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Electronics and Electrical Engineering Laboratory

Electricity Division

Programs, Activities, and Accomplishments

NIST CENTENNIAL 1901-2001

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 five programmatic divisions, two matrix-managed offices, and a special unit concerned with magnetic metrology:

- Electricity Division
- Semiconductor Electronics Division
- Radio Frequency Technology Division
- Electromagnetic Technology Division
- Optoelectronics Division
- Office of Microelectronic Programs
- Office of Law Enforcement Standards
- Magnetics Group

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 maintains the national standards of electrical measurement providing traceability for applications from electric-power distribution systems and electrical instrumentation, all the way to the electric power meters on every business and home. In addition, Division staff apply their measurement expertise to selected scientific and technological problems, such as the development of metrology standards for flat panel displays.

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U.S. DEPARTMENT OF COMMERCE
Norman Y. Mineta, Secretary

Technology Administration
Cheryl L. Shavers, Under Secretary of Commerce for Technology

National Institute of Standards and Technology
Karen H. Brown, Acting Director

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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 realizes the electrical units in terms of the International System of Units (SI) at the highest levels of accuracy, assures consistency with other national realizations of the electrical units through international comparisons, and provides 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, activties, and recent accomplishments of the 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/.

Dr. James K. Olthoff
Acting Chief, Electricity Division

James A. St.Pierre
Deputy Chief, Electricity Division

Division Programs

The Electricity Division focuses on strengthening the U.S. economy by searching out, evaluating, and addressing needs arising from improving 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 five fields of technology that the Division's work impacts are: national electrical standards, low frequency, power, video, 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 1 gigahertz or higher. 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 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 support for key monitoring devices.

Video

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 are the electronic displays that are becoming ubiquitous. Although displays are manufactured primarily offshore, U.S. manufacturers are the largest consumer of displays. To facilitate world-wide 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 semiconductor plasma processing fabrication techniques.

The Electronic Kilogram

Project Goals

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

Dave Newell performs a critical interferometer alignment procedure for the Electronic Kilogram.

Customer Needs

The kilogram is the only remaining SI base unit 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. Currently, the experimental apparatus is being rebuilt, incorporating upgrades and allowing preliminary testing of the major system components. Once a regular measurement schedule is implemented, it will be possible to identify and address residual noise sources and to evaluate sources of uncertainty. A second round of improvements may be required to optimize and achieve the ultimate performance of the complete system to enable monitoring of the drift of the kilogram.

MILESTONE: By 2001, begin regular measurement schedule to identify and address system limitations.

MILESTONE: By 2003, establish continuous measurement program and optimize for highest precision and accuracy.

MILESTONE: By 2004, begin regular monitoring of kilogram at uncertainty level of 0.01 pm.

Accomplishments

- The reconstruction of the next generation watt balance has progressed substantially and is meeting the expected time schedule for major milestones. The mass balance, computer instrumentation and data acquisition systems, vacuum system, and coil position servo-control

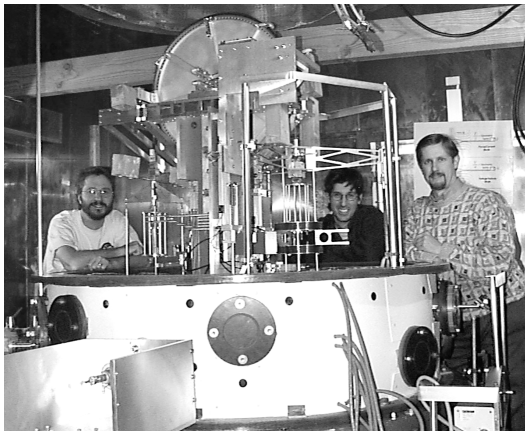
Technical Contact:
Richard L. Steiner

Staff-Years:
3.0 professionals
1.0 postdoc
1.0 guest scientist

Funding Sources:
NIST (100 %)

Parent Program:
National Electrical Standards

system, are being tested under full vacuum (~ 0.1 Pa) but without an applied magnetic field. Early tests have verified that coil heating in vacuum is minimal. The pickup coil exhibits some out-gassing that may limit cycle time, but is otherwise within acceptable limits. The next phase of operation will include a more sophisticated system operation and will allow improved voltage and position recording and refined system control parameters. A "zero-field" watt measurement is now possible and is under way. This 1 % resolution experiment helps the development of the normal modes of control and measurements. It also has the sensitivity to indicate nearby paramagnetic sources and will allow easier identification of environmental or system noise sources that would be masked by the much larger signal of normal operation.



Main balance wheel installed in the vacuum chamber for the newly reconstructed Electronic Kilogram facility.

- A separate test apparatus was assembled for testing the effects of knife-edge hysteresis, a significant contributor to the short-term errors of the prior experimental program. Results from this test apparatus indicate that knife edges made from tungsten carbide but coated with diamond-like carbon (DLC), and supported by a DLC-coated tungsten carbide flat exhibit significantly less hysteresis (factor of six) than the Tantun-G edge and boron nitride flat combination used in prior measurements. This reduction is expected to translate into similar improvement in the watt apparatus and represents significant progress toward the ultimate goal.

- The Microforce Realization and Measurements Project (MFMP) is a five-year, multi-Lab collaboration to provide force measurements, traceable to the International System of Units (SI), at the nano-Newton level. It 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. 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. While awaiting construction of these facilities, the MFMP group has taken the first steps toward the implementation of a suitable force comparator. Several preliminary electromechanical balances have been designed and assembled. Electromechanical balances provide a link to the SI via the highly stable practical realizations of the ohm and volt derived from the quantum Hall and the Josephson effects. Thus far, a force determination at the level of 10 μN with a combined relative uncertainty of 0.10 μN has been achieved. This is an important proof-of-principle of the experimental approaches and gives substantial confidence that the ultimate goals of the project will be achieved.

FY Deliverables

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

R. L. Steiner, D. B. Newell, J. P. Schwarz, E. R. Williams, and R. Liu, "Reconstruction and Preliminary Tests of the NIST Electronic Kilogram Experiment," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2000), May 14-19, 2000, Sydney, Australia, pp. 538-539 (May 2000).

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R.L. Steiner, D.B. Newell, J. Schwarz, and E.R. Williams, "Reference Standards, Uncertainties, and the Future of the NIST Electronic Kilogram," Proc. 1999 Natl. Conf. of Standards Laboratories (NCSL) Workshop and Symp., Jul 11-15, 1999, Charlotte, NC, pp. 391-326 (Jul 1999).

R.L. Steiner, D.B. Newell, and E.R. Williams, "A Result from the NIST Watt Balance and an Analysis of Uncertainties," IEEE Trans. Instrum. and Meas., **48**, No. 2, pp. 205-208 (Apr 1999).

E.R. Williams, R.L. Steiner, and D.B. Newell, "An Accurate Measurement of the Planck Constant," Physical Review Letters, **81**, No. 12, pp. 2404-2407 (Sep 1998).

Voltage Metrology

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.

Yi-hua Tang installs the cryoprobe in the 1 Volt programmable Josephson array voltage standard.

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 industries 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 industries 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 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 higher accuracy than is presently available through our standard volt calibration services. To provide that increased accuracy 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 four.

MILESTONE: By 2001, complete the documentation for the 10 V Zener MAP so it can be offered as a regular service to NIST customers.

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

Technical Contact:
Yi-hua Tang

Staff-Years:
2.3 professionals
0.3 guest scientist

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

Parent Program:
National Electrical Standards

these standards, a traveling compact Josephson voltage standard (JVS) is being developed 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.

