# Progress Report on Electrical Metrology at CENAM-Mexico 2019 - 2021

**Report prepared for the 32nd meeting of the Consultative Committee for Electricity and Magnetism (CCEM), April 2021**

## INTRODUCTION

During this period, several changes were carried out in Mexico in strong relation with metrology: a new law called the Quality Infrastructure Law, approved on July 1, 2020, confirms the scientific nature of CENAM, relying on its highly important role in the national economy with various attributions of the Law, which allow it to deploy its capabilities to offer metrological services of high technological level to the productive and social sectors. In this context CENAM should direct its efforts to support productive development, influencing the development of knowledge without neglecting the attention to the measurement needs associated with a better quality of life and social well-being. On the other hand, in 2019 the international community adopted the redefinition of four of the seven base units of the International System of Units, SI, based on fundamental constants of nature. With this international agreement on the SI, the scientific advance that underpins technological development in this era of digital transformation is supported. With these changes in 2020, the Electrical Metrology Area of CENAM proposed to orient its efforts to address the challenges imposed by the national and international context: 1) advance in the development of primary standards, particularly in quantum metrology, which associate the fundamental principles of science to the applications of measurements in technology.; 2) advance in the development of Metrology to adopt digital transformation, as the most effective and efficient way to bring the added value of primary Metrology in electromagnetism to society.

## 1. Low frequency

### 1.1. Programmable Josephson Voltage Standard (PJVS)

A system to calibrate AC voltage sources (high accuracy calibrators) was developed based on a PJVS by implementing the differential sampling technique. The achieve accuracy for 1V (RMS), 60 Hz is about 0.3 µV/V ($k = 2$) and for 1 kHz is about 1 µV/V.

The AC-DC voltage transfer difference of thermal voltage converters was calibrated using the PJVS and compared with the PTB's reference values. The differences are within the uncertainty given by PTB's multijunction thermal converter, which is transfer to one set of planar multijunction thermal converters maintained in CENAM's reference system from 60 Hz up to 1.2 kHz. During 2020 two calibration exercises were carried out, achieving differences lower than 1.9 µV/V up to 1.2 kHz bandwidth. In 2021 better uncertainties are expected by improving the CENAM's PJVS.

A reference system for high-resolution digitizers was developed. This new capability allows CENAM to lower uncertainty for those systems based on digital sampling such as power and energy, power quality, digital impedance bridges. The reference system is implemented using the PJVS directly for linearity, noise assessment, effective resolution, zero-crossing performance. It is expected to present these new capabilities during a coming peer review in 2022.

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## 1.2 Realization of the farad with traceability to the defining fundamental constants of the SI

In the CENAM Impedance laboratory, work is being done to develop the measurement standards and systems necessary to establish the traceability chain of capacitance measurements towards the quantized Hall resistance (figure 1). During the last years, a digitally-assisted impedance ratio bridge (DAIRB) has been in development. The bridge will define the value of homemade 100 kΩ standard resistors at a frequency of 1592 Hz, using a homemade 10 kΩ octofilar calculable resistor (CR) traceable to the quantum Hall effect. During a collaboration stay at the Federal Institute of Metrology (METAS) during 2017, the CENAM CR was tested employing the coaxial CR of METAS, achieving the results shown in figure 2. As can be seen in figure 3, the DARIB involved the development of high-accuracy measurement instruments. A two-stage guarded inductive voltage divider (IVD) to establish the bridge voltage ratio; an isolation transformer to supply the measurement current; a set of 6 computer-controlled sinusoidal signals, in conjunction with a signal conditioning stage and 100: 1 injection transformers, to balance the bridge and achieve the four terminal-pair impedance definition on Zx and Zs; a multiplexer in conjunction with a Lock-In amplifier to measure the nulls of the bridge balance signals. An automatic control algorithm based on fuzzy logic that allows the bridge's balance to be carried out is currently being implemented. Results of the DAIRB are expected this year.

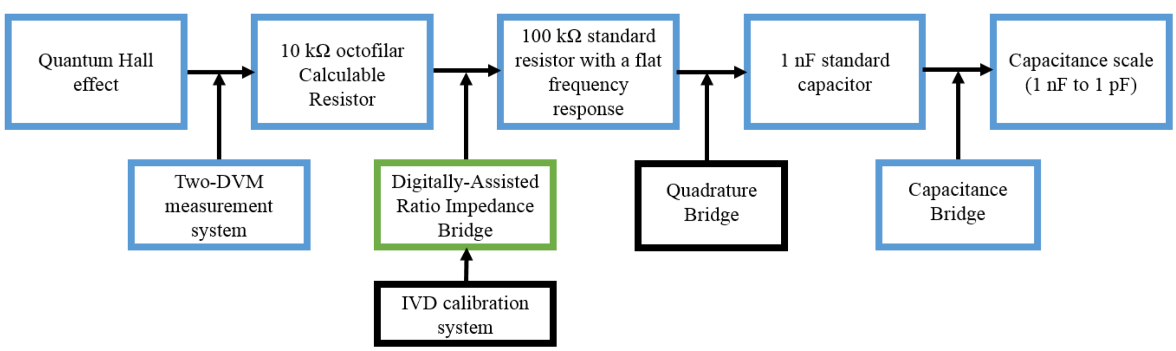


Figure 1.- Traceability chain for the realization of the farad unit from the quantum Hall effect. The blue, green, and black boxes represent the standard and measurement systems that are already developed, those in development, and those that have not been developed, respectively.

