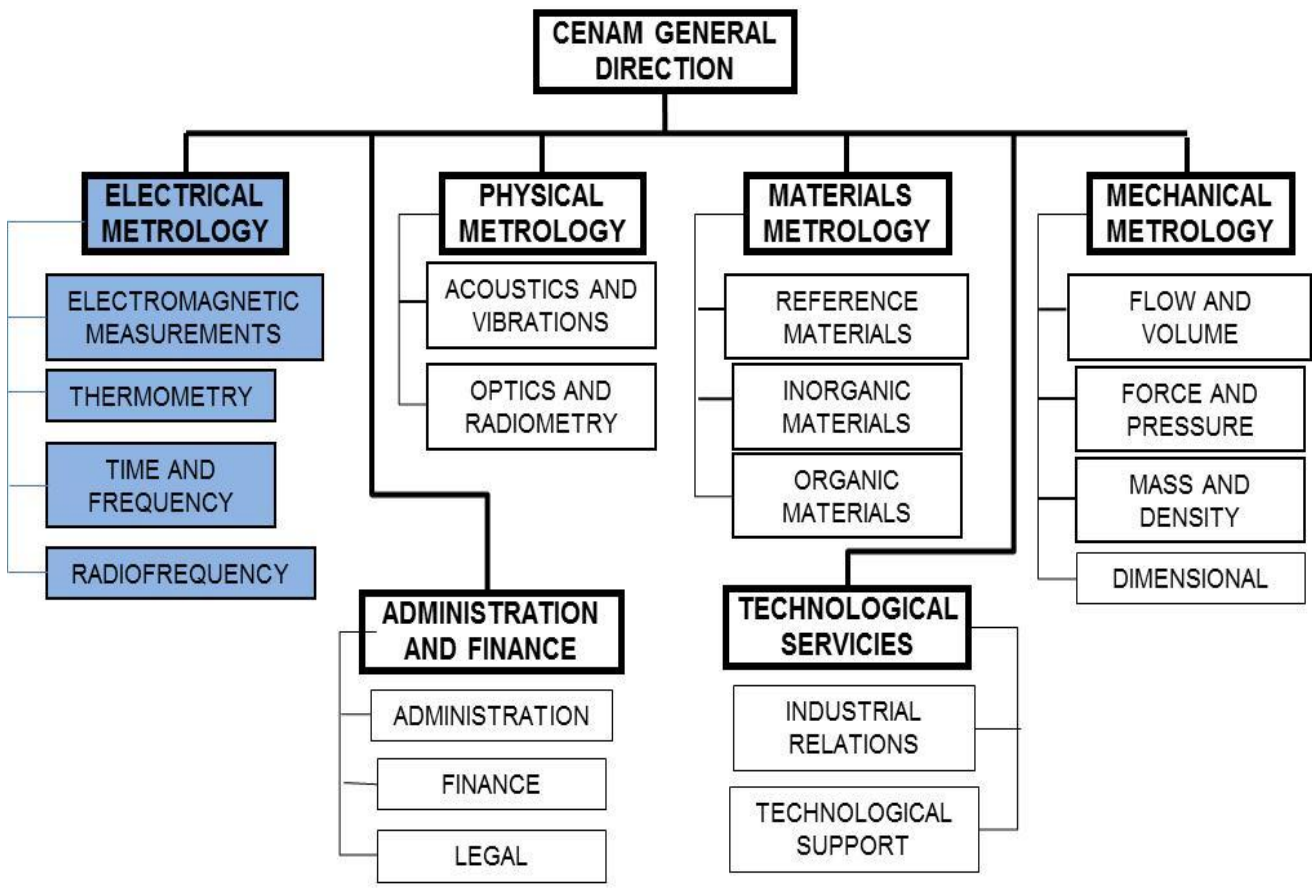
CENTRO NACIONAL DE METROLOGIA, CENAM

REPORT ON RESEARCH AND DEVELOPMENT ACTIVITIES IN ELECTRICITY AND MAGNETISM

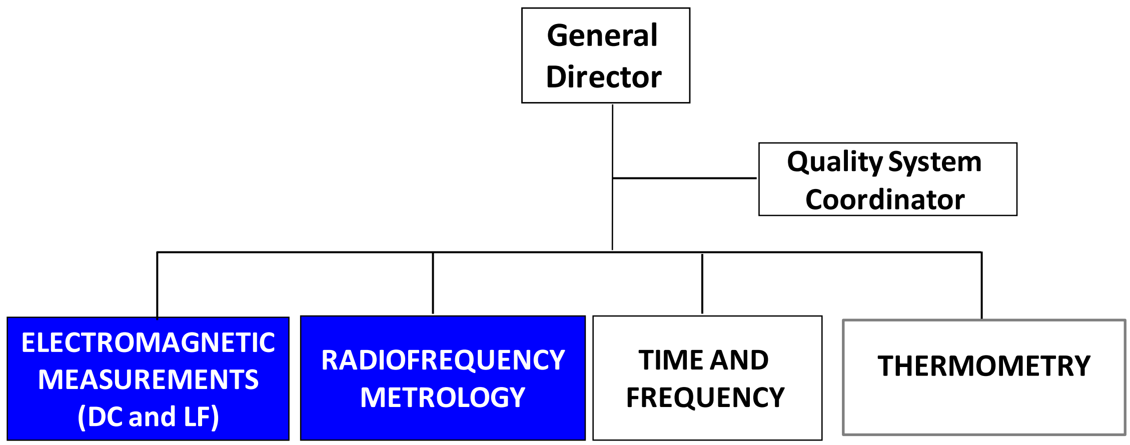
FEBRUARY 2015

CONTENTS

Organization of CENAM

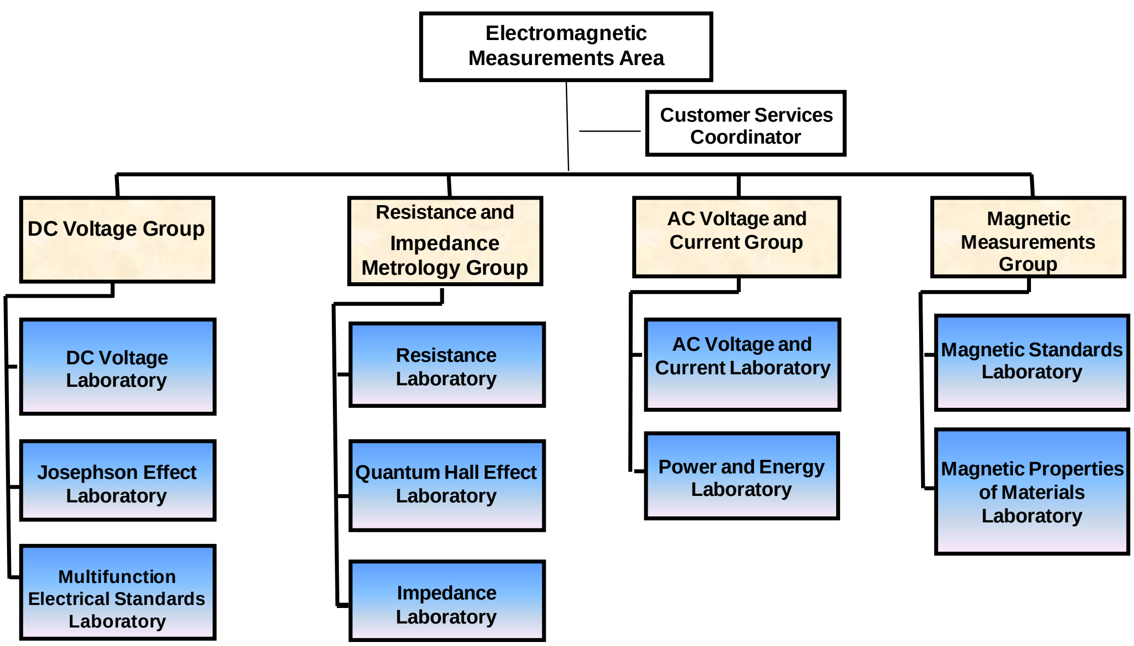


Organization of the Electrical Metrology Direction



ELECTROMAGNETIC MEASUREMENTS DIRECTION

Organization



Electromagnetic Measurements Direction: Main Research Projects 2015-2018

<table>
<thead>
<tr><th>PROJECTS</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th></tr>
</thead>
<tbody>
<tr><td rowspan="2">Josephson Effect</td><td></td><td>BIPM-CENAM comparison of Programmable Josephson Effect

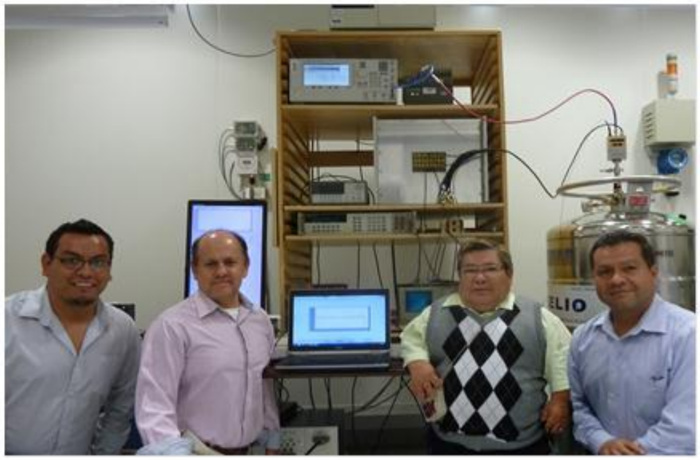
CENAM-David Avilés, Enrique Navarrete, Dionisio Hernández
BIPM-Stephan Solve</td><td></td><td></td></tr>
<tr><td colspan="2">Traceability of AC-Voltage to the Programmable Josephson Effect up to 10 kHz
David Avilés, Enrique Navarrete, Jesús Medina, Sara Campos,</td><td></td><td></td></tr>
<tr><td rowspan="2">Quantum Hall Effect and Resistance Metrology</td><td>Cryogenic Current Comparator
1 Ω to the QHE value
Felipe Hernandez, Benjamín Rodriguez</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Low Resistance Measurement Standard down to 1Ω at 1 kA
Felipe Hernandez, Ben Hur Morales</td><td></td><td></td></tr>
<tr><td rowspan="4">Impedance Measurements</td><td colspan="2">Broadening of the capacitance measuring range: 50 Hz to 20 kHz
Angel Moreno</td><td></td><td></td></tr>
<tr><td colspan="2">Calculable Resistor 1 kΩ , DC to 1592 Hz.
Aleph Pacheco</td><td></td><td></td></tr>
<tr><td colspan="3">AC Resistance Digital Measuring System: 1 kΩ a 100 kΩ at 4 terminals, 1592 Hz.
Angel Moreno and Aleph Pacheco</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Digital Quadrature Bridge.
Angel Moreno and Aleph Pacheco</td></tr>
<tr><td rowspan="3">AC Voltage and Current</td><td colspan="4">1 A and 5 A Planar Multi Junction Thermal Converter
Sergio Campos, René Carranza, Sergio Jiménez (CINVESTAV-IPN)</td></tr>
<tr><td></td><td colspan="3">100 MHz High Frequency Thermal Converter
David Aviles, Sara Campos</td></tr>
<tr><td colspan="2">Coaxial Current Shunts 100 mA to 1 A up to 100 kHz
Sara Campos, René Carranza</td><td>-</td><td>-</td></tr>
</tbody>
</table>

Electric Power and Energy	***Quality of Power Measurement Standard: Spectral Components/Static Conditions IEC61000-4-7 René Carranza; Adrian Castruita, Sergio Campos***
	Quality of Power Reference Measurement Standard: Spectral Components/Dynamic Conditions IEC61000-4-7 and IEEE C37.118.1 2011 and 2014 René Carranza; Marco Rodriguez, Adrian Castruita
	Smart Grid II. EMRP. PMU Metrology IEEE C37.118.1-2011 and 2014 Synchrophasor Measurement Standard - Non-stationary electric signals René Carranza, Marco Rodriguez, Sergio Campos, Sergio Jiménez (CINVESTAV) and René Romero (Universidad Autónoma de Querétaro)
	CCEM -K5 key comparison 50/60 Hz power. PTB/VSL/CENAM CENAM: René Carranza, Adrián Castruita
Magnetism Metrology	***Measurement Reference Standard of Magnetic Susceptibility (ferromagnetic, paramagnetic and diamagnetic materials) Marco Escobar and Mario Alatorre***
	Measurement Reference Standard of AC Magnetic Flux 100 µT a 3 mT; frequencies 50 Hz ≤ f ≤ 1 kHz, U= 30 mT/T Marco Escobar and Mario Alatorre

DC Voltage Group

Staff members

STAFF:



Eng. Jesús Medina	Dr. David Avilés	Eng. Dionisio Hernández	Dr. Enrique Navarrete
Engineer Collaborator	Scientific Coordinator of the Quantum Standards Group	Metrologist	Responsible for the Laboratory

David Avilés/ Group leader. caviles@cenam.mx
Enrique Navarrete/ Laboratory responsible. enavarre@cenam.mx
Dionisio Hernández/Metrologist. dhernand@cenam.mx
Jesús Medina/Engineer collaborator: jmedina@cenam.mx

THE DC VOLTAGE LABORATORY

FACILITIES:

DC Voltage Group Projects 2014-2018

1. Development of Programmable Josephson Voltage Standard Applications

A Programmable Josephson Voltage Standard (PJVS) was developed at CENAM, based on a NIST 10 V chip. The bias source and the control software were developed at CENAM. The cryo-probe was modified to increase the bandwidth. The main features of the standard are described in (Carlos David Avilés, Jesús Medina, and Enrique Navarrete, "The CENAM Programmable Josephson Voltage Standard", Proceedings CPEM 2014 Digest). The following applications based in the CENAM PJVS will be developed.

   a. DC voltage measurement system (-10 V < V < +10 V)
   b. Sampling multi-meters calibration system (0.1 Hz < f < 10 kHz, Vp < 10 V)
   c. Thermal voltage converters calibration in the low frequency range.

2. Thermodynamic Temperature Measurements, based on semiconductor electrical measurements. (collaboration CINVESTAV – CENAM)

Since many years, the PN junction of some semiconductors has been used for temperature measurements. We know that the PN junction is a very bad thermometer, because their parameters are temperature and time dependent, further some parasitic effects produce big errors in the temperature measurements, and frequent calibrations are necessary for its use as a temperature sensor.