MILESTONE: 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).

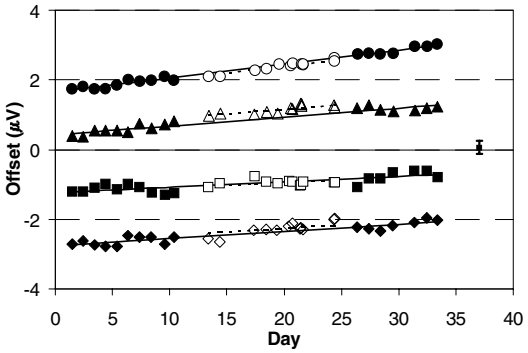
MILESTONE: By 2002, assemble a compact JVS system and evaluate its performance for both direct and indirect comparisons between geographically separated JVS systems. This will ultimately provide a significant improvement to the accuracy and reliability of JVS intercomparisons.

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.

MILESTONE: By 2003, implement a Josephson voltage system for daily use into the customer calibration service.

Accomplishments

- The detailed procedure for the 10 V Zener Measurement Assurance Program (MAP) has been designed and evaluated. This procedure includes the measurement protocols, the procedures for analysis of the measurement data, and the full error budget. The measurement protocol has been improved, compared to the protocol used for earlier Zener-based JVS intercomparisons, through the determination and application of corrections for environmental effects on the traveling Zener standards. The analysis and determination of the measurement uncertainty are fully compliant with the *Guide to the Expression of Uncertainty in Measurements (GUM)* set forth by the International Organization for Standardization. This MAP was offered as a special test for Lockheed Martin Astronautics (LMA) using a set of well-characterized Zener transport standards made available by the National Conference of Standards Laboratories (NCSL). The difference between the voltage unit at LMA and that maintained at NIST was found to be 0.059 (±0.190) μV. The uncertainty (expanded for 95 % confidence) represents an uncertainty of 1.9 parts in 10^8 in the measurement of the output of the 10 V traveling Zener standards.



Results of the 10V MAP showing the results of measurements on four separate Zeneer transfer standards, vertically offset for clarity. From the average of the four Zeners, the difference between LMA and NIST (indicated by the isolated point to the right) was found to be quite small, 0.059(±.190) μV.

- In order to provide the 10V Zener MAP as a regular service and achieve an uncertainty of five parts in 10^8 or better, it is necessary for NIST to have and maintain a set of very well characterized Zener standards. Based on extensive characterization over the past year, we have chosen four such Zener standards that have virtually no humidity effects and noise levels below 0.03 μV (2σ) at 10 V. We have measured their pressure and temperature coefficients and have carefully monitored their performance for several months. These are ready for use in the 10 V Zener MAP for JVS intercomparisons or for other voltage measurement systems.

- We have begun routine intercomparisons between the two JVS systems at NIST, NIST-1V and NIST-10V. Each is used to measure the Zener standards for the monthly voltage transfer from the JVS to the primary standard cell groups in the calibration laboratory. The value transferred to the primary cell group by the two systems differs by only 0.001 (±0.008) μV. This verifies that the two systems can be used interchangeably for the routine voltage transfer to

the calibration laboratory, thus increasing reliability of our voltage calibration services.

FY Deliverables

Calibrations

106 calibrations were performed with approximately $60,000 income received. (October 1, 1999 to September 30, 2000)

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.

Publications

W. B. Miller and Y.H. Tang, "Measurement Assurance Program for an Intercomparison of Josephson Voltage Standards between NIST and Lockheed Martin Astronautics," 2000 Natl. Conf. of Standards Laboratories Intl. Workshop and Symp. (NCSL), Jul 16-20, 2000, Toronto, ON, Canada (Jul 2000).

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D. Reymann, T. J. Witt, P. Vrabcek, Y.H. Tang, C. A. Hamilton, A. Katkov, B. Jeanneret, and O. Power, "Recent Developments in BIPM Voltage Standard Comparisons," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2000), May 14-19, 2000, Sydney, Australia, pp. 253-254 (May 2000).

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Y.H. Tang, R. Steiner, and J. Sims, "Comparison of Two Josephson Array Voltage Standard Systems Using a Set of Zener References," IEEE Trans. Instrum. and Meas., **48**, No. 2, pp. 262-265 (Apr 1999).

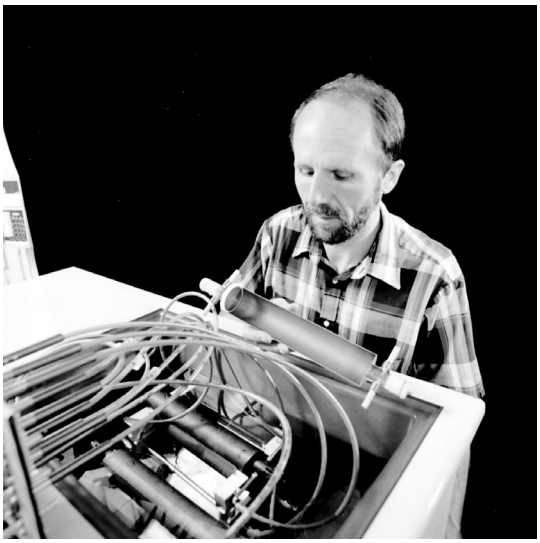
A. Hamilton and Y.H. Tang, "Evaluating the Uncertainty of Josephson Voltage Standards," Metrologia, **36**, pp. 53-58 (1999).

Y.H. Tang, "Comparison of Two Josephson Array Voltage Standard Systems Using a Set of Zener References," Conf. on Precision Electromagnetic Measurements Digest (CPEM'98), Jul 6-10, 1998, Washington, DC, pp. 357-358 (Jul 1998).

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, and traceable resistance standard that is readily and continuously available for the U.S. scientific and industrial base.



Rand Elmquist inspects a set of calculable AC/DC 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 is a growing need for improved resistance metrology at low ac frequencies. We are extending our measurement capabilities to bridge the gap that exists between our DC resistance and ac impedance services. This service, based on NIST 100 Ω and 1 k Ω calculable coaxial resistors and an ac Kelvin bridge, will support NIST calibrations of instruments including LCR-meters and digital multimeters, and standards for bridges used to calibrate inductors, strain gauges, and thermometers.

MILESTONE: By 2001, offer for NIST internal customers, an ac resistance characterization and calibration service in the frequency range 20 Hz to 2 kHz with fractional uncertainties in the range of 1×10^{-6} or below.

In response to the demand for improved measurements, NIST is extending measurement services to higher resistance values and continuing to develop and characterize higher resistance standards.

MILESTONE: By 2001, complete construction and characterization of additional Hamon transfer standards (100 GΩ/step, 1 TΩ/step, 10 TΩ/step) to extend measurement range to the 100 TΩ level. Provide a calibration service as a special test at the 100 TΩ level with an expanded uncertainty of 0.3 % or better.

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

Technical Contact:
Randolph E. Elmquist

Staff-Years:
5.0 professionals
1.3 technicians

Funding Sources:
NIST (90 %)
Other Government Agencies (10 %)

Parent Program:
National Electrical Standards

of this project is the study of those connections, their reliability, and their failure mechanisms.

MILESTONE: By 2001, investigate the reliability of QHR contacts prepared by a variety of connection methods.

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.

MILESTONE: By 2004, make an SI measurement of the ac QHR via the calculable capacitor.