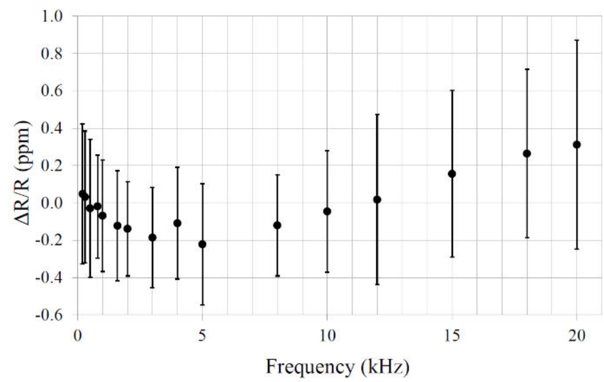


Figure 2.- Graph of the relative difference between the measured and the calculated frequency dependence of the equivalent parallel resistance of the 10 kΩ CENAM CR and the 1 kΩ METAS CR 10:1 ratio, as a function of frequency.

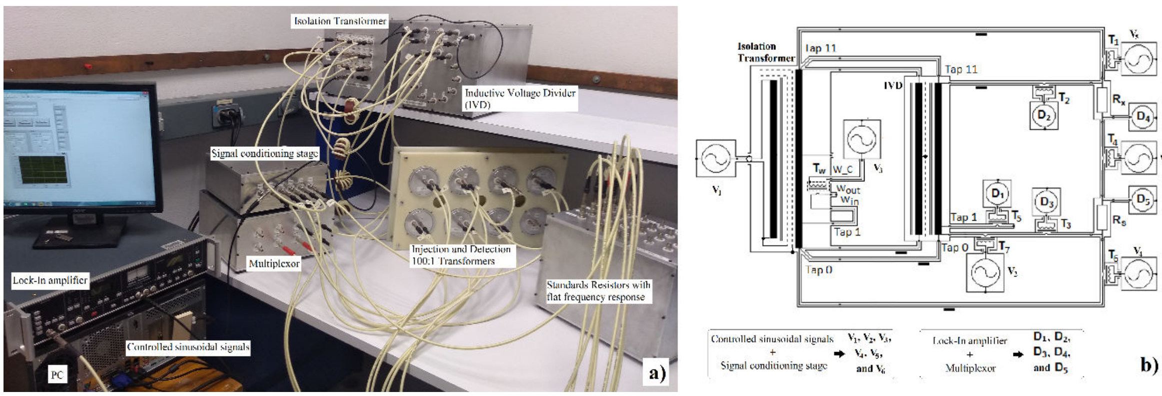


Figure 3.- Digitally-Assisted Ratio Impedance Bridge. a) Picture of the bridge; b) circuit of the bridge.


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## 1.3 Standard of Power Quality Disturbances

This standard provides traceability to the measurements of power quality parameters, such as sags, swells, interruptions, harmonics, both current and voltage, flicker. Those parameters are critical when quantification is required on transmission and distribution lines, including installed transformers. Currently, CENAM has developed a high-accuracy digital sampling system for the disturbances above based on a real-time platform (PXI). This system is the basis of the national power quality standard for spectral measurements under static and dynamic conditions.

During the development of the standard of power quality measurements, a travel standard was designed and constructed with uncertainties of 50 µV/V for voltage and 70 µA/A for current in harmonic measurements. This traveling standard responds to developing proficiency tests in Mexico and carrying out international comparisons in harmonics measurements within SIM region.

This national standard supports the achievement of national goals in smart grid issues. During 2020 the optimization of the first real-time measurement prototype was continued and finished, with measurement capabilities of up to 50 harmonics in 200 ms observation windows. The main components of uncertainty in the real-time power quality measuring standard is related with AC current and voltage transducers along with the ADC performance. The ADC characterization was made using the PJVS directly.

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### 1.4 Reference system for synchro-phasor calibration

This project was defined with the objective of providing traceability to wide-area meters in electric power networks known as PMU's. These meters are fundamental for the operational control of electricity networks in Mexico; currently, there are more than 400 meters deployed in various substations, which provide information on the state that the network keeps close to real- time.

During this period, we continued with the implementation of a real-time processing platform that includes four stages: 1) data acquisition, 2) processing through reference measurement method, 3) synchronization stage, and 4) system development of communications. During 2019-2020, stages three through four were carried out, and the communications stage is ongoing. This last stage will be completed during the first semester of 2021.