Recently a Mexican scientist published an article (J. Mimila Arroyo, "Free electron gas primary thermometer; the bipolar Junction transistor", Applied Physical letters, 103, 193509 (2013)) showing that under particular bias conditions, the collector current of a bipolar transistor follows very well the Maxwell Boltzmann statistics of a free electron gas, and then can be used as an absolute thermometer.

Some preliminary measurements made at CENAM show that it is possible to perform such measurements with an uncertainty of about 100 mK, but several improvements are possible to reduce this uncertainty level. A study is under way to find the limits, the systematic errors and uncertainty of this approach.

3. Development of a coaxial thermo-converter for AC voltage measurements (1 Hz < f < 100 MHz)

A PJVS standard can give traceability to AC voltage measurements in a low frequency range (0 – 1 kHz). The objective of this project is to give traceability to AC voltage measurements for frequencies until several hundreds of MHz. We think that it is possible to develop a coaxial thermo-converter for this purpose. The high frequency AC-DC difference could be calculated by the coaxial lines theory, and the low frequency AC-DC difference could be calibrated against the PJVS. A similar idea was presented by Filipski (P. Filipski, R. Clark, and D. Paulusse, "Calorimetric Thermal Voltage Converter as a Wideband Calculable Standard of AC–DC Difference", IEEE trans. on Inst. and Meas., vol. 48, No. 2, April 1999) but the low frequency AD-DC difference were calibrated against thermal voltage converters.

International collaboration:

CENAM-BIPM

Uncertainty sources of a direct comparison of PJVS

A collaboration between CENAM and BIPM is planned this year, in order to study the uncertainty sources in a direct comparison of PJVS at 10 V level. (Scientist involved: Stephan Solve (BIPM), David Avilés (CENAM)).

CENAM-NIST

Pulse driven JVS

CENAM collaborated in the electrical isolation from ground of the pulse driven JVS of NIST. A 10 GHz optical isolation system was developed at CENAM and tested at NIST with a Johnson noise thermometry system. The device worked properly.

CENAM – INM Colombia

Pre-audit of the standard 17025

David Avilés from CENAM performed a Pre-audit of the standard 17025 (part 5) in DC voltage measurements at the INM (National Institute of Metrology of Colombia) from 5 to 11 August 2012.

Participation in the Electricity and Magnetism Working Group of SIM

CENAM Representative: David Avilés

Primary reviewer Resistance: Felipe Hernández

Primary reviewer AC current: Sara Campos

Secondary reviewer DC voltage: David Avilés

Secondary reviewer AC voltage: Sara Campos

Secondary reviewer E&M fields: Israel García

Peer reviews performed to the DC voltage Laboratory of CENAM

YEAR:	CONDUCTED BY:	FROM:	CENAM LABORATORY
2006	DR. YI HUA TANG	NIST	DC VOLTAGE
2011	DR. STEPHAN SOLVE	BIPM	DC VOLTAGE

International Comparisons

Uncertainty of the Josephson Voltage Standard at CENAM:

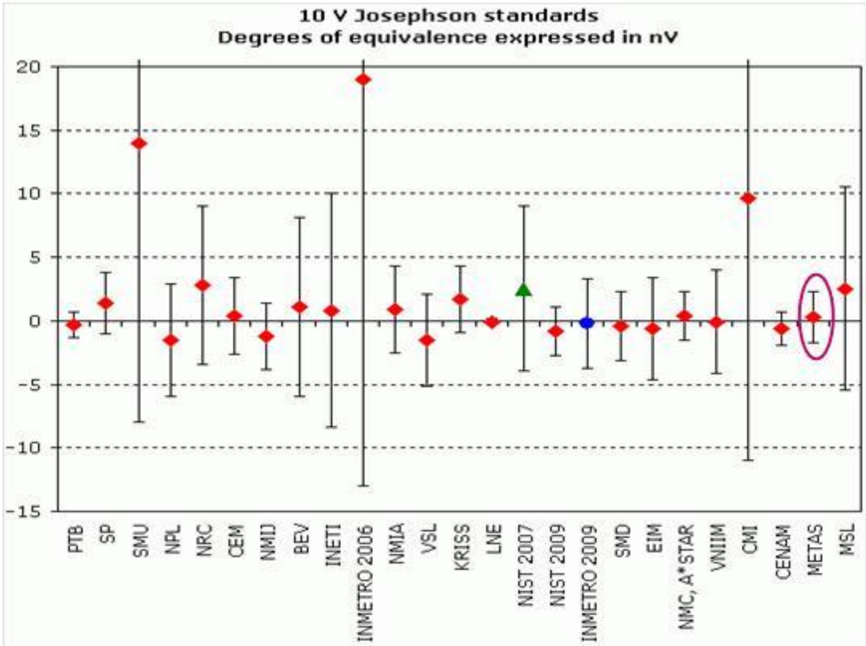
UNCERTAINTY COMPONENT	TYPE	STANDARD UNCERTAINTY [nV]		
		1996	2005	2011
Dispersion of data	A	5.8	6.9	0.5
Frequency	B	1.0	1.2	0.01
Leakage	B	6.0	0.3	0.02
DVM gain and lineality	B	3.0	3.0	0.5
Polarity inverter	B			0.3
Combined standard uncertainty (k=1)		8.9	7.6	0.77

Comparisons of CENAM's JVS at 10 V level

COMPARISON	DIFFERENCE [nV]	EXPANDED UNCERTAINTY (k=2) [nV]
NIST – CENAM (ILC-NCSL 1996)	26	100
NIST – CENAM (ILC-NCSL 1999)	67	216
NIST – CENAM (Bilateral 2006)	- 35	43
BIPM – CENAM (BIPM.EM-K10.b 2011)	-0.61	1.3

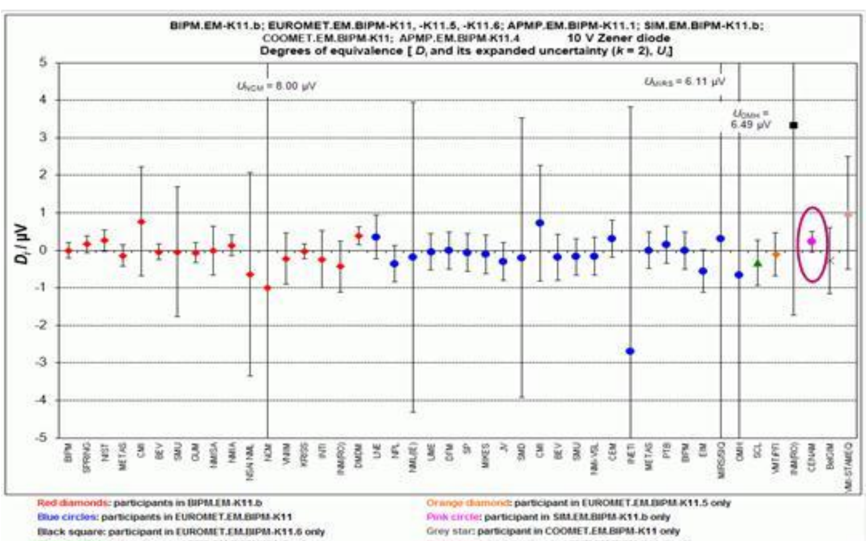
- Comparison of the Josephson Voltage Standards of the CENAM and the BIPM (BIPM.EM-K10.b)
  BIPM: S. Solve, R. Chayramy, and M. Stock, CENAM: D. Avilés, E. Navarrete and D. Hernández

Result: (U_{CENAM} − U_{BIPM}) / U_{BIPM} = -6.1×10^{-11} with u_c / U_{BIPM} = 1.2×10^{-10} (Type A uncertainty = 4.5×10^{-11})



- Comparison of DC voltaje Zener references between NIST and CENAM (SIM.EM.BIPM-K11.b)
  NIST: Yi-hua Tang CENAM: Dionisio Hernández, Enrique Navarrete, David Avilés

- Result: U_{CENAM} − U_{BIPM} = - 34.7 nV with Uc = 43.2 nV



Main Achievements

- The third lower uncertainty in the history of direct comparisons of Josephson Voltage Standard organized by the BIPM at 10 V level was obtained in the comparison BIPM-CENAM performed in 2011.

- A bias source was designed and constructed for the CENAM PJV. Having 24 channels, output voltage from – 12 V to + 12 V, frequency from 1 mHz to 10 kHz, raising and falling times of 20 ns, output current from – 30 mA to 30 mA, current resolution of 3 µA, battery backup time of 8 hours.

Articles published in Scientific Journals:

David Avilés, Enrique Navarrete, Dionisio Hernández, Stéphane Solve, and Régis Chayramy, "Direct comparison of Josephson Voltage Standards at 10 V between BIPM and CENAM", IEEE Instrumentation and Measurements . 01/2013; 62(6):1640-1645.

S. Solve, R. Chayrami, M. Stock, D. Avilés, E. Navarrete, and D. Hernández "Comparison of Josephson Voltage Standards of the CENAM and the BIPM (part of the ongoing BIPM key comparison BIPM.EM-K10.b)", Metrologia 01/2012; 49(1A):01011.

Dionisio Hernández, Enrique Navarrete, David Avilés and Yi-hua Tang, "Final report on bilateral comparison of dc voltage references between CENAM and NIST (SIM.EM.BIPM-K11.b)", Metrologia, 2007, 44, Tech. Suppl., 01011. http://iopscience.iop.org/0026-1394/44/1A/01011/.

Israel García – Ruiz, Carlos D. Avilés – Castro, Hildeberto Jardón - Aguilar, Juan Guerra –Vargas, "On the measurement of complex permittivity of layers embedded in a multilayered dielectric material with the use of a free-space method", Microwave and Optical Technology Letters, vol. 33, pp. 422 – 426, 2002.

Israel García-Ruiz, Carlos David Avilés-Castro and H. Jardón-Aguilar, "Measuring Complex Permittivity of Materials for Frequencies Under 18 GHz", Applied Microwave & Wireless, Volume 13. Issue 6pp. 56 – 66, June 2001.

García-Ruiz, D. Avilés-Castro and H. Jardón-Aguilar, "Development of a microwave dielectric spectroscopy system to characterize materials using an open-end coaxial probe technique", Mexican Review of Physics, 47(1) 62-69, February 2001.

García Ruíz I., JARDÓN Aguilar H., Avilés Castro D., "Sistema de medición de permitividad compleja en el intervalo de 12 GHz a 18 GHz usando antenas de microondas", The Mexican Journal of Electromechanical Engineering, México, ESIME-IPN, 2001 - Oct. pp. 169-175. Vol. 5. No. 4.

Largeteau, A.; Avilés-Castro, D. "Measure, one may calculate either the permittivity or permeability of solids materials over the frequency range from 300 KHz to 3 GHz starting form measurements of either admittance or transmissions". Materials Research Bulletin, Vol. 25. pp. I-III. 1990.

Ravez, J.; Thoret, J.; Simon, A.; Avilés-Castro, D. "High Frequency Relaxation in Ferroelectric Ceramics containing silver and with TKWB structure". Ferroelectrics, Vol. 109, pp. 179-183, 1990.

Articles published in Conference Proceedings

David Avilés, Enrique Navarrete, and Dionisio Hernández “Improvements of the 10 V CENAM Josephson Voltage Standard to reach a standard uncertainty at 1 nV level”, Proceedings CPEM 2012 Digest.

David Avilés, Enrique Navarrete, Dionisio Hernández, Stéphane Solve, and Régis Chayramy, “Direct comparison of Josephson Voltage Standards at 10 V between BIPM and CENAM”, Proceedings CPEM 2012 Digest.

Carlos David Avilés Castro, Dionisio Hernández Villaseñor y Enrique Navarrete García, “Calibración de referencias zener en el CENAM”, Proceedings Simposio de Metrología 2010, http://www.cenam.mx/simposio2010/info/pviernes/sm2010-vp04a.pdf.

David Avilés, Dionisio Hernández, Enrique Navarrete, “El patrón de efecto Josephson del CENAM; experiencias en 15 años de uso", Proceedings VIII SEMETRO Digest (International Congress on Electrical Metrology), João Pessoa, Brazil, June 17 – 19, 2009.

Avilés Castro D., Hernández Villaseñor D., Navarrete García Enrique, "Escalamiento en tensión eléctrica continua a nivel de mV usando un Divisor Kelvin Varley", Proceedings “Encuentro Nacional de Metrología Eléctrica 2009”, Querétaro, México, Centro Nacional de Metrología (CENAM), November 2009, http://www.cenam.mx/dme/pdf/PRE_T1-Mie-1.pdf.

Avilés Castro D., Hernández Villaseñor D., Navarrete García Enrique, "Diseño y construcción de una referencia de tensión eléctrica continua basada en un diodo Zener", Proceedings “Encuentro Nacional de Metrología Eléctrica 2009”, Querétaro, México, Centro Nacional de Metrología (CENAM), November 2009, http://www.cenam.mx/dme/pdf/PRE_T1-Mie-2.pdf

Avilés Castro D., Hernández Villaseñor D., Navarrete García Enrique, "Criterios sobre el diseño y construcción de una cámara ambiental para pruebas y mediciones eléctricas", Proceedings “Encuentro Nacional de Metrología Eléctrica 2009”, Querétaro, México, Centro Nacional de Metrología (CENAM), November del 2009, http://www.cenam.mx/dme/pdf/PRE_T1-Mie-3.pdf

C.D. Aviles, D. Hernandez, and E. Navarrete, “Design and characterization of a low voltage divider”, Proceedings CPEM 2008 Digest, pp. 242-243.

David Avilés Castro, Dionisio Hernández Villaseñor, Enrique Navarrete García, “Disminución de ruido electromagnético en el patrón de tensión eléctrica continua en base al efecto Josephson del CENAM”, Proceedings “Simposio de Metrología 2008”, http://www.cenam.mx/simposio2008/sm_2008/.

David Avilés Castro, Dionisio Hernández Villaseñor, Enrique Navarrete García, “15 años del patrón nacional de tensión eléctrica continua en base al efecto Josephson en el CENAM”, Proceedings “Simposio de Metrología 2008”, http://www.cenam.mx/simposio2008/sm_2008/.