Accomplishments

- A guarded active-arm bridge, consisting of programmable DC sources, detectors, and a guarded scanner, has been developed and installed for measuring high-resistance standards at and above 10 MΩ. The range of the bridge has been extended to 10 TΩ and 100 TΩ, and the bridge has been used to successfully provide a special test at 10 TΩ for a NIST customer, with an expanded uncertainty of 0.2 %. To accurately calibrate standards above 1 TΩ, several existing NIST-built Hamon transfer standards (1 GΩ/step and 10 GΩ/step) have been characterized using the guarded active-arm bridge, and bridge ratios of 1/100 and 1/1000 have been tested and implemented. A new active guarding system reduces uncertainty at the highest resistance levels. Resistance elements of nominal values 1 GΩ, 10 GΩ, and 100 GΩ have been characterized and are being used to construct better high-resistance standards for the NIST calibration service and DOD and DOE primary standards.

- An ac Kelvin bridge has been developed consisting of NIST-designed programmable binary inductive voltage dividers (IVDs) as the main and inner ratio arms. The binary IVDs exhibit terminal linearity within 0.2 ppm in phase over the frequency range 40 Hz to 2 kHz. Additional commercial programmable IVDs are used for the less critical Wagner earth balance. All IVDs, along with the bridge ac source and null detector, are remotely programmable through a standard IEEE-488 interface to provide complete automation of the measurement system. The system is designed to measure unknown ac resistors from 1 Ω to 10 kΩ against ac/dc standard resistors using the substitution technique. Measurements at 100 Ω and 1 kΩ indicate a bridge precision of 0.1 ppm or better. Problems with lead resistance errors, caused by the variable input impedances of the IVDs, are being solved using operational amplifier techniques. It is expected that a special test calibration service for ac resistors will be established in FY01.

High resistance standards, in the range 10 MΩ to 100 TΩ, developed and fabricated at NIST to improve NIST calibration services, support DOD and DOE primary standards laboratories, and support international comparisons.

- The effects of temperature, power dissipation, and aging were investigated on four calculable coaxial resistors designed and recently constructed at NIST. Measurements linking NIST's calculable capacitor experiment to the quantized Hall resistance standard are based in part on a calculable coaxial 1 kΩ resistor built over thirty years ago. Three new 1 kΩ standards and one 100 Ω standard were constructed, incorporating NIST advances in heat-treatment of resistance alloys into the coaxial straight-wire design. A series of comparisons were conducted at 1592 Hz and 15.92 kHz, determining the absolute phase angles and verifying that known physical and electrical differences among the resistors give predictable changes in measurement results. These calculable coaxial resistors ensure reliable transfer between ac and

dc resistance and will allow ac resistance measurements to be based on the quantized Hall resistance.

- An international comparison of dc resistance at 10 MΩ and 1 GΩ was organized under the auspices of the Comité Consultatif d'Électricité et Magnétisme (CCEM) and piloted by the National Institute of Standards and Technology (NIST). This CCEM comparison began in August of 1996 and was completed in March of 2000 with 14 other national metrology institutes (NMIs) participating. The traveling package included three wire wound 10 MΩ standards and three film-type 1 GΩ standards in special containers designed by NIST. As the pilot NMI, NIST was responsible for organizing the comparison, analyzing the reported results, and preparing the final report. The first draft, draft A, was submitted only to the participating NMIs for their comments. The subsequent draft B was submitted for approval to the CCEM Working Group on Key Comparisons, which met at the International Bureau of Weights and Measures (BIPM) on September 13, 2000. Results of this key comparison indicate that the differences at 10 MΩ and 1 GΩ between each NMI's reported value, and the respective reference value, are all within each NMI's combined expanded uncertainty at a coverage factor k = 2. The results demonstrate the equivalence of the participating NMIs' national standards of resistance at the high end of the resistance scale. This is one of the essential objectives of the Mutual Recognition Arrangement (MRA) organized by the International Committee on Weights and Measures (CIPM) to provide mutual recognition of the NMIs' calibration capabilities and traceability to the SI in order to eliminate technical barriers to international trade.

- A reliable procedure was developed for preparing high-quality ohmic contacts to the semiconductor heterostructures used in quantum Hall resistance (QHR) standards. It has been a continuing challenge in making metallic contacts to semiconductors to ensure that the metal makes intimate and uniform contact with the semiconductor. QHR devices made from III-V compound semiconductor heterostructures have proven especially sensitive to defects and non-uniformities in the contact region. In particular, oxides on the semiconductor substrate are difficult to remove, but are thermodynamically stable during the contact alloying reaction and have very damaging performance effects on the final contacts. A solution to the oxide contamination was found in the use of an alcohol-based hydrochloric acid etch which removed the oxide and passivated the heterostructure surface with adsorbed chlorine. Though sufficiently stable to survive transfer into the evacuated alloying chamber, the adsorbed chlorine was readily removed by heating and did not interfere with reliable contact formation. This procedure has potential to find general application to improve contacts in commercial devices made from GaAs/AlGaAs heterostructures. This work received considerable interest when it was reported at the 197th Conference of the Electrochemical Society.

FY Deliverables

Calibrations

356 calibrations were performed with approximately $328,300 income received. (October 1, 1999 to September 30, 2000)

Publications

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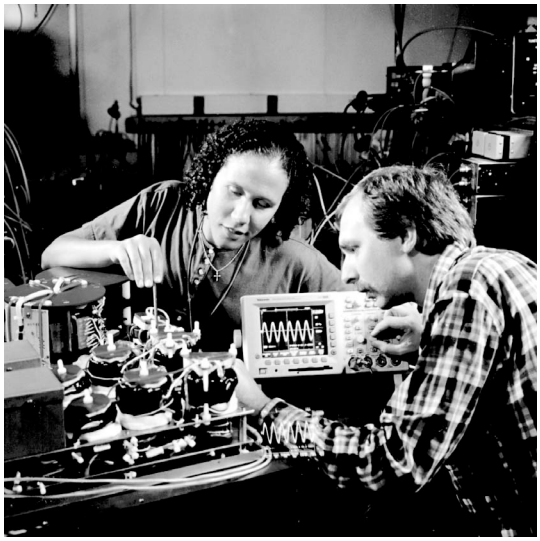
Realization of the SI Farad and Ohm

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.



Anne-Marie Jeffery and Scott Shields test the high-precision multi-frequency capacitance bridge.

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.

At present, all ac measurements linking the calculable capacitor to the farad and the ohm are done at 1592 Hz. The capacitance unit that is transferred from the calculable capacitor to the calibration laboratory is only provided at that frequency. However, customer standards are calibrated at other frequencies; as a result, the uncertainty provided for customer calibrations is significantly increased to account for differences in the capacitance unit due to frequency dependence. Multi-frequency measurement capabilities must be developed to better support customers' needs in the frequency range from 100 Hz to 10 000 Hz. Better calibrations at 1 kHz will also lower uncertainties of the high-frequency impedance work (>1 MHz) at NIST which are based on 1 kHz measurements. A new impedance bridge has been built that works at frequencies in the range from 100 Hz to 2000 Hz that will be used for these measurements. The systematic uncertainties of this bridge must be thoroughly evaluated in the same way as the bridges that are part of the present measurement system.

MILESTONE: By 2001, complete testing of new multi-frequency impedance bridge.

MILESTONE: By 2001, provide the capacitance unit to the calibration laboratory at 1000 Hz.

MILESTONE: By 2002, provide the capacitance unit to the calibration laboratory at 400 Hz.

MILESTONE: By 2003, provide the capacitance unit to the calibration laboratory at 100 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

Technical Contact:
Anne-Marie Jeffery

Staff-Years:
2.2 professionals
0.7 technician

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

Parent Program:
National Electrical Standards

establishing a calculable capacitor measurement 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.