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## 2. Radiofrequency

### 2.1 Radiofrequency power standard characterization to 50 GHz

To establish the RF power traceability up to 50 GHz by means of a primary standard for microwave and millimeter wave power, the metrological characterization of our new coaxial microcalorimeter system in 2.4 mm line size along with its thermoelectric type transfer standards was performed. The evaluation involved the determination of both the microcalorimeter correction factor and the effective efficiency of the thermoelectric transfer standards from 50 MHz up to 50 GHz. The effective efficiency was evaluated with a LF power substitution method and the achieved expanded uncertainty ($k$ = 2) at 50 GHz is 0.0316 (a relative uncertainty of approximately 3.55%).

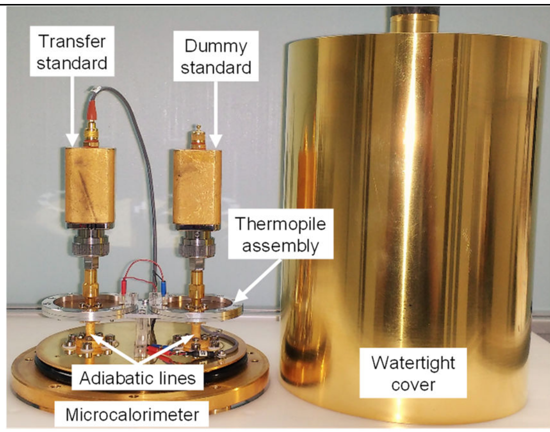


Fig. 4. CENAM’s coaxial primary standard for microwave and millimeter-wave power in 2.4 mm line size.

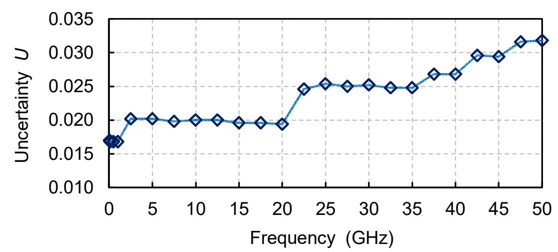


Fig. 5. Expanded uncertainty (coverage factor of 2) in the measurement of effective efficiency.

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## 2.2 Reflection and Transmission coefficient measurement capabilities to 50 GHz

Calibration and measurement services for reflection and transmission coefficients have continued growing; most of those services are provided in Type N connector up to 18 GHz, though recently enforcement of local regulations in telecommunications and electromagnetic field measurements have pushed the demand of services in type 3.5 mm, 2.92 mm and 2.4 mm up to 50 GHz. A commercial high performance VNA is used for providing calibration services and traceability to the SI units has been establish through sets of precision standard airlines in Type N, 3.5 mm, 2.92 mm and 2.4 mm, respectively.

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## 2.3 Antenna and electromagnetic fields calibration (Extension of the frequency range to 40 GHz)

As for other RF quantities, the recent enforcement of local regulations for telecommunications and electromagnetic fields have pushed the demand of antenna calibration and electromagnetic fields measurements. Traceability to the SI units is provided by sets of calculable dipoles for the lower frequency range and calculable gain horns for the microwave range up to 18 GHz. Calibration services from 30 MHz to 8 GHz for dipole-alike antennas are performed in an open area calibration site compliant with IEC/CISPR 16-1-5.

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## 3. Participation in Comparisons

**CCEM-K2.2012**, Comparison of resistance standards at 10 MΩ and 1 GΩ. CENAM measurements performed in 2012. Final report received on February 2020

**CCEM-K5.2017**, Active power, 53 Hz, at 120 V - 5 A and 240 V - 5 A, each at five different power factors (1, 0.5 lead, 0.5 lag, 0 lead, 0 lag). Final round measurements in progress.

**SIM.EM-S13**, Voltage, Current and Resistance Comparison, Draft B in preparation.

## 4. List of Publications

S. Campos-Montiel, S. Jiménez-Sandoval, L. Lira, and **R. Carranza-López-Padilla**, "Design of a 1 ampere high-precision thin-film resistive current transducer with negligible frequency dependence from DC to 100 kHz", Revista Mexicana de Física 66 (5) 589–603 SEPTEMBER-OCTOBER 2020.

**M. Rodriguez**, **R. Carranza**, R. Romero-Troncoso, R.A. Osornio Rios, "High Rate Report Synchrophasor Technique during Dynamic Conditions", in Journal of Scientific & Industrial Research, Vol. 79, February 2020.

**Pacheco-Estrada, A.H.**; **Hernandez-Marquez, F.L**.; Aviles, C.D.; Duarte-Galvan, C.; Rodríguez-Reséndiz, J.; Aguirre-Becerra, H.; Contreras-Medina, L.M. "A Simple Methodology to Develop Bifilar, Quadrifilar, and Octofilar Calculable Resistors". Appl. Sci. 2020, 10, 1595. https://doi.org/10.3390/app10051595

**M. Botello-Perez**, J.-Y. Kwon, **I. Garcia-Ruiz,** and H. Jardon-Aguilar, "A 2.4 mm Coaxial Microcalorimeter for Use as Millimeter-Wave Power Standard at CENAM," *IEEE Transactions on Instrumentation and Measurement*, vol. 70, pp. 1–10, Sep. 2020. *DOI: 10.1109/TIM.2020.3024340*.