Marco A. Rodriguez Guerrero, David Licea Panduro, David Aviles Castro, “Calibration of multifunction calibrators in the function of thermocouples output simulation”, Proceedings NCSL 2007 Digest.

Dionisio Hernández V., David Avilés C., Enrique Navarrete G., “Evaluación del servicio de calibración de referencias electrónicas en base al diodo zener ofrecidos por el CENAM”, Proceedings “Encuentro Nacional de Metrología 2007”.

David Avilés, Dionisio Hernández, Enrique Navarrete, Marco A. Rodríguez, “Validación de los métodos de calibración en tensión eléctrica continua del laboratorio multifunciones”, Proceedings “Encuentro Nacional de Metrología 2007”.

David Avilés, Dionisio Hernández, Enrique Navarrete, “Desarrollo de un divisor resistivo para calibración de vóltmetros y nanovóltmetros en los intervalos de mv”, Proceedings “Encuentro Nacional de Metrología 2007”.

Marco A. Rodríguez G., David Avilés C., David Licea P., “Calibración de calibradores multifunción en simulación de termopares”, Proceedings “Encuentro Nacional de Metrología 2007”.

Enrique Navarrete, Dionisio Hernández, David Avilés, “Estimación de la incertidumbre del patrón nacional de tensión eléctrica en corriente continua basado en el efecto Josephson”, Proceedings “Simposio de Metrología 2006”, http://www.cenam.mx/memsimp06/index.htm.

Dionisio Hernández, Enrique Navarrete, David Avilés, Yi-hua Tang, “Josephson voltage standards comparison between CENAM and NIST at 10 v level”, Proceedings “Simposio de Metrología 2006”, http://www.cenam.mx/memsimp06/index.htm.

García Ruíz I., Avilés Castro D., Jardón Aguilar H., Guerra Vargas J.. "On the measurement of the complex permittivity of layers embedded in a multilayered dielectric material with the use of a free-space method", Microwave and Optical Technology Letters, USA, John Wiley & Sons, Wiley Interscience, 2002, Volume 33, Issue 6, pp. 422-426.

García I., Avilés C.D., Jardón H., “Medición de Permitividad Compleja con aplicaciones en Caracterización de Materiales”, Proceedings “Simposio de Metrología 2001”, 30 y 31 de May del 2001, Querétaro, México.

C.D. Avilés, I. García, J.M. Arias, “Medición de Humedad por Microondas”, Proceedings “Simposio de Metrología 2001”, 30 y 31 de mayo del 2001, Querétaro, México.

C. Sánchez, D. Avilés, D. Hernández, G. Durán. “Cryogenic Current Comparator Implementation at CENAM”. Proceedings CPEM Digest, Sydney Australia, May 2000.

I. García, C.D. Avilés. H. Jardón, “Sistema de Medición de Permitividad Compleja en el intervalo de 12 GHz a 18 GHz usando antenas de microondas”, Proceedings “Seminario de Metrología Eléctrica del año 2000”, Centro Nacional de Metrología, México.

García Ruíz I., Avilés Castro D., Jardón Aguilar H.. "A broadband technique to characterize materials and microwave substrates for the 100 MHz – 26.5 GHz frequency range.". Proceedings “Quinta Conferencia de Ingeniería Eléctrica CIE99”. México, D.F., CINVESTAV, September 1999, pp. 120–124.

I.García, D. Avilés, H. Jardón. Espectroscopía dieléctrica en microondas y sus aplicaciones”. Proceedings “XXV años de Ingeniería Física en México”, 4-8 October 1999. UAM – Azcapatzalco.

C. Sánchez, D. Avilés, C.M. Wang, C.A. Hamilton. “Comparación de patrones de tensión en corriente continua basados en el efecto Josephson entre NIST y CENAM”. Proceedings 3° SEMETRO Digest, Curitiba Brazil, September de 1998.

D. Avilés, O. Gutierrez. “Automation of the Multi-functions Laboratory”. Proceedings CPEM Digest. Washington D.C., USA, July de 1998.

F. Hernández, M. Escobar, C. Sánchez, D. Avilés, “The ohm reproduction by the quantum Hall effect at CENAM”. Proceedings CPEM Digest. Washington D.C., USA, July 1998.

I.García, D. Avilés, H. Jardón. “Desarrollo de un sistema de medición de permitividad compleja usando sondas coaxiales abiertas”. Proceedings “Congreso Nacional de Instrumentación 1998”, 5-9 de October, Ensenada, Baja California, México.

S. López, C. Sánchez, D. Avilés, “Implementación del volt en México”, 2° SEMETRO Digest, Curitiba Brazil, September de 1996, p 46-53.

D. Avilés, J.L. Miane. "Improvement on the Coaxial to Circular Waveguide Transition Method for Complex Permittivity Measurements, Proceedings CPEM 1996 Digest.

S. López, I. Sánchez, C. Sánchez and D. Avilés. "Establishment of the volt at CENAM of Mexico", Proceedings CPEM 1996 Digest.

J.L. Miane, D. Avilés, J. Ravez. “Caracterisation de materiaux absorbants par des méthodes en cavité”. Proceedings “Journées d'etudes sur la Caractérisation micro-onde des matériaux absorbants”, February de 1991, Limoges, France.

J.L. Miane, D. Avilés, J. Ravez. “Modelisation des materiaux hétérogenes (isolant/conducteur)”, Proceedings “12'eme Colloque Optique Hertzienne et Diélectriques”, July 1991, Hamamed, Tunez.

J.L. Miane, J.P. Parneix, D. Avilés, E. Achour. “Propietés Electriques de milieux hétérogenes (modelisation)”, Proceedings “Congres International Micro-ondes et Hautes Fréquences”, Octubre de 1991, Nice, France.

J.L. Miane, D. Avilés, J.P. Bonnet, J. Ravez. “Propiétés Electromagnétiques en Haute Frequences et Microondes de Céramiques a Couches d’Arret”. Proceedings International Discussion Meeting on Relaxations in Complex Systems, Heraklion, Greece, 1990.

D. Avilés, O. El Farj, J.L. Miane. “Mesure des permittivités, Conditions d aplication d une méthode large bande (1 MHz - 3 GHz)”, Proceedings 10'eme Colloque Optique Hertzienne et Diélectriques”, September 1989, Rennes, France.

J.L.Miane, D. Avilés, A. Largetau, J. Ravez “Methodes de Mesure des proprietes électriques et Magnetiques de céramiques en Hyperfréquences”, Proceedings “Journée d'etudes sur les Céramiques en Hyperfréquences et Nouvelles Applications”, November 1989, Issy les Moulineaux, France.

Resistance and Impedance Metrology Group

Staff members

 Felipe Hernandez Marquez (fhernand@cenam.mx) – Group Leader

 Benjamin Rodriguez Medina (brodrigu@cenam.mx) – Resistance Laboratory

 Ben-Hur Morales Soto (bmorales@cenam.mx) – Resistance Laboratory

 Jose Angel Moreno Hernandez (jmoreno@cenam.mx) – Impedance Laboratory

 Aleph Pacheco Estrada (apacheco@cenam.mx) – Impedance Laboratory

Research and Development Projects:

Graphen-based quantum Hall resistance standard

In 2010 we started a collaboration with NIST (Dr. Randolph E. Elmquist) in order to develop high quality graphene samples using the sublimation of Si from SiC technique. A measurement system was implemented to characterize the electric properties of the graphene samples, also a modified two terminals cryogenic current comparator bridge was develop in order to compare graphene samples with the well know semiconductor AlGaAs/GaAs heterostructures. Now a new cryogenic current comparator bridge is under development (see next project) in order also to compare graphene samples with semiconductor heterostructures, with the advantage that this system can carry out measurements at four terminals.

New Criogenic Current Comparator (0.1 Ω to 1 MΩ)

In 2014 we started a collaboration with NIST (Dr. Randolph Elmquist) in order to develop a new cryogenic current comparator for the range of 0.1 Ω to 1 MΩ. With this system it will be possible to perform measurements directly from the quantized Hall resistance (12 906.403 5 Ω) to resistors of 100 Ω, this will improve the measurement uncertainties of our resistance scale in the indicated range, as well as our calibration services. Two probes have been developed, as well as the selection winding boxes. The CCC control box, the SQUID and its control unit has been implemented for one of the systems and tests are under way in order to evaluate the system performance.

Broadening of the low resistance measurement capabilities

In Mexico, the electrical power distribution and industrial sectors have always had a need for calibration of very low resistance at high currents. These calibrations have been limited to 1 mΩ at a maximum current of 100 A which falls short of the needs of our customers. Recently, the electrical resistance laboratory at CENAM acquired a system capable of measuring very low resistance at high currents and installation of the system is currently under way. When the system becomes fully operational in the near future, a whole new range of calibration services will be offered, extending the actual calibration and measurement capabilities (CMCs) of the laboratory all the way down to electrical resistance as low as 1 µΩ at a maximum current of 1000 A. With these extended capabilities, we will be able to solve many of our customer's needs for calibration in this magnitude.

Development of calculable resistors

A Calculable Resistor (CR) is a resistor with a known geometry that allows to have a model to calculate the AC-DC difference of its value. With the calculable resistors it is possible to determine its value from 0 Hz to 1.6 kHz traceable to the quantized Hall resistance. At CENAM it has been working in the development of CRs with Quadrifilar and Octofilar geometry. On December 2014 we finish a Quadrifilar CR of 1 kΩ of nominal value and during 2015 we will develop Octofilar CRs of 10 kΩ and 12906 Ω. This CR of 1 kΩ CR has a stability of

0.9 nΩ/Ω/hour, a deviation from its nominal value of only 49 μΩ/Ω, a thermal coefficient of -83.9 nΩ/Ω/° C and a power coefficient of 60 μΩ/Ω/W. The development of this new resistance standard is very important because with them in junction with a couple of impedance bridges, we are going to be able to provide traceability to the capacitance measurements based on the quantized Hall resistance.

Broadening of Capacitance measuring range from 50 Hz to 20 kHz

This project aims to create the required infrastructure to offer calibration services of standard capacitors and high accuracy digital capacitance bridges in the range of 1 pF to 1 nF at other frequencies different than 1 kHz. These calibration services will support calibrations for other quantities related with electrical power and energy and vibration and acoustics at CENAM. Other national institutes of metrology in central and South America will benefit with this project.

At the moment, they have been studied the stray impedances involved in the frequency dependence of air capacitors. These stray impedances have been quantified using theoretical models and confirmed through measurements, particularly inductances present in cables and connectors. The effect over the behavior of capacitance in parallel plates capacitors has been evaluated through theoretical models based on the actual physical arrangement of such capacitors, which predicts small contributions due these stray impedances.

The evaluation of the effects of the dielectric response in the frequency dependence in capacitors is still on development. They have been constructed prototype capacitors with cylindrical electrodes working under the Thompson-Lampard configuration to evaluate such effects using a high accuracy digital bridge.

It is foreseen the use of new containers to reduce the effect of some stray inductances in the case of 1 nF capacitors, and the use of dry nitrogen as dielectric to reduce the change of capacitance at low frequencies.

Four Terminal Resistance AC Ratio Bridge

This year we'll start the development of a digital impedance bridge in order to evaluate the ratio of resistors with 1:1 and 1:10 ratios at frequencies from 0 Hz to 1.6 kHz. With this impedance bridge we will be able to compare the calculated value of a couple of Calculable Resistors in order to verify their value predicted by the theoretical model. Scaling from a 10 kΩ calculable resistor to a 100 kΩ resistor at a frequency of 1592 Hz is important for us, because with that resistor, a 1 nF standard capacitor and a Quadrature Bridge we can provide traceability to the capacitance measurements based on the quantized Hall resistance at CENAM.

INTERNATIONAL ACTIVITIES

Participation in Comparisons

CCEM-K2 : Comparison of resistance standards at 10 MΩ and 1 GΩ

SIM.EM-S10 : High value resistance comparison with two-terminal cryogenic current comparator

SIM:EM-K1 : Comparison of resistance standards at 1 Ω

SIM.EM-K2 : Comparison of resistance standards at 1 GΩ

SIM.EM-S6 : Comparison of resistance standards at 1 MΩ

We plan in this year to pilot a comparison of low resistance standards at 100 mΩ, 10 mΩ, 1 mΩ, and 0.1 mΩ

SIM.EM-K3 (in progress): Comparison of inductance standards at 10 mH and 1 kHz. CENAM acts as pilot in this comparison

SIM.EM-K4 : Comparison of capacitance standards at 10 pF, 1 kHz, and 1592 Hz

SIM.EM-S4 : Comparison of capacitance standards at 100 pF, 1 kHz, and 1592 Hz

SIM.EM-S3 : Comparison of capacitance standards at 1000 pF and 1 kHz

Peer reviews performed to the Resistance and Impedance Laboratories

YEAR	CONDUCTED BY	NMI	LABORATORY
2014	DR. LUCA CALLEGARO	INRIM	IMPEDANCE LAB
2012	DR. RANDOLPH ELMQUIST	NIST	RESISTANCE LAB
2009	DR. YICHENG WANG	NIST	IMPEDANCE LAB
2006	DR. RANDOLPH ELMQUIST	NIST	RESISTANCE LAB
2003	DR. RAE DUK LEE	KRISS	IMPEDANCE LAB

Peer reviews conducted by CENAM staff

YEAR	CONDUCTED BY	NMI	COUNTRY
2014	JOSE ANGEL MORENO	ICE	COSTA RICA
2013	FELIPE HERNANDEZ MARQUEZ	UTE	URUGUAY
2012	FELIPE HERNANDEZ MARQUEZ	ICE	COSTA RICA
2010	JOSE ANGEL MORENO	ICE	COSTA RICA

PUBLICATION AND PARTICIPATION IN CONGRESSES AND CONFERENCES

Hernandez F., Bierzychudek M. E., Jones G. R. Jr. and R. E. Elmquist, ”Precision high-value resistance scaling with a two-terminal cryogenic current comparator”, Rev. Sci. Instrum. 85, 2014

Marcos E Bierzychudek, Randolph Elmquist and Felipe Hernández, "RMO COMPARISON FINAL REPORT High value resistance comparison with two terminal cryogenic current comparators", Metrologia 51, 2014

Moreno, J.A., "Determinación De Coeficientes De Temperatura De Patrones De Autoinductancia", Simposio de Metrología, Querétaro, México, 2014