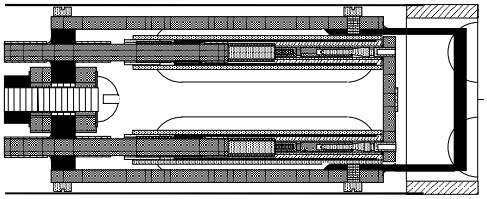
MILESTONE: By 2001, verify the equivalent circuit model for the ac QHR system.

MILESTONE: By 2004, make an SI measurement of the ac QHR via the calculable capacitor.

Accomplishments

- A measurement of the calculable capacitor has been performed at 1000 Hz. This is the first time that this measurement, the basis for obtaining the US capacitance unit, has been made at a frequency other than 1592 Hz. Successful completion of this measurement required the re-evaluation of several auxiliary measurements and systematic uncertainties associated with the calculable capacitor at this frequency. An important outcome of this work is expected to be a significant reduction in the uncertainty of capacitance calibrations at 1000 Hz.

- The design of the ac QHR probe needed for the ac QHR measurements is complete. The probe was designed to reduce as much as possible the wire-to-wire capacitances on the probe header. A detailed circuit analysis of the QHR sample indicated that these capacitances have a significant effect on the frequency dependence of ac QHR measurements. Once construction and assembly is complete, experimental studies will begin of anomalies in the frequency dependence of ac QHR measurements.



Cross sectional view of the newly designed ac QHR probe. This probe was designed to meet the stringent, and sometimes conflicting, demands of both ac and dc resistance metrology.

- Testing of the new multi-frequency bridge is continuing. The bridge was compared to an existing bridge for the measurement of 10:1 capacitance ratios at 1592 Hz and 1000 Hz and agreed to within a few parts in 10^9. This bridge can now be used for regular measurements of the 10 pF bank at several frequencies. The transformer ratio of the new bridge has also been measured at frequencies of 1592 Hz and 1000 Hz. However, it was observed that the ratio varies by a few parts in 10^8 over time whereas transformer ratios of existing bridges are stable to parts in 10^9 over years. This has been under investigation and it has been established that the changes observed in the ratio are not due to the voltage dividers that provide the bridge adjustment but rather something related to the transformer itself. Several possibilities have been investigated including magnetization of the cores, magnetization of the Mu-metal shielding, humidity effects on the windings, and loading effects, but none of these appear to be the source of the problem. Further testing will be done to determine the source of this drift in the transformer ratio. The instability of the transformer ratio does not hinder the use of this bridge for measurements of the 10 pF bank at several frequencies.

- Three different techniques for mounting QHR samples for mounting quantized Hall resistors in ac QHR measurements have been developed. Two of the methods use special soldering techniques to attach the device to a sample holder, and the third connects the device to the electrical connections on the sample holder using bonded wires. A report was prepared assessing the advantages and disadvantages of each of the three techniques. The report also evaluates the ease of use, the relative performance, and the reliability and resistance to degradation or failure of each of the devices fabricated by the three techniques.

FY Deliverables

Collaborations

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

Publications

A. Jeffery, "Report on the CCEM Comparison of 10 pF Capacitance Standards," Digest for Conf. on Precision Electrical Measurements (CPEM 2000), May 14-19, 1999, Sydney, Australia, pp. 327-328 (May 2000).

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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.

Bill Huber examines an SET transistor encased in a nano-Faraday cage under an optical microscope.

Customer Needs

This project addresses three different needs: the development of a fundamental representation of capacitance, of a fundamental representation of electrical current, and of general applications of SET devices.

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.

Technical Strategy

This project is addressing these needs through the development of single-electron tunneling (SET) technologies. SET devices are being developed which 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 which is expected to meet the desired specifications of precisely tunable value, stability, frequency independence, etc.

MILESTONE: By 2001, evaluate the frequency dependence, stability, and performance of the capacitor and integrate with the SET electron pump.

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

Technical Contact:
Neil Zimmerman

Staff-Years:
1.0 professional
1.0 postdoc

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

Parent Program:
National Electrical Standards

systematic error evaluated, quantified and understood.

MILESTONE: By 2002, 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 move electrons one-by-one provides promise of a current standard based on controlled pumping of single electron charges. This then allows the possibility of use in the metrology triangle

MILESTONE: By 2001, evaluate possible experimental approaches for closing the metrology triangle.

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

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

At present, a primary difficulty with 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.

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

At present, a primary difficulty with the metrology triangle is that a single SET device can supply only a current of 1 pA. This is too small to be useful by at least a factor of one hundred. The 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.

MILESTONE: By 2003 (if previous milestone suggests feasibility), produce a prototype device with parallel SET electron pumps.

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

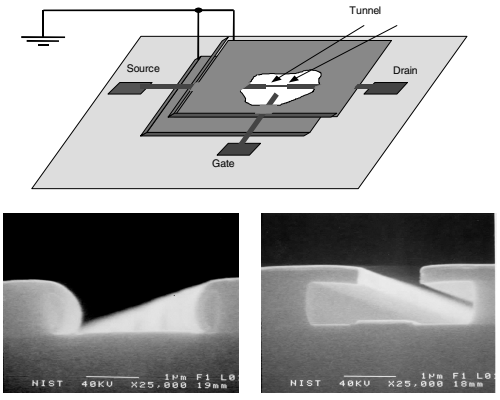
This project's expertise in fabricating SET devices lends itself to other nano-fabrication technologies, which has led to fruitful collaborations with other NIST researchers. In particular, a program to develop sub-100 nm electrochemically deposited copper metallization lines is being pursued with the Metallurgy Division. This program's relevance is due in part to the proprietary nature of other possible electrochemical baths, making NIST's version a potential industry-wide test case.

MILESTONE: By 2001, develop 50 nm-wide trenches in polymer resist for testing seed- and bath-depositions.

MILESTONE: By 2003, develop 50 nm-wide trenches in inorganic solid, for testing copper line resistance and electromigration.

Accomplishments

- The long-term time dependence of the charge offset of several SET Transistors (SETT) has been investigated and noise associated with that offset was found to diminish with time. These measurements demonstrated that there is a transient charge offset fluctuation, which decreases with time after fabrication. This transient is produced by the presence of amorphous/nano-crystalline aluminum oxide in the near vicinity of the SETT. The transient appears to be correlated with the relaxation of the amorphous structure in the oxide. This correlation has been confirmed by agreement between the measurements and a theoretical model of the time and temperature dependencies of both the long-term drift and the short term noise.



Top: Schematic of the "nano-Faraday cage", designed to shield SET devices from electromagnetic interference. Bottom left: failure of thin-film stencil (collapse) using previous process. Bottom right: success of stencil (horizontal ledges) using new, stiffened stencil process.

- In one of many attempts to reduce/eliminate the charge offset, the "nano-Faraday cage" was invented, fabricated and tested. This is a SETT totally confined by metal layers, to shield the transistor from electromagnetic fluctuations. Although this device did not substantially reduce the charge offset noise, it did make more robust

and reliable SETTs. In particular, the resistance to damage by environmental degradation (water) and by electrons (exposure in an electron microscope at 40 kV) of caged SETTs was found to be superior to that in unprotected SETTs.

- Achieved the first transport confirmation of metallization in xenon. This was done in collaboration with workers at the Carnegie Institution, in an attempt to identify superconductivity in noble solids (gasses compressed to megabar pressures).

