Electrical
Engineering Laboratory

National Institute of Standards and Technology

Technology Administration

U.S. Department of Commerce

NISTIR 6842

January 2002

Electricity Division

Programs, Activities, and Accomplishments

The Electronics and Electrical Engineering Laboratory

Through its technical laboratory research programs, the Electronics and Electrical Engineering Laboratory (EEEL) supports the U.S. electronics industry, its suppliers, and its customers by providing measurement technology needed to maintain and improve their competitive position. EEEL also provides support to the Federal government as needed to improve efficiency in technical operations, and cooperates with academia in the development and use of measurement methods and scientific data.

EEEL consists of six programmatic divisions and two matrix-managed offices:

Electricity Division

Semiconductor Electronics Division

Radio-Frequency Technology Division

Electromagnetic Technology Division

Optoelectronics Division

Magnetic Technology Division

Office of Microelectronics Programs

Office of Law Enforcement Standards

This document describes the technical programs of the Electricity Division. Similar documents describing the other Divisions and Offices are available. Contact NIST/EEEL,
100 Bureau Drive, MS 8100, Gaithersburg, MD 20899-8100,
Telephone: (301) 975-2220,
On the Web: www.eeel.nist.gov

Cover Caption:

The Electricity Division actively supports various customers, such as the electric power industry, users of flat panel displays, and the electronic instrumentation industry.

Electronics and Electrical Engineering Laboratory

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U.S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary

Technology Administration
Phillip J. Bond, Under Secretary of Commerce for Technology

National Institute of Standards and Technology
Arden L. Bement, Jr., Director

Contents

Welcome

The Electricity Division maintains and disseminates the national standards of electrical measurement, such as the volt, ohm, farad, and watt. It also develops the measurement methods and services needed to support electrical materials, components, instruments, and systems used for the generation, transmission, and application of conducted electrical power. In addition, the Electricity Division performs related activities in support of the electronics industry, including research on video technology, electronic product data exchange, and semiconductor fabrication.

Maintenance of the national electrical standards requires that the Division realize the electrical units in terms of the International System of Units (SI) at the highest levels of accuracy, assure consistency with other national realizations of the electrical units through international comparisons, and provide a sound measurement basis for fundamental electrical constants that are of importance to the scientific community.

The Division widely disseminates the results of its research, especially in the areas of advanced measurement technology and dissemination of national standards, through a variety of channels – for-fee calibrations, publications, software, conferences and workshops, and participation in standards organizations and consortia. NIST also actively seeks industrial, academic, and non-profit research partners to work collaboratively on projects of mutual benefit.

This book describes the research programs, activities, and recent accomplishments of the Electricity Division organized by research project. After the project descriptions is a list of the calibration services that the Division provides, NRC Postdoctoral Research opportunities within the Division, and finally an organization chart to facilitate contacting our staff members. For additional information about the Electricity Division, please visit our web site at http://www.eeel.nist.gov/811/.

James K. Olthoff

Barry A. Bell

Dr. James K. Olthoff

Chief, Electricity Division

Barry A. Bell

Deputy Chief, Electricity Division

Division Programs

The Electricity Division focuses on strengthening the U.S. economy by searching out, evaluating, and addressing needs that must be met to improve U.S. industry's ability to compete in the global marketplace. Our aim is to identify the needs that are of highest economic impact, that industry cannot effectively meet without the Division's help, and that the Division, with its technical expertise, can meet with deliverables appropriate to its mission. The Division serves the electronics, electrical-equipment, and electric power industries, government agencies, educational institutions, and through them all, the general public. These supported industries are pursuing sweeping changes including rapid exploitation of higher levels of technology, shorter product development cycles, increased product diversity, lower prices per function, and broader entry to mass commercial and consumer markets.

As part of the Electronics and Electrical Engineering Laboratory (EEEL), the Electricity Division conforms to the program structure used by the Laboratory to describe its programs. The six fields of technology that the Division's work impacts are: national electrical standards, low frequency, power, display metrology, electronic data exchange, and semiconductors.

National Electrical Standards

The availability of highly accurate, reliable, and robust measurement technologies is very important to research and development, manufacturing quality control, and marketplace exchange. Measurements of electrical quantities, such as the volt, farad, ohm and watt, are particularly important. In fact, electrical quantities are the common currency of measurements; that is, many non-electrical quantites are converted into electrical quantities to facilitate measurement by electronic instrumentation. Further, the foundational International System of Units (SI), and all research based on it, rely on a time-invariant, internationally-consistent realization of the electrical units. The Division strives to improve the accuracy of these standards in response to ever-increasing needs by industry and research organizations for ever higher levels of performance. To achieve these goals, the Division has turned to quantum phenomena. They enable relating electrical quantities to unvarying fundamental atomic constants, such as the charge on an electron. Continued success in the implementation of electrical standards based on quantum phenomena could motivate a future redefinition of the SI to provide definitions more readily implemented by a broad range of users.

Low Frequency

Measuring derived electrical quantities linked to the SI units and national electrical standards is vital to supporting the vast array of "low frequency" electrical and electronic products available in today's marketplace. Such products include industrial electronics, consumer electronics, telecommunications equipment, computers, medical equipment, and automatic test systems. These products operate anywhere within a broad frequency range, extending from zero (direct current) up to 10's of gigahertz. Although the Division does not have the resources to provide metrology support specifically targeted at each of these product areas, it does provide such support in fundamental forms that benefit them all. Typical measurement quantities of interest include ac voltage amplitude, ac current amplitude, impedance, dissipation factor, phase angle, ac ratio, power, linearity, total harmonic distortion, settling, delay/rise time, effective bits, signal-to-noise ratio, aberrations, 3 dB bandwidth, etc. Both manufacturers and users depend heavily on product accuracy for these derived quantities and need improved measurement methods as well as measurement linkages to standards maintained at NIST. Future work is focused on achieving higher accuracies at higher frequencies for evaluation of components, circuit assemblies, and equipment; and advancing measurement efficiency.

Power

The Division's support of electric power systems is driven principally by needs in the areas of energy efficiency, power quality measurements, and reliability. The U.S. consumes more than $215 billion of electricity annually. The fair, reliable, and efficient generation and delivery of this power is critical to U.S. industry and consumers, especially in light of the increasingly deregulated and fragmented areas of power generation, transmission, and distribution. The Division continues to develop improved measurement methods, supporting measurement reference standards, and calibration services to support revenue metering, equipment evaluation, and power quality. In an effort to preserve the reliability of power systems, suppliers are moving steadily toward more sophisticated control and monitoring technology. The Division is helping by providing measurement and security support for key monitoring devices.

Display Metrology

Television, computers, and telecommunications are merging into advanced digital video and computer systems that will provide new services for education, engineering, manufacturing, robotics, entertainment, medicine, defense, security, transportation, publishing, advertising, banking, and government. A critical element in this convergence is that electronic displays are becoming ubiquitous. Although displays are manufactured primarily offshore, U.S. manufacturers are the largest consumer of displays. To facilitate worldwide commerce in displays, a well-defined method for specification and verification of display quality is needed to ensure that the display will work under the necessary lighting conditions. NIST is working with industry standards-developing organizations to ensure such equity in the marketplace by developing the metrology base for displays.

Electronic Data Exchange

To implement new strategies for decreased time to market and reduced product design and manufacturing costs, manufacturers must implement strategies such as flexible manufacturing, collaborative development (internally and externally), concurrent engineering, and other advanced design and manufacturing techniques. These techniques are founded on the ability of manufacturers and suppliers to share information in computer-accessible digital formats. Three goals have been identified that are particularly relevant to the industries that the Division serves. We work with industry to develop: 1) standardized data structures for describing product designs in a universal manner, 2) the standards needed to create an electronic marketplace that fosters collaborative efforts, and 3) standards to facilitate development of factory-automation software that is modularized in a standard manner to enable substitution of software modules from different vendors ("best-of-breed").

Semiconductors

Although the semiconductor industry is primarily served by the Semiconductor Electronics Division within EEEL, the Electricity Division with its expertise in electrical breakdown in gases, supports the semiconductor industry through the derivation of fundamental data required for the development of real-time control and predictive modeling of plasma processing techniques for semiconductor fabrication.

The Electronic Kilogram

Project Goals

To realize the electrical unit of voltage and to provide an alternative definition of the unit of mass that is based on measured quantities determined by fundamental physical constants of nature.

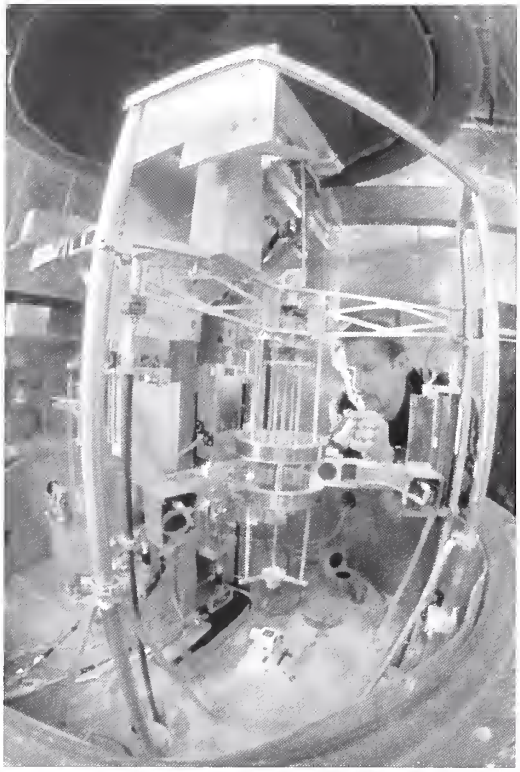

Photo © Robert Rathe

Richard Steiner places a test mass on the balance for the Electronic Kilogram.

Customer Needs

The kilogram is the only remaining base unit in the International System of Units (SI) whose definition is based on a physical artifact rather than on fundamental properties of nature. Environmental contamination or material loss from surface cleaning, or other unknown mechanisms, are causing the mass of the kilogram to vary by about 3 parts in 10^8 per century relative to sister prototypes. This observed drift highlights a significant shortcoming of the SI system. The measured values of many physical constants are based on mass, and these constants are regularly used in quantum-based measurement systems, such as the Josephson effect, which are becoming more significant to the growth of international technology and trade accreditation. Thus, with a time-drifting mass standard, adjustments to the value of physical constants must be made periodically to maintain the consistency of the SI system. Moreover, each future change will adversely affect a continuously growing technology base that relies increasingly on electronic testing, quality control, and environmental monitoring. The adoption of the electronic kilogram as the mass standard will improve the consistency of the SI and will also provide better determinations of many fundamental physical constants, such as the charge and mass of the electron, that serve the general scientific and technological communities.

Technical Strategy

The equivalence of electrical and mechanical power provides a convenient route to the measurement of mass in terms of other quantum mechanically defined measurement units. The apparatus at the Electronic Kilogram facility is a balance that compares both kinds of power in a virtual measurement that is unaffected by the dissipative forces of friction and electromagnetic heating. The experimental observables are length, time, voltage, and resistance. These quantities are all measured with respect to fundamental and invariant quantum phenomena: atomic clocks, lasers, the Josephson effect, and the quantum Hall effect, respectively.

It is necessary to reduce the total measurement uncertainty of this experimental apparatus by a factor of 10 to the level of 0.01 ppm to monitor the mass of the kilogram artifact mass standard. A substantial upgrade of the facility to reduce many known sources of error has been effected to achieve this goal. The experiment assembly was completed this year and is fully operational in most subsystems, so quantifying the improved designs has begun. The first round of tests has found that most design changes to the force balance are working satisfactorily and will indeed improve the uncertainty, while the recent understanding of an old noise source has suggested design changes to the induction coil. A second round of improvements is now under way.

DELIVERABLES: By 2004, achieve fully integrated operation of all run modes and subsystems of the watt balance. Establish long term stability of alignment, data acquisition, and reference standards for the repeatability of watt data at an uncertainty of 0.1 ppm. Further optimize the system for regular monitoring of the kilogram at an uncertainty level of 0.01 ppm.

Technical Contact:
Richard L. Steiner

Staff-Years:
3.0 Professionals
0.5 Postdoc
1.0 Guest Scientist

Funding Sources:
NIST (100 %)

Parent Program:
National Electrical Standards

Related to this work is a multi-lab effort to provide the measurement of micro-scale forces that are traceable to the International System of Units (SI). The accurate realization and measurement of micro- and nano-Newton level forces requires the development of a new kind of force comparator housed in an appropriate laboratory environment with vibration isolation, climate control, and low airborne contaminant levels. This five-year competence project, the Microforce Realization and Measurements Project (MFMP), includes researchers from the Automated Production Technology and Precision Engineering Divisions of the Manufacturing Engineering Laboratory (MEL), from the Ceramics Division of the Material Science and Engineering Laboratory (MSEL), and from the Electricity Division.

DELIVERABLES: By 2002, Complete development of the preliminary electromechanical force balance and demonstrate the comparison of mechanical to electrical forces at a level of 10^{-5} N with a total relative uncertainty of 10^{-3}.

DELIVERABLES: By 2005, establish a metrological basis for small force measurement by developing an electronic realization of force traceable to the SI in the regime between 10^{-8} N and 10^{-4} N.

"Wow – this is moving faster than I expected!"

Ray Kammer
Former NIST Director

Accomplishments

- As result of improvements implemented in the rebuilding of the watt balance apparatus, several critical alignment procedures, such as aligning the superconducting magnet along earth's gravity and related alignments of the main induction coil, proved easier than before. Another study found that using harder ceramic knife-edge and flat materials, tungsten carbide coated with diamond-like carbon, has reduced hysteresis forces by about a factor of 6. This research also revealed that brass counterweight material with ferromagnetic impurities contributes a hysteretic effect. Selecting better materials should result in a factor of 10 improvement in the hysteresis-induced noise of the force mode.

- Working with the nonmetallic vacuum chamber proved that, although there is outgassing from it and the coil windings, a vacuum pressure of 0.3 Pa can be easily maintained and is sufficient for operations. Force/current mode testing with 12 g masses showed that without air currents and buoyancy fluctuations, the force balance noise is about four times quieter. This testing also proved that there are no ferromagnetic masses located near the coils and that the force mode procedure cancels even nearby ferromagnetic effects.

Richard Steiner working with the test balance used for studies of knife-edge hysteresis.

- The volt/velocity mode is fully operational at the 1 V level. The new induction coil has a profile of 70 ppm peak-to-peak, which is a factor of 5 better than the previous coil and should reduce the uncertainties in the profile curve-fitting algorithm. However, vibration-induced noise in the tens of Hertz range is greater by a factor of 5 or more over the old coil. The source of this noise was identified as two mechanical flexing modes within the coil structure, so the coil's electromagnetic response to vibrations was unsynchronized with the motion of the interferometer corner cubes. Finding this solved a poorly understood noise problem in previous experiments. New coil designs are being tested that should substantially reduce this problem.

- A new electrostatic balance has been completed for the Microforce Realization and Measurements Project. All axes have been aligned with respect to gravity to within 5 mrad. An initial uncertainty analysis associated with the alignment, length, mass, voltage, and capacitance measurements yield a total uncertainty below a part in 10^4. An electrical and mechanical force comparison of a 5 mg mass shows a discrepancy of 0.3 %. Electrical and mechanical force comparisons have been made using 1, 2, 5, and 20 mg dead weights. Discrepancies as large as a few percent have been found. Results were presented at Second International Conference of the European Society for Precision Engineering and Nanotechnology (EUSPEN) in Turin, Italy (May 2001). Currently, measurements are being repeated with different offset voltages during both the dC/dz measurements and the weighings to investigate the possibility of time-dependent systematic effects arising from dielectric films on the electrodes.

FY Outputs

Collaborations

Edwin Williams and David Newell are collaborating with the Automated Production Technology, Precision Engineering, and Ceramics Divisions at NIST in a competence project for Microforce Realization and Measurement.

Publications

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Voltage Metrology

Technical Contact:
Yi-hua Tang

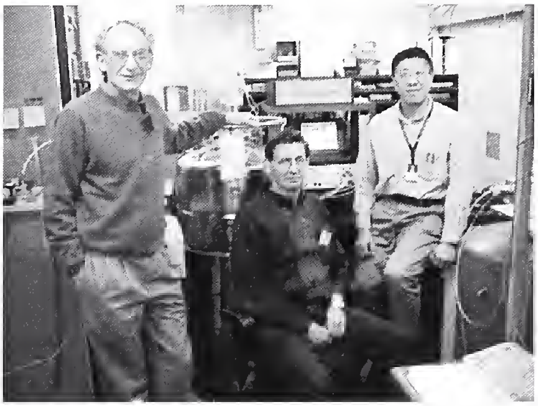
Staff-Years:
2.0 professionals

Funding Sources:
NIST (70 %)
Calibrations (30 %)

Parent Program:
National Electrical Standards

Project Goals

To maintain the U.S. legal volt and to provide for the dissemination of an internationally consistent, accurate, reproducible, and traceable voltage standard that is tied to the SI units and readily and continuously available for the U.S. scientific and industrial base.



Stu Kupferman and Mel Salazar (left and center, respectively, from Sandia National Laboratory), collaborate with Yi-hua Tang to evaluate the use of the portable compact Josephson voltage system as the transfer standard for interlaboratory comparisons.

Customer Needs

All voltage measurements performed in the U.S., whether for the purpose of direct voltage reading or for the determination of another parameter (such as temperature) through the use of a transducer that converts that parameter into a voltage signal, rely for consistency on traceability to international standards through the U.S. legal volt. Because of the length of the calibration chain that connects measurements by an end user with the U.S. legal volt, it is common for the measurement uncertainty of the end user to exceed the NIST primary uncertainty by a factor of 100 or more. The continued development and deployment by the U.S. electronics instrumentation industry of increasingly sophisticated and accurate instrumentation places ever-increasing demands for higher accuracy voltage metrology both in calibration and testing laboratories and on production lines and factory floors. Consequently, NIST is continuously pressed to reduce measurement uncertainty at the beginning of this chain and to develop improved mechanisms for dissemination to the end user. Through maintenance, development, and dissemination of the U.S. legal volt, this project provides the robust base for voltage metrology that enables the U.S. electronics instrumentation industry to compete successfully in the global market.

Technical Strategy

A representation of the SI unit of voltage has been established via the Josephson effect, to maintain and disseminate the U.S. legal volt. The measurement systems required to measure and transfer that voltage to other electronic systems and to chemical or electronic standards have been developed. To continually achieve the lowest possible uncertainty, project members 1) perform regular checks for subtle systematic errors in both the Josephson voltage standard systems and the subsequent transfer systems, 2) perform regular comparison checks between our systems, 3) maintain long-term observations of well-characterized check standards, and 4) periodically verify our consistency with the international community through very careful international comparisons. Research continues on the physical and statistical limitations of metrology equipment and protocols both presently in use and under development in order to support future technological advances.

There has been an increasing demand in recent years, by industrial users of Josephson voltage standards, for NIST to provide voltage calibrations with reduced uncertainty than is presently available through our standard volt calibration services. To provide that reduced uncertainty in the voltage dissemination we are developing a measurement assurance program (MAP), based on 10 V Zener reference standards, which will reduce the uncertainty delivered to our customers by approximately a factor of 4.

In recent years, an increasing number of Josephson voltage standards have been deployed both around the world and throughout the U.S. It has proven very difficult to verify in the field the performance of voltage metrology systems based upon Josephson standards because the accuracy of these measurements is limited by the performance of the Zener voltage references used as transfer standards. Because the ultimate performance of Josephson voltage systems should be much better than can be verified using these standards, a traveling compact Josephson voltage standard (JVS) is being developed, in collaboration with Division 814 in Boulder, along with measurement protocols appropriate for its use in the intercomparison of Josephson systems. The elimination of problems associated with traveling Zener standards will substantially reduce the uncertainty of Josephson voltage intercomparisons.

DELIVERABLES: By 2002, perform a JVS MAP at the highest possible level of accuracy between NIST and Sandia National Laboratory (the pivot lab for the 2002 NCSL JVS intercomparison).

DELIVERABLES: By 2002, complete the documentation for the 10 V Zener MAP and establish as a regular service for NIST customers.