Medina, B.R., Estrada, A.P., Marquez, F.H., "Improvements in high resistance measurements at CENAM", Precision Electromagnetic Measurements (CPEM), 2012

Gregory A. Kyriazis, J. Angel Moreno, Jürgen Melcher, "A Two-Stage, Guarded Inductive Voltage Divider with Small Ratio Errors for Coaxial Bridge Applications", Acta IMEKO, Brazil, 2012

Moreno, J.A., Marquez, F. H., "Inductance Measurements At CENAM", CPEM, Washington 2012

Moreno, J.A., Marquez, F. H., "Soporte Técnico para una Comparación Internacional de Patrones de Autoinductancia", Simposio de Metrología, Querétaro, México, 2012

Alepth Pacheco Estrada, Benjamín Rodríguez Medina, y Felipe Hernández Márquez, "MEJORAS EN LAS MEDICIONES DE ALTA RESISTENCIA EN EL CENAM", Simposio de Metrología 2012, pag 190-195, 2012

Ben-Hur Morales, Felipe L. Hernández, Benjamín Rodríguez, "NUEVAS INSTALACIONES DEL LABORATORIO DE RESISTENCIA ELÉCTRICA DEL CENAM", Simposio de Metrología 2012, pag 677-681, 2012

Randolph E. Elmquist, Tian Shen, George R. Jones, Felipe L. Hernandez-Marquez, Mariano Real, and David B. Newell, "Graphene production for electrical metrology", Kvantovaya Elektronika No. 6, pp 22-25, 2011

G. A. Kyriazis, J. A. Moreno, J. Melcher, "A Two-Stage Inductive Voltage Divider For Coaxial Bridges", SEMETRO, Natal, Brazil 2011

Moreno, J.A., Marquez, F.H., "Hacia la Calibración de Simuladores de Capacitancia para el Intervalo de 100 µF a 100 mF en el CENAM", Simposio de Metrología, Querétaro, México, 2010

Jarrett, D.G., Elmquist, R.E., Nien Fan Zhang, Tonina, A., Porfiri, M., Fernandes, J., Schechter, H., Izquierdo D., Faverio, C., Slomovitz, D., Inglis, D., Wendler, K., Hernandez-Marquez, F, Rodriguez-Medina, B., "SIM comparison of DC resistance standards at 1 Ω, 1 MΩ, and 1 GΩ", Instrumentation and Measurement, IEEE Transactions on, Vol. 58, No. 4, pp 1188-1195, 2009

Hernández F. "Resultados de una comparación en el nivel de 1GΩ empleando un puente de ramas activas." Artículo en extenso del Encuentro Nacional de Metrología Eléctrica 2009. Querétaro, México. Centro Nacional de Metrología (CENAM). 2009

Flandes E. D.G., Hernández F. L., "Consideraciones presentes en la calibración de multímetros en bajos niveles de corriente eléctrica continua." Encuentro Nacional de Metrología Eléctrica 2009. Querétaro, México. Centro Nacional de Metrología (CENAM). 2009

Rodríguez B., "Construcción y resultados de un dispositivo de transferencia tipo Hamon de 1kΩ/paso" Presentación durante el Encuentro Nacional de Metrología Eléctrica 2009. Querétaro, México. Centro Nacional de Metrología (CENAM). 2009

Jarrett, D.G., Elmquist, R.E., Nien Fan Zhang, Tonina, A., Porfiri, M., Fernandes, J., Schechter, H., Izquierdo D., Faverio, C., Slomovitz, D., Inglis, D., Wendler, K., Hernandez-Marquez, F, Rodriguez-Medina, B., “SIM comparison of DC resistance standards at 1 Ω, 1 MΩ, and 1 GΩ”, Precision Electromagnetic Measurements (CPEM), Conference on, pp 146-147, 2008

Elmquist, R., Jones, G.R., Pritchard, B., Bierzychudek, M., Hernandez, F., “High resistance scaling from 10 kΩ and QHR standards using a cryogenic current comparator“, Precision Electromagnetic Measurements (CPEM), Conference on, pp 268-269, 2008

Moreno, J.A., “La Nueva Norma Mexicana 17025”, Encuentro Nacional de Metrología Eléctrica, Querétaro, México, 2007

Hernández Márquez F. "Aspectos técnicos relevantes en la medición de valores de resistencia menores a 1Ω" Artículo en extenso del Encuentro Nacional de Metrología Eléctrica 2007. Querétaro, México. Centro Nacional de Metrología (CENAM). 2007

Hernández Márquez F. "Aspectos técnicos relevantes en la medición de valores de resistencia mayores a 1MΩ." Artículo en extenso del Encuentro Nacional de Metrología Eléctrica 2007. Querétaro, México. Centro Nacional de Metrología (CENAM). 2007

Hernandez-Marquez, F., Rivera-Alvarez, Z., Guillen, A., Huerta-Ruelas, J., Hernandez, I.C., Mendez-Garcia, V.H., Lopez-Lopez, M., “Recent measurements of the Quantum Hall Effect in AlGaAs/GaAs Heterostructures to Obtain a Resistance Standard”, Electrical and Electronics Engineering, 3rd International Conference on, pp 1-5, 2006

Kyriazis G. A., Vasconcellos R. T. B., Ogino L. M., Melcher J., Moreno J. A., “A Two Terminal-Pair Coaxial Capacitance Bridge Constructed at INMETRO”, CPEM, Torino, Italy, 2006

Nieto J. L., Guzmán L., Moreno, J.A., “Estimación De Incertidumbre En La Medición De Absorción De Humedad En Aislamientos Y Cubiertas Protectoras De Conductores Eléctricos Por El Método Eléctrico”, Simposio de Metrología, Querétaro, México, 2006

Moreno, J.A., “Desarrollo De Un Puente Maxwell-Wien Para El Mejoramiento Del Patrón Nacional Inductancia”, Simposio de Metrología, Querétaro, México, 2006

F. Hernández-Márquez, Z. Rivera-Alvarez, A. Guillen-Cervantes, J. Huerta-Ruelas, Ivan C. Hernández, L. Zamora-Peredo, A. Lastras-Martinez, V.H. Méndez-García, and M. Lopez-Lopez, "Evaluation of AlGaAs/GaAs Two Dimensional Electron Gas Heterostructures to Obtain a Resistance Standard.", IEEE Proceedings of the 2005 2nd International Conference on Electrical and Electronics Engineering, 2005

Hernández F. L., "Consideraciones técnicas en la medición de resistencia eléctrica" Encuentro Nacional de Metrología Eléctrica 2005. Querétaro, México. Centro Nacional de Metrología (CENAM). 2005

Rodríguez B., Hernández F. L., "Construcción de patrones de transferencia de resistencia eléctrica tipo Hamon" Presentación durante el Encuentro Nacional de Metrología Eléctrica 2005. Querétaro, México. Centro Nacional de Metrología (CENAM). 2005

Moreno J. A., “Metodología Para El Cálculo De Incertidumbre”, Encuentro Nacional de Metrología Eléctrica, Querétaro, México, 2005

Kyriazis G. A., Vasconcellos R. T. B., Ogino L. M., Melcher J., Moreno J. A., “Design and construction of a two terminal-pair coaxial capacitance bridge”, SEMETRO, Rio de Janeiro, Brazil, 2005

Moreno J. A., “Propuesta De Documentación De Validación De Métodos Para Cumplir Con La Norma ISO/IEC 17025:1999”, Encuentro Nacional de Metrología Eléctrica, Querétaro, México, 2005

Moreno J.A., Garay J.E., “Calibrando Medidores De Capacitancia Empleando Equipos Multifunción”, Encuentro Nacional de Metrología Eléctrica, Querétaro, México, 2005

Moreno J. A., Lee, R.D. ; Kim, H.J., “Bilateral Comparison KRISS-CENAM of 10 pF and 100 pF Standard Capacitors”, CPEM, London, England, 2004

Kyriazis G. A., Melcher J., Moreno J. A., “A Two-Stage Guarded Inductive Voltage Divider For Use In Coaxial Bridges Employed In The Derivation Of Capacitance Unit From Quantized Hall Resistance”, CPEM, London, England, 2004

Campos S. A., Moreno J.A., “Patrón Nacional De Tensión En Corriente Alterna”, Simposio de Metrología, Querétaro, México, 2004

Guillén-Cervantes, Z. Rivera-Alvarez, F. Hernández, J. Huerta-Ruelas, V. H. Méndez-García, L. Zamora, R. Peña Sierra, M. Meléndez-Lira y M. López-López. "Desarrollo en México de patrones de resistencia eléctrica basados en el Efecto Hall Cuántico." Memorias del Simposio de Metrología 2002

V.H. Méndez-García, L. Zamora, A. Lastras-Martínez, N. Saucedo, R. Peña, A. Guillén, Z. Rivera, M. Meléndez, M. López, F. Hernández, and J. Huerta. "Photoreflectance spectroscopy of AlGaAs/GaAs heterostructures with a two-dimensional electrón gas system" Journal of Vacuum Science & Technology B, Vol. 20, Issue 3, pp. 1238-1242,. 2002

Rivera E., Moreno J. A., “Determinación De Un Coeficiente Con Comportamiento De Segundo Orden Y Su Incertidumbre”, Simposio de Metrología, Querétaro, México, Octubre 2001

Moreno J. A., Hanke R., “Maintenance and Development of The Capacitance Unit at CENAM", CPEM, Sydney, Australia, May 2000

Moreno J. A., Alatorre M. G., “Basic Construction of High Accuracy Inductive Voltage Dividers", SOMI XIII, Ensenada, México, Octubre 1998

F. Hernández, M., A. Escobar, C. Sánchez, and D. Avilés. "Reproduction of the ohm based on the Quantum Hall Effect at CENAM.", Conference on Precision Electromagnetic Measurements – Conference Digest, pp. 414-415, 1998

Moreno J. A., Alatorre M. G., “Basic Construction of High Accuracy Inductive Voltage Dividers", SOMI XIII, Ensenada, México, Octubre 1998

Moreno J. A., Aviles C. D., “Incorporating a new capacitor set to the CENAM capacitance reference”, Metrology for the Americas, Miami, Florida, United States of America, November 1995

AC Voltage and Current Group

Staff: Sara Campos ; René Carranza
scampos@cenam.mx
rcarranz@cenam.mx

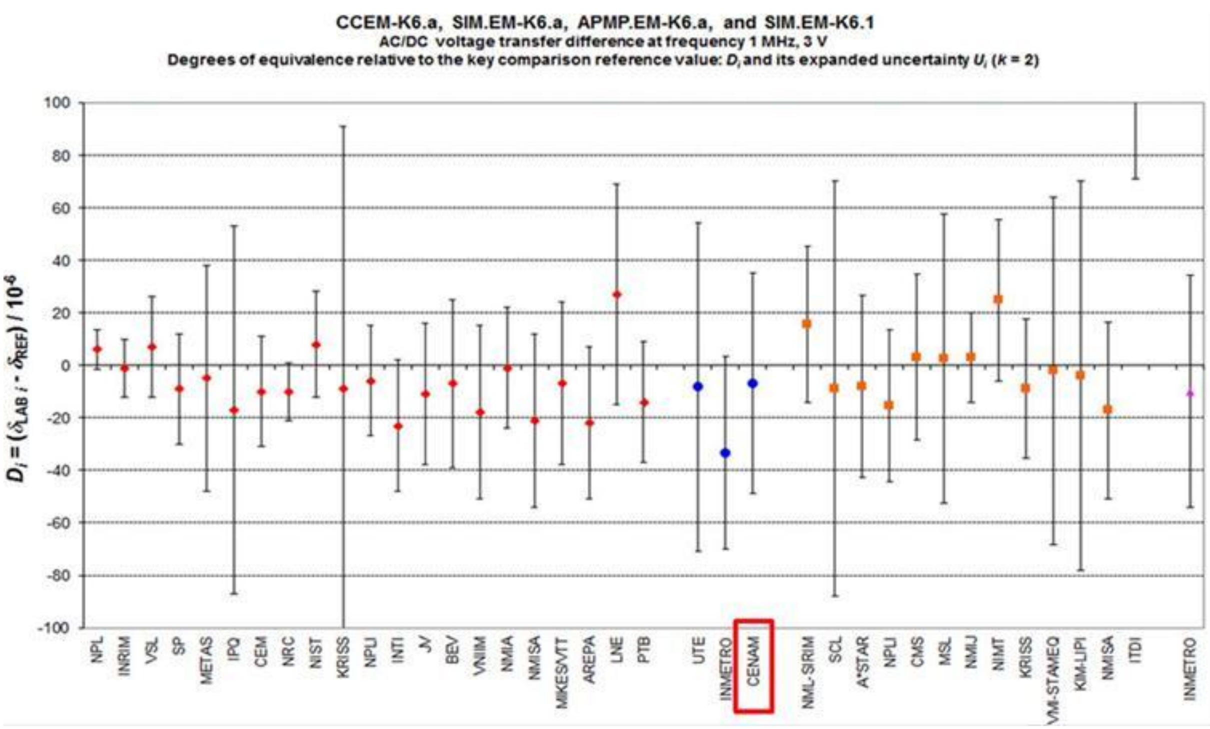
Scientific Collaboration:
1997, collaboration with Dr. Cees Van Mullem, NMI-VSL, The Netherlands, on techniques for scaling down AC-DC difference voltage

1998-2000, collaboration with Dr. Manfred Klonz, from PTB-Germany, for the construction and characterization of range resistors for its use with PMJTCs for CENAM AC Voltage standard.

