the uncertainty between 150 kV and 500 kV a study of the voltage dependence of the high voltage capacitor is under evaluation.

3.2. New voltage and current transformer bridges

(Contact José Luis Casais, jcasais@inti.gob.ar)
We usually calibrated current and voltage transformers with uncertainties of $60 \cdot 10^{-6}$ and $30 \cdot 10^{-6}$ respectively using commercial bridges. To reduce these uncertainties and increase speed, new high accuracy voltage and current transformer comparison systems was built. They are based on current comparators, inductive dividers and data acquisition boards to digitally process the measured data. With this new system INTI reduces the uncertainties in current and voltage measurement transformers to 10.10^{-6}.

3.3. New partial discharge calibrator

(Contact José Luis Casais, jcasais@inti.gob.ar)

A new calibrator for partial discharge measuring systems was development. It allows the determination of the factor scale and resolution time of the impulses registered in the PD system under calibration. It is based on wetted mercury relays and it is synchronized with the grid frequency by means of capacitive coupling. It fulfills the requirements of IEC 60270.

3.4. 150 kV reference DC voltage divider

(Contact José Luis Casais, jcasais@inti.gob.ar)

A new reference resistive divider up to 150 kV DC was development and calibrated. It was made by 150 high stability resistors of 1 MOhm.

4. RF Metrology

4.1. Scattering parameters

(Contact Guillermo Monasterios, guillem@inti.gob.ar)

Vector Network Analyzers (VNA) are used as working standards to measure scattering parameters (complex values) of systems that use Type-N and 3.5 mm connectors, covering a frequency range up to 32 GHz.
The modeling of the air lines used as characteristic impedance standards has been improved. Accurate S-parameter values of the lines are reached based on diameter and length measurements at INTI's dimensional metrology laboratory. In addition, the determination of the effective resistivity is determined by means of HF attenuation measurements.

The first Key Comparison in microwave frequencies within the SIM (Sistema Interamericano de Metrología) region has been carried out. It was piloted by INTI (Argentina). The measurands were the S-parameters of 50 ohm coaxial devices with Type-N connectors and were measured at 2 GHz, 9 GHz and 18 GHz. SIM.EM.RF-K5b.CL was the identification assigned and it was based on a parent CCEM key comparison named CCEM.RF-K5b.CL. This key comparison has met the need for ensuring traceability in high-frequency measurements across America by linking SIM's results to CCEM’s ones. Six NMIs have participated in this comparison. A linking method of multivariate values was proposed and implemented to allow the linking of 2-dimensional results.
3D Electromagnetic modeling of coaxial elements such as offset-short and open terminations are being carried out. This technique requires full-dimensional characterization of their inside parts. Therefore complex dimensional measurements techniques are necessary to fulfill this task. The aim of this work is to replace the current air lines characteristic impedance standard by much more stable and easy-handling coaxial terminations working as reflection standards.
A comprehensive study of new calibration algorithms is in progress. The programming of upgraded software that is based on those algorithms is currently being done in order to validate VNAs firmware and available metrological software.
The HF metrology group of INTI has taken part in the revision of the new version of the EURAMET guide cg-12 “Guidelines on the Evaluation of Vector Network Analyzers” as external reviewer. This document is the world-wide reference in the evaluation of VNA measurement uncertainties and has been completely reviewed and updated after a long time since the publication of the prior version by EURAMET.

4.2. Power Standard

(Contact Alejandro Henze, ahenze@inti.gob.ar)

Full-automatic thermistor mount or thermoelectric power sensors calibration for type-N connector between 10 MHz and 18 GHz is provided with basic accuracies between 0.5 % and 2 %. 3.5 mm connector power sensor calibration service up to 26.5 GHz is intended to be offered in the near future.
Low frequency power calibration system for ranges between 1 MHz and 100 MHz is being developed with traceability to DC calorimetric power standard.

5. Electromagnetic Fields

5.1. Performance of broadband hybrid antennas for EMC measurements

(Contact Luciano Blas, emc@inti.gob.ar)

This work studies the critical metrological characteristics of the hybrid broadband antennas, like the used BiConiLog antenna, when they are used as reception antennas in the 10m measurements of electromagnetic field strength, polarized horizontally. This study's finality is to evaluate the hybrid broadband antennas contribution in the measurement uncertainty budget.