DELIVERABLES: By 2002, assemble a compact JVS system and evaluate its performance for both direct and indirect comparisons between geographically separated JVS systems. This will ultimately provide a significant improvement to the accuracy and reliability of JVS intercomparisons.

The NIST voltage calibration service presently relies on banks of electrochemical cells for the daily workload of calibrating customer standards. While these cells are quiet and predictable voltage sources and therefore convenient to use as calibration standards, they are physical artifacts with built-in limitations in their use and in their deliverable uncertainty. In order to simplify the chain of transfers which links the calibration bench with the Josephson voltage standard, it would be very useful to incorporate the Josephson array standard more directly into the customer artifact calibration system. In collaboration with the NIST Electromagnetic Technology Division, project staff are investigating alternative means for the incorporation of a Josephson array system into the daily service.

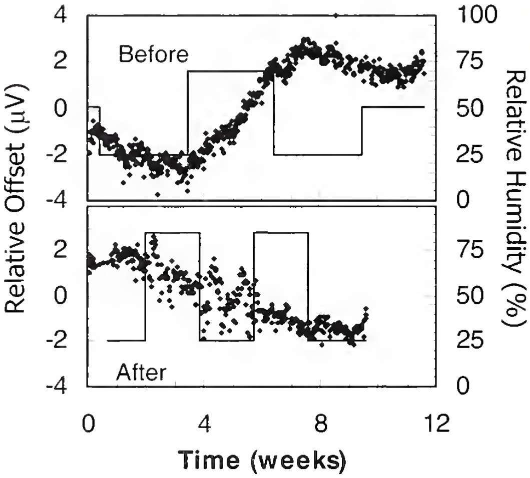
DELIVERABLES: By 2003, implement a programmable Josephson voltage system for daily use in the Volt Laboratory and evaluate its potential as a replacement for the primary standard cells.

Accomplishments

- A 10 volt Measurement Assurance Program was conducted with Sandia National Laboratory as a complete field test of our measurement service under development. Measurements were performed using two different types of Zener transport standards. The total uncertainty (95 % confidence) of one such MAP experiment was found to be 0.35 μV (relative error of 3.5×10^{-8}). However, non-linearity of the Zener drift over the time period led to a rather significant apparent difference between the measurements of two laboratories of 0.51 μV. This exercise demonstrated the effectiveness of corrections applied to account for environmental effects in the Zener voltage outputs and demonstrated the importance of careful and detailed characterization of the Zener transport standards for properties such as transportability, linearity in drift, and noise. These are critical factors for a MAP with a total expected uncertainty of only a few parts in 10^8.

- A technical note for the NIST Zener Measurement Assurance Program (MAP) at 10 volts has been drafted. The draft provides both a complete description of the measurement protocol and a detailed discussion of the data analysis and determination of the measurement uncertainty.

- The detailed characterization of Zener transport standards for the 10 volt MAP revealed a strong correlation between the Zener output voltages and environmental humidity. As a result of NIST's detailed measurements, the manufacturer was able identify the source of this sensitivity and to design a retrofit for their product line, which largely eliminated the observed dependence on humidity.



Response of Zener standard to changes in relative humidity, before (upper) and after (lower) implementation of retrofit by the manufacturer.

- Researchers in the Electricity Division collaborated in a substantial revision and update for the "Recommended Intrinsic / Derived Standards Practice" document for Josephson Voltage Standard (RISP-1) organized by the National Conference of Standards Laboratories International.

- Steps have been taken to further ensure the integrity of the Volt Laboratory's physical environment. A number of temperature and power disturbances occurred in the Volt Laboratory during FY 2001. Such disturbances are potentially very damaging both to NIST primary reference systems and to customer instruments at NIST for calibration. System improvements are expected to substantially reduce our risk of damage during power outages and other disturbances. In addition, some aging measurement system equipment in the Laboratory was replaced or serviced. This included the replacement of a crossbar switch and the addition of diagnostic circuitry to detect any eventual future crossbar release failures.

FY Outputs

Calibrations

74 calibrations were performed with division income of approximately $42,000 received (October 1, 2000 to September 30, 2001).

Collaborations

Yi-hua Tang is working with Sam Benz of the NIST Electromagnetic Technology Division to develop a Josephson voltage standard that can be used more directly in the customer calibration system.

Yi-hua Tang collaborated with Fluke corporation to reduce the sensitivity of Zener voltage standards to environmental humidity.

Publications

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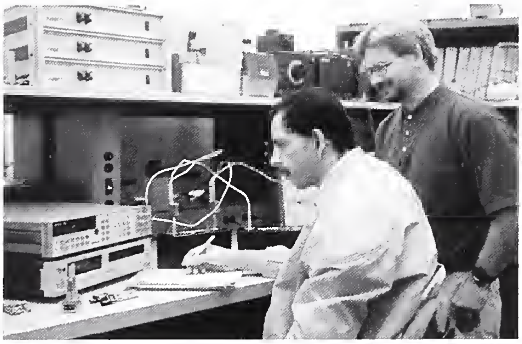
Metrology of the Ohm

Project Goals

To maintain the U.S. legal ohm and to provide for the dissemination of an internationally consistent, accurate, reproducible, scalable, and traceable resistance standard that is readily and continuously available for the U.S. scientific and industrial base.



Dean Jarrett (NIST) (R) assists Harold Sanchez (ICE, Costa Rica) in the development and evaluation of a measurement technique to be used in Costa Rica for the calibration 10 GΩ and 100 GΩ high resistance standards.

Customer Needs

The U.S. electronics instrumentation industry, along with military and aerospace industries, maintains a position of world leadership through the development and deployment of increasingly sophisticated multi-function, high-precision and low-maintenance instruments. The ready availability of accurate and reliable precision electrical metrology is a critical need of continued instrumentation development. In addition, the U.S. electrical power industry relies on precise and accurate electrical metrology in both the distribution and metering of electrical power. To meet the present challenging needs and in anticipation of the increased demands of upcoming advanced instruments, this project is focused on the maintenance and dissemination of a reliable unit of resistance. Because reliable and stable resistance standards have been available for many years, many electrical measurements (e.g., at very high/low current levels) are converted to resistance measurements. Because of this very broad customer need, resistance dissemination is required to support a wide variety of impedance measurements, over a wide range of resistance levels, over a wide range of frequency, and at very high levels of accuracy. The activities of this project enable U.S. industry to demonstrate and verify in a cost-effective way the accuracy of electrical measurements and the performance of high-precision instrumentation in a competitive world environment.

Technical Strategy

Maintenance of the U.S. legal ohm requires research and the pursuit of scientific breakthroughs in quantum metrology to maintain a local representation of the unit, and requires close collaboration with other National Metrology Institutes, including participation in international metrology comparisons to ensure international consistency of electrical measurements.

There has in recent years been a marked improvement both in the capability of measurement laboratories to perform high resistance measurements and in the quality of available high resistance standards. The recently completed CCEM-K2 key comparison of high resistance standards clearly demonstrated this ability for National Metrology Institutes around the world. High resistance standards are also now commercially available with technical specifications that exceed, by as much as an order of magnitude, performance that can be verified with our routine services. This is particularly important given the severe demands placed on calibrations by the performance of newer generations of 8.5-digit digital multimeters.

Our present uncertainties for the calibration of high resistance standards are limited by the scaling measurements from the quantum Hall resistance (QHR) to the 1 MΩ level. Unlike the scaling down to 1 Ω and up to 10 kΩ, which presently rely on the Cryogenic Current Comparator (CCC) for direct scaling from the QHR and support relative uncertainties of about 1×10^{-7}, the scaling up to 1 MΩ starts at 10 kΩ and involves time-consuming and labor-intensive measurements using Hamon-type networks. Using a CCC to scale directly from the QHR to the 1 MΩ level and to achieve an uncertainty below 1×10^{-7} requires a new approach, one that is well adapted to very low levels of current and voltage.

Resistance-scaling to 1 MΩ using the CCC and SQUID as the only high-resolution detector has been demonstrated, using a special technique to eliminate effects of lead resistance. The measurement technique can be applied to resistance levels of 1 MΩ and above. In addition to its use in calibrations, this CCC system could be used for characterizing cryogenic resistance

Technical Contact:
Randolph E. Elmquist

Staff-Years:
4.5 professionals
1.0 technicians

Funding Sources:
NIST (70 %)
Calibrations (25 %)
Other Government Agencies (5 %)

Parent Program:
National Electrical Standards

samples developed for the quantum metrology triangle experiment.

DELIVERABLES: By 2002, construct and characterize a CCC for direct comparison of 1 MΩ resistance standards against the quantum Hall resistance.

A continuing concern in the metrology community is the lack of a reliable source of quantum Hall resistance (QHR) devices with operational characteristics suitable for performance as resistance standards. Of particular importance is the difficulty of making reliable electrical connections to the underlying two-dimensional electron gas. An important part of this project is the study of those connections, their reliability, and their failure mechanisms.

DELIVERABLES: By 2002, provide a fully-characterized, standards quality QHR device that is suitable for use in both dc and ac QHR measurements.

Because of the difficulty in establishing a calculable capacitor measurement system, many national laboratories are developing the capability to do ac quantum Hall resistance (QHR) measurements as a means to obtain a capacitance unit. From NIST's position of world leadership with the calculable capacitor, we have an opportunity and an obligation to ensure the soundest possible metrological foundation for any eventual change in the realization of capacitance. In the same way that the value of the dc quantum Hall resistance was obtained through a series of precision measurements beginning with the calculable capacitor, a similar set of measurements will be needed as a check on the value of the ac quantum Hall resistance. These measurements, in collaboration with the project for the Realization of the SI Farad and Ohm will link the ac quantum Hall resistance to NIST's present unit of capacitance.

DELIVERABLES: By 2004, make an SI measurement of the ac quantum Hall resistance traceable to the calculable capacitor.

The development of ac QHR probes will also allow direct comparisons between QHR samples, mounted on shielded sample headers, and ac resistance standards at frequencies between 1000 Hz and 10 kHz.

DELIVERABLES: By 2002, complete construction and characterization of a calculable coaxial resistor with a resistance of 1290.6 Ω.

DELIVERABLES: BY 2002, complete characterization of the ac/dc QHR probe and measurement systems for use over extended frequency ranges.

The combination of quantum-based voltage, resistance and current standards in a single measurement has been referred to as the quantum metrology triangle, since these three units are often defined from one another by Ohm's law. One technique under development at NIST is to measure the small current of a single-electron pump using a 100 MΩ film resistor. Low- and medium-resistance samples of CuSi alloys and other likely materials are being produced in Gaithersburg and Boulder with lithographic techniques. Development of the cryogenic resistor material and characterization of high-valued cryogenic resistors provides an area of new research that makes use of the CCC technology developed for high-resistance scaling.

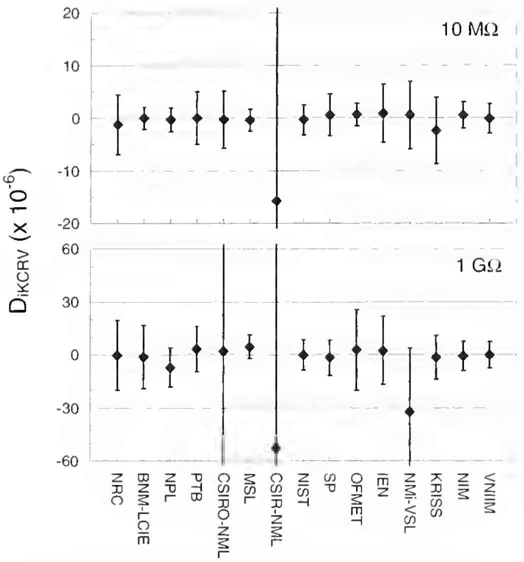
DELIVERABLES: By 2002, fabricate a cryogenic thin film resistor with a nominal value of 1 MΩ and evaluate its performance for use as high precision resistance standard.

DELIVERABLES: By 2003, fabricate and characterize 100 MΩ cryogenic resistance standard suitable for use in the metrology triangle measurements.

Accomplishments

- NIST provided special calibrations of 1 Ω and 100 Ω resistors for Sandia National Laboratory (SNL) in late March. The measurements were made using cryogenic current comparator (CCC) bridges and were based on QHR scaling. This is the first time 100 Ω resistors have been compared directly to the QHR representation of the ohm for an external NIST customer, with resulting total uncertainties below 0.01 parts-per-million. The special tests also determined the resistance values of three 1 Ω Thomas-type standard resistors with improved uncertainty of 0.024 parts-per-million. SNL also requested that load coefficients of resistance (LCR) be determined to help them improve the uncertainty of their in-house resistance scaling. Typically, internal power dissipation causes a significant change in the value when a resistor is used in scaling at two widely different current levels. NIST staff designed special tests to measure LCR for 1 Ω and 100 Ω resistors, and now can offer this special service as well as measurements of a resistor's temperature coefficient (TCR) and pressure coefficient (PCR).

- The successful CCEM intercomparison using NIST-built 10 MΩ and 1 GΩ transportable standards showed that the heat-treatment and hermetic packaging process can improve the reliability of high-value resistance standards. NIST has completed construction of more than 24 additional transport standards, and sets of these will be supplied to the U.S. Navy and Air Force primary standards laboratories. The new standards will be capable of supporting an order-of-magnitude reduction in calibration uncertainties between 10 MΩ and 10 GΩ.



Results of CCEM-K2 intercomparison of high resistance standards, demonstrating the high level of agreement among national metrology laboratories.

- A potentiometric measurement system was used to make high-resolution measurements of plateau voltages on a QHR heterostructure between 1.4 K and 4.2 K for the $i = 4$ plateau, and between 1.4 K and 7 K for the $i = 2$ plateau. One NIST sample, GaAs (7), is probably still the best resistance standard in the world. In most heterostructure devices the values of the quantum Hall voltages and longitudinal voltages are extremely temperature-dependent, but for this device the quantized Hall resistance was constant to within 0.01 ppm for all three sets of sample contacts between 1.4 K and 4 K.

- Two new probes have been built for the two high-field QHR cryostats. Both have coaxial leads and could be used for ac and dc measurements. Measurements to determine the effect of lead and contact admittance are underway and may help to explain observations of frequency dependence in the QHR.

FY Outputs

Calibrations

262 calibrations were performed with approximately $254,000 income received (October 1, 2000 to September 30, 2001).

Publications

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Realization of the SI Farad and Ohm

Project Goals

To maintain the farad and tie the U.S. legal farad and ohm to the international system of units, to support NIST's impedance measurement services, and to ensure the critically needed access of the U.S. industrial base to internationally consistent, reliable, reproducible, and traceable electrical measurements.

Scott Shields assembles the probe to be used for measurements of the ac quantum Hall effect.

Customer Needs

This project ties the U.S. legal system of electrical units to the International System of units (SI) through the realization of the SI unit of capacitance. Because of the central role played by this experimental effort in maintaining both the consistency of the electrical units and the equivalence of electrical measurements within the U.S. to those of other nations, it is essential that this unit be determined with the highest possible accuracy and precision. This work also forms the foundation of NIST's measurement services for electrical impedance, ensuring the sound metrological basis for all impedance measurements, both nationally and internationally, and ensuring that the claims of measurement accuracy by U.S. industries are recognized and accepted worldwide. Additionally, this project provides critical measurements for determining the value of essential fundamental physical constants.

Technical Strategy

This project ties the U.S. legal system of electrical units to the international system of units with smaller uncertainties than those of any other nation and provides the U.S. with a very solid basis for the measurement of electrical quantities. The central facility is the NIST calculable capacitor, with which the measurement of capacitance is effectively achieved through a measurement of length. Both the calculable capacitor and the chain of high precision measurements that transfers the SI unit to the calibration laboratories must be maintained and improved. NIST also conducts international comparisons with other national metrology laboratories to ensure measurement consistency on an international level.

Until very recently, ac measurements linking the calculable capacitor to the farad and the ohm were performed only at 1592 Hz. The capacitance unit that was transferred from the calculable capacitor to the calibration laboratory was only provided at that frequency. However, customer standards are calibrated at other frequencies; as a result, the uncertainty provided for customer calibrations was significantly increased to account for differences in the capacitance unit due to frequency dependence. We have recently successfully completed a transfer from the calculable capacitor to the calibration laboratory at 1000 Hz, resulting in a significant decrease in calibration uncertainties at that frequency. However, to better support customers' needs in the broader frequency range from 100 Hz to 10 000 Hz, measurement capabilities for the calculable capacitor need to be extended over a broader range of frequencies. A new impedance bridge has been built for this purpose, but a complete assessment of the systematic uncertainties of this bridge must be completed.

DELIVERABLES: By 2004, provide the capacitance unit to the calibration laboratory at frequencies of 100 Hz and 400 Hz.

Many national laboratories are developing the capability to do ac quantum Hall resistance (QHR) measurements as a means to obtain a capacitance unit because of the difficulty in establishing a calculable capacitor measurement

Technical Contact:
Anne-Marie Jeffery

Staff-Years:
1.8 professionals
0.7 technician

Funding Sources:
NIST (95 %)
Other Government Agencies (5 %)

Parent Program:
National Electrical Standards

system. They hope to eventually use it as the definition of the capacitance unit in a similar way to how the resistance unit is defined in terms of the dc quantum Hall resistance. At present, however, measurements of the ac quantum Hall resistance show a linear frequency dependence that is not understood. NIST has developed a model that may explain some of the problems encountered in these measurements. This model must be verified through a series of high precision measurements of the ac quantum Hall resistance. Because of the availability at NIST of the calculable capacitor, NIST is ideally situated to perform measurements to link the capacitance as determined with the ac quantum Hall resistance to that determined from NIST's present unit of capacitance. This determination will be done in collaboration with the project for Metrology of the Ohm.

DELIVERABLES: By 2002, verify the equivalent circuit model for the ac QHR system.

DELIVERABLES: By 2004, perform SI measurements of the ac QHR via the calculable capacitor.

Accomplishments

- Recent work in the Electricity Division has resulted in a factor of 3 decrease in the uncertainty for certain of the highest-level calibrations of fused-silica capacitance standards. Electricity Division staff have recently completed a detailed characterization of the transfer of the farad unit from the calculable capacitor to calibration laboratory reference standards at a frequency of 1 kHz (previously only done at 1592 Hz). As a result, the total uncertainty (95 % confidence) for the calibration of 10 pF and 100 pF fused-silica capacitance standards at 1 kHz has decreased from 1.5 ppm to 0.5 ppm.

- Construction of the probe for ac measurements of the quantum Hall resistance has been completed, along with preliminary testing to verify that sufficiently high leakage resistances between the leads have been maintained. The next major step is to perform all measurements necessary to determine all resistances, capacitances, and inductances that will affect the ac QHR measurements.

- Anne-Marie Jeffery chaired the SIM (Inter-American Metrology System) metrology working group in electricity and magnetism. Significant accomplishments this year include the coordination of the review by SIM of other regions' calibration metrology certificates (CMCs) and receipt of final approval from EUROMET, APMP, and SADCMET for the SIM CMCs. These CMCs, which comprise Appendix C of the Mutual Recognition Arrangement between the National Metrology Institutes of the participating nations, provide a basis for international recognition of measurement capabilities.

> ***"I certainly think [the improvement in 1000 Hz calibrations] is a move in the right direction!"***
>
> *Andeen-Hagerling, Inc.*

FY Outputs

Collaborations

Anne-Marie Jeffery collaborated with the Physical and Chemical Properties Division in a competence project to develop an atomic standard of pressure based on capacitance metrology.

Publications

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M.E. Cage, A. Jeffery, and J. Matthews, "Equivalent Electrical Circuit Representations of AC Quantized Hall Resistance Standards," J. Res. Natl. Inst. Stand. Technol., 104, No. 6, pp. 529-556 (Nov/Dec 1999).

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Single Electron Tunneling

Project Goals

To develop applications of single-electron tunneling (SET) technologies which are relevant to high precision electrical metrology.