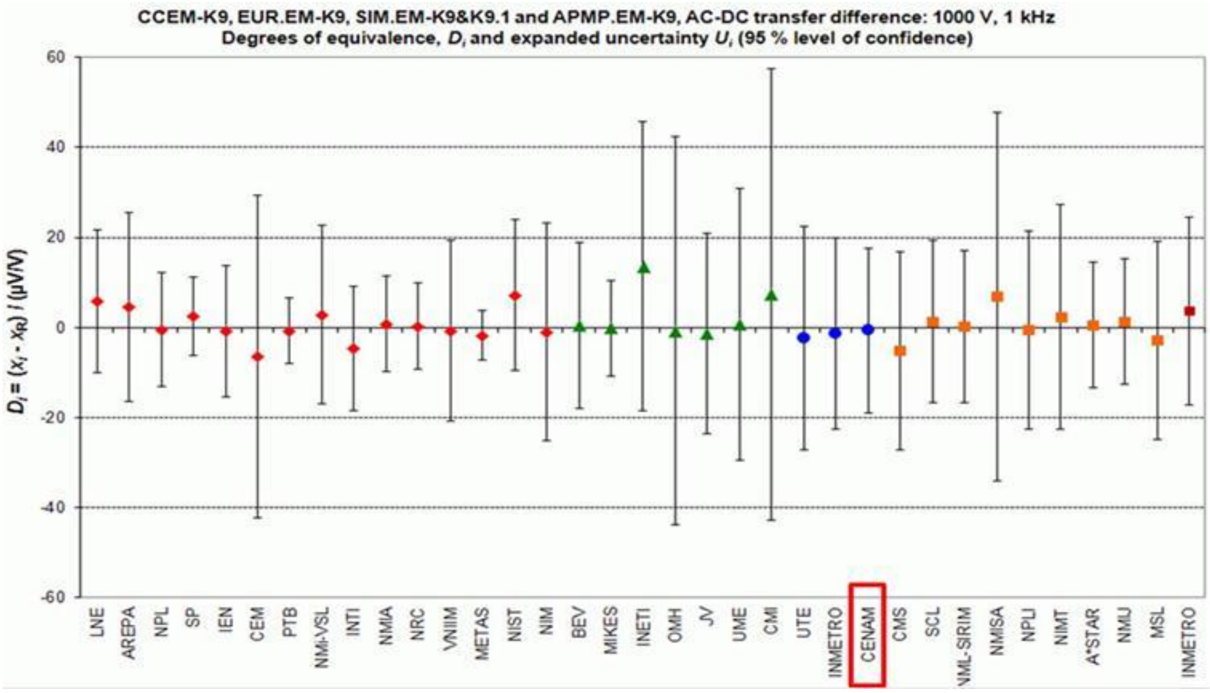
Participating in comparisons

Type	Quantity
SIM.EM- K12 , 2011	AC Current transfer difference. Final Report in progress
SIM.EM- K11 , 2004	AC Voltage transfer difference

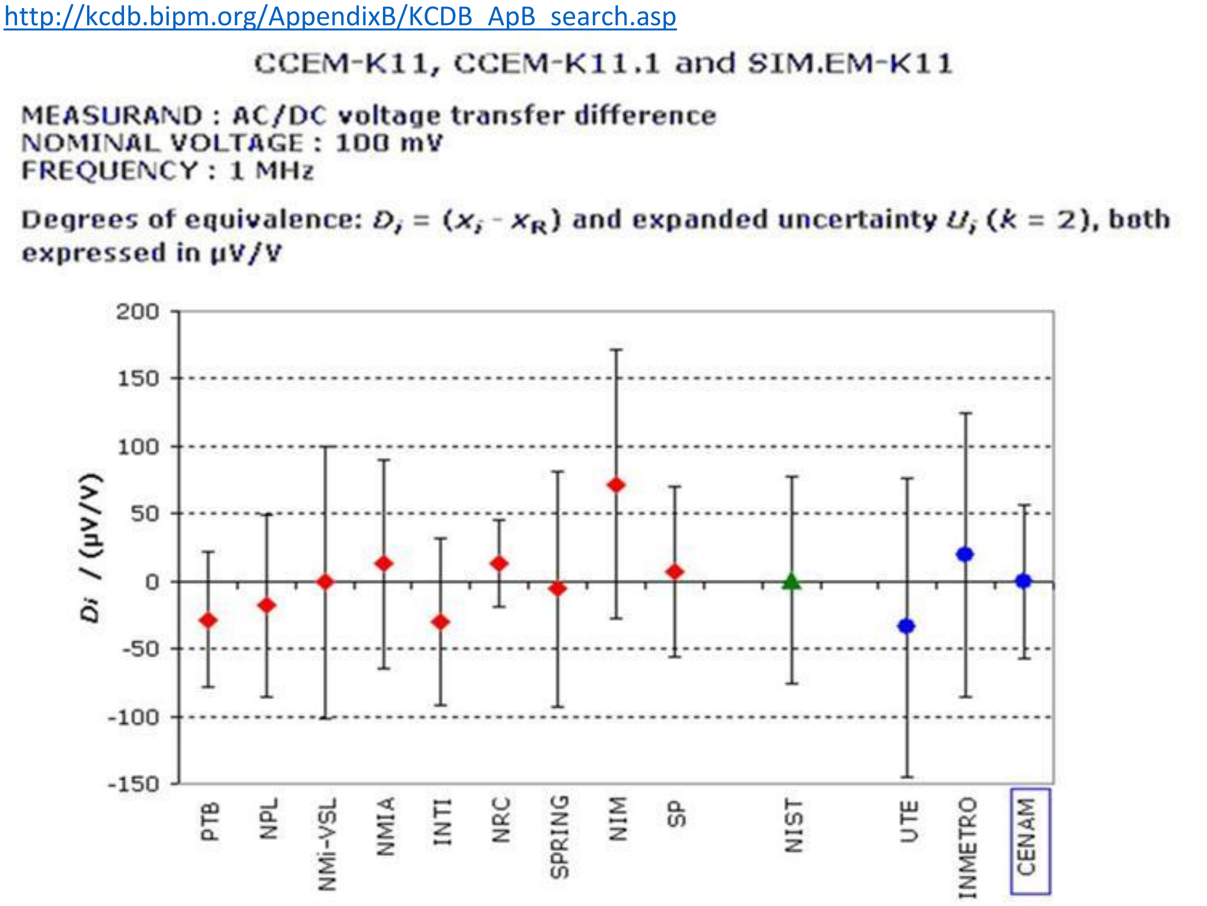
SIM.EM- K9 , 2004	AC Voltage transfer difference
SIM.EM- K6.a , 2004	AC Voltage transfer difference
NACC-ICN-VAC1, 2001	AC Voltage transfer difference ; AC Voltage
Bilateral NRC-CENAM, 2000	AC Voltage transfer difference
Bilateral NIST- CENAM , 2000	AC Voltage transfer difference
International Comparison of the Calibration of a MTS Part 2. PTB-E-71. ISBN 3-89701-622-2, 1997-1998	AC Voltage and AC Current



http://kcdb.bipm.org/AppendixB/KCDB_ApB_search.asp



http://kcdb.bipm.org/AppendixB/KCDB_ApB_search.asp



http://kcdb.bipm.org/AppendixB/KCDB_ApB_search.asp

CMCs	**Measurement range**
AC-DC voltage transfer difference	
AC Voltage (meters & calibrators)	2 mV to 1 kV ; 20 Hz to 1 MHz
AC-DC current transfer difference	
AC Current (meters & calibrators)	1 mA to 20 A ; 40 Hz to 5 kHz

The above CMCs are published in the BIPM KCDB. They have been reviewed by:
Dr. Manfred Klonz from PTB-Germany on October 2004
Dr Peter Filipski from NRC-Canada on October 2010
Dr Manfred Klonz from PTB-Germany on October 2014

References:

S. Campos, P. Filipski, D. Izquierdo, E. Afonso, R. Landim, L. Di Lillo, T. Lipe "Final report: SIM regional comparison of ac-dc voltage transfer difference (SIM.EM.K6a, SIM.EM-K9 and SIM.EM-K11) in Metrologia, 2009, 46, Tech. Suppl., 01004

S. Campos "Termoconvertidores: ¿Qué se necesita para hacer mediciones de tensión en c.a. con mediana y alta exactitud?" In presentation during ENME 2007. Querétaro, México. July 2007

S. Campos. "Management of the AC-DC voltage transfer difference comparison in the SIM region" in NCSLI Conference Proceedings. Agust 2006

S. Campos, J.A. Moreno. "Patrón Nacional de Tensión en corriente alterna" in Simposio de Metrologia 2004 Digest. Queretaro, Qro. Oct 2004.

S. Campos, M.Klonz, C.J. van Mullem "Improvements in AC-DC Voltage Transfer at CENAM" in CPEM 2002 Digest.June 2002

S.Campos. "Mejoras en Transferencia c.a.-c.c. en el CENAM" In Seminario de Metrología Eléctrica 2002. Querétaro, México. 2002

S. Campos, M. Klonz. "Termoconvertidores con resistores planos para la transferencia c.a.-c.c. de 100 V a 1000 V" in Simposio de Metrología 2001 Digest. pp. Ca16-Ca19. May 2001

S. Campos. “Transferencia c.a.-c.c. en el intervalo de 100 V a 1000 V” In Seminario de Metrología Eléctrica 2001 Digest. Queretaro, México. July 2001

S. Campos “Escalamiento en tensión en corriente alterna empleando termoconvertidores multiunión tipo planar (PMJTCs)”. In Seminario de Metrología Eléctrica 2000 Digest. Queretaro, pp.20-23

R. Carranza, S. Campos “Optimización del uso de una transferencia térmica de unión sencilla tipo Fluke 540B” In XIV Seminario Nacional de Metrología Digest. Aguascalientes México pp. M11-1 - M11-6. Agust 1998

S. Campos, R. Carranza. “Efectos de carga en transferencias térmicas de estado sólido”. In XIV Seminario Nacional de Metrología Digest. Aguascalientes México pp. M8-1 - M8-7. Agust 1998

Power and Energy Laboratory

Staff:

René Carranza	Sergio Campos	Marco Rodríguez	Adrian Castruita
rcarranz@cenam.mx	acampos@cenam.mx	mrodrigu@cenam.mx	acastruit@cenam.mx
Group leader	Metrologist	Metrologist	Metrologist

Facilities:

Power and Energy Laboratory

Projects 2014-2018

1. Measurement standard for Quality of Power for Static Conditions (2015)
   René Carranza; Adrián Castruita; Sergio Campos

A reference standard for the measurement of spectral components in the frequency range up to 6 kHz under static conditions was recently developed. The meter is based on a measuring method that corrects for non-coherent digital sampling, and errors associated with the digitizer (integration time and bandwidth). The main features of the method are described in [1]. The measuring capabilities are:

- Voltage spectral components, amplitude and phase up to 6 kHz, 69 V to 240 V
- Current spectral components, amplitude and phase up to 6 kHz, 0.1 A to 20 A

2. <u>Measurement standard for Quality of Power for Dynamic Conditions (2015-2017)</u>
   René Carranza; Marco Rodríguez; Adrián Castruita; Sergio Campos

A reference standard is under development for the measurement of spectral components in the frequency range up to 6 kHz subject to dynamics conditions that may be observed in an electric power system. The kind of phenomenon to be measured is better known as a non-stationary AM-PM process, corresponding to simultaneous occurrence of amplitude and phase variations of voltage or current in a real power system. The most recent publication of the IEEE C37.118 in 2014 takes into account the complexity of the simultaneous measurement of amplitude and phase modulation observed during transient conditions in real power systems. The expected measurement capabilities are:

- Voltage spectral components: under amplitude and phase modulation within 2 Hz, in frequency up to 6 kHz; 69 V to 240 V
- Current spectral components: under amplitude and phase modulation within 2 Hz, in frequency up to 6 kHz; 0.1 A to 20 A

3. <u>Smart Grid II. EMRP. PMU Metrology (2015-2017)</u>
   René Carranza, Marco Rodríguez, Sergio Campos, Sergio Jiménez and René Romero

In December 2014 CENAM was accepted as a collaborator in the European Metrology Research Programe Project: Measurement Tools for Smart Grid Stability and Supply Quality Management. CENAM is in the work package 2: *Phasor measurement units in distribution networks*. It is expected to implement a reference measurement standard for providing traceability to PMU calibrators under dynamic conditions. CENAM's experts joined other researchers in México for the investigation of methods for the measurement of electric signals under non stationary conditions and for the development of a current multi-junction thermal transfer standard (1 A and 5 A), aimed at an uncertainty near to some parts per million. A further investigation issue is the time stamping for PMU traceability purposes. The main features of the project main may be found in [2].

4. <u>CCEM-K5 key comparison 50/60 Hz power. (2015-2016)</u>
   René Carranza, Adrián Castruita

As proposed at the CCEM in its last meeting at CPEM 2014/Rio de Janeiro, Brazil, a key comparison of power at 50/60 Hz will be coordinated by VSL-The Netherlands, PTB-Germany and CENAM-Mexico. In the SIM region, the results of the key comparison of power SIM.EM-K5 were recently published in the Technical Supplement of Metrologia 52 2014 [3]. This comparison was coordinated by CENAM.

References

1. R. Carranza, S Campos, A Castruita, M Rodríguez, "Corrección de fuga espectral al utilizar la Transformada Discreta de Fourier con digitalización incoherente‟. Simposio de Metrología 2002, México
2. R. Carranza, S. Campos, A. Castruita y M. Rodríguez, "Medición simultánea de amplitud y frecuencia en sistemas eléctricos de potencia". Encuentro Nacional de Metrología 2014, México, Oct. 2014.
3. R. Carranza et al, "Final report: Key comparison of 50/60 Hz power SIM.EM-K5", 2015 Metrologia 52 01002 doi:10.1088/0026-1394/52/1A/01002.
4. SIM international comparison of 50/60 Hz energy (2002-2007) Tom Nelson, Nien Dan Zhang, Nile Oldham, E. So, R. Carranza, Carlos Sauders, Henry Postigo, Carlos Faveiro. Metrologia 01/2008; 451A:01009.
5. V. Vountesmeri, J. R. Cuevas, R. Carranza, "Error Source Determination of a Magnetoresistive Active Power Sensor at Industrial Frequencies", IEEE Trans. Instrumentation and Measurement, Vol. 51, No. 5, Oct. 2002.
6. N. Oldham, T. Nelson, R. Bergeest, G. Ramm, R. Carranza, A. C. Corney, M. Gibbes, G. Kyriazis, H. Laiz, L. Liu, S. Lu, U. Pogliano, K. Rydler, E. Shapiro, E. So, M. Tempa, P. Wright, "An International Comparison of 50/60 Hz Power (1996-1999)", IEEE Trans. Inst. and Meas., Vol. 50, No. 2, Abr. 2001.
7. P. J. Moore, R. D. Carranza and A. T. Johns, "Model systems tests on a new numeric method of power system frequency measurement", IEEE Trans. on Power Delivery, Vol. 11, No 2, April, 1996. Document 95 SM 439-0, IEEE Power Summer Meeting, Portland, Oregon, EUA, 1995.
8. P. J. Moore, R. D. Carranza and A. T. Johns, "A new numeric technique for high-speed evaluation of power system frequency", Proceedings of IEE, Part C, Generation, Transmission and Distribution, Vol. 141, No 5, Sept. 1994.
9. R. D. Carranza, P. J. Moore and A. T. Johns, "Validity of a band pass plus orthogonal decomposition technique for the digital measurement of power system frequency", 28th Conference of Universities on Power Systems, Staffordshire University, England, 1993.
10. P. J. Moore, R. D. Carranza and A. T. Johns, "Performance of a new high-speed technique for measuring power system frequency", 5th International Conference on Development on Electrical Power Protection Systems, IEE, York, England, 1993.
11. P. J. Moore, R. D. Carranza and A. T. Johns, "Improved digital measurement of power system frequency", 27th Conference of Universities on Power Systems, England,1992.