- "Superfill", the complete filling of trenches without any voids, has been demonstrated by electrochemical deposition in trenches as small as 90 nm. This is the result of a collaboration with workers in the Metallurgy Division. The SET project's contribution has been the fabrication of the trenches, and some of the microscopy before and after copper deposition. This successful filling is well beyond that reported by the industry, in terms of the small width of the trenches.

FY Deliverables

Collaborations

Bill Huber and Neil Zimmerman collaborate with Dan Josell of the MSEL Metallurgy Division on theory and experiments related to thin-film deposition, and on the copper line program.

Neil Zimmerman and Bill Huber collaborate with Bruce Kane of University of Maryland, and Marc Manheimer and Keith Schwab of the Laboratory for Physical Sciences, on SET fabrication, and on issues related to measurements and the charge offset problem in the context of quantum computing.

Neil Zimmerman and Bill Huber collaborate with Mikhail Eremets and coworkers of the Geophysical Laboratory and Center for High Pressure Research of the Carnegie Institution of Washington, on a search for superconductivity at sub-1 K temperatures and high pressures in noble gasses.

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

Publications

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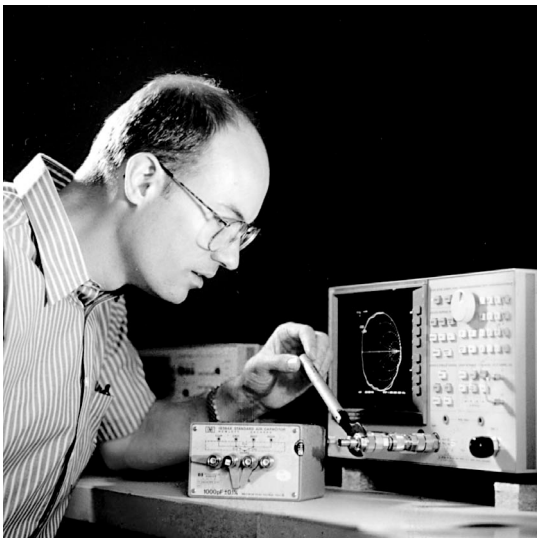
M. Kenyon, J.L. Cobb, A. Amar, D. Song, F.C. Wellstood, C.J. Lobb, N.M. Zimmerman, "Behavior of a Charged Two-Level Fluctuator in an Al-AlOx-Al Single-Electron Transistor," IEEE Trans. Appl. Supercond. **9**, p. 4261 (1999).

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

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 voltmeters. Hence, the general strategy for achieving a new generation of automated laboratory test systems will be to utilize the development at NIST of a wideband (100 Hz to 200 MHz) sampling voltmeter (WSV) that has excellent linearity, frequency flatness, and stability. Using the voltmeter effectively in precision bridge applications will require the miniaturization and integration of the voltmeter, together with a compact waveform generator, in a phase-locked configuration.

MILESTONE: By 2001, develop a wideband sampling voltmeter implemented with field programmable gate array logic and fabricated on a PCI bus-based printed circuit board, with performance comparable to the present benchtop instrument.

Development of general wideband impedance measurement services requires characterizable reference standards over the covered impedance range. 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. Bootstrapping techniques may be applied to extend the characterization from the 1 nF standard to higher-valued capacitance standards up to 1 μF.

MILESTONE: By 2002, develop and implement a system to 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.

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

Staff-Years:
2.5 professionals
2.0 technicians
0.75 contractor

Funding Sources:
NIST (62 %)
Calibration Services (33 %)
Other Government Agencies (5 %)

Parent Program:
Low Frequency

The present sources of reference waveforms for use in the 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, a new generation of synthesized waveform generator is required that can provide the necessary modes, synchronization, ranges, resolutions, and accuracies for amplitude, waveshape, frequency, and phase required for the aforementioned NIST calibration services.

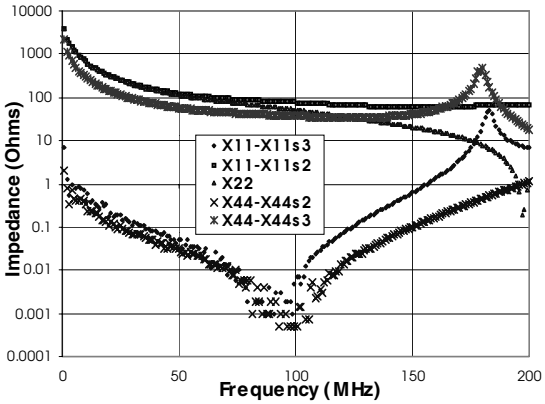
MILESTONE: By 2003, develop a synthesized arbitrary waveform generator that, together with the PCI bus WSV described above, can provide the performance needed to support the NIST calibration and Special Test services for state-of-the-art waveform analyzers, wattmeters/watthourmeters, power analyzers, and impedance standards.

To address the need for improved power calibrations, a new power bridge (50 Hz to 400 Hz) that is intended to extend the voltage and current ranges of the present NIST power bridge (see Metrology for Electric Power Systems). This bridge will use a classical current comparator and impedance standards to measure current, and thermal converter standards to measure voltage. However, a promising technique has been demonstrated recently that uses waveform sampling technology for making such measurements conveniently and accurately, thus improving the efficiency of making these measurements and extending the frequency range.

MILESTONE: By 2004, develop a limited range sampling wattmeter capable of measuring complex power with frequency components up to 500 kHz.

Accomplishments

- A NIST special test of a 4TP capacitor set (1 pF, 10 pF, 100 pF, and 1000 pF at frequencies from 1 kHz to 10 MHz) was completed and a test report generated for the Sandia National Laboratories. This is the first time that a national measurement laboratory has had the capability to provide direct measurement support for the traceability of 4TP capacitors. The basic model for 4TP capacitors and the methodology for characterizing these devices originated at NIST in the 1960s with the work of R. Cutkosky and R. Jones. Until now, however, the techniques for, and the *de facto* standards used in providing the calibration of 4TP capacitors rested with a well-known U.S. electronics manufacturer's subsidiary in Japan.



Single port difference data for a 10 pF 4TP standard. Capacitance and dissipation factor are computed from this data.

- Staff in the Electricity Division of EEEL have demonstrated an Internet-assisted calibration of an electronic instrument located at the Sandia National Laboratories (SNL). This is the first example of a so-called "e-calibration" in the electrical area on a remote programmable instrument for a NIST customer. The instrument under test at SNL was a multifunction calibrator used to calibrate the five electrical measurement functions available on most digital multimeters (DMMs). The reference at NIST for this test was a commercial multifunction calibrator, which is periodically characterized using basic NIST electrical standard artifacts. Artifact calibration of commercial calibrators is also used at many industrial standards laboratories; however, even with automation, it takes a skilled metrologist about one week to perform the characterization. The objective of the new e-calibration service is to relieve NIST customers of this burden by performing an *in-situ* calibration of their calibrator using a precision DMM, calibrated by the NIST-characterized multifunction calibrator, as a traveling transfer standard.

- The MCOM Subcommittee for Capacitance Calibration Services completed its technical review of the needed documentation for supporting the uncertainties used in the NIST Low Frequency Capacitance Calibration Services. Printed copies of NIST Special Publication 250-52 on "Error Analysis and Calibration Uncertainty of Capacitance Standards at NIST" by M. Chang (dated January 2000) are now available and are being included in customer's test reports.

- All of the Interamerican Metrology System (SIM) data taken on precision DMMs - used as transfer standards for five electrical quantities - has been collected and analyzed. A report of the results was posted on the SIMnet website for comments, prior to presenting a corresponding paper in December at the Metrologia-2000 convention to be held in Sao Paulo, Brazil.