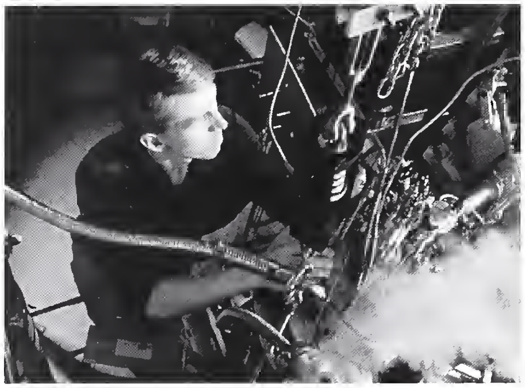


Photo © Robert Rathe

NRC Postdoc Bill Huber preparing for measurements on SET devices at temperatures near 30 mK.

Customer Needs

This project addresses the development of three different needs: a fundamental representation of capacitance, a fundamental representation of electrical current, and general applications of SET devices, with a particular emphasis on quantum computing.

The present representation of the SI farad is through silica-based artifact capacitors. Although these capacitors are of high quality, they are susceptible to drift in time and they may depend on other parameters such as temperature, pressure, and frequency. The metrology community, including both the national standards laboratories and domestic secondary calibration laboratories, needs a capacitance representation that is based on fundamental physical principles and not on properties of individual physical artifacts.

At present, there is no fundamental representation of current; the representation of current is via the representations of voltage and resistance. Though these representations are based on fundamental physical principles and are of high quality, the representation of current is dependent upon them. An independent representation of current could provide significant additional confidence in the coherency of the representations of the SI electrical units through closure of the "metrology triangle" V = IR with all measurements based on fundamental constants.

Integrated circuit (IC) applications of SET effects are becoming more important, either deliberately, e.g., single-electron memory or quantum computing, or accidentally as design rules continue to shrink. One very important practical problem with implementing SET-based device integration is the "charge offset" phenomenon. This phenomenon makes it difficult or impossible to integrate multiple SET-based devices together, thus engendering problems for the IC industry. That industry needs devices that are resistant to the charge offset.

One particular application of SET devices in ICs is for charge based qubits in quantum computing (QC). The charge-offset causes two problems in QC: Firstly, as noted above, it makes it very difficult to integrate devices. Secondly, the associated time-dependent noise is implicated as the major source of decoherence, which presently limits device operation to no longer than a few nanoseconds.

Technical Strategy

This project is addressing these customer needs through the development of single-electron tunneling (SET) technologies. SET devices are being developed that will allow the reliable and reproducible control of individual electrons and hence will provide a standard of charge through control of these fundamental particles.

In collaboration with the Electromagnetic Technology Division of EEEL, SET devices are being used to develop an electron-counting capacitance standard. By depositing a counted number, N, of electrons (of order 10^8) onto the plate of a capacitor (of value approximately 1 pF) and measuring the resulting voltage (approximately 1 V), one can calibrate the capacitance, C, through the definition of capacitance, $C = Q/V$, with the charge determined by the number of electrons, $Q = Ne$.

To be useful as a capacitance standard, the capacitor used in this measurement must have rather special and very well characterized performance properties. A precision cryogenic vacuum-gap capacitor is being developed that is expected to meet the desired specifications of precisely tunable value, stability, frequency independence, etc. In addition, for purposes of calibrating other capacitance meters, we prefer a fairly large value.

Technical Contact:
Neil Zimmerman

Staff-Years:
1.0 professional
0.5 Postdoc
0.5 Graduate Student

Funding Sources:
NIST (60 %)
OA (40 %)

Parent Program:
National Electrical Standards

DELIVERABLES: By 2002, design and evaluate a new version of the cryogenic capacitor, with either or both a larger value (10 pF as compared to 1 pF at present) and the ability to tune to a nominal value.

To be useful as a standard, the performance of the integrated system must be thoroughly tested and characterized, it must be calibrated with respect to the SI farad, and all sources of systematic error evaluated, quantified, and understood.

DELIVERABLES: By 2003, perform detailed performance verification of the SET-based capacitance standard, determine its value relative to the calculable capacitor, and perform detailed uncertainty analysis of the integrated system.

The ability to control electrons one-by-one in SET devices offers promise for several valuable new technologies. Possibilities include a current standard based on controlled pumping of single electron charges and the use of SET-based charge qubits as the building block to achieve quantum computing. At present, a primary difficulty with all applications of SET devices is that, because these devices are designed to control single-electron charges, they are extraordinarily sensitive to perturbations from tiny and uncontrolled sources of charge within a device; this charge offset is the biggest problem to be overcome and at present precludes convenient integration of multiple SET devices.

DELIVERABLES: By 2002, evaluate various methods to eliminate/ameliorate charge offset noise.

We have recently demonstrated that some Si-based SET transistors have a long-term charge offset drift that is about one thousand times smaller (better) than in metal-based devices. Unfortunately, the basic techniques used for the fabrication of these devices cannot readily be generalized to allow the fabrication of multi-junction devices suitable for use in more general devices such as the electron pump. We are investigating other fabrication techniques that offer potential solutions to our fabrication needs.

DELIVERABLES: By 2003, design, fabricate, and evaluate a simple, easy-to-fabricate, and more reliable Si-based SET transistor.

DELIVERABLES: By 2003, quantify and evaluate the differences in charge offset between metal-based and Si-based SET devices; suggest ways of improving the performance of the metal-based ones.

At present, a primary difficulty with the application of SET devices to fundamental electrical metrology is that a single device can supply a current of only 1 pA. This is too small by at least a factor of 100 for application in precision metrology. This project is pursuing approaches to integrate a large number of SET devices, so as to increase substantially the delivered current. However, this requires (in part) solving the charge offset, either intrinsically by virtue of device geometry or material, or by designing a charge offset-insensitive architecture.

DELIVERABLES: By 2003, produce a prototype device with parallel SET electron pumps.

DELIVERABLES: By 2006, produce a reliable SET current source with at least 100 pA of current.

One of the primary motivations for developing larger currents is our work to close the metrology triangle.

DELIVERABLES: By 2002, evaluate possible experimental approaches for closing the metrology triangle.

DELIVERABLES: By 2005, pursue individual elements, including larger-current SET-based current source, resistor, null detector, and control/monitoring electronics.

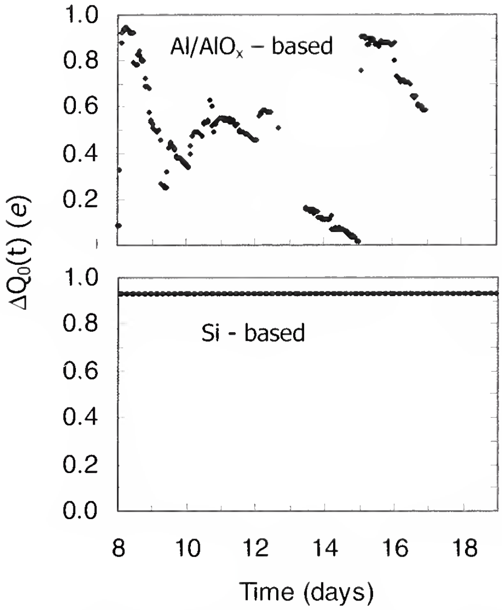
DELIVERABLES: By 2007, close metrology triangle to within 0.02 ppm.

Accomplishments

- We have designed, fabricated, and are testing several new cryogenic capacitors; the new design is now of a cylindrical geometry, which should be less sensitive to mechanical and thermal shocks. In addition, we have succeeded in making capacitors with a value ten times larger than previous (now 10 pF), without an increase in total size. The new capacitors appear to be stable enough in time (drift less than 10^{-8}/day) to be directly compared to the calculable capacitor (and thus, don't need to be tuned); also, initial indications are that their hysteresis on thermal cycling is small enough (about 10^{-4}) that we will try to make a tunable version, thus allowing comparisons to transfer standards calibrated by the calculable capacitor.

- Our most important accomplishment is the demonstration of a major improvement in the long-term drift in the charge offset: in Si-based devices, made by collaborators at NTT in Japan, the drift is about one thousand times smaller than we have observed in any metal based device.

This improvement gives us great hope that we can integrate a large number of SET devices; in particular, we are planning to parallelize a large number of Si-based SET pumps to make a large-value current standard.



Top: long-term drift of charge offset in a metal-based SET transistor; Bottom: drift in a Si-based transistor.

- We have designed and are in the process of developing the fabrication processes necessary to make simple, easy-to-fabricate SET transistors. One of the new technologies is the use of anisotropic chemical etching to make well-formed, regular Si wires (see micrograph below):

Micrograph of triangle etched in Si: this picture was taken at a tilt of 80°; the black area to the left is the cleaved edge of the Si wafer. Note that, over tens of microns, the triangle has basically no deviations in shape or size.

FY Outputs

Collaborations

Neil Zimmerman collaborates with Bruce Kane of the University of Maryland, and Marc Manheimer and Keith Schwab of the Laboratory for Physical Sciences (jointly operated by the University of Maryland and the National Security Agency), on SET fabrication, and on issues related to measurements and the charge offset problem in the context of quantum computing.

The Electron Counting Capacitance Standard is being developed in collaboration with Mark Keller and John Martinis of the EEEL Electromagnetic Technology Division.

Neil Zimmerman collaborates with researchers from the NTT Basic Research Laboratories in Japan for the fabrication and characterization of Si-based SETTs.

Publications

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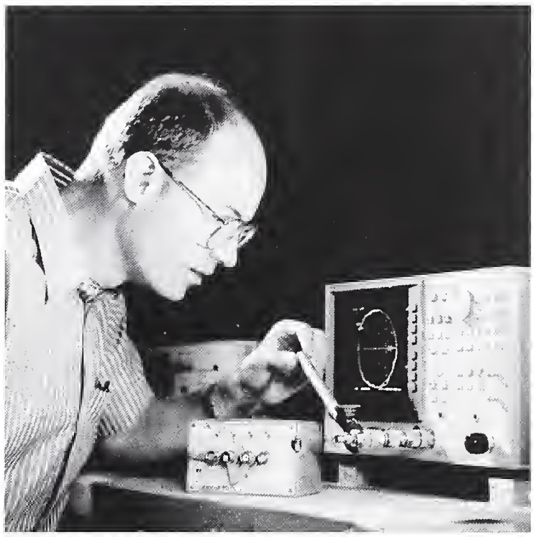
Waveform Synthesis and Impedance Metrology

Project Goals

To develop new waveform generation and measurement capability at NIST to support the maintenance and dissemination of ac voltage, current, phase angle, power/energy, ratios, and impedance over the frequency range from dc to 100 MHz.



Andrew Koffman performing single-port, high frequency (100 to 200 MHz) measurements with a network analyzer for determining the capacitance of four-terminal-pair capacitor standards, up to 10 MHz.

Customer Needs

U.S. manufacturers in the electronic instrumentation and test equipment industry are continuing to market new digital multimeters (DMMs), multifunction calibrators, phasemeters, wattmeters/watthour meters, inductive voltage dividers (IVDs), capacitance and inductance standards, and impedance (LCR) meters having better performance specifications. The accuracy claims of these products are supported through calibration and standards laboratories traceable to the basic electrical units maintained and disseminated by NIST. Thus, the need continues for better test and calibration tools at NIST with which to verify these claims objectively, achieve consistency, and help avoid technical trade barriers. A new generation of automated laboratory test systems is particularly needed at NIST for supporting improved impedance and power calibrations. Another need is to provide the verification of electrical quantities, remote from the NIST laboratories, in order to expedite the dissemination of the units.

Technical Strategy

Development of general wideband impedance measurement services requires reference impedance standards that can be characterized over the impedance and frequency ranges of interest. NIST has recently completed development of a system to characterize commercial four-terminal-pair (4TP) capacitance standards from 1 pF to 1 nF over the frequency range from 1 kHz to 10 MHz. This system is being used to offer special tests for 4TP capacitors as well as provide reference standards for general impedance measurements using the NIST Digital Impedance Bridge and commercial LCR meters. A bootstrapping technique using a commercial LCR meter and an inductive voltage divider (IVD) can be used to extend the characterization from the 1 nF standard to higher-valued capacitance standards up to 1 μF. A major source of error associated with the bootstrapping technique is due to the in-phase and quadrature errors of the IVD. Consequently, a bridge based on the 'straddling' method is currently under development that will allow for the accurate self-calibration of single-decade, two-stage reference IVDs over the 20 Hz to 100 kHz frequency range.

DELIVERABLES: By 2003, develop and implement a system to bootstrap characterize four-terminal-pair capacitance standards of values from 1 pF to 1 μF for use as primary reference standards for measuring general impedances (inductors, capacitors, and resistors) at frequencies from 20 Hz to 100 kHz.

DELIVERABLES: By 2004, develop and implement an IVD self-calibration bridge to characterize single-decade, two-stage IVDs at frequencies from 20 Hz to 100 kHz.

To address the need for improved power/energy calibrations, a promising technique has been demonstrated recently that utilizes the development at NIST of a wideband (10 Hz to 200 MHz), multi-channel, sampling voltmeter (WSV) that has excellent linearity, frequency flatness, and stability. Power and energy measurements can be made conveniently and accurately, thus improving the efficiency of making these measurements and extending the frequency range. An advantage of this technique over traditional bridge techniques is that it is suitable for making accurate measurements of sinusoidal as well as distorted power signals.

Technical Contacts:
Bryan C. Waltrip and
Andrew D. Koffman

Staff-Years:
2.5 professionals
2.0 technicians
0.75 contractor

Funding Sources:
NIST (70 %)
Calibration Services (18 %)
Other Government Agencies (12 %)

Parent Program:
Low Frequency

DELIVERABLES: By 2003, develop a limited range sampling wattmeter capable of measuring sinusoidal and distorted power with frequency components from 50 Hz to 3 kHz.

The present multi-channel sources of reference waveforms for use in NIST calibration test sets were developed in the 1980s. These sources are beginning to show signs of performance and reliability problems, which make the need for new ones imperative. Although there are commercially available sources that provide some of the capabilities needed, they usually lack adequate amplitude and phase resolution and linearity. The strategy chosen to overcome these limitations is to develop new scaling and signal combining circuitry with parts-per-million precision to enhance the performance of commercially available arbitrary waveform generators. With the new circuitry, the in-phase and quadrature output signals of dual-channel, commercially available arbitrary waveform generators can be scaled and combined to produce an arbitrary number of signal channels, each with independently adjustable amplitudes and phases. One of the major advantages of this strategy is that the accuracy, stability, and resulting complexity and cost of the new circuitry can be tailored to suit the measurement requirements.

DELIVERABLES: By 2003, develop new scaling and signal combining circuitry to enhance the resolution and linearity of commercially available arbitrary waveform generators that, together with the NIST WSV can provide the performance needed to support the NIST calibration and Special Test services for state-of-the-art waveform analyzers, wattmeters, watthourmeters, power analyzers, and impedance standards.

The precise measurement of steady-state electrical quantities, such as ac phase, power/energy, and impedance, typically relies on bridge techniques that employ a phase-sensitive null detector and/or very linear and stable ac voltmeter. However, these measurements can be improved by using wideband sampling waveform analyzers. Hence, the general strategy for achieving a new generation of automated laboratory test systems will be to utilize the aforementioned NIST WSV. Using the voltmeter effectively in precision bridge applications will require the miniaturization and integration of the present benchtop instrument.

DELIVERABLES: By 2004, develop a wideband sampling voltmeter implemented with field programmable gate array (FPGA) logic and a high-speed, low-noise, optically isolated serial interface, with performance comparable to the present benchtop instrument.

Accomplishments

- A preliminary capacitance scaling bridge has been developed to support the characterization of high-accuracy, multi-frequency capacitance meters over the 1 pF to 10 nF capacitance range and 20 Hz to 20 kHz frequency range. The bridge uses previously developed binary inductive voltage dividers (BIVDs), new injection and detection circuitry, and sampling phase techniques to compare a known capacitance standard to an unknown one over a ratio of up to 10:1. The bridge performance was verified by comparing its results to those obtained using an Andeen Hagerling 2700A multi-frequency capacitance meter. For 1:1 capacitance ratios, agreement is within 1 ppm at 1 kHz, and within 3 ppm at 10 kHz. For 10:1 capacitance ratios, agreement is within 1 ppm at 1 kHz, and within 6 ppm at 10 kHz. The IVDs used in the bridge are presently being redesigned to improve measurement accuracy. An IVD self-calibration bridge based on the ‘straddling’ method is also under construction to characterize the new IVDs.

- Recent work in the Electricity Division has resulted in a factor of 3 decrease in the uncertainty for certain of the highest-level calibrations of fused-silica capacitance standards. Electricity Division staff have recently completed a detailed characterization of the transfer of the farad unit from the calculable capacitor to calibration laboratory reference standards at a frequency of 1 kHz (previously only done at 1592 Hz). As a result, the total uncertainty (95 % confidence) for the calibration of 10 pF and 100 pF fused-silica capacitance standards at 1 kHz has decreased from 1.5 ppm to 0.5 ppm.

Guest Researcher Svetlana Avramov-Zamurovic adjusting the new wideband capacitance scaling bridge.

- The Electricity Division conducted its first official Internet-Assisted, On-site Special Test in July 2001. Multifunction calibrators at the Sandia National Laboratories (SNL) were tested using an SNL-owned digital multimeter (DMM) as a traveling standard. Before the test, NIST control software was sent electronically to SNL during a web conference. This software and the SNL software were used to test the traveling DMM using three different SNL calibrators. Differences between the NIST and SNL software were resolved, the DMM was sent to NIST for testing, and it was then returned to SNL for final tests - to compensate for drifts in the traveling DMM during the test. Data were transferred via the Internet and differences between the NIST and SNL values were used to assign corrections to the three calibrators, which never left their test racks at SNL. In the spirit of Internet-based tests, password-accessible test reports were posted on an Electricity Division web site. A paper describing the process was presented at the NCSL2001 Workshop and Symposium in Washington DC, with half of the presentation made from the NIST DMM lab via an Internet connection to a notebook computer at the speaker's podium. SNL is considering providing comparable on-site calibrations for the other laboratories within the Department of Energy.

- A similar project is underway with the Navy Primary Standards Laboratory (NPSL) to support on-site test of calibrators and network analyzers. The task is complicated by the fact that, unlike NIST and SNL, NPSL does not have an available Internet server outside its firewall, which is configured to block web conferencing. A scheme to use data encryption to allow certain features of web conferencing through the firewall is being investigated.

- A paper describing the SIM International Comparison was presented at Metrologia-2000 in Sao Paulo, Brazil. An extended version of this paper with detailed results for five electrical units from 20 countries is being prepared for submission to SIM and the BIPM comparison database.

FY Outputs

Calibrations

190 tests were performed on 142 artifacts for 66 customers for impedance standards and inductive voltage dividers providing income of approximately $153,000 (October 1, 2000 to September 30, 2001).

16 phase meters, bridges, generators, VOR meters, and quadrature detectors; 19 DMMs, ac-dc transfer standards, current sources, and shunts were tested for 28 customers providing income of approximately $45,000 (October 1, 2000 to September 30, 2001).

Collaborations

The SIMnet effort has been a collaboration between staff in the NIST Manufacturing Engineering Laboratory and N. Oldham and M. Parker, with the help of other National Metrology Institutes (NMI) such as P. Filipski of NRC, Canada, and O. Gutierrez of CENAM, Mexico.

Nile Oldham and Mark Parker collaborated with members of the Sandia National Laboratory in performing Internet-based DMM calibrations.

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Measurements for Complex Electronic Systems

Project Goals

To develop and disseminate methods and techniques for optimum testing scenarios by using new or improved modeling and test procedures, and estimating confidence levels and test coverage.

Guest Researcher Hans Engler (Georgetown University) examines new methods for predicting device failure rates from I_{DDQ} data.

Customer Needs

The U.S. test equipment industry is maintaining its world position through the development and deployment of increasingly accurate, easier-to-use automatic test systems that can also achieve high throughput rates. Both the manufacturers and users of such systems often need to improve their productivity in a highly competitive environment. Optimizing the testing procedures and reducing the test time required are goals beneficial to realizing the return on investment for expensive automatic test systems. Hence, there is an urgent need for better modeling methods and testing algorithms that can reduce the number of test points while maintaining a comprehensive test coverage.