Articles published in Conference Proceedings

E So D Angelo T Nelso, Z. Lu, Y. T. Parck, W. M.S Wijesinghe, R. Carranza, " An international comparison of 50/60 Hz reactive power meter calibrations between NRC, NIST, CENAM , NIM and KRISS". CEPM Digest 01/2012 DOI:10.1109 CPEM 2012.6205

T. Nelson, N. F. Shang, N. Oldham, R. Carranza, S. Campos, M. Monge, H. Sanchez, A. M. Franco, L. DiLillo, R. Duarte, E. So, C. Sauders, H. Postigo y C. Faviero, SIM International comparison of 50/60 Hz energy (2002-2007), INFOSIM, Qro, México, Dic. 2008

R. Carranza López Padilla, J. Valencia R., L. O. Becerra Santiago, G. Silva Pineda, E. Martinez López, V. Martínez Fuentes, J. Nava Fuentes, P. Vera Alfaro, "Incertidumbre en las mediciones", Sistema Interamericano de Metrología, Organización de Estados Americanos. Julio 1999.

R. Carranza, Sara Campos Hernández, "Optimización del uso de una Transferencia Térmica de Unión sencilla, tipo Fluke 540B", XIV Seminario Anual Asociación Mexicana de Metrología, A. C. Aguascalientes, México, 1997.

R. Carranza, J. Camacho, L. Reyes. Jorge Ruíz E., S. Navarrete, R. Prieto y J. Amaya, Norma Oficial Mexicana para instrumentos de mediciones eléctricas, NOM CH-110/1991. Comité Consultivo Nacional de Normalización en Metrología, México, 1991.

R. Carranza, "Procedimiento de calibración de divisores de tensión de referencia en corriente directa", 4o Taller de Termometría y Metrología Eléctrica, CINVESTAV-IPN, LAPEM-CFE y DGN-SECOFI, Irapuato, México, 1991.

R. Carranza, "Tensión en corriente alterna: método de transferencia desde una tensión en corriente directa", 4o Seminario Anual de Metrología, CINVESTAV, México, 1987.

R. Carranza, "Control de fase y amplitud como una referencia para potencia eléctrica", 3er Taller de Termometría y Metrología Eléctrica, CINVESTAV-IPN, LAPEM-CFE y DGN-SECOFI, México 1989.

R. Carranza, "Resultados de medición del volt mantenido en México comparado con el mantenido en Cuba", 3er Seminario Anual de Metrología, CINVESTAV, México, 1986.

R. Carranza, "Procedimiento de calibración en potencia eléctrica activa a 60 Hz", 3er Seminario Anual de Metrología, CINVESTAV, México, 1986.

R. Carranza. "Corrección por frecuencia en la medición de energía reactiva al usar RM11. " En. Presentación durante el Encuentro Nacional de Metrología Eléctrica, México. Jun. 2005

R. Carranza, CAMPOS Montiel S.A., GARCÍA Fierro E. "Calidad de la energía eléctrica: métodos de calibración de medidores industriales." En. Presentación durante el Encuentro Nacional de Metrología Eléctrica, México. Nov. 2009

R. Carranza, CAMPOS Montiel S.A., GARCÍA Fierro E. "Calidad de la energía eléctrica: métodos de calibración de medidores industriales." En. Artículo en extenso del Encuentro Nacional de Metrología Eléctrica. México. Nov. 2009

R. Carranza, CAMPOS Montiel S.A., GARCÍA Fierro E. "Taller sobre técnicas digitales para la medición de alta exactitud de tensión, corriente y potencia." En. Presentación durante el Encuentro Nacional de Metrología Eléctrica. México. Nov. 2009

R. Carranza "Propuesta para la expresión del alcance de acreditación de laboratorios de calibración. " En. Presentación durante el Encuentro Nacional de Metrología Eléctrica 2005. Querétaro, México. Centro Nacional de Metrología (CENAM). Jun. 2005

R. Carranza "El panorama de la metrología eléctrica. " En. Presentación durante el Encuentro Nacional de Metrología Eléctrica 2005. Querétaro, México. Centro Nacional de Metrología (CENAM). 2005 - Jun.

Rodríguez Guerrero M.A., Carranza López Padilla R.D., Análisis Tiempo-Frecuencia en Sistemas Eléctricos de Potencia, Encuentro Nacional de Metrología Eléctrica, Octubre 2014, México.

Rodríguez Guerrero M.A., Resultados preliminares del ensayo de aptitud para la calibración de calibradores multifunciones de mediana exactitud. 2012-2014, Encuentro Nacional de Metrología Eléctrica, Octubre 2014, Querétaro, México.

Rodríguez Guerrero M.A., Evolución de Laboratorios Acreditados en Metrología Eléctrica a través de ensayos de aptitud Revisión 2006 – 2014 Perspectivas de 2015 en adelante, Encuentro Nacional de Metrología Eléctrica, Octubre 2014, Querétaro, México.

Gutiérrez González E., Rodríguez Guerrero M.A., Consideraciones generales en la calibración de calibradores multifunciones de mediana exactitud, Encuentro Nacional de Metrología Eléctrica, Oct2014, México.

Rodríguez Guerrero M.A., Hernández Villaseñor D., Validación del método de calibración para multímetros de 8 ½ dígitos en tensión eléctrica continua en el intervalo de medición de 1 mV a 100 mV usando un divisor resistivo, Simposio de Metrología 2012, Oct 2012, México.

Rodríguez Guerrero M.A., Resultados del ensayo de aptitud para la calibración de calibradores multifunciones de mediana exactitud, ENME 2012, Oct 2012, México.

Rodríguez Guerrero M.A., Buenas Prácticas de medición utilizando un calibrador multifunciones como simulador de termopares, ENME 2009, Nov 2009, México.

Flandes Eusebio D.G., Hernández Márquez F., Consideraciones presentes en la calibración de multímetros en bajos niveles de corriente eléctrica continua., ENME 2009. Nov 2009, México.

Rodríguez Guerrero M.A., Prueba de aptitud: “Asegurando la trazabilidad de las mediciones en la calibración de calibradores de mediana exactitud, Encuentro Nacional de Metrología Eléctrica 2009, Nov 2009, México.

Rodríguez Guerrero M.A., Licea Panduro D., Avilés Castro C.D., Calibration of multifunction calibrators in the function of thermocouples output simulation, NCSL International 2007, St. Paul M.N., USA, Aug. 2007.

Rodríguez Guerrero M.A., Licea Panduro D., Avilés Castro C.D., Calibración de Calibradores Multifunciones en Simulación de Termopares, Encuentro Nacional de Metrología Eléctrica 2007, Jul. 2007, México.

Rodríguez Guerrero M.A., Islas Hernández M., Consideraciones en la calibración de equipos multifunción: Vcc e Icc, Encuentro Nacional de Metrología Eléctrica 2005, Jun 2005, Querétaro, México.

Islas Hernández M., Rodríguez Guerrero M.A., Consideraciones en la calibración de equipos multifunción: Vca e Ica, Encuentro Nacional de Metrología Eléctrica 2005, Jun 2005, Querétaro, México.

FLANDES Eusebio D.G., HERNÁNDEZ Márquez F. "Consideraciones presentes en la calibración de multímetros en bajos niveles de corriente eléctrica continua." Encuentro Nacional de Metrología Eléctrica 2009. Querétaro, México. Centro Nacional de Metrología (CENAM). Nov. 2009

GUTIÉRREZ Galván O. "Interpretación de especificaciones de equipos multifunción (calibradores y multímetros 8½)." Encuentro Nacional de Metrología Eléctrica 2007. Querétaro, México. Centro Nacional de Metrología (CENAM). Jul. 2007

GUTIÉRREZ Galván O. "Simulación de temperatura por tensión eléctrica simulación de termopares." Encuentro Nacional de Metrología Eléctrica 2005. Querétaro, México. Centro Nacional de Metrología (CENAM). Jun.2005

ISLAS Hernández M. "Consideraciones importantes en el uso de equipos multifunciones: tensión e intensidad de corriente alterna. " Encuentro Nacional de Metrología Eléctrica 2005. Querétaro, México. Centro Nacional de Metrología (CENAM). Jun. 2005

S. Campos, R. Carranza, A. Parada, “Bobina Rogowski como sensor de corriente para monitoreo de transformadores de distribución transformadores de distribución.” CIDESI, 2011, México

MAGNETIC MEASUREMENTS GROUP

Magnetic Standards and Magnetic Properties of Materials Laboratories

Staff

Mario Alatorre
malatorr@cenam.mx
Metrologist

Marco Antonio Escobar
mescobar@cenam.mx
Group Leader

Facilities:

Magnetic Standards and Magnetic Properties of Materials Laboratories

Projects 2014-2018

1. Measurement system for the determination of the magnetic susceptibility χ of diamagnetic, paramagnetic and ferromagnetic materials

The magnetic susceptibility, χ, is a characteristic parameter of the materials whose value is important to know for their applications in the industry and metrology laboratories. At CENAM we are developing a system for the determination of the magnetic susceptibility of diamagnetic, paramagnetic and ferromagneteic materials, by the Gouy balance method. The principle of this method of measurement is based on the force of a magnetic field produced by an electromagnet, on the sample of the material whose magnetic susceptibility value is required.

2. Measurement system for the characterization of the magnetic properties of permanent magnets (collaboration with INRIM)

In the automotive industry, auto parts, electronics, appliances and metrology laboratories are used permanents magnets that need to be characterized in order to know its magnetic properties, such as: the value of the magnetic remanence, coercivity field value and the value of the product $(BH)_{max}$. This information is required for the design of components and to provide traceability to the measurements carried out in the industry and laboratories.

3. System of generation and measurement of magnetic fields of low frequency (collaboration with INRIM)

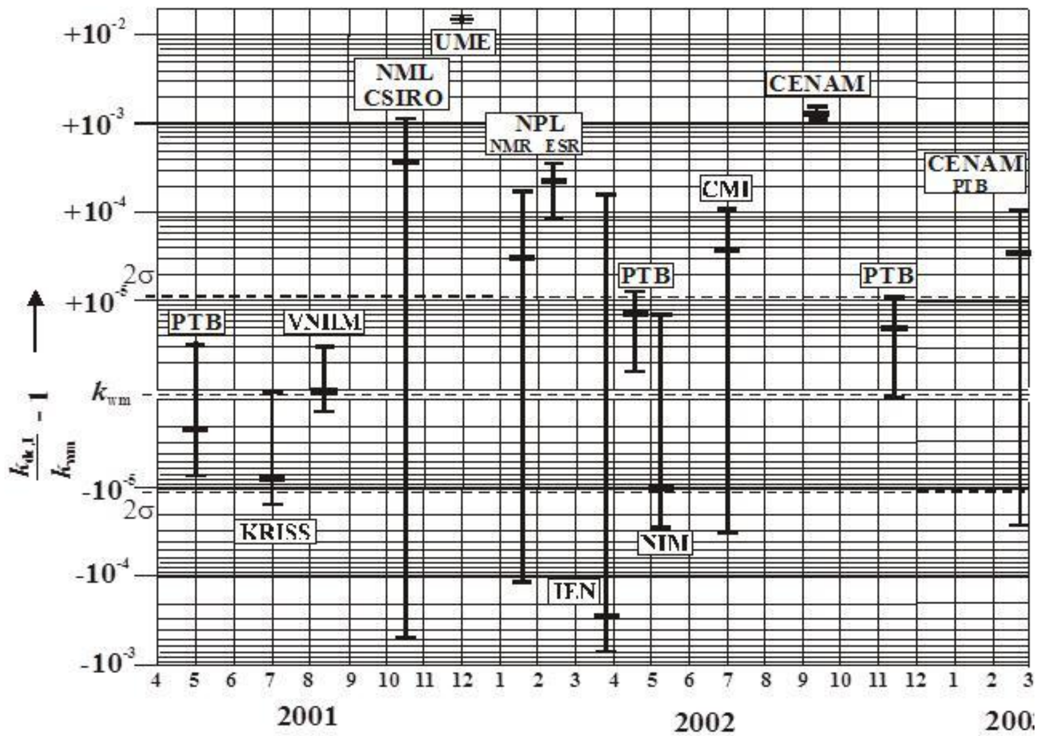
In recent years, the study of magnetic fields generated by different sources, such as electronic devices and high-voltage power lines among others, has increased, due to the interest that exists about the levels of these alternating magnetic fields, to which the population is exposed and evaluate its possible effects on living organisms. For the reliable measurement of these magnetic fields, required the use of calibrated magnetometers, which implies developing and establishing systems of generation of alternating magnetic fields of reference, to provide traceability to the measurements of alternating magnetic fields.

For the generation of magnetic fields in alternating current, are used systems of generation with Helmholtz coils with different geometries and different technical specifications, these systems have to be designed for cover the ranges of magnetic field and frequency, which are exposed in everyday life the population and workers.

INTERNATIONAL ACTIVITIES

Participation in Comparisons

1. CCEM. M.-K1: Magnetic Flux Density by means of Transfer Standard Coil



Dc coil constant determination by the various institutes plotted against the period when the measurements were carried out. The 2 σ lines represent the uncertainty of the weighted mean value k_{wm}.