FY Deliverables

Calibrations

The FY00 results include 265 tests on 162 artifacts for 88 customers for impedance standards and inductive voltage dividers for a total FY income of approximately $300,000.

The FY00 results also include 15 phase meters, bridges, generators, VOR meters, and quadrature detectors; 22 DMMs, ac-dc transfer standards, current sources, and shunts tested for 25 customers providing approximately $60,000 of income.

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.

B. Waltrip participated in an international intercomparison of RMS voltage flatness measurements with several NMIs, including: NIST, NRC (Canada), VSL(Netherlands), and PTB (Germany). The intercomparison was performed using a 1 Vrms calorimetric thermal voltage converter (CTVC) as the transfer device. The measurements were made at 1 Vrms over the 1 kHz to 100 MHz frequency range. Conventional thermal voltage converter (TVC) techniques were used in the 1 kHz to 1 MHz frequency range, while the NIST Wideband Sampling Voltmeter was used in the 1 MHz to 100 MHz frequency range.

Publications

Y. M. Chang, "NIST Measurement Services: Error Analysis and Calibration Uncertainty of Capacitance Standards at NIST," NIST SP 250-52, Natl. Inst. Stand. Technol., 89 pages (Jan 2000).

S. Avramov-Zamurovic, A. D. Koffman, N. M. Oldham, and B. C. Waltrip, "The Sensitivity of a Method to Predict a Capacitor's Frequency Characteristic," IEEE Trans. Instrum. Meas. , **49**, No. 2, pp. 398-404 (Apr 2000).

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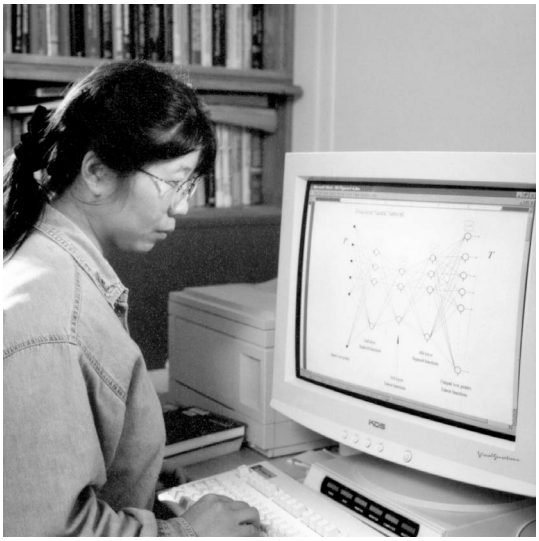
Measurements for Complex Electronic Systems

Project Goals

To develop and disseminate methods and techniques for optimum testing scenarios by using new or improved modeling and test procedures, estimating confidence levels and test coverage, and extending this methodology to address software-embedded systems.



Xiaolian Han using the five layer Principal Component Neural Network developed for modeling nonlinear error behavior.

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 prove 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. With the advent of embedded firmware in not only digital but also mixed-signal devices and instruments, the task of accounting for pernicious nonlinear, time-variant interactions between the hardware and software becomes more difficult in an efficient, yet comprehensive, testing strategy.

Technical Strategy

Expansion of the present NIST expertise in modeling and testing complex electronic systems requires the investigation and application of statistical analysis methods to ill-posed problems. Appropriate inverse transformations may be required to "de-embed" the effects of firmware, along with modeling and accounting for time dependencies. Improved methods are needed to efficiently test nonlinear behavior.

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. Recent investigations into the use of artificial neural networks have shown promise of achieving efficient models for handling nonlinear dependencies. Of particular interest is the employment of nonlinear principle component neural networks, which reduce the data dimensionality relative to linear modeling for nonlinear devices.

MILESTONE: By 2001, develop a neural network-based approach that can realize a significant improvement to the present HELP testing strategy for modeling the behavior of instruments.

MILESTONE: By 2001, implement online dissemenation 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.

MILESTONE: By 2002, add the capability to include incomplete data sets into the HELP Toolbox.

The ability to make engineering changes quickly in the design of a complex electronic product is

Technical Contact:
Gerard N. Stenbakken

Staff-Years:
2.5 professionals
1.0 guest scientist
0.25 contractor

Funding Sources:
NIST (100 %)

Parent Program:
Low Frequency

necessary to meet the demands of the marketplace. To achieve these changes by simply modifying the embedded software used in the product is very cost effective. However, such changes are likely to change the model that has been developed to predict the performance of the product and, thus, its testing strategy.

MILESTONE: By 2003, develop the means for an adaptive modeling approach that can be incorporated into the present HELP testing strategy, which can be applied to changes in product design.

Correlated noise, such as 1/f noise, can enter the modeling process in the form of drift in the instrumentation making measurements used for the modeling set. This noise has a characteristic structure. The data sets used at NIST to model an instrument's error behavior have been analyzed to show a significant amount of 1/f noise. Since 1/f noise in measured data can substantially affect the empirical error models built from that data, and since 1/f noise is ubiquitous, this is a potentially serious problem in time-variant behavior in general. The fact that we are able to glean this information from an instrument's calibration data indicates there may be ways to reduce this error source.

MILESTONE: By 2004, develop methods for determining the amount of 1/f noise in a modeling data set, the effect this noise has on the confidence intervals predicted using this model, and methods for reducing these errors.

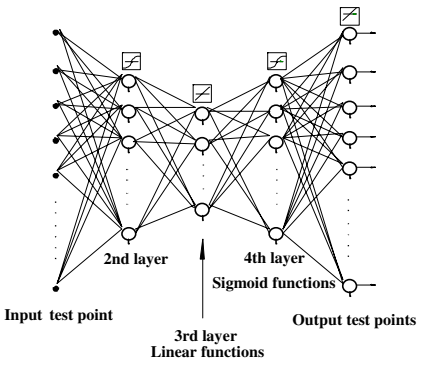
Accomplishments

- A Workshop on Software-Embedded Systems Testing (WSEST) was held at NIST-Gaithersburg on November 8-9, 1999. Sixteen attendees represented government (6), academia (7), and industry (3), where the focus was on problems in testing mixed-signal systems with embedded software. Topics included metrology support for built-in-test, controlling test complexity, maintaining accurate models, and software validation. The subjects covered a wide range of disciplines, including metrology, software, hardware, mathematical algorithms, and instrument manufacturing. A concluding panel discussion was held on research needs in the testing of software-embedded systems.

- Further research was pursued on modeling nonlinear behavior in error data. A Neural Network Toolbox was used in conjunction with Constructive Neural Network software to build models of simulated nonlinear data. The limitations of this approach were explored in terms of speed of convergence, noise immunity, and level of complexity. In modeling a five parameter bandpass filter, for example, it was found that a five-fold improvement in the mean squared error was obtained using a neural network nonlinear modeling approach vs a linear model when the parameter values change by 20 %. A paper on this research was presented at the Instrumentation and Measurement Technology Conference (IMTC) 2000.

- The algorithm for minimizing cumulative time-base quantization errors was presented at the WSEST and documented in a paper given at the IMTC 2000. It describes the errors expected as a function of the number of samples taken, the number of signal cycles sampled, and the number of bits for the reference digital-to-analog converter used in the time-base. However, further study of nonrandom amplitude errors in sampling systems did not lead to a generic approach to correcting such sources of error as was hoped.

- A comparative analysis was begun of the data from a manually operated, multi-range thermal transfer instrument with that from an automated version of the manual one, using a linear empirical model in conjunction with the NIST-developed HELP (High-dimensional Empirical Linear Prediction) Toolbox. The results thus far indicate that error structure of the automated version exhibits fewer degrees of freedom, i.e., less complexity than its manual counterpart, contrary to what was expected. Model prediction variance as a function of model size and number of test points selected has also been investigated.