One industry need for testing strategies capabilites is the need to analyze I_{DDQ} data to determine defective devices. I_{DDQ} is the quiescent supply current for a CMOS digital device measured as a function of the digital state. For modern devices the faulty signature is buried in noisy data. Although these are digital devices, this is an application where analog testing strategies may be able to significantly extend the usefulness of this screening technique.

Technical Strategy

The High-dimensional Empirical Linear Prediction (HELP) testing approach developed at NIST has generated considerable industry interest since it provides fewer test points needed to predict global behavior. This approach has been combined into an easy to use software package that allows convenient exploration of the empirical error modeling problems. The package will assist in determining the model size needed, allow for the exploring the tradeoff of model size versus number of test points versus the uncertainty in the predictions. Quality control features are included to warn for the effects of non-model errors.

DELIVERABLES: By 2002, implement online dissemination of the HELP Toolbox and documentation via the Internet.

Incomplete data sets cannot be used in conventional empirical model building. For example, when new test points are added to the requirements for test coverage, this means that the older data sets cannot be used to build new models that predict these new test points. But with the use of a statistical prediction method, expectation maximization, this old data can be used along with new data sets. The incorporation of both old and new data sets using expectation maximization provides data points with more accurate predictions.

DELIVERABLES: By 2002, add the capability to include incomplete data sets in the HELP Toolbox.

Methods for increasing the effectiveness of the I_{DDQ} data analysis for faulty CMOS device predictions include the use of HELP modeling techniques and other statistical modeling techniques such as cluster analysis. An industry-sponsored data set is available that has been used to evaluate various I_{DDQ} methods. Data sets representing newer devices are being sought and a cooperative evaluation of the data with industry is underway.

DELIVERABLES: By 2003, develop methods for using empirical testing strategies and clustering analyses to provide improved resolution to I_{DDQ} data analysis.

Accomplishments

Multiple methods for building models with partial data sets have been developed. Preliminary analyses indicate that two have significantly better performance than the others.

Technical Contact:
Gerard N. Stenbakken

Staff-Years:
1.0 professionals
0.25 contractor

Funding Sources:
NIST (100 %)

Parent Program:
Low Frequency

These results are being presented in a paper submitted for publication.

An analysis of the International SEMATECH I_{DDQ} data set shows that HELP testing strategies approaches offer a significant improvement over current industry methods to predict devices that will fail burn-in.

FY Outputs

Collaborations

Collaborative work with Prof. Gene Hwang of Cornell University continues, with a grant from the Information Technology Laboratory (ITL) at NIST, on missing data analysis using methods for building models from partial data sets. This work also involves predicting the uncertainty of models built with varying amounts of data at each test point. Hung-kung Liu of ITL is providing valuable support for this project.

Collaborative work with Prof. Hans Engler of Georgetown University continues in the testing strategies in general and I_{DDQ} analysis methods.

Standards Committee Participation

IEEE Computer Society standards committees on P1149 Standard Testability Bus, WG.04 Mixed Signal Test Bus, and P1500 Standard Testability Method for Embedded Core-Based ICs: G. N. Stenbakken is a member of these various standards committees.

Publications

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Waveform Acquisition Devices and Standards

Project Goals

To expand and improve present NIST time domain waveform measurement services to support high performance samplers and digitizers, as well as fast pulse and impulse sources, operating at frequencies from dc to 50 GHz.

Don Larson measuring the step response on a fast pulse generator under the NIST Special Test service for fast repetitive pulse transition parameters.

Customer Needs

The U.S. electronic instrumentation and test equipment industry is maintaining its world position through the development and deployment of increasingly accurate, easier-to-use arbitrary waveform generators, fast electrical pulse/impulse sources, waveform samplers, and high-speed digitizers. To prove their accuracy in a highly competitive environment, manufacturers and users need objective calibration methods and standards that are traceable back to the derived electrical units maintained and disseminated by NIST. There is a need for better means of characterizing the parameters of pulse and arbitrary waveform generators, the power spectrum of impulse generators, the step response of fast digitizers, and the delay in coaxial delay lines. Manufacturers and users of high-performance data converters have developed a performance standard (IEEE Std. 1241) with which to objectively compare such devices and have expressed the need for calibration support at NIST.

Technical Strategy

Accurate measurements of arbitrary waveform parameters, from basic root-mean-square (rms) values to crest factor, signal-to-noise ratio (SNR), harmonic distortion, etc. have been realized at NIST using a specially designed strobed analog comparator device. However, the signal bandwidth and settling performance of this comparator have been limited by the gain-bandwidth product of the high frequency transistors used in its design. New high-frequency transistors are now available that can effectively double the bandwidth of the comparator that, together with an improved design architecture of the supporting electronics, will improve the performance of the comparator.

DELIVERABLES: By 2002, develop a custom integrated wideband sampling comparator (and associated probe electronics) that has > 5 GHz 3 dB bandwidth and settling to within 0.1 % in < 1 ns, and is compatible with the present NIST wideband sampling voltmeter.

Various pulse measurement systems have been developed at NIST for purposes of providing Special Test services for impulse generators. The system presently used for these purposes is beginning to show signs of performance, reliability, and software obsolescence, which makes the need for an improved version imperative to keep the costs of providing these NIST services reasonable.

DELIVERABLES: By 2003, develop a measurement system that can provide a more flexible, self-documenting, and automated system for performing the SP 250 65100 series tests.

To estimate the impulse response of high-speed samplers requires very short duration electrical pulses. Until recently, a laser-generated source of optical pulses having the requisite small (<1 ps) pulse duration needed for activating a fast photoconductive switch (to produce a corresponding fast electrical pulse) has not been available, except for bulky and expensive Ti: Sapphire lasers. New fiber laser-based systems are now on the market that can generate approximately 200 fs wide optical pulses, are compact, and are relatively low cost. Such a laser source could be the basis for generating a relatively Gaussian-shaped reference electrical impulse.

Technical Contact:
Nicholas G. Paulter, Jr.

Staff-Years:
3.0 professionals
1.0 technician
0.75 contractor

Funding Sources:
NIST (35 %)
Other Government Agencies (62 %)
Calibration Services (3 %)

Parent Program:
Low Frequency

DELIVERABLES: By 2003, develop a fiber laser-photoconductor-based electrical impulse source and sampling system that can be used to estimate the impulse response of 50 GHz bandwidth equivalent-time samplers.

A precision time delay system is being developed. Using an input strobe, the system will provide three electrical output pulses where one of the output pulses can be delayed relative to the others from tens of femtoseconds to tens of milliseconds. The uncertainty in the delay will be on the order of femtoseconds for delays less than 1 ns and a few picoseconds for longer delays. The delay system will expand the measurement range of and reduce the uncertainties in the SP250 65400S series tests, reduce the uncertainties in the 65100S series tests, and will be used to develop cycle-to-nth-cycle jitter measurement capability, which is an important performance parameter in digital telecommunications and computing systems.

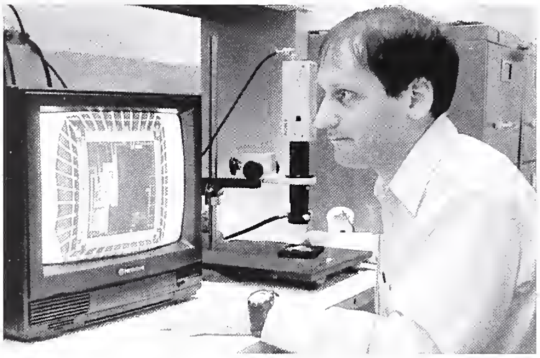
DELIVERABLES: By 2003, develop programmable time delay system with tens of femtoseconds to tens of millisecond delay capability.

Accomplishments

- Improvements were made to the Fast Repetitive Pulse Transition Parameters Special Test service, SP250 65200S, which is for measurements of the step response of high-speed (transition duration $\leq$ 350 ps) samplers and output characteristics of high-speed pulse generators. This service has been improved by using new measurement instruments and procedures, more accurate estimates of the test instrument characteristic response, and a better uncertainty analysis. The improvements include reduced uncertainties for transition duration (best case reduced from ±3 ps to ±1.5 ps), introduction of the parameters of overshoot and undershoot (not previously measured) and reduction in the pulse amplitude uncertainty (best case reduced from ±2 mV to ±1 mV).

- NIST and the National Physical Laboratory (NPL), United Kingdom, completed an interlaboratory comparison of their pulse measurement services. This comparison verified that the two services provide similar results. The differences between the laboratories are within the published uncertainties for transition duration and pulse amplitude. The differences are dominated by the different impulse responses and impulse response estimates of the samplers used and the waveform reconstruction process used.

- The effects of the nose-to-nose (ntn) sampler calibration method on the reported pulse parameters were analyzed. To minimize the contribution of the ntn related uncertainty on the pulse uncertainty the magnitude of the offset voltage (a critical ntn measurement setting) $|V_{off}|$, should be in the range 50 mV to 500 mV. The slight failure of the assertion that the kick-out pulse and the sampler impulse response are identical leads to errors in the reported transition duration parameter. This analysis estimated that this assertion introduces less than ±600 fs uncertainty into the transition duration parameter uncertainty.



David Bergman examining the new low-thermal-error ASIC sampling comparator.

- Follow-up versions of a low-frequency sampling comparator probe were designed, constructed, and tested. Compared to the existing wideband sampling comparator probe, the new low frequency probe design provides higher input impedance (1 MΩ), lower noise (< 70 μV rms), a wider input voltage range (±10 V), better linearity (< 20 ppm), and comparable gain flatness over the 10 Hz to 100 kHz frequency range (20 ppm). These electrical characteristics are needed to support NIST Special Test and Calibration services for pulse settling, distorted power, impedance, and amplitude flatness. An effort is underway to package the probe in a compact enclosure suitable for delivery to NIST customers engaged in applications including calibration of a commercial automated ac measurement standard and accurate measurement of 100 V pulses. As a complement to the accurate probe development work, an application specific integrated circuit (ASIC) sampling comparator device was designed, laid out, fabricated, packaged, and designed into a test probe circuit board. The effort was undertaken to test a novel method for minimizing signal induced thermal errors in accurate sampling comparators. Test results show improved step settling and gain flatness as a function of frequency when the thermal control mechanism is enabled. Further testing is underway to assess the usefulness of the fabrication process to other ongoing waveform metrology activities.

FY Outputs

Calibrations

20 tests performed on 20 items for eleven companies and government agencies with approximately $33,031 income received. (October 1, 2000 to September 30, 2001)

Collaborations

An on-going intercomparison with the National Physical Laboratory (NPL) was continued regarding high-speed electrical pulse parameters.

Standards Committee Participation

IEEE I&M Society TC-10 - N. Paulter, D. Larson, B. Waltrip, and D. Bergman participate as members of the TC-10 on Waveform Measurement and Analysis and the subcommittees on Waveform Recorder, A/D Converters, and Pulse Techniques.

N. Paulter participates as chair of the D-21b (High-Frequency Board Design) and D-21c (High-Frequency /High-Speed Controlled Impedance) IPC task groups and as chair of the IEEE Subcommittee on Pulse Techniques (SCOPT).

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AC-DC Difference Standards and Measurement Techniques

Project Goals

To provide U.S. industry with the link between the dc and corresponding ac electrical standards, by maintaining and improving the U.S. national standards of ac-dc difference, that are used to provide calibrations and measurement services for thermal converters and shunts.

Tom Lipe installing new transition edge sensor (TES) chip in cryogenic-based thermal transfer standard system.

Customer Needs

Increasingly accurate, easier-to-use instruments and devices for precision ac voltage and current measurements are being developed by U.S. electronic instrumentation and test equipment manufacturers for use in a wide variety of industrial and scientific applications throughout the world. The need continues for better calibration tools with which to verify accuracy claims, achieve consistency, and to help avoid technical trade barriers. Research and development are needed to maintain and to expand NIST calibration and special test services for thermal converters and shunts, especially for calibrating high current shunts and high voltage converters. More reliable and easily fabricated thermal converter devices are needed. A new national primary standard is needed to support measurement uncertainties at the 0.1 μV/V level to support the electrical measurement industry. Several NIST customers that support the electric power industry require lower uncertainties at power frequencies at 120 V and 240 V.

Technical Strategy

Maintenance and development of primary standards and associated measurement systems used for NIST's world-class ac-dc difference capability requires the investigation and development of new or improved methods in thermal transfer technology. This capability is also needed for participation in international comparisons with other national metrology institutes to ensure international consistency.

AC current shunts are used in a variety of applications for current monitoring and limiting in transformers, motors and generators, bus bar switching, amplifiers, fusing, etc. In more exacting applications the value of such shunts must be accurately determined. Customer requests for an expanded parameter space (up to 100 kHz at 100 A) will be addressed by validation of the performance of the comparator systems and NIST ac-dc transfer shunts.

DELIVERABLES: By 2002, improve the NIST current shunt comparator system to provide calibrations up to 100 A and at frequencies above 10 kHz.

Vacuum wire-type thermal converters have been established as the preferred thermal converter technology for several decades. In recent years, however, thin-film-type devices have been developed using semiconductor fabrication methods, and show promise for realizing lower manufacturing costs and improved performance. In collaboration with Sandia National Laboratories, NIST has designed and developed thin-film multijunction thermal converters that are suitable for low voltages and currents. In response to requirements for measuring currents above 2 A, NIST is designing a module incorporating multiple thermal converters for use up to 20 A.

DELIVERABLES: By 2002, design, fabricate, and test a thin film multi-converter module suitable for currents of 20 A or more.

Technical Contact:
Joseph R. Kinard, Jr.

Staff-Years:
2.0 professionals

Funding Sources:
NIST (64 %)
Other Government Agencies (12 %)
Calibration Services (24 %)

Parent Program:
Low Frequency

"The development of this capability [high current ac shunts] by NIST has presented us with a whole new business opportunity."

Precision Measurements, Inc.

In order to measure higher voltages than are normally accommodated by thermal converters, a range resistor is placed in series with the heater element of the converter. However, the convenient means for bootstrapping the uncertainties achievable at lower voltage levels up to hundreds of volts involves additional measurement uncertainties due to heating in the range resistor and additional current leakage paths, which are also frequency dependent. Several national measurement institutes are developing different means for achieving better high-voltage ac-dc difference measurements. A comparator system using inductive voltage dividers has been constructed and tested at NIST. A simpler design, which promises improved performance is in the planning stage.

DELIVERABLES: By 2002, develop a high voltage test set using binary inductive voltage dividers to achieve an improved means for scaling up to 1000 V.

The electric power industry in the United States depends on NIST to provide the basis for the quantities of ac voltage and current. Recently, NIST customers that support this industry have requested uncertainties at power frequencies and voltages that are significantly smaller than the standard NIST uncertainties. In response to these requirements, NIST will re-evaluate the voltage build-up to 120 V.

DELIVERABLES: By 2003, recharacterize the NIST reference and working standards of ac-dc difference in order to reduce the NIST uncertainty at 120 V and 240 V, 50 Hz and 60 Hz to 5 μV/V or less.

The thermal errors due to Peltier and Thompson effects in the heater structure of a thermal converter are temperature dependent. NIST has proposed to minimize these errors by developing a cryogenic-based thermal transfer standard that can operate at 6 K. A prototype system has been constructed that shows promising results in significantly reducing thermal errors. As the demand for a primary thermal transfer standard that can realize a zero ac-dc difference with an uncertainty (with $k = 2$) of < 0.1 μV/V increases, the need to pursue this cryogenic approach becomes more critical.

DELIVERABLES: By 2003, complete the research, design, and construction of a prototype cryogenic-based thermal transfer standard that has a target ac-dc difference uncertainty of 0.1 μV/V.

Accomplishments

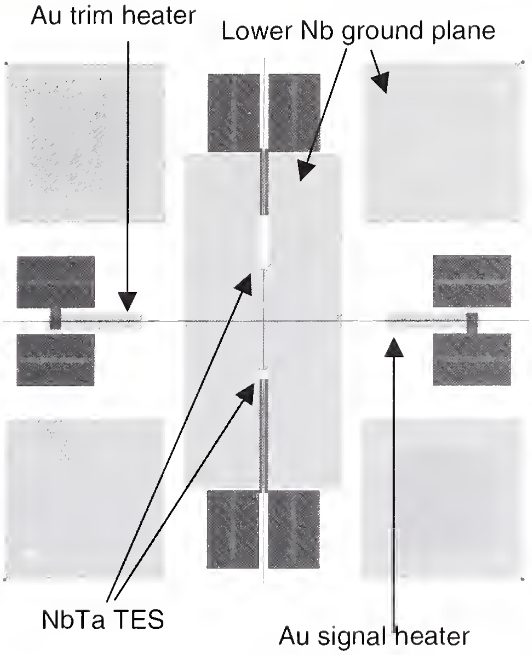
- The ac-dc comparator system for current has been studied at frequencies up to 100 kHz at 100 A by comparing commercially-made ac-dc transfer shunts to each other and to a shunt made by NIST. Results indicate that the probability of offering calibrations at these points is reasonable, and that reducing uncertainties at lower currents and frequencies is possible.

- Vacuum-mounted thin-film multijunction thermal converters have been supplied to NIST by Sandia National Laboratories. These converters have a large obelisk of silicon beneath the heater to increase the time constant of the devices and to improve their low-frequency performance. Tests on the first vacuum-mounted converter indicate that the ac-dc difference of the device is less than 3 μV/V at 10 Hz, and has a frequency flatness of less than 5 μV/V up to 20 kHz. This performance is nearly identical to a similar converter mounted in nitrogen at atmospheric pressure. Vacuum-mounted converters suitable for current measurements are due to be delivered to NIST by Sandia.

- The binary inductive voltage divider (BIVD) comparator system was used to measure the voltage coefficients of resistors up to 600 V and 20 kHz. Measurements indicate that the BIVD comparator system agrees with the traditional build-up method to within 3 μV/V at 600 V and 20 kHz. The improved stability of the new comparator system has resulted in the reduction of the uncertainties for the system from 10 μV/V to 7 μV/V, which compares favorably with the uncertainties resulting from the build-up.

- NIST participated in the CCEM-K9, an international intercomparison of thermal converters at voltages of 250 V, 500 V, and 1000 V, from 1 kHz to 100 kHz. Owing to problems in the stability of the measurements (possibly due to the traveling standards), these measurements will be repeated during November and December of 2001.

- A model of the magnetic fields produced by the signal heater of the Cryogenic Thermal Transfer Standard sensor chip indicates that as much as 0.7 A/m is coupling into the transition-edge sensor. This field suppresses the T_c of the niobium-tantalum sensor and results in a large ac-dc difference at audio frequency. A new chip, incorporating superconducting niobium ground planes, has been designed and fabricated at NIST in Boulder, CO. Models on the new design indicate that the magnetic field coupling will be reduced by a factor of 30 or more.



New cryogenic transfer standard chip.

FY 01 Outputs

Calibrations

516 calibration points for 19 customers at a cost of $108,968 (October 2000 – September 2001).

Collaborations

Active collaborations continue with Carl Reintsema in the Electromagnetic Technology Division, NIST-Boulder on the development of the cryogenic-based thermal transfer standard using resistive temperature edge sensor technology, and with Sam Benz, Charlie Burroughs, and Paul Dresselhaus in the development of an ac-based Josephson voltage standard.

The design, fabrication, and packaging of thin film, multijunction thermal converter chips are being carried out in collaboration with Tom Wunsch at the Sandia National Laboratories.

Extensive collaboration continues with the U. S. Air Force Primary Standards Laboratory in Newark, OH, and with a manufacturer of ac current shunts being bought by the Air Force as high-current standards. The collaboration is working to help the Air Force establish broadband ac current measurement capability at 100 A.

Collaboration continues with Henry O. Wolcott of Metrology Instruments of Simi Valley, CA to develop improved high-voltage range resistors for thermal converters.

Collaboration continues with NRC in Canada and CENAM in Mexico to confirm the consistency of their ac-dc transfer standards with other NMIs.

External Recognition

Joseph Kinard and Thomas Lipe were co-recipients (with Thomas Wunsch of Sandia National Laboratories) of the Algie Lance Best Paper Award, given at the 2001 Measurement Science Conference for the paper "Recent Advances in Ac-dc Transfer Measurements Using Thin-film Thermal Converters".