2. Bilateral comparison between CENAM and INRIM: Measurement of magnetic properties of electrical steels by Epstein method

Results of the magnetic characterization of grain-oriented Epstein strips

Peak magnetic polarization $(J_p \pm U)$ T		Specific power loss $(P_s \pm U)$ W/kg		Apparent power loss $(S_S \pm U)$ VA/kg	
INRIM	CENAM	INRIM	CENAM	INRIM	CENAM
1.4997 ± 0.0075	1.501 ± 0.003	0.845 ± 0.013	0.85 ± 0.002	1.01 ± 0.02	1.01 ± 0.01
1.7 ± 0.0085	1.7 ± 0.004	1.1695 ± 0.018	1.174 ± 0.002	1.955 ± 0.04	2.014± 0.02

Peer review performed to the Magnetic Standards Laboratory

YEAR	CONDUCTED BY	NMI	LABORATORY
2012	DR. FAUSTO FIORILLO	INRIM	MAGNETIC STANDARDS LAB

Review conducted by Prof. Fausto Fiorillo/INRIM, 2012

Articles published in Conference Proceedings

[1] Mario Alatorre, Marco Escobar, “Detection of needs of magnetic characterization of materials in the country and strategies to meet them”. Presentation at the national meeting of electrical metrology 2005. Querétaro, México. National Center of Metrology (CENAM)

[2] Mario Alatorre, Marco Escobar, “Measurement of magnetic susceptibility of materials”. Presentation at the national meeting of electrical metrology 2005. Querétaro, México. National Center of Metrology (CENAM)

[3] Pablo García, Marco Escobar, “Technical considerations of measurement of continue magnetic flux density”. Presentation at the national meeting of electrical metrology 2005. Querétaro, México. National Center of Metrology (CENAM)

[4] Mario Alatorre, Marco Escobar, “Capabilities of measurement and calibration of the magnetic flux density laboratory”. Presentation at Symposium of metrology 2008. Querétaro, México. National Center of Metrology (CENAM)

[5] Mario Alatorre, Marco Escobar, “Determination of the K constant of a Helmholtz coil used for the calibration of magnetometers”. Presentation at Symposium of metrology 2010. Querétaro, México. National Center of Metrology (CENAM).

[6] Mario Alatorre, Marco Escobar, “Reference system for the measurement of magnetic properties of electrical steels by Epstein method”. Presentation at Symposium of metrology 2012. Querétaro, México. National Center of Metrology (CENAM).

[7] Mario Alatorre, Marco Escobar, “Magnetic traps in the agro alimentary industry: technical suggestions for the measurement of magnetic fields generated for the magnetic traps and the safety of the food”. Presentation at the national meeting of electrical metrology 2014. Querétaro, México. National Center of Metrology (CENAM).

RADIOFREQUENCY METROLOGY DIRECTION

Organization

The Radiofrequency Metrology Direction is organized in two main working groups: Metrology for guided waves and Metrology for radiated waves.

Radiofrequency Metrology Director
Israel Garcia
igarcia@cenam.mx

Metrology for guided waves

Radiofrequency Power
Contact: Mariano Botello
mbotello@cenam.mx
Rafael Castañeda
rcastane@cenam.mx

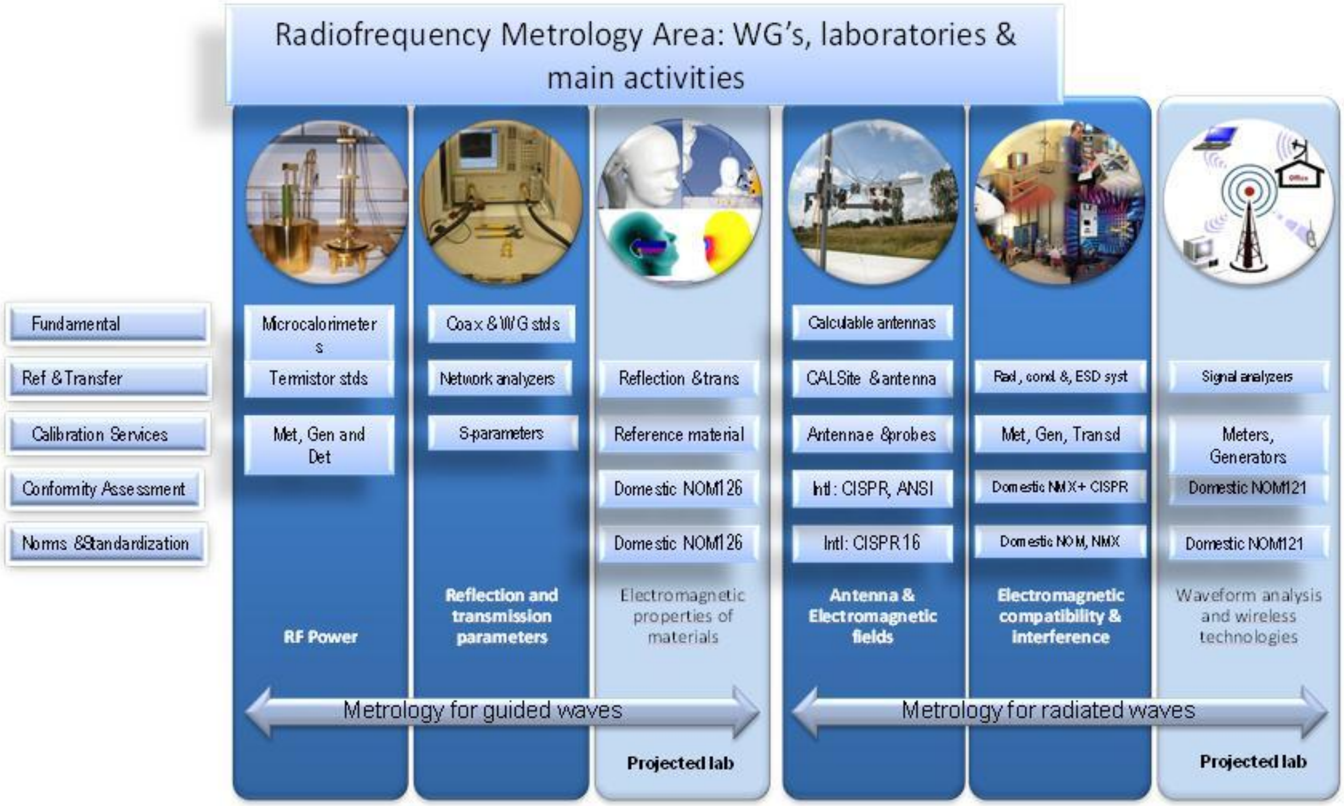
Reflection and transmission parameters
Contact: Susana Padilla
spadilla@cenam.mx

Metrology for guided waves

Antenna and electromagnetic fields
Contact: Luis Carrión
lcarrion@cenam.mx

Electromagnetic compatibility and Interference
Contact: Miguel Muñóz
mmunoz@cenam.mx

The technical and scientific work performed in the different fields of each of the RF laboratories can be summarized in the following chart.



2. Main research lines and projects 2014-2018

Current and future projects of CENAM's RF working groups are as in the following chart.

RADIOFREQUENCY WG's	2014	2015	2016	2017	2018
Electromagnetic Compatibility and Interference	Reference system for EMI absorbing clamps and radiated emissions (Miguel Muñoz and Israel García)				
	Reference system for ESD pulse calibration system up to 15 kV (Miguel Muñoz and Israel García)				
			Improvement of ESD calibration system Miguel Muñoz and Israel García		
			Reference system for current injection clamps (Miguel Muñoz and Israel García)	Electric and Magnetic Field Measurement System (Miguel Muñoz and Israel García)	
Electric Power at Radiofrequencies (RF Power)	Reference System for Radiofrequency Power Calibration Transfer up to 50 GHz (Mariano Botello and Rafael Castañeda)				
	RF Power Primary Standard to 50 GHz Mariano Botello, Israel Garcia, Jae-Yong Kwon (KRISS)			RF Power Primary Standard to 75 GHz (Mariano Botello, Israel García)	
Reflection and transmission parameters	Measurement Reference System for Scattering Parameters up to 40 GHz (Susana Padilla, Israel García)				
		Reference system for Scattering Parameters up to 50 GHz (Susana Padilla, Israel García)		Reference system for Scattering Parameters to 75 GHz (Susana Padilla, Israel García)	
Antenna and Radiated Electromagnetic Fields		Improvement of CALTS frequency range (Luis Carrión and Israel García)		Improvement of Antena Factor measurement to vertical polarization (Luis Carrión)	
			Reference System for Antenna Calibration to 40GHz (Luis Carrión and Israel García)		
			Antenna Reference Standard at 40 GHz (Luis Carrión and Israel García)		
				Antenna Gain to 75 GHz (Luis Carrión and Israel García)	

3. Technical & scientific cooperation

a. With other NMI's

1. NMI: NIST 2009-2011
   Objective: Development of a Type N coaxial microcalorimeter for the 50 MHz to 18 GHz frequency range
   CENAM expert: Mariano Botello
   Project leader at NIST: Tom Crowley
2. NMI: KRISS 2015-2016
   Objective: Development of a 2.4 mm coaxial microcalorimeter up to 50 GHz
   CENAM expert: Mariano Botello
   Project leader at KRISS: Jae-Yong Kwon

b. With domestic research institutes

1. Institute: Center for Research and Postgraduate Studies of the National Polytechnic Institute (CINVESTAV-IPN) 2003-2004

Objective: Development of a broadband double ridged horn antenna from 1 GHz to 18 GHz
Experts: Mariano Botello (CENAM), Hildeberto Jardón (CINVESTAV), Israel García (CENAM)

2. Institute: Center for Research and Postgraduate Studies of the National Polytechnic Institute (CINVESTAV-IPN) 2015-2017
   Objective: Development of an RF power primary standard up to 50 GHz
   Experts: Mariano Botello (CENAM), Hildeberto Jardón (CINVESTAV), Israel García (CENAM)

4. International activities

a. Comparisons

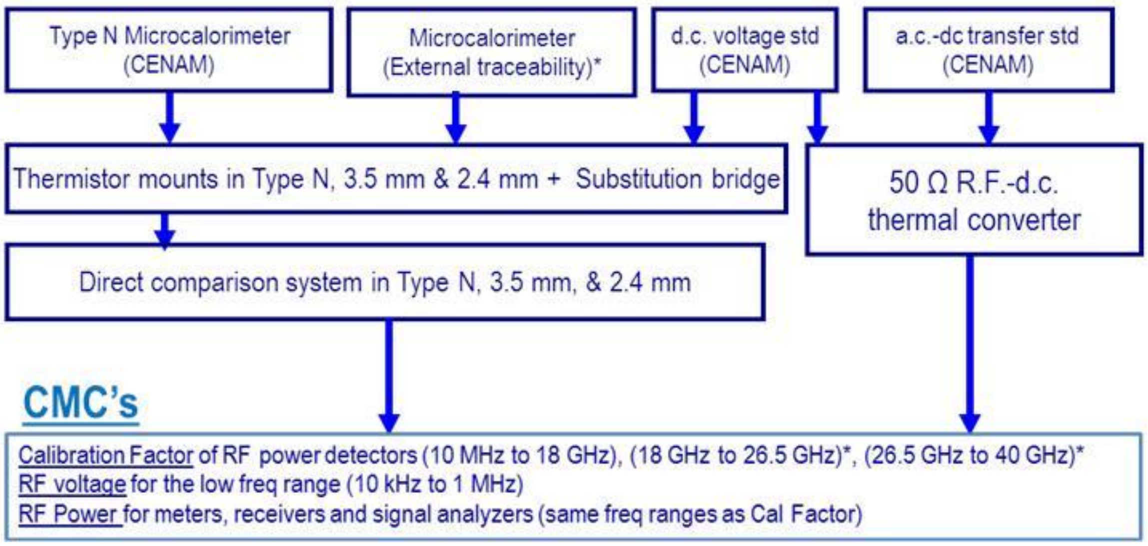
SIM.EM.RF-K5b.CL : Scattering Coefficients by Broad-Band Methods, 2 GHz to 18 GHz, Type N Connector
Participants: INTI (Pilot), NRC, NIST, CENAM, NPL-I, KRISS
Years: 2012-2015
Results: Comparison still in progress, CENAM's measurements completed in 2013.

b. Peer reviews

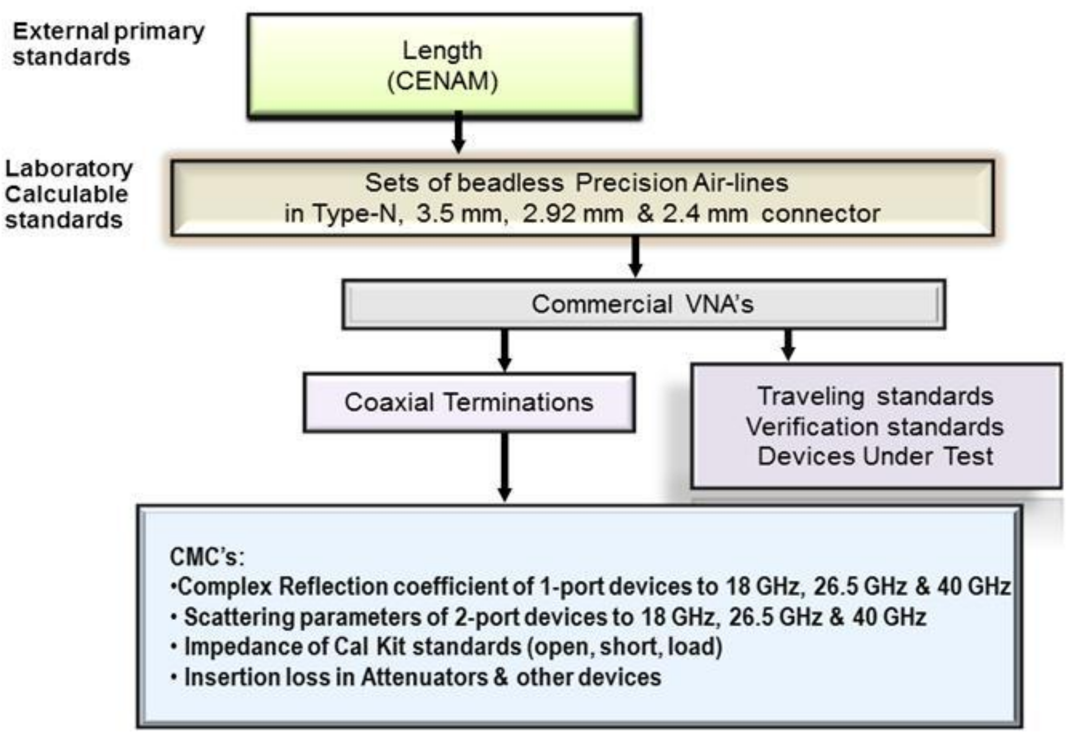
Year: 2011
Scope: CENAM CMC's and QMS on RF power and Scattering parameters in the frequency range form 10 MHz to 18 GHz, RF voltage from 10 kHz to 100 MHz
Reviewer: Mr. Ronald Ginley (NIST)
Year: 2011
Scope: CENAM CMC's and QMS on Antenna measurements in the frequency range from 30 MHz to 1000 MHz
Reviewer: Mr Dennis Camell (NIST)