Five layer Principle Component Neural Network developed for modeling nonlinear error behavior.

FY Deliverables

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 an expectation maximization approach. This work also involves Hung-kung Liu in the ITL.

Prof. Fernando Von Zuben of the State University of Campinas, Brazil spent a week at NIST helping the project members understand neural networks and how they can be incorporated into the NIST HELP Toolbox. Prof. Von Zuben consults with the project periodically.

The Software-embedded Systems Testing Competence project is one of the five 1997 NIST Competence projects which are collaborating their efforts with quarterly meetings and project interactions.

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

G. N. Stenbakken, D. Liu, J. A. Starzyk, and B. C. Waltrip, "Nonrandom Quantization Errors in Timebases," Proc. of 17th Instrumentation and Measurement Technology Conference (IMTC/2000), 1, May 1-4, 2000, Baltimore, MD, pp. 235-240 (May 2000).

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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 generator waveforms, 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 are attempting to develop a performance standard (IEEE PAR 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 which, together with an improved design architecture of the supporting electronics, will improve the performance of the comparator.

MILESTONE: By 2001, 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 automatic waveform analysis and measurement systems have been developed at NIST for purposes of providing test environments for supporting the Special Test services for fast pulse measurements. 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 in order to keep the costs of providing these NIST services reasonable.

MILESTONE: By 2002, develop a PC-LabVIEW™ –Tektronix 11801-based measurement system that can provide a more flexible, self-documenting, and automated system for performing the SP250 65X00 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 diode 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

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

laser source could be the basis for generating a relatively Gaussian-shaped reference electrical impulse.

MILESTONE: By 2003, develop a diode 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.

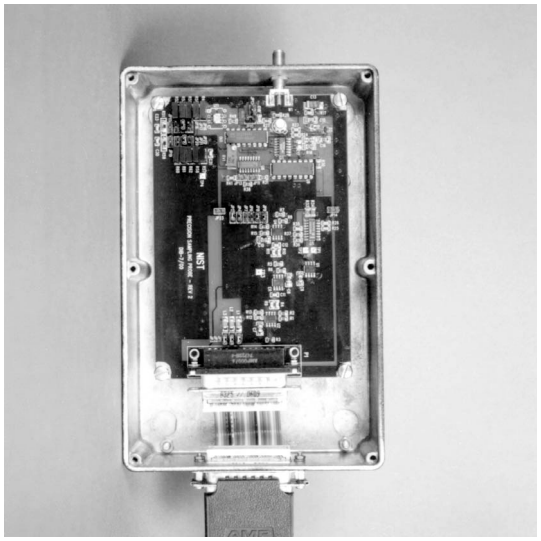
Jitter is a limiting factor in the performance of high frequency/high speed telecommunications and computer systems. In a telecommunications system, where a series of clock-recovery circuits are typically used, jitter degrades data recovery performance. Jitter measurements on telecommunications components and equipment are needed to assure compatibility between manufacturers and to identify sources of jitter. For microprocessor chips, the jitter in the on-chip clock's phase-lock-loop circuit is used by the manufacturer to sort the microprocessor for speed usage. Large errors in the measurement of clock jitter represent manufacturing yield loss. Several types of jitter measurements that are important are: transition-to-transition jitter, jitter relative to a fixed clock, jitter spectrum and data dependent jitter. These measurements are important for determining the source of jitter and component compatibility. Controlled jitter generation is important to test components accurately. Industry has reported to NIST that they get inconsistent results from jitter measurement using different techniques and would welcome a neutral party to evaluate the limits of the many measurement methods.

MILESTONE: By 2003, develop the capability for measuring jitter and jitter spectrum with low uncertainty for calibration of commercial jitter measurement equipment.

Accomplishments

- Special calibrations were performed using NIST pulse waveform testing systems on two commercial prototype oscilloscope calibrators that have internal high-speed (short transition duration) pulse generators. These high-speed pulse generators are used to test the transient response performance of several popular brands of real-time sampling oscilloscopes that offer bandwidth specifications (-3 dB attenuation) as high as 3 GHz. With the high frequency response roll-off of newer real-time analog and digital oscilloscopes increasing, verifying the important performance specification of 3 dB bandwidth has become increasingly difficult. In addition to testing for the pulse rise time (or transition duration), the NIST pulse testing systems were able to make accurate determinations of the waveform aberrations (deviations from flatness in settling).

- A new low-frequency sampling comparator probe prototype was designed, constructed, and tested. Compared to the existing wideband sampling comparator probe, the new low frequency probe provides higher input impedance (1 Mohm), lower noise (< 40 μV rms), a wider input voltage range (± 10 V), better linearity over the full input range (< 20 ppm), and comparable gain flatness over the 10 Hz to 100 kHz frequency range (about 20 ppm). These electrical characteristics are needed to support NIST Special Test and Calibration services for pulse settling, power, impedance, and amplitude flatness. Follow-up versions of the probe with minor modifications are under development for delivery to NIST customers engaged in applications including calibration of a commercial automated AC measurement standard and accurate measurement of 100 V pulses.



Prototype printed circuit board and module for the low frequency sampling comparator probe with the input signal connector shown at the top.

- Certain limitations were determined on the nose-to-nose technique for characterizing the impulse response of diode-bridge type, high-frequency samplers used in certain commercial 20 GHz and 50 GHz (3 dB bandwidth) equivalent-time, digitizing oscilloscopes. In general, having an accurate estimate for the impulse response of these samplers is important for measurement accuracy; moreover, these diode-bridge type samplers are used by NIST for pulse waveform calibration services. Poor

estimates for the impulse response of the samplers will degrade the uncertainties quoted for the calibration services. In particular, it has been established that there are regions of nonlinear behavior in the amplitude and bandwidth of the kickout pulses from the diode bridge sampler as a function of offset voltage. The technique assumes that these pulses are stable and symmetrical between the samplers used for the nose-to-nose testing procedure. A temperature-dependent time shift (drift) in the kickout pulse was also observed, over the manufacturers recommended operating temperature range (15 °C to 35 °C). The amplitude of the pulses changed, as expected, but the pulse width was unchanged.

- In conjunction with staff in the Semiconductor Electronics Division, a technique was established for performing accurate time-domain reflectometry (TDR) measurements in low-impedance (< 30 Ω) environments found in some printed wiring boards. The technique uses the NIST-developed transmission-line test vehicle a 50 Ω, 30 GHz probe, and commercially available, high-speed pulse generators and samplers. The signal launch end of the test vehicle was modified to reduce the amplitude of the spurious signal content, thereby improving TDR performance. This technique has been tested in a 10 Ω transmission line environment and for a 10 % impedance discontinuity and exhibited a 5-fold increase in signal-to-noise ratio compared to a conventional 50 Ω TDR.

FY Deliverables

Calibrations

15 tests performed on 14 items for eight companies and government agencies with approximately $30,400 income received. (October 1, 1999 to September 30, 2000)

Collaborations

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

A new collaboration is underway with the Center for Measurement Standards of the Industrial Technology Research Institute located in Taiwan. This collaboration is centered around time delay interval measurements, a service we offer as Special Test #65400S.

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 SCs on Waveform Recorder, A/D Converters, and Pulse Techniques.

N. Paulter participates as co-chair of the D-21b (High-Frequency Board Design) and D-21c (High-Frequency /High-Speed Controlled Impedance) IPC task groups.