Joseph Kinard and Thomas Lipe were invited to the 2001 meeting of EUROMET ac-dc technical experts in Prague, Czech Republic, June 17-18, 2001. While at the EUROMET meeting, Kinard presented two papers describing recent developments in ac waveform synthesis using Josephson arrays, and developments in the NIST 100 A ac current shunt calibration service. Lipe presented developments in the NIST high-voltage thermal converter programs and the cryogenic ac-dc thermal transfer standard project.

Joseph Kinard presented an invited paper on the calibration of transfer shunts at NIST to the British Electrical Measurements Conference, Harrogate, Yorkshire, UK, on November 8, 2001.

Publications

T. F. Wunsch, J. R. Kinard, R. P. Manginell, T. E. Lipe, O. P. Solomon, and K. C. Jungling, "Recent Advances in Ac-dc Transfer Measurements Using Thin-Film Thermal Converters," 2001 Measurement Science Conference Digest, Session II-B.

H. O. Wolcott, J. R. Kinard, and T. E. Lipe, "Improved Range Resistors for Ac-dc Transfer Measurements," 2001 Measurement Science Conference Digest, Session II-B.

T. E. Lipe, J. R. Kinard, and C. D. Reintsema, "Improvements in the NIST Cryogenic Thermal Transfer Standard," IEEE Transactions on Instrumentation and Measurement, vol. 50, no. 2, April 2001, pp. 326-329.

T. F. Wunsch, J. R. Kinard, R. P. Manginell, T. E. Lipe, O. P. Solomon, and K. C. Jungling, "A New Fabrication Process for Thin-Film Multijunction Thermal Converters," IEEE Transactions on Instrumentation and Measurement, vol. 50, no. 2, April 2001, pp. 330-332.

T. F. Wunsch, J. R. Kinard, R. P. Manginell, T. E. Lipe, O. P. Solomon, and K. C. Jungling, "Evaluation of Coaxial Single-Range Thermal Converters with Multijunction Thin-Film Thermoelements," Proceedings of the 2001 Instrumentation and Measurement Technology Conference, May 21-23, 2001, Budapest, Hungary, pp. 449-452.

J. R. Kinard, T. E. Lipe, and S. Avramov-Zamurovic, "A New Binary Inductive Divider Comparator System for Measuring High-Voltage Thermal Converters," Proceedings of the 2001 Instrumentation and Measurement Technology Conference, May 21-23, 2001, Budapest, Hungary, pp. 2145-2148.

H. O. Wolcott, J. R. Kinard, and T. E. Lipe, "Novel High-Voltage Range Resistors for Ac-dc Thermal Converters," Proceedings of the 2001 NCSL International Workshop and Symposium, July 29-August 2, 2001, Washington, DC, USA.

T. E. Lipe, "Recent Developments in the NIST Cryogenic Thermal Transfer Standard Project," Proceedings of the 2001 NCSL International Workshop and Symposium, July 29-August 2, 2001, Washington, DC, USA.

T. E. Lipe, "Recent Developments in the NIST Ac-dc Difference Calibration Service for Thermal Transfer Standards," AUTOTESTCON 2001 Proceedings, August 20-22, 2001, Valley Forge, PA, USA, pp. 105-114.

Metrology for Electric Power Systems

Project Goals

To maintain and disseminate precision electrical measurements, high voltage, high current, and power, in support of U.S. industry for such applications as the transmission and distribution of electric power and high current welding.

Ken Stricklett connects a high voltage dc divider to the NIST reference divider and high voltage power supply.

Customer Needs

The fair and reliable transmission and distribution of electric power requires accurate and traceable measurements of electrical quantities. Electrical energy metering throughout the U.S. is traceable to NIST calibrations and results in annual revenues exceeding $215 billion. To ensure the accurate measuring and monitoring of electric power, U.S. industry requires traceable calibration services of ac, dc, and impulse high voltages, power and energy, high current, and electromagnetic fields. To maintain reliable delivery of electric power and to compete in an international market, U.S. utilities and industry require support in developing technically sound international standards governing the use of technologies related to electric power.

Technical Strategy

This project supports the electric power industry by maintaining calibration services in the areas of high voltage, high current, power and energy, and electromagnetic fields. These services are continually improved to meet the changing measurement needs of U.S. industry. The technical expertise utilized in providing these services is applied to the development of key national and international standards.

This project maintains the U.S. standard for power and energy, which is used by utilities and meter manufacturers to ensure the accurate sale of electric power in the U.S. In order to improve NIST's ability to perform measurements for systems containing harmonics, a new automated sampling test system is being constructed to replace the aging manual current comparator system currently in use.

DELIVERABLES: By 2004, complete construction of automated sampling test system and begin use for customer power and energy meter calibrations up to 100 A and 600 V.

International comparisons are essential for the validation of measurement techniques used at National Metrology Institutions. To ensure the accurate measure of power in North and South America, NIST will serve as the pilot lab for an intercomparison between SIM countries.

DELIVERABLES: By 2003, complete SIM power and energy measurement intercomparison.

New power generators that are gaining access to the power grid under deregulation produce high levels of electric power when on line, but are consumers of low levels of power when off line. This new application requires a wider dynamic range of power/energy metering.

DELIVERABLES: By 2004, develop calibration capability for low power metering down to 120 V, 10 mA.

Technical Contact:
Thomas L. Nelson

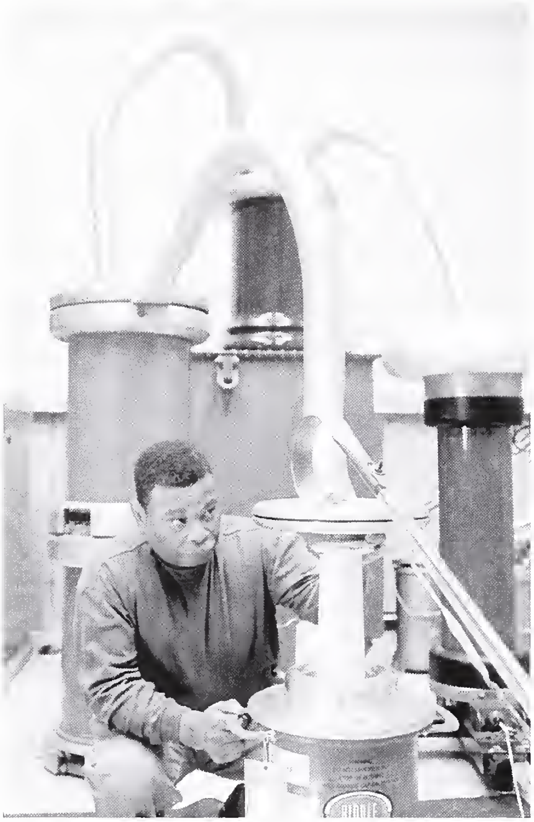
Staff-Years:
2.5 professionals
0.5 guest scientist
0.5 technician

Funding Sources:
NIST (85 %)
Calibrations (15 %)

Parent Program:
Power

"The aggregate annual economic impact [for not having adequate measurements and standards in place for the electric power industry] ranges from $3.1 t $6.5 billion."

"Changing Measurements an Standards Needs in a Deregu- lated Electric Utility Industry," NIST Planning Report 00-



James Pitt connecting a capacitive high voltage divider to the ac high voltage power supply.

Accomplishments

- A prototype measurement system was assembled for evaluation of the sampling technique for characterization of the fundamental and harmonic power, and testing was performed. The tests showed that the sampling technique had uncertainties comparable to the bridge method for power frequency.

- An affordable system to emulate the magnetic fields produced by metal detectors was developed and delivered to the Food and Drug Administration. The system will be used to simulate the magnetic fields of metal detectors to evaluate the susceptibility of personal medical devices (PMDs) such as pacemakers to voltages induced by exposure to metal detectors, and possible PMD malfunction.

- A NIST Technical Note was completed that covers all ac high voltage measurement services offered by NIST. The document includes a description of operating principles for the capacitance ratio bridge used for all the ac high voltage calibrations, step-by-step procedures for performing the tests, uncertainty analyses, and a troubleshooting guide for problems that may be encountered during the tests.

Draft B for the CCEM-sponsored power comparison was completed and posted on the website at:
http://www.velocecorp.net/business/nist/ccem.

FY Outputs

Calibrations

Calibrations were performed for 46 companies and government agencies with approximately $140,000 income received. (October 1, 2000 to September 30, 2001).

Standards Committee Participation

IEEE Instrument Transformer Subcommittee (C57.13): T. L. Nelson is the Working Group Chair in charge of the revision of the IEEE Standard on Requirements for Instrument Transformers.

ANSI/NEMA Electricity Metering Committee (C12): T. L. Nelson served as the chair in FY01.

IEEE Electricity Metering Subcommittee: T. L. Nelson served as secretary in FY01.

Publications

M. Misakian, O. Petersons, J.J. Kasianowicz, and B. Robertson, "Frequency Response of Alternating Currents through the Staphylococcus aureus alpha-hemolysin Ion Channel," Bioelectromagnetics.

N. Oldham, T. Nelson, R.Bergeest, G. Ramm, R.Carranza, A. Corney, M.Gibbes, G.Kyriazis, H.Laiz, L.Liu, Z. Lu, U. Pogliano, K.Rydler, E.Shapiro, E. So, M.Temba, and P.Wright, "An International Comparison of 50/60 Hz Power (1996-1999)," IEEE Trans. Instrum. Meas. vol. 50, no. 2, pp. 356-360 (April, 2001).

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E.D. Simmon, G.J. FitzPatrick, and O. Petersons, "A Users' Guide to the NIST Capacitance Ratio Bridge," NIST Technical Note #1442, 75 pages (April 2001).

R.J. Van Brunt, T.L. Nelson, and K.L. Stricklett, "Early Streamer Emission Lightning Protection Systems: An Overview," IEEE Electrical Insulation Magazine, 16, No. 1, pp. 5-24 (Jan/Feb 2000).

M. Misakian, "Exposure Parameters during Studies with ELF Magnetic and Electric Fields," Proc. Of Second World Congress for Electricity and Magnetism in Biology and Medicine, June 8-13, 1997, Bologna, Italy, publ. KluwerAcademic/Plenum Publishers, New York, NY pp. 323-326 (Dec. 1999).

E. D. Simmon, G. J. FitzPatrick and O. Petersons, "Calibration of Dissipation Factor Standards," IEEE Trans. Instrum. and Meas., 48, No. 2, pp. 450-452 (Apr 1999).

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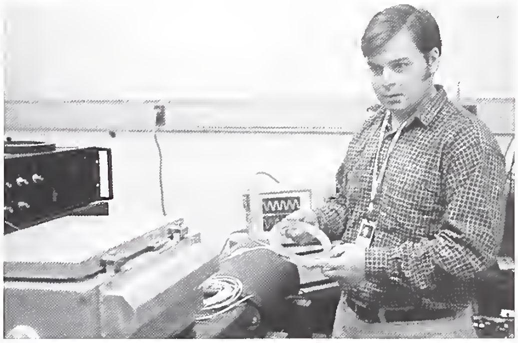
Advanced Power System Measurements

Project Goals

To assess and develop new measurement technologies for the increased reliability and quality of the U.S. electric power system.



Eric Simmon with an optical current sensor for testing in a high-current coaxial cage.

Customer Needs

With deregulation of the electric power industry, new diagnostic technologies are needed to ensure the reliability of the increasingly complex U.S. electric power infrastructure. New web-based sensor technologies raise questions of security and access to power system information and control to unauthorized persons. For consumers, the expanding usage of sensitive microelectronic devices increases the need for high-quality power. Additionally, economic and environmental pressures are motivating the drive toward more efficient electrical devices. Activities in this project provide the support required by the electric power and electric equipment industries to maintain the security and reliability while utilizing new cost-saving measurement technologies related to the transmission, distribution, and use of electric power.

Technical Strategy

Electric power generation, transmission, and distribution comprise an infrastructure that enables the motor of modern society to run. Any interruption of electric power creates at a minimum an inconvenience, but can be life-threatening. There has been a proliferation of modem- and web-connected sensors and actuators used to control the operation of electric power systems. Because they are designed to meet functional specifications such as speed and not security considerations, the communications among them may be vulnerable to attack and inadvertent or malicious misoperation. NIST is identifying the security weaknesses of these process control systems in an attempt to raise industry awareness of the potential vulnerabilities and to establish a set of security requirements for power system controls and communications.

DELIVERABLES: By 2002, review IEEE, IEC, and ISA security standards activities and identify security requirements for inclusion in power industry standards.

DELIVERABLES: By 2003, develop procedures and methodologies for testing information security of electric power control systems.

As power quality becomes increasingly important to consumers, manufacturers, and utilities, the questions of how to define, measure, and improve power quality become critical to all parties. The development of national and international standards designed to promote reliable performance, equitable trade, and safety is required. NIST participates in several standards organizations to help develop these standards.

DELIVERABLES: By 2002, complete tutorials for contribution to IEC standards on lightning protection of low voltage power systems.

In an effort to reduce the consumption of electric power, the U.S. Department of Energy (DOE) designates minimum efficiencies of electrical equipment. Distribution power transformers and electric motors are two categories of equipment for which DOE is developing efficiency standards. NIST is advising DOE by developing technically sound sampling strategies and instrumentation for the testing of these devices.

DELIVERABLES: By 2002, develop a portable system for testing the efficiency of distribution transformers.

DELIVERABLES: By 2004, contribute to DOE final rule for the efficiency of fractional horsepower motors.

Optical sensors hold promise as lower cost devices to measure high currents and voltages on transmission and distribution systems. The number of these types of measurements is expected to increase due to deregulation. However, the reliability and accuracy of these devices must be proven in order for electric utilities to integrate them into their systems. Measurements and calibrations that are traceable

Technical Contact:
Gerald J. FitzPatrick

Staff-Years:
3.0 professionals
0.5 technician
0.5 guest scientist

Funding Sources:
NIST (65 %)
Other Government Agencies (35 %)

Parent Program:
Power

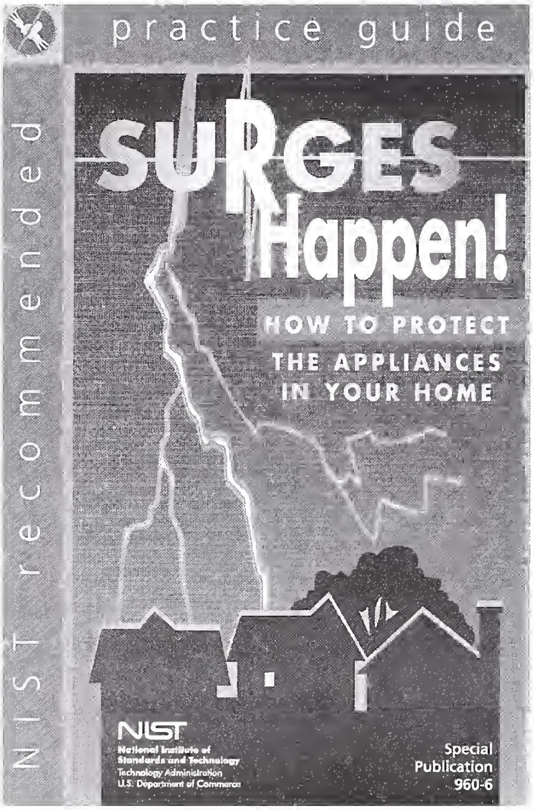
> ***"NIST involvement is very important to the acceptance of optical current sensors by the electric power industry."***
>
> *HarGil Group, Inc.*

to NIST would advance the use of these devices by U.S. utilities.

DELIVERABLES: By 2002, extend calibration techniques of metering quality optical current sensors to cover a wider dynamic range.

Accomplishments

- NIST Recommended Practice Guide, "Surges Happen! How to Protect the Appliances in Your Home," was published. This tutorial Guide is written in a user-friendly style and provides very useful consumer information about what surges are, where they come from, and what they can do to electrical and electronic appliances. Various options for protecting against surges are discussed, and guidance is provided for selecting the right solution to match the individual consumer needs. The Guide concludes with installation hints for both the homeowners and contractors, and a list of additional information sources and websites. The Guide is written in a user-friendly fashion and provides very practical information in manner that is accessible to the layman. It is available in print and has been posted on the NIST Web site (http://www.nist.gov/public_affairs/practiceguides/surgesfnl.pdf)



The consumer guide on protecting appliances from electrical transients entitled "Surges Happen!"

A NISTIR entitled "Optical Current Transducers for Electric Power Systems: Overview and Literature Survey" was completed. The publication summarizes the literature in optical current transducers (OCTs) used in electric power systems. Over two hundred references are cited in the bibliography. The document includes a discussion of the different OCT types, their operating principles, measurement errors, and application in electric power system metering, relaying, and diagnostic applications.

- A prototype system for measuring transformer power losses was designed, assembled, and tested. It is intended to be a low-cost measurement system having sufficiently low measurement uncertainties that is capable of demonstrating the compliance of distribution transformers with energy efficiency regulations now under development by the Department of Energy. The results demonstrated that the design criterion of 0.1 % or less error for power loss measurements was met.

- IEEE Standard P114, "Draft Standard Test Procedure for Single-Phase Induction Motors," has been approved by the IEEE Industry Applications Society. NIST staff served to chair the Working Group that developed the standard, which covers methods for determining the efficiency of single-phase electrical motors.

FY Outputs

Collaborations

NIST collaborated with the EPRI Power Electronics Application Center (EPRI/PEAC), Knoxville, TN, to develop a 50-page test protocol on surge and noise immunity of home-entertainment systems. A guide covering test protocols for distributed resources (DR) was also completed for EPRI/PEAC.

Standards Committee Participation

IEEE Industrial Applications Society, Electric Machines Committee: K. L. Stricklett chaired the working group updating IEEE P114, the "Draft Standard Test Procedure for Single-Phase Induction Motors."

IEEE Power Engineering Society Surge Protection Devices Committee: F. D. Martzloff served on multiple working groups of this committee, including working groups on Surge Characterization, Multiport Surge Protective Devices, and Secondary Arrestors.

IEC Technical Committee 81 on Lightning Protection: F.D. Martzloff served as the official delegate of the U.S. National Committee.

IEEE Power Engineering Society Power Systems Instrumentation and Measurement Committee: G. J. FitzPatrick served as the Secretary of the Committee and Secretary of the Optical Sensors Subcommittee.

American Welding Society: Eric Simmon served on the Resistance Welding Committee.

Publications

E.D. Simmon and G.J. FitzPatrick, "Optical Current Transducers for Electric Power Systems: Overview and Literature Survey," NISTIR 6805, 157 pages (Sept 2001).

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F.D. Martzloff, "A New IEC Standard on the Measurement of Power Quality Parameters," Proc. EMC Europe 2000 Symposium, Brugge, Belgium (Sept. 2000).

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K.L. Stricklett and M. Vangel, "Test Procedures for Electric Motors Test Under 10 CFR Part 431, "Tech Note 1432, Natl. Inst. Stand. Technol. 14 pages (Jun 2000).

T. Key, D. Nastasi, K. Phipps, F. Martzloff, and J. May, "Update on a Consumer-Oriented Guide for Surge Protection," Conf. handout presented at PQA '99, May 24-27, 1999, Charlotte, NC, spon. EPRI, Palo Alto, CA, 14 pages (Jun 1999).

A. Mansoor, K. Phipps, and F. D. Martzloff, "The Fallacy of Monitoring Surge Voltages: SPDs and PCs Galore," Proc. PQA'99, May 24-27, 1999, Charlotte, NC, 11 pages (June 1999).

K. L. Stricklett, M. Vangel, and O. Petersons, "An Analysis of Efficiency Testing Under the Energy Policy and Conservation Act: A Case Study with Application to Distribution Transformers," NIST TN 1427, Natl. Inst. Stand. Technol., co-sponsored with the U.S. Dept. of Energy, 52 pages (Apr 1999).

Flat Panel Display Metrology

Project Goals

To develop robust, reproducible, and unambiguous metrology methods to characterize electronic displays—particularly flat panel displays (FPDs)—to support the domestic industry of display users.