5. Measurement systems & CMC's

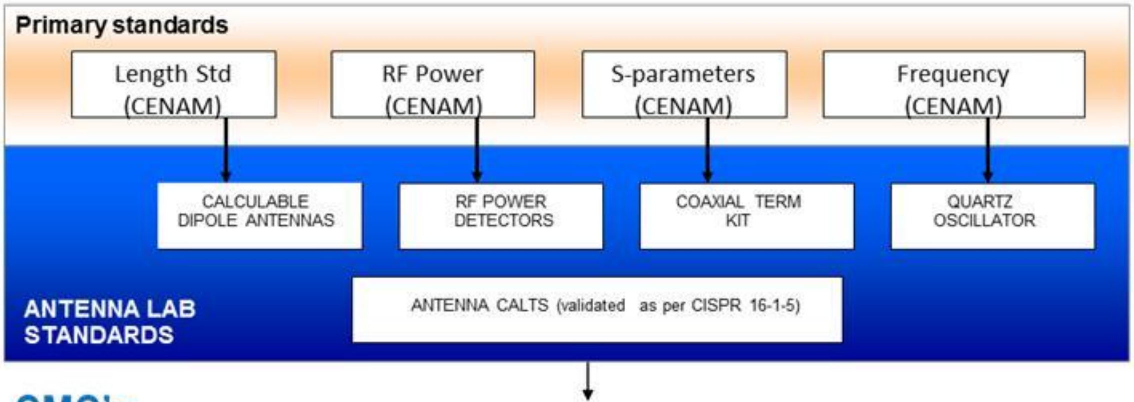
RF POWER



S-parameters



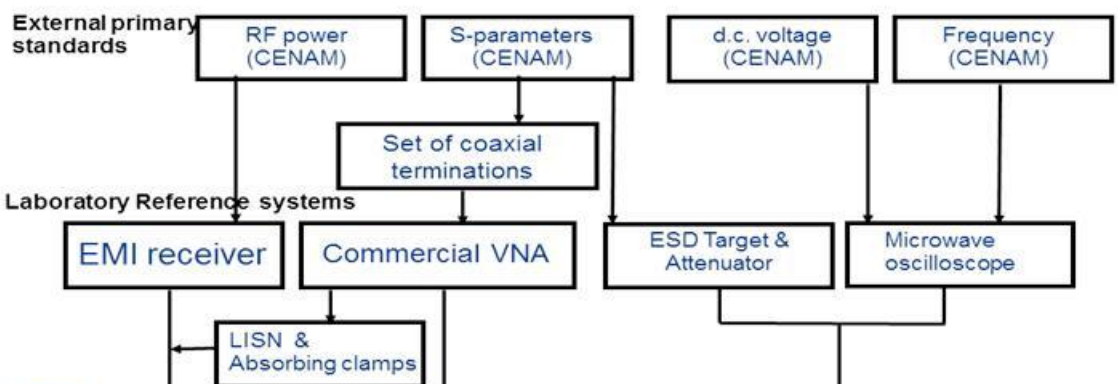
Antenna & EM Fields



CMC's

- Antenna Factor of EMC antennas using the Standard Site Method (SSM):
  - Biconical: 30 MHz to 300 MHz
  - Log-periodic: 200 MHz to 1000 MHz
  - Hybrids or other dipole arrangements
- Gain and radiation pattern of other antennas in the 30 MHz to 1000 MHz frequency range

EMC



CMC's*

- Impedance & Insertion loss of transducers for EMI conducted measurements (10 kHz – 30 MHz).
- Pulse parameters of ESD generators (2 kV - 15 kV)
- Transfer parameters of absorbing clamps for EMI radiated measurements (30 MHz – 300 MHz)
- Disturbing power of Conducted emissions testing in appliances

* not yet in CIPM database

6. Technical and Scientific publications

Antenna and electromagnetic fields metrology

V. Molina-Lopez, M. Botello-Perez, I. Garcia-Ruiz, "Validation of the Open Area Antenna Calibration Site at CENAM". *IEEE Transactions on Instrumentation and Measurement*, Vol. 58, No. 4, pp. 1126–1134, Abril 2009. *DOI: 10.1109/TIM.2008.2008473*

M. Botello-Pérez, V. Molina-López, I. García-Ruiz, "Realización del Patrón Nacional de Factor de Antena", *Simposio de Metrología 2010*, Querétaro, México, Octubre de 2010.

M. Botello-Pérez, V. Molina López, I. García-Ruiz, "Avances en el desarrollo del patrón nacional de factor de antena," *Simposio de Metrología 2008*, Querétaro, México, Octubre de 2008.

V. Molina López, M. Botello-Pérez, I. García-Ruiz, "Establishment of the Open Area Antenna Calibration Site at CENAM," *2008 Conference on Precision Electromagnetic Measurements (CPEM) Proceedings*, Boulder , Colorado, USA, pp. 510–511, Junio de 2008. *DOI: 10.1109/CPEM.2008.4574877*

V. Molina-López, I. García-Ruiz, M. Botello-Pérez, "Significado de la atenuación de sitio y de la atenuación de sitio normalizada en la validación del sitio de referencia para calibración de antenas del CENAM," *Simposio de Metrología 2006*, Querétaro, México, Octubre de 2006.

V. Molina-López, I. García-Ruiz, M. Botello-Pérez, "Estimación de incertidumbre en la medición de la atenuación de sitio en la validación del CALTS-CENAM," *Simposio de Metrología 2006*, Querétaro, México, Octubre de 2006.

M. Botello-Pérez, V. Molina-López, I. García-Ruiz, "Desarrollo de antenas patrón tipo dipolo resonante de media longitud de onda para la validación del CALTS-CENAM," *Simposio de Metrología 2006*, Querétaro, México, Octubre de 2006.

M. Botello-Pérez, V. Molina-López, I. García-Ruiz, "Desarrollo de una antena de banda ultra ancha para compatibilidad electromagnética y para calibración de antenas," *Simposio de Metrología 2006*, Querétaro, México, Octubre de 2006.

M. Botello-Pérez, I. García-Ruíz, H. Jardón-Aguilar, "Design and Simulation of a 1 to 14 GHz Broadband Electromagnetic Compatibility DRGH Antenna", *Proceedings of the 2nd Conference on Electrical and Electronics Engineering (ICEEE)*, México, D.F., pp. 118-121 Septiembre de 2005. *DOI: 10.1109/ICEEE.2005.1529587*

M. Botello Pérez, I. García Ruiz, "Interpretación de parámetros y especificaciones de antenas para Compatibilidad electromagnética (EMC)", *Encuentro Nacional de Metrología Eléctrica (ENME'09)*. Querétaro, Qro. México, Noviembre de 2009.

M. Botello-Pérez, I. García-Ruiz, V. Molina-López, "Servicios de Calibración en el laboratorio de antenas," *Encuentro Nacional de Metrología Eléctrica (ENME'07)*, Querétaro, México, Julio de 2007.

M. Botello-Pérez, I. García-Ruiz, H. Jardón-Aguilar, "Antena de corneta piramidal con doble cresta para compatibilidad electromagnética: importancia y desempeño", *Encuentro Nacional de Metrología Eléctrica (ENME'05)*, Querétaro, México, Junio de 2005.

V. Molina-López, I. García-Ruiz, M. Botello-Pérez, "Medición de las características de una antena", *Encuentro Nacional de Metrología Eléctrica (ENME'05)*, Querétaro, México, Junio de 2005.

José Alfredo Tirado-Méndez, Hildeberto Jardón-Aguilar, Flavio Iturbide-Sánchez, Israel Garcia-Ruiz, Victoria Molina-Lopez, Rene Acevo-Herrera, "A proposed defected microstrip structure (DMS) behavior for reducing rectangular patch antenna size", *Microwave and Optical Technology Letter*s, 12/2004; 43(6):481 - 484.

Leal Uribe A.M., Muñoz Sancén M.A. García Ruiz I. "Extended characterization of an open-area antenna calibration test site", *IEEE 29th Conference on Precision Electromagnetic Measurements 2014*, Río de Janeiro, Brazil; August 2014

Victoria Molina, Israel García, "Características de diseño y construcción del sitio de calibración a campo abierto del CENAM (CALTS-CENAM)", *Simposio de Metrología 2004.* Querétaro, México, Octubre 2004.

RF Power metrology

M. Botello-Pérez, I. García-Ruiz, "Patrón Primario Para Medición de Potencia Eléctrica en Radiofrecuencias de 0.05 GHz a 18 GHz", *Simposio de Metrología 2014*, Querétaro, México, Octubre de 2014.

M. Botello-Pérez, R. Castañeda-Castillo, I. García-Ruiz, "Calibración de Vóltmetros de RF Mediante Termoconvertidores de Tensión", *Simposio de Metrología 2014*, Querétaro, México, Octubre de 2014.

M. Botello-Pérez, I. García-Ruiz, "Sistema de Referencia Para la Calibración de Detectores de Potencia por Comparación Directa", *Simposio de Metrología 2012*, Querétaro, México, Octubre de 2012.

M. Botello-Pérez, I. García-Ruiz, "Development of a Direct Comparison System for Radiofrequency Power Calibration Transfer from 10 MHz to 18 GHz", *2012 Conference on Precision Electromagnetic Measurements (CPEM) Proceedings*, Washington D.C., Maryland, USA, pp. 730–731, Julio de 2012. *DOI: 10.1109/CPEM.2012.6251137*

Reflection and transmission coefficients metrology

S. Padilla-Corral, I. García-Ruiz, "Actualización del Patrón Nacional de Coeficientes de Reflexión y Transmisión", *Simposio de Metrología 2014*, Querétaro, México, Octubre de 2014.

S. Padilla-Corral, I. García-Ruiz, "Ampliación del alcance en frecuencia del patrón Nacional de coeficientes de reflexión y transmisión hasta 30 GHz", *Simposio de Metrología 2012*, Querétaro, México, Octubre de 2012.

S. Padilla-Corral, I. García-Ruiz, "Estimación de la incertidumbre de medición de un Analizador Vectorial de Redes", *Simposio de Metrología 2010*, Querétaro, México, Octubre de 2010.

S. Padilla-Corral "Aplicación de los parámetros de dispersión en la caracterización de componentes y equipos de radiofrecuencias para la industria de telecomunicaciones", *Encuentro Nacional de Metrología Eléctrica 2009*. Querétaro, México. Centro Nacional de Metrología (CENAM). 2009.

S. Padilla-Corral, I. García-Ruiz "Entendiendo el uso de los equipos y componentes de RF y microondas", *Encuentro Nacional de Metrología Eléctrica 2007.* Querétaro, México. Centro Nacional de Metrología (CENAM). 2007.

S. Padilla-Corral, I. García-Ruiz "Importancia de la calibración de componentes y equipos de medición que operan en el intervalo de RF y microondas.“ *Encuentro Nacional de Metrología Eléctrica 2005*. Querétaro, Qro. Centro Nacional de Metrología (CENAM). 2005.

S. Padilla-Corral, I. García-Ruiz "Método de corrección de errores del analizador de redes empleando como referencia las líneas coaxiales patrón“, *Simposio de Metrología 2004*. Querétaro, México, Octubre 2004.

I Garcia-Ruiz, S Padilla-Corral, “Establishment of the National Standards for S-Parameters and Related Quantities in Mexico, *Conference on Precision Electromagnetic Measurements Digest, 2004*, DOI: 10.1109/CPEM.2004.305422.

Israel García-Ruiz, Susana Padilla-Corral, “Establishment of the mexican national standard for RF and microwave scattering (s-) parameters“, *Simposio de Metrología 2004*. Querétaro, México, Octubre 2004.

C. A. Bonilla Barragán, A. Dueñas Jiménez, H. Jardón Aguilar, I. García Ruiz, “Definición de las funciones objetivo y restrictiva para la calibración de un reflectómetro hexaportal”, *Simposio de Metrología 2006*, Querétaro, México, Octubre de 2006.

Electromagnetic compatibility and Interference metrology

Muñoz Sancén M.A. Méndez J. A. Tirado Linares y Miranda R "Development of a semi-isotropic antenna for radiated emission and immunity in the frequency range of 300 MHz to 3 GHz“, *Proceedings of the Simposio de Metrologia 2012*. Queretaro, Mexico. October, 2102.

Muñoz Sancén M.A. García Ruiz I. "Measuring System for Electrostatic Discharge", *Proceedings of the Symposium of metrology 2014*. Queretaro, Mexico. October 2014.

V M López, I G Ruiz, F Sepúlveda, D Á Jiménez, R J López, E M Martínez, “Perspectivas del desarrollo de las normas para la implantación de la EMC en México“, Proceedings *of the Encuentro Nacional de Metrología Eléctrica, ENME, 2007*.

Electromagnetic properties of materials metrology

Israel Garcia-Ruiz, Carlos D. Aviles-Castro, Hildeberto Jardón-Aguilar, Juan Guerra-Vargas, On the measurement of the complex permittivity of layers embedded in a multilayered dielectric material with the use of a free-space method, *Microwave & Optical Technology Letters 33*: 422–426, 2002. DOI 10.1002/mop.10340.

I Garcia-Ruiz, CD Aviles-Castro, H Jardon-Aguilar, Measuring complex permittivity of materials for frequencies under 18 GHz, *Applied microwave and Wireless,* 01/2001; 13:56-85.

I García-Ruiz, D Avilés-Castro, H Jardón-Aguilar, Development of a microwave dielectric spectroscopy system for materials characterization using the open-ended coaxial probe technique, *Revista Mexicana de Física 01/2001*; 47:62-69.

C. D. Avilés, I. García, J. M. Arias, Medición de humedad en sólidos por microondas, *Proceedings of the Simposio de Metrologia 2002*. Querétaro, México, October, 2002.