Paul Boynton makes adjustments on an instrument to measure the scattering properties of candidate liquids to be used with the simulated-eye-design camera.

Customer Needs

The United States is a major buyer of electronic displays for computer, consumer, automotive, and avionics use. A well-defined method for specification and verification of display quality is necessary to enable worldwide commerce of displays. Sound metrology is urgently needed in this highly competitive environment of new and emerging display technologies. Further, a universally recognized and accepted document is needed to provide customers with a tool to use in choosing the best display for their application.

Technical Strategy

This project is concerned with display metrology in general and there are numerous ongoing tasks. However, specific issues identified by industry as particularly important are being emphasized in our research.

We are working to develop and refine measurement procedures in support of ongoing electronic display metrology, and applying the results in the development of national and international standards for flat panel display characterization.

DELIVERABLES: By 2002, assist the Society of Automotive Engineers in developing reflection measurement methods suitable for automotive use.

DELIVERABLES: By 2002, assist in the grand revision of the ISO visual display ergonomic standards.

The characterization of the three components of reflection (Lambertian, specular, and haze) associated with displays is being developed. Development and implementation of robust metrics is needed to characterize display reflection performance under actual conditions, e.g., the readability of automotive displays in high ambient light conditions.

DELIVERABLES: By 2002, conduct inter-laboratory comparison, using a NIST developed reflectance sample with measured bidirectional reflectance distribution function (BRDF) parameters to compare BRDF measurements with other display measurement laboratories.

DELIVERABLES: By 2002, investigate the development of simplified methods to measure reflection properties based upon the parameterization of the BRDF for electronic display reflection characterization.

To determine the measurement capabilities of participating laboratories in an inter-laboratory comparison effort, this project has developed a uniformly-lit target assembly. The combination of all the targets will stress the capabilities of most laboratories in making conventional luminance and color measurement. This program is conducted with the assistance of the Physics Laboratory's Optical Technology Division.

DELIVERABLES: By 2002, implement an inter-laboratory comparison based upon the Display Measurement Assessment Transfer Standard (DMATS) with the Optical Technology Division.

In order to reduce stray-light contributions to the reference image and enable more accurate luminance measurements of complicated scenes involving high contrasts, a liquid-filled camera is under development that simulates the optics of the human eye.

DELIVERABLES: By 2003, investigate a second-generation eyeball-like camera and report progress at an industry conference.

Accomplishments

- The second public version of the VESA Flat Panel Display Measurements Standard (FPDM2) was published with major contributions from NIST.
- The Display Measurement Assessment Transfer Standards (DMATS) prototype was refined and computer control was added in anticipation of the first round-robin testing.

Technical Contact:
Edward F. Kelley

Staff-Years:
3 professionals

Funding Sources:
NIST (100 %)

Parent Program:
Video

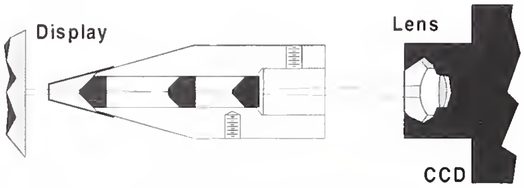
The Flat Panel Display Measurements Standard, Version 2.0 is an outstanding technical document. It offers a wealth of clearly specified and richly detailed procedures for measurement of virtually all characteristics which determine flat-panel display performance."

Louis D. Silverstein
Chief Scientist
VCD Sciences, Inc.

DMATS will serve to determine the worldwide color measurement capabilities and methods, and industry is anxious for its implementation. The DMATS solution is essential to resolving issues of color transportability in E-commerce.

- NIST demonstrated how seriously stray light can affect results of small area measurements of small noise blocks on the screen. Without using some sort of a narrow-frustum stray-light-elimination tube, errors of over 1000 % can be anticipated.

> ***"The work you're doing with flat panel display measurement is extremely important to the display industry and especially the aviation community where we are driven as much by safety as perceived quality and cost."***
>
> *Alan Jacobsen*
> *Technical Fellow*
> *Boeing*



The narrow-frustum stray light elimination tube (SLET) can be used to minimize the effects of stray light in making small-area measurements on displays, particularly important in properly rendering high-contrast detail.

- A resolution measurement technique suitable for making intrinsic resolution measurements on front-projection displays was implemented.

- An invited "Applications Seminar" on Flat Panel Display Measurements and Standards was presented at the Society for Information Display (SID) 2001 International Symposium. The Seminar was attended by approximately 300 people. Emphasis was placed on (1) techniques being as important as good equipment and (2) reflection metrology is more complicated than currently envisioned by the display industry.

FY Outputs

Collaborations

In addition to the collaborations that follow naturally from standards activities (see below) and other routine advisory roles, there are some specific collaborations of interest that are currently underway:

We are working with the Food and Drug Administration on making small-area measurements of radiological images using stray-light-reducing probes. Reflection measurements are also being made based upon the BRDF.

Robust and meaningful reflection measurements of reflective displays are being developed in collaboration with Kent Displays, Inc., and E-Ink, Inc.

Reflection measurement procedures in the ISO display standards are being investigated for robustness and reproducibility.

Standards Committee Participation

VESA Display Metrology Committee: E. F. Kelley chaired this committee, which produced the Flat Panel Display Measurement (FPDM) Standard, a scientific and comprehensive document, prepared with significant input from NIST, to address display metrology. Kelley now serves as its editor. (VESA, Video Electronic Standards Association)

ISO TC159/SC4/WG2 Visual Display Requirements: P. A. Boynton is a member of this committee, which is developing a revision of all of its display standards. NIST is coordinating the development and evaluation of the metrology sections. (ISO, International Organization for Standardization)

ANSI & PIMA IT7-3 Electronic Projection: P. A. Boynton is a member. The IT7-3 is presently evaluating and revising present ANSI/PIMA projection standards for the future revision. (ANSI, American National Standards Institute; PIMA, Photographic & Imaging Manufacturers Association)

SAE J 1757 Standard Metrology for Vehicular Flat Panel Displays: E. F. Kelley is a member and is providing support in the evaluation of reflection measurement standards. (SAE, Society for Automotive Engineers)

CORM CR-5 (Flat Panel Displays). All project personnel are members. J. M. Libert is working with the committee to evaluate the DMATS program. (CORM, Council for Optical Radiation Measurements)

CIE TC2-42 Colorimetric Measurements for Visual Displays. P. A. Boynton is a member. The committee is preparing a recommended practice for display colorimetry metrology. (CIE, International Commission on Illumination)

Publications

P. A. Boynton and E. F. Kelley, "Compensation for Stray Light in Projection-Display Metrology," 2001-SID International Symposium Digest of Technical Papers, Society for Information Display, Vol. 32, pp. 334-337, San Jose, CA, June 4-8, 2001.

E. F. Kelley, "Electronic Display Metrology--Not a Simple Matter," Proc. of SPIE, Vol. 4450, pp. 44-53, NIST/SPIE Centennial Symposium/Celebration, San Diego, CA, August 1, 2001.

E. F. Kelley and J. V. Miseli, "Setup Patterns for Display Measurements - Version 1.0," NISTIR 6758, 14 pp., June 2001.

E. F. Kelley, "Proposed Diffuse Ambient Contrast Measurement Methods for Flat Panel Displays," NISTIR 6738, 6 pp., April 2001.

E. F. Kelley, "Flat Panel Display Measurements and Standards," Applications Seminar A4, 2001-SID International Symposium, Society for Information Display, San Jose, California, pp. A-4/1 through A-4/66, June 2001.

P. A. Boynton and C. Fenimore, "Characterization of Projection Systems for the MPEG-4 Digital Cinema Compression Scheme Evaluation," NISTIR 6792, 2001.

J. W. Roberts and E. F. Kelley, "Measurements of Static Noise in Display Images," Proceedings of the SPIE V4295B-27, Electronic Imaging Symposium, San Jose, CA, pp. 211-218, January 23, 2001.

P. A. Boynton and E. F. Kelley, "Light Measuring Device Diagnostics for the Photometric and Colorimetric Measurement of Flying-Spot Displays," Proceedings of the SPIE V4295, Electronic Imaging Symposium, San Jose, CA, January 23, 2001.

J. M. Libert, Paul A. Boynton, Edward F. Kelley, Steven W. Brown, Yoshihiro Ohno, and Farshid Manoocheri, "A Standard Illumination Source for the Evaluation of Display Measurement Methods and Instruments," Proceedings of the SPIE V4295, SPIE Electronic Imaging Symposium, San Jose, CA, January 23, 2001.

J. M. Libert, "Video Quality Experts Group: Current Results and Future Directions," Digital Cinema 2001 Conference, NIST, pp. 120-122, January 11, 2001.

P. A. Boynton, "Tools and Diagnostics for Projection Display Metrology," NISTIR 695: Digital Cinema 2001 Conference Proceedings, Gaithersburg, MD, January 11-12, 2001

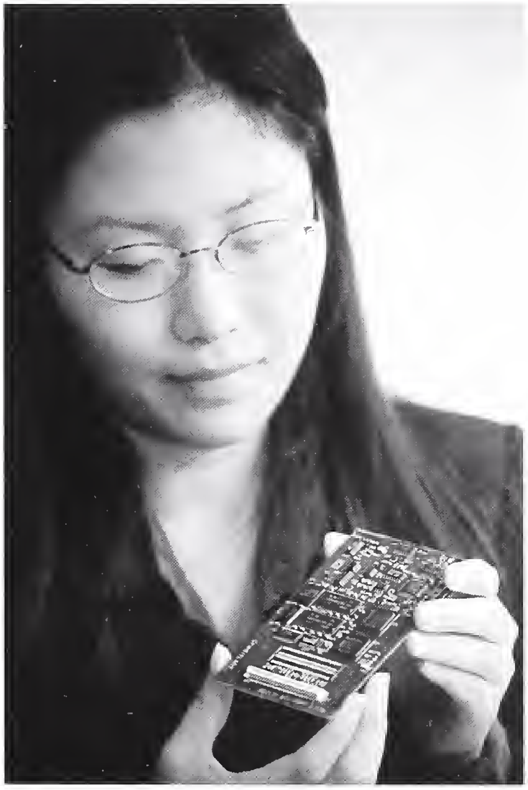
E. F. Kelley, "Impediments to Reproducibility in Display Metrology," Digital Cinema 2001 Conference, NIST, pp. 91-101, January 11, 2001.

J. M. Libert, P. A. Boynton, E. F. Kelley, S. Brown, and Y. Ohno, "An Assessment Standard for the Evaluation of Display Measurement Capabilities," Proceedings of the Society for Imaging Science & Technology (IS&T) / Society for Information Display (SID) Eighth Color Imaging Conference: Color Science and Engineering, Scottsdale, AZ, November 7-10, 2000.

Infrastructure for Integrated Electronic Design & Manufacturing

Project Goals

To actively contribute to the technical development of neutral product data exchange specifications, manufacturing specifications, and component information infrastructure for the electronics industry. The project focuses its efforts on two areas: Electronic Commerce of Component Information (ECCI) and Internet Commerce for Manufacturing (ICM). The ECCI staff work with industry and other government laboratories to develop a program to promote the transfer of technical information and computer models between different Original Equipment Manufacturers (OEMs) and the manufacturers of electronic parts and those who need parts for the design, manufacture, and repair of electronic systems. The ICM focuses on providing an environment in which small manufacturers of mechanical and electronic components may participate competitively in virtual enterprises that manufacture printed circuit assemblies (PCA). In particular, the ICM focus will identify and overcome some of the manufacturing information technology problems that exist at the intersection of manufacturing and electronic commerce.



Ya-Shian Li with the LART board that was produced using the GenCam standard.

Customer Needs

To reduce the time to market and improve communications between separated business units, electronic component manufacturers, component suppliers, and OEMs are using the Internet to distribute electronic information. To support this growing need, industry must adopt a uniform set of common standards. Common standards will provide industry with a means to directly integrate component information with their internal software tools used for computer-aided design and computer-aided-manufacturing. OEMs are experiencing a need to partially outsource the manufacturing of new products to decrease manufacturing costs. The ability to quickly and efficiently exchange design information will accommodate this increasing industrial need. Finally, industry also needs neutral test beds in which to evaluate new standards and the risks associated with technology adoption.

Technical Strategy

This project is working with industry to enable the infrastructure needed to support electronic commerce for both electronic components and manufacturing. For ECCI, the technical areas being addressed are: the fundamental terminology used to describe components, the organization of the component data and metadata, and the ability to access this data and incorporate it into the life cycle of a design specification. Development of standards within this domain is crucial in order for U.S. electronics manufacturers to take advantage of the global marketplace. This project assists industry in the development of standards that are crucial to the infrastructure, but that no single company will pursue because of the broad-based benefit. Industry and standards groups in both Japan and Europe are actively working on ECCI related projects. In working with these groups NIST will try to minimize overlapping standards development and to ensure interoperability between U.S. and international ECCI standards.

DELIVERABLES: By 2003, develop the infrastructure necessary to allow U.S. manufacturers to perform international interoperability testing of component information exchange with RosettaNet (USA), ECALS (Japan), MERCI (Europe), and others.

Technical Contact:
John Messina

Staff-Years:
4.5 professionals

Funding Sources:
NIST (100 %) (SIMA)

Parent Program:
Electronic Data Exchange

> ***"The Dictionary-Builder is an ongoing open-source development project, being developed by RosettaNet and PTC, with assistance from Si2 and NIST."***
>
> *RosettaNet announcement*

One key aspect of this work, as identified by industry, is the need for on-line traceable dictionaries in order to effectively distribute electronic component data via the Internet. On-line dictionaries enable the industry to properly evaluate electronic component information. In support of on-line dictionaries, NIST has been working with large industry consortiums, such as the Silicon Integration Initiative (Si2) and RosettaNet, providing technical expertise in the design of electronic dictionary formats and the tools necessary to maintain and to expand the newly created dictionaries.

In conjunction with the dictionary work, this project has been working with industry exploring ways to make existing tools and interoperability information regarding electrical project data standards and dictionaries available to the U.S. electronics industry. Working closely with Si2, this project has helped develop a Quick Data standard as part of the Si2 Electronic Component Information Exchange (ECIX), which has since been adopted by RosettaNet as PIP2A9. This standard provides the infrastructure necessary to share electronic component information between suppliers and purchasers using the Extensible Markup Language (XML). To prove this standards feasibility, NIST, in collaboration with Si2, developed and publicly demonstrated a reference toolkit that demonstrates how the PIP2A9 specification, along with an electronic dictionary, can be used to support electronic commerce for electronic components.

DELIVERABLES: By 2002, develop dictionary maintenance tools (in collaboration with industry) and sponsor workshops to harmonize component dictionaries, and standards in the Electronic Component Technical Dictionary (ECTD) format to support B2B applications for the electronics industry.

The project has also established the ICM Testbed in order to validate new technology and demonstrate to industry the use of new standards. In a series of industry based scenario development workshops, NIST is working to identify industry's needs in a variety of business scenarios. Using an overview of current research in electronic commerce frameworks, demonstration components have been acquired to establish a basis for a technical information exchange demonstration validating the various business scenarios within the Testbed.

The ICM focus is also part of a multi laboratory effort at NIST to support the manufacturing industry. As a member of the National Advanced Manufacturing Testbed (NAMT), the team has the opportunity and responsibility to make our results widely known. The team participates in a variety of in-house demonstrations and internal seminars, as well as conference demonstrations in collaboration with IPC, National Electronic Manufacturing Initiative (NEMI), and CommerceNet. The manufacturer's business case, standards roadmaps, and proceedings from all workshops will be published and disseminated through the project website.

DELIVERABLES: By 2002, establish the infrastructure to support a web-based B2B Portal project that can be used to validate existing electronic design and manufacturing specifications within the ICM Testbed.

Accomplishments

- NIST manufactured and assembled four LART (Linux Asynchronous Receiver Transmitter) boards as a proof-of-concept test of IPC's GenCAM (IPC-2511A) specification. The boards were manufactured with the assistance of the Center for Board Assembly Research (CBAR) Laboratory at Georgia Institute of Technology.

- NIST continues to provide technical support for the Si2 QuickData Standard (now RosettaNet's PIP2A9), and development of reference implementation software: 1) the existing Query Generator toolkit was modified to use RosettaNet's new PIP2A9 and RNIF specifications in its electronic components queries and responses, 2) RosettaNet's new ECTD format (developed from Si2's CIDS specification) was incorporated into the toolkit to enable component class query construction, 3) the reference software was demonstrated in conjunction with Si2 and Mentor Graphics at the 2001 DAC, and 4) NIST was invited to join RosettaNet's design review team for the PIP2A9 specification.

- NIST co-sponsored an electronic dictionary workshop in conjunction with Wolfgang Wilkes of MERCI in San Francisco. Attendance included over 36 industry representatives (both U.S. and international).

- NIST participated in the Open Applications Group (OAG) technical meeting (Feb 20-22) - A number of opportunities for influencing OAG standardization work in B2B standards were identified. Dialog is in process with OAG and OEM members related to the development of technologies for formal process specification based on agent work.

- NIST co-led the development and publication of the IPC Product Data eXchange (PDX) suite of standards. The three standards published in November 2001 enable the exchange of bills of material, engineering change orders and as-built product configuration. A fourth standard for product quality data has been released as a Standard Proposal. These standards were validated and demonstrated at the IPC APEX conference (January 2001) and the European Productronica conference (November 2001)

FY Outputs

Collaborations

We are working with the Silicon Integration Initiative (Si2) and RosettaNet to develop certification testing programs for the Computer Aided Engineering (CAE) industry.

We are working with the Institute for the Packaging of Electronic Circuits (IPC) to develop a Conformance test module for GenCam.

We are working with the Virtual Socket Interface Alliance (VSIA, with142 member companies) to test and validate their emerging standards for virtual components, and work towards a common terminology

Within NIST, this project is part of the Internet Commerce for Manufacturing project, a NIST inter-laboratory project with the Information Technology Laboratory, the Manufacturing Engineering Laboratory, and the Manufacturing Extension Partnership Program.

Barbara Goldstein co-chairs the National Electronics Manufacturing Initiative (NEMI) Factory Information Systems (FIS) Technical Implementation Group (TIG), and co-leads its Virtual Factory Information Interchange Project (VFIIP) which initiated the Product Data eXchange (PDX) suite of standards.

Standards Committee Participation

IEC/TC93/WG5 Test Validation, Conformance and Qualification for Standards: John Messina is convener of IEC/TC93/WG5, which is the working group responsible for defining methodologies and/or guidelines for the conformance and certification testing of any product which implements a TC93 standard.

IEC/TC93/WG6 Libraries of Reusable Parts for Electrotechnical Products: John Messina is co-convener, working on standards and infrastructure necessary to support the exchange of component information at the international level.

IEC/TC93/WG3 Electrotechnical Product Design Interchange Formats: Curt Parks is a member of WG3, which is concerned with design interchange standards in the domain of electronic and electrical design.

IEC/TC93/WG1 Electrotechnical data harmonization: Curt Parks is a member of WG1. The WG1 goal is to propose to TC 93 an overall strategy and practical working approach for the harmonization and interoperability of electro technical data description standards.

RosettaNet - John Messina, Kevin Brady, and Michael McCaleb have been working with RosettaNet to develop and evaluate technical standards for B2B E-commerce transactions for electronic components, and technical dictionaries for describing electronic components

IEC/TC3/SC3D/WG2 - TC3 (Documentation and graphical symbols) SC3D (Data sets for libraries of electric component data) IEC 61360 Standard data element types with associated classification scheme for electric components. Michael Mclay is a member of the U.S. TAG (Technical Advisory Group) for IEC/TC3/SC3D. Michael has been involved with WG2 because we are using the 61360 standard, which they developed as the basis for much of the dictionary related work in ECCI.

IPC Data Transfer Solutions Committee: Michael McLay is co-chair of this committee, which is developing the GenCAM standard.

IPC Supply Chain Communications Committee: Barbara Goldstein chairs this committee, which publishes the Product Data eXchange (PDX) suite of standards. She also co-chairs the IPC 2571 subcommittee.

Publications

B.L.M. Goldstein, S. J. Kemmerer, and C. H. Parks, "A Brief History of Early Product Data Exchange Standards," NISTIR 6221, Natl. Inst. Stand. Technol. (U.S.), 17 pages (Sep 1998).

K. G. Brady and J. A. St. Pierre, "Conformance Testing Object-Oriented Frameworks Using JAVA," Conf. Proc. Second Annual: Role of Distributed Objects in Healthcare, Oct 29-30, 1998, National Institute of Standards & Technology, Gaithersburg, MD, 12 pages (Oct 1998).

J. V. Messina, J. A. St. Pierre, and M. R. McCaleb, "Design and Development of a Dictionary Translator," National Institute of Standards & Technology. (U.S.) NISTIR 6219, 12 pages (Jan 1999).

B.L.M. Goldstein, "Electronics Factory Integration: The National Electronics Manufacturing Initiative (NEMI)

Factory Information Systems (FIS) Roadmap and Projects," Proc. of Technical Program NEPCON West '99, Feb 23-25, 1999, Anaheim, CA, publ. Reed Exhibition Companies, Norwalk, CT, pp. 1059-1066 (Mar 1999).

Curtis Parks, "Internet Commerce for Manufacturing Product Data," NISTIR 6320, NIST, Gaithersburg, MD, April 14, 1999.

J. A. St. Pierre, C. H. Parks, and R. Waxman, "Conference Report on the Electronic Commerce of Component Information Workshop [Jul 15-17, 1998]," J. Res. National Institute of Standards & Technology. (U.S.), 104, No. 3, pp. 291-297 (May/June 1999).

Barbara Goldstein and John Cartwright, "Opening Up to Standardization," (Lead Article), Circuits Assembly, Volume 10, Number 6, June 1999.

Barbara Goldstein, John Cartwright, Joanne Friedman, and John Minchella, "Virtual Factory Project Tackles Integration," Future EMS International, Volume 2, September, 1999.

B. M. Goldstein and A. Dugenske, "A Standards-Based Approach to Integrating Information Across the Electronics Manufacturing Supply Network," Electronic Circuits World Conference (ECWC), Sep 6-10, 1999, Tokyo, Japan.

B. Goldstein and T. Rhodes, "Integrating Manufacturing Across Electronics Supply Chain Partners: the NIST Internet Commerce for Manufacturing Project," Manufacturing Development Europe, Issue 2 2001, Cornhill Publiclications Limited/Deloitte Consulting, England, p 42-44.

B. Goldstein, "The Changing Face of the Electronics Supply Chain" presented at IPC Expo, San Diego, April 5, 2000.

J. Cartwright and B. Goldstein, "NEMI's Virtual Factory Project Focuses on Improving Supply Chain Communications for Electronics Manufacturers," accepted for publication in Circuits Assembly, September 2000.

Information System to Support Calibrations

Project Goals

To develop and refine a workflow application to enable the automatic tracking of technical and administrative calibration information. This tracking system, the Information System to Support Calibrations (ISSC), reduces the percentage of time NIST scientists and support staff spend on producing the necessary calibration forms and associated reports.

Jennifer Lindeman shows an authentication card that will be used to gain remote access to the ISSC.

Customer Needs

The ISSC continues to eliminate the paper-intensive and manual processes involved with calibrations performed at NIST. The ISSC automates processes and decreases the administrative requirements of the technical and support staff. Income, workflow information, and mechanisms to report current income and projecting future income are readily available to management. ISSC staff continue to look for ways to improve the total experience of the customer along with decreasing the turn around time of the calibration process.

Providing calibration customers information electronically is an on-going goal. As security mechanisms are implemented in web browsers (e.g., digital signatures), we will be able to provide customers with access to calibration data, calibration reports, and other information on-line.

Technical Strategy

The ISSC is a structured-query language database-driven application. The ISSC stores all of the administrative, technical, and financial data involved with items calibrated at NIST. The system has over 250 users. The web-based system allows access from a plethora of different machines and operating systems used by personnel at NIST. The ISSC has reduced the time to complete the required paperwork by automating the entire workflow process.

A custom interface has been developed for the Calibration Program (a central calibration coordination office) to monitor and assist in the administrative aspects of the calibration process. The Chief Financial Officer's personnel have been provided access to generate the required billing information and print customer invoices directly from the system.

Each of the twelve divisions at NIST that performs calibrations has been given access to the ISSC. User's access is controlled and separated by job functions: administrative, technical, and data entry.

The ISSC developers are working with staff from Technology Services to transition the system so it will not reside in a technical Laboratory.

DELIVERABLES: By 2002, transition the development and maintenance of the ISSC to Technology Services.

One feature of the ISSC is the ability to produce a calibration report based on the calibration data entered and stored in the ISSC. This provides a standard format for reports across all the NIST divisions, helping to develop a standard method and format for reporting calibration results.

The ISSC also generates a cover letter for technical reports.

DELIVERABLES: By 2005, provide the capability to allow calibration reports to be generated by every division.

A committee was formed to provide an input mechanism for the technical staff into the development and enhancements to the ISSC. The Information System to Support Calibrations Oversight Committee (ISSCOC) is comprised of a representative from each calibration division, the Information Technology Laboratory, the Calibration Program, and the office of the Chief Financial Officer. The committee meets bimonthly to resolve problems encountered with the software and to determine enhancements to the software.

The ISSC generates all of the paperwork required with calibrations; such as letters to the customer, standard forms, and even mailing labels.

Technical Contact:
Jennifer A. Lindeman

Staff-Years:
1.0 professionals

Funding Sources:
NIST (100 %)

> ***"This is great! We no longer have to interrupt the NIST Tech with 'Is it done, yet?' questions. Quick, easy, and we don't bother the NIST technician."***
>
> *Robert M. Graham*
> *Primary Calibration Lab*
> *Sandia National Laboratories*

Multiple financial and turn-around-time reports can be instantly generated from the ISSC.

DELIVERABLES: By 2004, add extensive reporting capabilities to allow users to build ad hoc, custom reports.

The ISSC warns technicians as deadlines approach and notifies management if deadlines are missed. This has improved turn-around-time, forced technicians to generate sensible estimated completion dates, and ensured items do not fall in between the cracks, thus increasing customer satisfaction.

Access to the status of a calibration while a device is in for calibration will be given to customers who desire this kind of real time information. The access is secure, using web-based security mechanisms, so the customer is the only one with access to their information. As security is enhanced, we will be able to provide more information electronically (e.g., electronically provide a calibration report).

DELIVERABLES: By 2002, formalize security policies and disaster recovery plan.

DELIVERABLES: By 2002, implement increased security using Secure Socket Layers (SSL) technology for NIST users.

Accomplishments

- ISSC has been deployed NIST-wide to 12 Divisions, the CFO's office, and the Calibration Program, with little-to-no interruption in day-to-day activities. All calibration personnel at both the Boulder and Gaithersburg NIST campuses now use the ISSC. A new system did not need to be procured by NIST, which saved dollars and the time that would have been required to develop and integrate a new customized calibration system. Communication between Boulder and Gaithersburg is nearly seamless, and the web-based system allows Gaithersburg staff to assist Boulder in day-to-day calibration administrative operations.

- Kevin Brady, Jennifer Lindeman, and John Messina received the Department of Commerce Bronze Medal Award for their work with the ISSC.

- Technical and customer support has been provided to over 250 users. The Electricity Division staff is providing technical support to the ISSC user community. ISSC Training classes have been held for the technical, data entry, and administrative areas. Online tutorials are available.

- ISSCOC committee has been a success. The ISSCOC has given the NIST technical staff the vehicle they needed to provide input into the development and improvement process of the ISSC. The committee meets bi-monthly to gather requirements from a representative of each calibration division using the ISSC. The committee has also provided an excellent forum for the exchange of calibration questions not related to the ISSC.

- Customer access pages have been implemented for every calibration done at NIST. Every NIST customer who sends in an item to be calibrated can now check the status via a secure web page. A Secure Socket Layer (SSL) implementation has been put in place to provide security, and the pages are updated nightly with status information. A customer survey and comments page is also available for customers to provide feedback on the calibration process at NIST.

ISSC development team awarded the NIST bronze medal, Kevin Brady, John Messina and Jennifer Lindeman.

FY Outputs

Collaborations

We are working with Technology Services to transition the development and maintenance of the ISSC to their control.

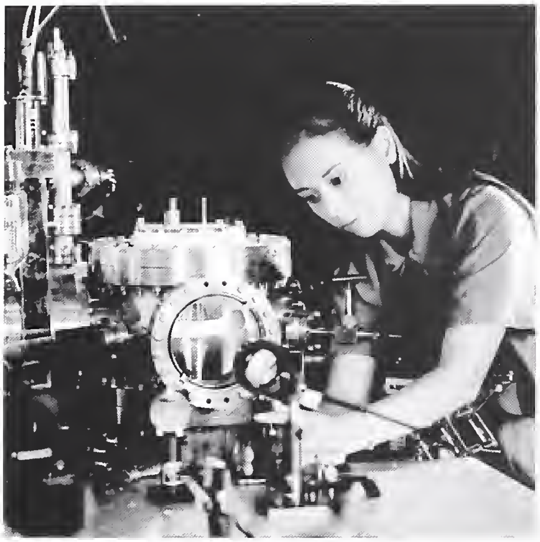
Publications

K. G. Brady, "An Information System to Support Calibration," NISTIR 6425, Natl. Inst. Stand. Technol. (U.S.), December 1999.

Plasma Processing and Gaseous Dielectrics

Project Goals

To develop the diagnostic techniques and physical understanding of low temperature discharges necessary for the development of robust plasma processes and predictive modeling of semiconductor plasma etching and deposition processes.



Amanda Goyette adjusts optics near the Gaseous Electronics Conference reference cell.

Customer Needs

To maintain its competitive world position, the U.S. semiconductor industry is continually developing microelectronic devices with smaller feature dimensions. This trend requires ever increasing control of the plasma discharges used in the fabrication processes, preferably in real time. Additionally, the development of new processes relies increasingly on predictive system modeling due to the increasing complexity of the fabrication tools and systems. The activities performed in this project assist the industry in developing complex plasma processes and provide the fundamental data required to develop and validate plasma models.

Technical Strategy

Standardized, reference discharges are used to develop and validate mass spectrometric and optical diagnostics for use as plasma monitors. The most intensively studied discharges are generated in Gaseous Electronics Conference (GEC) Radio Frequency Reference Cells, which are used by numerous research labs around the world. The performance of diagnostics can be determined by studying well-defined discharges, and the measurements can be used to validate various plasma models. Additionally, the assessment and determination of fundamental data describing collision processes in reactive plasmas allows for the development of accurate plasma models.

The determination of the identity and energy of ions generated in plasma discharges is critical for the understanding and modeling of reactive plasmas, particularly those containing complex gas mixtures.

DELIVERABLES: By 2002, develop improved laboratory diagnostic measurement techniques.

The density of reactive radicals produced in processing plasmas is an equally important parameter for determining the performance of an etching plasma. Advanced optical absorption methods are being developed to enable the accurate measurement of absolute plasma radical densities.

DELIVERABLES: By 2002, measure radical densities in reference reactive plasmas containing fluorocarbon gases, and correlate with measurements of ion flux densities.

Electron-interaction data are the most fundamental input parameters of plasma processing models. NIST provides the most reliable source of such data in the world for a small number of plasma processing gases. The assessment and derivation of available electron-interaction data continues for gases of interest to the plasma processing community as determined by interactions with semiconductor manufacturers and plasma tool companies.

DELIVERABLES: By 2002, complete an assessment of the available electron-interaction data for the most commonly used plasma processing deposition gases.

Accomplishments

Detailed measurements of ion energy distributions in CF_4 high-density plasmas with the lower electrode under various biasing conditions were performed. Energetic ions play a crucial role in plasma etching and other plasma processes. Ions exiting the plasma are accelerated to high energies by strong, radio-frequency electric fields in plasma sheaths, which are thin regions located at the boundaries of plasmas.

Technical Contact:
Yicheng Wang

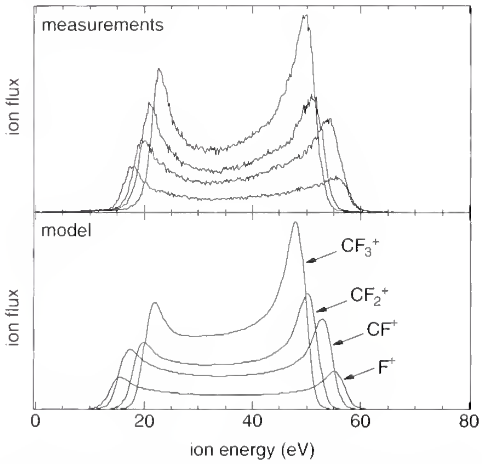
Staff-Years:
1.5 Professionals
0.3 Postdoc

Funding Sources:
NIST (100 %)

Parent Program:
Semiconductors

> ***"Motorola has directly benefited from [NIST's] work on ... SF_6, which forms the backbone of our model for the deep Si etch process."***
>
> *Motorola*

The complicated ion dynamics in plasma sheaths are usually modeled using simplifying assumptions that have never been sufficiently validated. The tests, performed in CF_4 discharges, showed that ion energy distributions predicted by simple, commonly used, analytical sheath models did not agree with measurements. The data are currently being used to evaluate a more sophisicated model developed by researchers in the NIST Chemical Science and Technology Laboratory.



Ion energy distributions in a high-density CF4 plasma: measurements (top) and model predictions (bottom).

- NIST hosted the Ninth International Symposium on Gaseous Dielectrics from May 21 to May 25, 2001, at the Turf Valley Resort & Conference Center, in Ellicott City, Maryland. The Symposium was organized by staff of the Electricity Division and co-chaired by Loucas Christophorou and Jim Olthoff. The symposium enjoyed sponsorship from the Air Force Research Laboratory, ABB, Hitachi, Ltd., Kansai Electric Power Company, Mitsubishi Electric Corporation, Tokyo Electric Power Company, and Toshiba Corporation. The Symposium had over 100 participants from 16 countries and covered an array of topics from the basic physics of gaseous dielectrics and understanding of fundamental gas discharge mechanisms to the very practical issues of recycling of used SF_6. The main theme of the meeting was SF_6 replacements and in particular SF_6/N_2 mixtures. The meeting was attended by some of the world's foremost authorities in the basic and applied aspects of gaseous dielectrics, as well as in the engineering and industrial aspects.

- Absolute, mass-resolved ion fluxes and densities of selected radicals were simultaneously measured in the presence of a silicon wafer in capacitively coupled plasmas generated in processing gases including C_4F_8 and SF_6. The results indicate that the wafer significantly influences the ion and radical composition in each gas as evidence of the complex chemistries present in the etching plasmas. These results are useful to validate and refine reactor modeling codes used in the development of plasma processing methods.

- Electron drift velocities and effective ionization coefficients were measured and analyzed for C_2F_4. C_2F_4 is a dominant fragment formed in highly dissociated C_4F_8 etching plasmas. These data were required as input parameters for newly developed process models describing C_4F_8 etching processes. The determination of these previously unavailable data enabled the development of a more accurate chemical code describing the primary reactions in C_4F_8 discharges.

FY Outputs

Standard Reference Data

Measurement techniques and data provided by NIST continue to assist our customers in industry to improve their plasma modeling and characterization efforts. Examples from this fiscal year include:

- Mass-resolved ion fluxes and ion energy distributions measured in high density SF_6 plasmas used by Motorola for modeling deep trench etching processes.

- The web-based NIST "Electron Interactions with Plasma Processing Gases" database (http://www.eeel.nist.gov/811/refdata/) that distributes fundamental data to plasma modelers throughout industry and academia. This web site has experienced thousands of hits in FY 2001 and tens of thousands of hits throughout its history.

Collaborations

Collaborations continued with researchers in the Physics Laboratory and Chemical Science and Technology Laboratory (NIST) related to the correlation of optical and electrical measurements with mass spectrometric diagnostic results.

Electron transport measurements in plasma processing gases are being made in collaboration with researchers from Centro de Cincias Fisicas, UNAM, Mexico.

Publications

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Martin Misakian, Eric C. Benck, and Yicheng Wang, "Time evolution of ion energy distributions and optical emission in pulsed inductively coupled radio frequency plasmas." J. Appl. Phys. 88, 4510 (2000).

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Electricity Division Calibration Services

The Electricity Division provides a number of for-fee calibration services of electrical standards. Below is an abbreviated listing of those services. More information can be found in the NIST Calibration Services Users Guide SP250 available from the Calibration Program at NIST, (301)-975-2002, calibrations@nist.gov, or on the Web at: http://ts.nist.gov/. (Click on "Measurement.") A fee schedule is also available both in hard copy and on the Web.

Information about the availability and shipping requirements for the Electricity Division services listed below may be obtained by contacting Denise D. Prather, (301) 975-4221, denise.prather@nist.gov. Technical information may be obtained by contacting the specific technical representatives listed below for each service.

A. Resistance Measurements

A.1	DC Resistance Standards and Measurements	Randolph E. Elmquist (301) 975-6591 George R. Jones (301) 975-4225
A.2	High-Voltage Standard Resistors	Kenneth L. Stricklett (301) 975-3955 Gerald J. FitzPatrick (301) 975-2737

B. Impedance Measurements
(Except Resistors)

B.1	Low-Frequency Capacitance and Inductance Measurements and Standards	Andrew D. Koffman (301) 975-4518 Summerfield B. Tillett (301)975-4244
B.3	Power-Frequency Capacitors	Eric D. Simmon (301) 975-3956 Gerald J. Fitzpatrick (301) 975-2737

C. Voltage Measurements

C.1	DC Voltage Measurements and Standards	June E. Sims (301) 975-4238 Yi-hua Tang (301) 975-4691
C.2	AC Voltage Measurements	Mark E. Parker (301) 975-2413 Nile M. Oldham (301) 975-2408
C.3	AC-DC Thermal Voltage and Current Converters (to 1 MHz)	Joseph R. Kinard (301) 975-4250 Thomas E. Lipe (301) 975-4251

D. Precision Ratio Measurements

D.1	Inductive Dividers	Andrew D. Koffman (301) 975-4518 Andrew J. Secula (301) 975-4243
D.2	Resistive Dividers	Kenneth L. Stricklett (301) 975-3955 Gerald J. FitzPatrick (301) 975-2737
D.3	Capacitive Dividers	Gerald J. FitzPatrick (301) 975-2737 James A. Pitt (301) 975-2417
D.4	Mixed Dividers	Gerald J. FitzPatrick (301) 975-2737 James A. Pitt (301) 975-2417
D.5	Voltage and Current Transformers	Eric D. Simmon (301) 975-3956 Thomas L Nelson (301) 975-2986

E.	**Phase Meters and Standards and VOR Measurements**	Mark E. Parker (301) 975-2413 Nile M. Oldham (301) 975-2408
F.	**Power and Energy Measurements, Low-Frequency**	Thomas L Nelson (301) 975-2986
I.	**Pulse Waveform Measurements**	Donald R. Larson (301) 975-2437 Nicholas G. Paulter (301) 975-2405

Postdoctoral Research Associateships

The Electricity Division at the National Institute of Standards and Technology (NIST), in cooperation with the National Research Center (NRC), offers awards for postdoctoral research for American citizens in the fields described below. The Division conducts research in fundamental electrical metrology, mixed signal testing strategies, power and energy metrology, electrical discharge-physics and metrology to support digital video and video display characterization to provide, through both experimental and theoretical work, the necessary basis for solving the measurement-related requirements of the electronics and electrical-equipment industries.

NIST affords great freedom and an opportunity for both interdisciplinary research and research in well-defined disciplines. These technical activities of NIST are conducted in its laboratories, which are based in Gaithersburg, a large complex of modern laboratory buildings in a Maryland suburb of metropolitan Washington, DC. Although applications for NIST Research Associateships are accepted throughout the year, they are evaluated by the panels only during February. Additional information can be found at the NRC Research Associateships Program website: http://nationalacademies.org (click on Careers and Fellowships and then Graduate and Postdoctoral Fellowships, Associateship Programs).

High-Speed Signal Acquisition

Contact: B.A. Bell

As part of a metrology program to meet the need for improved signal acquisition and processing systems, NIST researchers are developing theoretical models, experimental methods, and standards for waveform metrology of conducted signals. This theoretical and experimental research is applied to the development of standards for high-speed A/D converters and waveform recorders operating at signal frequencies up to 5 GHz. Theoretical aspects of the work include Fourier analysis, deconvolution techniques, and time-domain analysis, while the experimental part of the program includes work in precision pulse generation, static and dynamic testing, and programming for hardware control in assembly and higher level languages.

Synthesized Waveform Standards

Contact: B.A. Bell

Theoretical and experimental research is being conducted in synthesizing precision alternating current (ac) waveforms for use in ac voltage and arbitrary waveform standards operating nominally below 100 MHz. Theoretical work includes the use of Walsh and triangular functions as the basis for improved waveform fidelity, while experimental work involves high-speed, high-accuracy digital-to-analog conversion; precision, high-speed switching; assembly and higher level language programming for hardware control; and wideband, fast-settling amplifiers.

Testing Electronic Systems

Contact: B.A. Bell

New strategies are needed to evaluate the performance of complex electronic circuits, devices, and instruments using the fewest possible tests. The testing strategies program in progress includes theoretical studies in modeling of nonlinear systems, optimization techniques using linear matrix methods, statistical and random processes, and neural networks. In addition, experimental work addresses strategies for component and instrument testing, fault diagnosis, functional testing, and calibration. Desktop computers, workstations, and supercomputers are available for computer simulation and analysis.

Picosecond Electrical Pulse Metrology

Contact: B.A. Bell

Theoretical and experimental research opportunities exist to study different problems related to picosecond electrical pulse metrology. These problems generally fall into one of three categories: fast pulse generation, with a goal of creating better pulse generator standards; fast pulse transmission, with goals of characterizing and understanding various transmission line structures from a time domain perspective; and fast pulse measurement, with goals of developing faster, more accurate and more robust pulse measurement systems. Most of these problems also offer opportunities to study signal processing as it relates to discrete, time domain measurement systems. Research facilities include several automated, fast electrical pulse sampling systems, and fast-pulse laser systems useful for electro-optic sampling, photoconductive switch pulse generation, and other experiments.

AC-DC Measurements and Standards

Contact: B. A. Bell

This research area provides U. S. industry with the link between the dc and corresponding ac electrical standards by improving and maintaining the U. S. national standards of ac-dc difference, which are used to provide calibrations and measurement services for thermal voltage converters and current shunts. We are developing a new capability for calibrating high current (100 A) shunts and high voltage (500 V to 1000 V) thermal converters. More reliable semiconductor thin-film converter devices are also being developed that can be readily fabricated and have state-of-the-art ac-dc differences. A new national primary standard is also being developed to support measurement uncertainties at the 0.1 microvolt per volt level.

Electrical Discharge Phenomena in Insulating Materials

Contact: Y. Wang

The physics of electrical discharges in gases, liquids, and at gas-solid interfaces is investigated using measurement systems and theoretical models. Unique measurement systems allow observation of the stochastic behavior and memory effects associated with such pulsating electrical discharges as Trichel-pulse corona, partial discharge, and dielectric barrier discharges. Theoretical models are used to study stochastic properties of partial discharge, electron-avalanche growth and transitions from avalanche to streamer or glow discharge in nonuniform fields. Other research includes (1) studying the electron avalanche-to-streamer transition in insulating gases such as SF_6-N_2 and O_2-N_2 mixtures using intensified gated charge coupled device camera, (2) making fast measurements of correlations between electrical and optical emission characteristics of transient discharges, and (3) determining correlations between acoustical and electrical detections of partial discharges in liquids.

Plasma Chemistry

Contact: Y. Wang

Experimental and theoretical research is under way to investigate chemical processes in radio-frequency (rf) glow discharges, corona discharges, and dc Townsend discharges that are relevant to processing of semiconductor materials or gas decomposition in gaseous dielectrics. Experiments are performed to measure the mass and kinetic energy of ions emanating from rf and dc discharges using a quadruple mass spectrometer equipped with an energy analyzer. This diagnostic has been applied to rf and dc discharges in low-pressure gases such as argon, oxygen, SF_6, CF_4, and their mixtures in "standard reference" discharge cells. Comparisons are made to complementary optical and electrical diagnostic measurements, including optical absorption, optical emission, Langmuir probe, LIF, and electrical measurements. Related research includes (1) measurements on ion transport and ion-molecule chemistry using a uniform-field drift tube mass spectrometer system; and (2) measurements of corona discharge-induced oxidation and decomposition rates for SF_6 and other gaseous dielectrics using a gas chromatograph mass spectrometer, and (3) development of chemical kinetics models for glow-type corona discharges in electronegative gases.

Fundamental Processes in Gas Discharges and Plasma Processing

Contact: L.G. Christophorou

We use novel methods combining laser, electron, and ion technologies to study fundamental processes underpinning the behavior of gas discharges and their applications. Many of the processes studied involve neutral species in their ground and excited states, positive and negative ions, slow electrons, and photons. Special emphasis is placed on electron attachment to neutral molecules, excited molecules, and radicals; electron impact ionization; electron detachment processes; and reaction mechanisms involving neutral and charged species in a variety of environments. Current work focuses on electron interactions with excited molecules and radicals, and on the measurement of ion transport parameters in plasma processing gases. Both are important in plasma processing technologies. A related project is underway to develop a data base of critically analyzed electron-collision cross sections for industrial gases such as CF_4, CHF_3, and Cl_2.

Precision Measurements of AC and Pulsed Currents and Voltages

Contact: G.J. FitzPatrick

Because of their immunity to electromagnetic interference, optical sensors based on the electro-optic Pockels' and Kerr effects and on the magneto-optic Faraday effect are advantageous for measuring high voltages and currents. These sensors are now being employed by the electric power industry in diagnostics, metering, and protection applications. They have been used for diagnostics in large pulse-power machines such as radiation simulators and electromagnetic launchers. Our research goals are to develop and evaluate the performance of electrical measurement systems and to develop techniques to ensure their long-term reliability. We are evaluating the response of sensors to steady-state signals and submicrosecond pulses, and assessing measurement uncertainties in well-characterized systems, such as high voltage dividers, Rogowski coils, and derivative (E-dot and B-dot) sensors. For ac measurements, new circuit designs are being developed for active high-voltage dividers with improved stability and reduced measurement uncertainties. In addition, experiments and mathematical models are used to characterize the dependence of the electrical and optical properties of optical sensor materials on environmental parameters (e.g., temperature, pressure, and radiation). Finally, numerical techniques are developed and applied to identify the sources and magnitudes of measurement errors and to compensate for them.

Fundamental Constants, Precision Measurements, and Electrical Units

Contact: E.R. Williams

The Division is engaged in research on methods to improve accuracies of fundamental physical constants and to develop better and more accurate techniques for measuring and maintaining basic electric units. Research includes developing nuclear magnetic resonance-based current and voltage standards and measurements of the proton gyromagnetic ratio, absolute ampere, absolute volt, absolute farad and ohm, quantized-Hall resistance, and fine-structure constant. We are particularly interested in refining our current techniques and/or initiating new experiments to increase knowledge of these quantities or other constants of comparable importance, especially those involving the electrical units.

"Electronic Kilogram"—The SI Determination of the Ratio of the Mechanical Watt to the Electrical Watt

Contact: R.L. Steiner

Our goal is to accurately define the electrical Watt as determined from Josephson Volt and Quantum Hall Ohm in terms of their SI definitions, which are related to the Kilogram, Second, and Meter. This experiment uses an ampere balance and has the potential to electronically monitor the Kilogram, which is the last artifact standard and may not be a true constant, and also to determine Planck's constant and the mass of the electron. To perform this difficult and timely experiment, scientists are needed with experience in precision measurements of force and mass (balance design), velocity and index refraction (interferometer design), and voltage and current (magnets and moving coils) to 0.01 ppm uncertainty. A good understanding of classical electromagnetics, mechanics, and optics is necessary, and experience with electromagnetic interference protection and vibration isolation would be useful.

Single Electron Effects

Contact: N.M. Zimmerman

In nanoscale electronic circuits, we can observe Coulomb blockade or single electron tunneling (SET) effects. For metrological applications, the basic device is the single electron pump, which allows control of electrical flow in units of 1 *e*. This device enables accurate measurements of electrical current or charge. The Electricity Division studies such effects and their implications for precision metrology of the electrical units. We are pursuing two goals, both in close collaboration with our Boulder location. The first involves using the electron pump to charge up a cryogenic capacitor. Then, by comparison to the Calculable Capacitor and Josephson Volt experiments, we will make metrological measurements of the electrical charge, *e*, or the fine structure constant, α. Our second goal is to investigate ways to increase the value of the current, for use as a direct current standard. Our current approach is to use Si-based SET pumps, which hold the potential to be parallelized.

Quantum Computing Using Single-Electron Tunneling Devices

Contact: Neil M. Zimmerman

The use of quantum coherence for computing has gathered a lot of attention in the past few years, since it was shown that some computing algorithms can be vastly sped up using quantum computers (QC). One type of device envisioned for QC is that based on single-electron tunneling (SET) devices in the superconducting state, where the quantum computer "qubit" is the presence or absence of one extra pair of electrons. We are studying such an application in collaboration with a number of groups, including the University of Maryland and SUNY Stonybrook. One of our interests is in the problem of the charge offset and noise, which limit any possible use in QC. In addition, we are interested in the use of Si-based SET devices for detection of single spins, which form the basis for another possible QC qubit.

High-Temperature Superconductor Cryogenic Current Comparator Research

Contact: R.E. Elmquist

NIST is developing cryogenic current comparator (CCC) systems using high-temperature superconductor (HTS) magnetic shields, current carrying sheaths, and SQUIDS. The goal is to develop HTS CCC systems achieving resistance ratio uncertainties at 77 K of about 1 part in 10^9—two orders of magnitude better than room-temperature current comparators. The CCC systems have the potential to become the industrial standard for high-accuracy resistance ratio comparisons.

Research focuses on designing and developing complex HTS structures for use as shields and sheaths for HTS CCC systems. The sheaths must have excellent superconducting properties to support SQUID-based measurements of small dc surface currents (I_s) with decay and rms noise of less than $10^{-6} I_s$ per second. We are investigating thick-film and bulk HTS high-density superconducting phase materials with transition temperatures above 77 K. An external HTS hollow shield is required to provide a region of low ambient magnetic field (shielding factor = 1000) around the SQUID and current carrying sheaths.

Facilities include a wide range of ultra-high-precision electrical measuring apparatus for testing cryogenic instruments and quantized Hall resistance standard.

Physics of Josephson Junctions at Microwave Frequencies and Precision Voltage Measurement

Contact: R.L. Steiner

The physics of Josephson junctions, driven at microwave or millimeter wave frequencies, has important applications to ultra-high-precision voltage measurements. Among the behaviors observed but not well understood are resonance patterns within series-array Josephson junctions at frequencies between 70 GHz to 95 GHz, variable stability in time of quantized voltage steps in these devices, and the generation of Shapiro voltage steps at fractional values in both series arrays and high-temperature superconducting single junctions. Related applications in voltage measurement include the characterization of noise in electronic instrumentation, especially Zener-diode based references, at submicrovolt levels for normal measurement frequencies (>10 mHz), and nonlinear noise for much lower frequencies (>1 μHz).

Research facilities include three Josephson array voltage calibration stations, wideband frequency sources up to 40 GHz, phase-locking millimeter wave sources (70 GHz to 95 GHz), a high-resolution spectrum analyzer, power meters, an assortment of high-precision voltage and frequency measurement and reference instrumentation, and various waveguide-equipped probes and magnetically shielded Dewars for cryogenic measurements.

Resistance Standards and Measurements Research

Contact: R.F. Dziuba

Research focuses on developing improved reference standards of resistance and more accurate measurement systems for comparing resistance standards with the quantum-Hall effect. This research will involve investigation of new resistance alloys at room and cryogenic temperatures, alternating current/direct current (ac/dc) characteristics of resistors, and designs for constructing ruggedized standards. The following measurement systems are also being developed: (1) cryogenic current comparator resistance bridges, (2) SQUID-based nanovoltmeters, (3) ac resistance bridges, and (4) automated resistance bridges.

Research facilities include a resistor fabrication/heat-treatment laboratory equipped with a 1,000 C programmable process furnace, cryogenic equipment consisting of dc and radio-frequency SQUID instrumentation, and a 16 T quantum-Hall system with a ^{3}He refrigerator.

Quantum Hall Effect

Contact: M.E. Cage

The Electricity Division is involved in a continuing research program on the quantum Hall effect, with emphasis placed on using it to maintain the U.S.-legal unit of resistance and to determine the fine structure constant to the highest possible accuracy. Any experiments that would further the understanding of the quantum Hall effect or explore its limitations would be of interest. Such experiments could include temperature and current dependence, current localization distributions (edge and bulk effects), voltage quantization (breakdown effect), and ac operation to quantized Hall resistance measurements that lead to ac impedance standards. Theoretical studies are also needed in all of these areas.

The apparatus consists of a two 16 T persistent-current superconducting magnets, a top-loading He-3 refrigerator, a variable temperature insert, and an automated quantized Hall resistance measurement systems with parts-per-billion uncertainties.

In support of this research, a clean-room sample preparation facility has been installed that is equipped with a micrometer photo-mask aligner, wire bonder, annealing oven, and probe test station as required for the definition, mounting, ohmic contracting, and room-temperature testing of semiconductor samples for quantum Hall experiments.

Quantized Hall Resistor Fabrication and Research

Contact: Kevin C. Lee

National Standards Laboratories around the world use quantized Hall resistors to maintain their resistance standards. However, too little is known about the physical principles affecting their operation and the mechanisms responsible for their degradation. Furthermore, there are no reliable or repeatable techniques for fabricating devices of standards quality. Research in this area spans the fields of chemistry, materials, and physics. This program centers on (1) furthering the understanding of the physical principles that influence device performance under typical operating conditions; (2) developing techniques to fabricate reliable, standards-quality quantized Hall resistors; and (3) extending the range of operation of these devices to higher temperatures, lower magnetic fields, and higher currents. Sample preparation facilities include a clean room with equipment for optical photolithography, a wire bonder, an alloying furnace, and thin-film deposition. Research facilities include a cryostat with a superconducting magnet capable of testing samples at temperatures as low as 1.1 K in fields up to 16 T and an automated digital voltmeter-based measurement system capable of uncertainties as low as 0.05 ppm.

Capacitance Standards and Measurement Research

Contact: Anne-Marie Jeffery

This work ties the U. S. legal system of units for capacitance and resistance to the SI system of units. This is done through the calculable capacitor experiment that can also be used to determine a value for the fine structure constant by comparison with the quantized Hall resistance. This determination of the fine structure constant currently has an uncertainty of 2 in 10^8, which is the lowest in the world for this method. Work is in progress to further reduce the uncertainty of this determination. Other research in this area involves the development of precision ac transformer bridges for capacitance and resistance measurements with uncertainties of a few parts in 10^9. The techniques for building these bridges have been developed at NIST for scaling of resistance and impedance measurements of the highest levels of accuracy. Current efforts include extending these bridge measurements from 1592 Hz, which is currently used, to frequencies between 100 Hz to 2000 Hz. These ac bridges will also be used in the ac quantum Hall experiment and the single electron tunneling experiment.

Flat Panel Display Metrology

Contact: E. Kelley

NIST's flat panel display laboratory serves the display industry by developing and quantifying good electronic display metrology for industrial use. With the explosion of the information age, the Internet, and e-commerce, the use of flat panel displays has become a growing need for U. S. industries. Good display measurement methods are needed because of the fierce competition between technologies, allowing consumers to compare features of displays accurately and fairly. NIST is doing research in (1) equipment on improving measurements made on displays; (2) development of display metrology with various standards organizations; (3) development of display metrology assessment methods and equipment to provide guidance for the implementation of good measurement methods in the display industry; and (4) display reflectance characterization, measurements, and modeling using the bi-directional reflectance distribution function.

Electricity Division Organization

Division Office (811.00)

2400	OLTHOFF, James K., Division Chief
2419	BELL, Barry A., Deputy Chief
4689	EVERETT, Pamela W., Admin. Officer
2400	FROMM, Sharon L., Secretary
4223	BELECKI, Norman B. (GR)
2868	CHANDLER, Joseph W.
4941	DORSEY, Roy W.
4221	PRATHER, Denise D.

Electronic Instrumentation and Metrology (811.02)

2419	STENBAKKEN, Gerard N. (ACT GL)
2402	GREEN, Kathy H., Secretary

Waveform Synthesis and Impedance Metrology

4518	KOFFMAN, Andrew D. (co-PL)
2438	WALTRIP, Bryan C. (co-PL)
2412	LAUG, Owen B.(CTR)
2408	OLDHAM, Nile M. (CTR)
2441	PALM, Robert H. Jr.
2413	PARKER, Mark E.
4244	TILLETT, Summerfield B.

Waveform Acquisition Devices and Standards

2405	PAULTER, Nicholas G., Jr. (PL)
4464	BERGMAN, David I.
2437	LARSON, Donald R.
2412	LAUG, Owen B.(CTR)
2441	PALM, Robert H., Jr.
2406	SOUDERS, T. Michael (CTR)

AC-DC Difference Standards and Measurement Techniques

4250	KINARD, Joseph R., Jr. (PL)
4247	CHILDERS, Clifton B. (GR)
4251	LIPE, Thomas E., Jr.

Measurements for Complex Electronic Systems

2440	STENBAKKEN, Gerard N. (PL)
4464	BERGMAN, David I.
4518	KOFFMAN, Andrew D.
2406	SOUDERS, T. Michael (CTR)

Fundamental Electrical Measurements (811.04)

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Metrology of the Ohm

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4224	CAGE, Marvin E.
4240	JARRETT, Dean G.
4225	JONES, George R., Jr.
4236	LEE, Kevin C.
4224	MATTHEWS, John (GR)
4243	SECULA, Andrew J.

Realization of the SI Farad and Ohm

4246	JEFFERY, Anne-Marie (PL)
4224	CAGE, Marvin E.
6591	ELMQUIST, Randolph E.
4236	LEE, Kevin C.
4231	LEE, Lai H. (GR)
4246	SHIELDS, John Q. (GR)
4232	SHIELDS, Scott H.

Voltage Metrology

4691	TANG, Yi-hua (PL)
4238	SIMS, June E.
4226	STEINER, Richard L.

Single Electron Tunneling

5887	ZIMMERMAN, Neil M. (PL)
4815	FOGLE, William (GR)
4219	SOULEN, Robert (GR)

The Electronic Kilogram

4226	STEINER, Richard L. (PL)
6556	LIU, Ruimin (GR)
4228	NEWELL, David B.
4206	WILLIAMS, Edwin R.

Electrical Systems (811.05)

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Metrology for Electric Power Systems

2986	NELSON, Thomas L. (PL)
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2426	MISAKIAN, Martin (GR)
6658	PITT, James A.
3956	SIMMON, Eric D.
4278	WANG, Yicheng

Advanced Power System Measurements

2737	FitzPATRICK, Gerald J. (PL)
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2409	MARTZLOFF, Francois D.
2417	PETERSON, Oskars (CTR)
6658	PITT, James A.
3956	SIMMON, Eric D.
3955	STRICKLETT, Kenneth L.

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2502	GOYETTE, Amanda N.

Electronic Information Technologies (811.06)

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4222	FROMM, Sharon L., Secretary

Flat Panel Display Metrology

3842	KELLEY, Edward E. (PL)
3014	BOYNTON, Paul A.
3828	LIBERT, John M.

Infrastructure for Integrated Electronic Design and Manufacturing

4284	MESSINA, John V. (PL)
4478	ARONOFF, Matthew L. (S)
3644	BRADY, Kevin G.
4478	LI, Ya-Shian
4099	McLAY, Michael J.
4229	McCALEB, Michael R.
3517	PARKS, Curtis H.
4479	GALE, John (S)

Information System to Support Calibrations

3263	LINDEMAN, Jennifer A. (PL)

Legend:

CTR = Contractor
GL = Group Leader
GR = Guest Researcher
PD = Postdoctoral Appointment
PL = Project Leader
PT = Part Time
S = Student
ACT = Acting

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