Publications

D. R. Larson and N. G. Paulter, "The Effect of Offset Voltage on the Kick-Out Pulses Used in the Nose-to-Nose Sampler Impulse Response Characterization Method," Proc. 17th IEEE Instrumentation and Measurement Technology Conference (IMTC/2000), **3**, May 1-4, 2000, Baltimore, MD, pp. 1425-1428 (May 2000).

S. Roy and T. M. Souders, "Non-Iterative Waveform Deconvolution Using Analytic Reconstruction Filters with Time-Domain Weighting," Proc. of 17th IEEE Instrumentation and Measurement Technology Conference (IMTC/2000), **3**, May 1-4, 2000, Baltimore, MD, pp. 1429-1434 (May 2000).

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N. G. Paulter, "An Accurate Method for Measuring the Dielectric Constant of Printed Wiring Board Materials," Circuit World, MCB University Press, **26**, No. 1, pp. 27-32 (Oct 1999).

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.

Joe Kinard running new NIST Special Tests for the ac-dc difference of 100 A ac current shunts.

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 at NIST with which to verify accuracy claims, achieve consistency, and to help avoid technical trade barriers. Research and development is needed to maintain and to expand NIST calibration and Special Test services for thermal converters and shunts. A new capability is needed at NIST for calibrating high current shunts and high voltage converters. More reliable semiconductor thin film converter devices are needed that can be easily fabricated. A new national primary standard is needed to support measurement uncertainties at the 0.1 μV/V level.

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. NIST presently calibrates ac shunts at currents up to 100 A at frequencies of 10 kHz as special tests, thus meeting the milestone for this work that was indicated last year. However, now there are several customer requests to increase the frequency range to 100 kHz and to reduce the uncertainties of NIST current calibrations above 20 A by about a factor of two.

MILESTONE: By 2001, improve the characterization and reduce the uncertainties for NIST ac current shunt standards 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. A program is underway to develop improved thin-film multijunction thermal converters taking advantage of sophisticated microfabrication and packaging technologies, available at the Sandia National Laboratories.

MILESTONE: By 2001, in collaboration with Sandia National Laboratory, design, fabricate, and test improved thin-film multijunction thermal converters featuring vacuum mountings, suitable for use at currents ranging from the milliampere range to one ampere or more.

Technical Contact:
Joseph R. Kinard, Jr.

Staff-Years:
2.0 professionals
0.5 technician
1.0 guest scientist

Funding Sources:
NIST (44 %)
Other Government Agencies (38 %)
Calibration Services (18 %)

Parent Program:
Low Frequency

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, this 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 promising independent approach using inductive voltage dividers and precision digital voltmeters has been started at NIST.

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

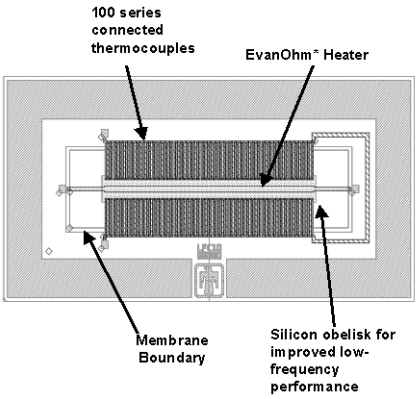
The thermal errors due to Peltier and Thompson effects in the heater structure of a thermal converter are temperature dependent. NIST has proposed to minimize these errors by developing a cryogenic-based thermal transfer standard that can operate at 6 K. A prototype system has been constructed that shows promising results in significantly reducing thermal errors. As the demand for having 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 is imperative.

MILESTONE: 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

- Four commercial shunts, based on a NIST design, were compared to the NIST-developed and fabricated shunts. These consisted of a 10 A to 30 A shunt, 30 A to 50 A shunt, 50 A to 80 A shunt, and 80 A to 100 A shunt. A current build-up from a 20 A NIST reference to the 100 A commercial shunt was performed; data indicate that the build-up measurements disagree with direct comparison to the NIST 100 A reference standard by about 1000 parts in 10^6 (1000 ppm) at 100 kHz. To support the NIST reference shunts, comparisons were made with a set of NIST-made two-stage, amplifier-aided current transformers (CTs) out to 100 kHz. The frequency coefficients of these CTs were characterized by direct comparison to NIST working standard thermal converters using an automated current comparator system, based on 50 Hz as the reference frequency. The effort to develop these CT and shunt standards now permits NIST to offer measurement services for high-current ac shunts up to 100 A, the only national measurement institute with this capability.

- Thin-film multi-junction thermal converters (FMJTCs) of several designs were fabricated at the Sandia National Labs using reactive ion etching. Four coaxial FMJTC designs, two for voltage (TVCs), and two for current (TCCs), were implemented with Evanohm heaters (TVCs) or gold heaters (TCCs) and 100 pairs of thermocouples each. One of the TVC designs retained a silicon obelisk beneath the heater to improve the time constant; subsequent measurements showed about a five-fold improvement in ac-dc difference at 10 Hz and 20 Hz over chips having no obelisk. The TCCs have gold heaters and are suitable for carrying a current of 1 A; one design having no window beneath the heater may be capable of carrying currents of 5 A or more.



One of the configurations of the thin-film multijunction thermal converters under development in collaboration with Sandia National Laboratories.

- Completed making inter-comparisons between the NIST thermal converter working standards and the reference TVCs from 1 V to 1000 V, 10 Hz to 100 kHz. Also completed the re-characterization of all of the high frequency (100 kHz to 1 MHz) reference TVCs in the range from 0.5 V to 50 V, updating the associated correction tables in the computer files for each standard. Voltage buildup measurements indicated agreement compared to the previous buildup to within 1 μV/V (1 ppm) at low voltage and 10 μV/V at 1000 V (10 ppm), 100 kHz.

- A software-implemented PID controller was developed with which to improve the stability of the cryogenic thermal transfer standard (CTTS). The latest measurements on the CTTS indicate that as a voltage converter the new high temperature superconducting transmission line has reduced the ac-dc difference at 100 kHz from 1650 x 10^{-6} (1650 ppm) to 360 x 10^{-6} (360 ppm), more than a four-fold improvement. Analyses of voltage converter measurements, current converter measurements, and voltage/current level dependence indicates that a major source of ac-dc difference is the suppression of the T_c of the transition edge sensor (TES) by the magnetic fields coupled into the signal and trim heaters. A new TES design will be necessary to overcome these effects.

FY Deliverables

Calibrations

By the end of FY 00, 515 calibration points at a cost of $101 992 were performed for 11 customers, in addition to four no-cost internal calibrations encompassing 196 points.

Collaborations

Active collaborations continue with Carl Reintsema and Erich Grossman 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 Charlie Burroughs and Sam Benz 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.

A visiting Guest Scientist from CENAM, Mexico, was hosted for two weeks by the ac-dc difference laboratory in March and April.

Extensive collaboration continues with the US 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.

Collaborated with the National Research Council in Canada to confirm the consistency of their ac-dc transfer standards with other NMIs and to test the performance of their new Calorimetric Thermal Transfer Standard.

External Recognition

Joseph Kinard served as chairman for the CPEM 2000 session on ac-dc transfer and also attended the international CCEM meeting of ac-dc difference experts.

Publications

P. S. Filipski, C. J. van Mullem, D. Janik, M. Klonz, J. R. Kinard, T. Lipe, and B. Waltrip, "Comparison of High Frequency AC-DC Voltage Transfer Standards at NRC, VSL, PTB, and NIST," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2000), May 14-19, 2000, Sydney, Australia, pp. 226-227 (May 2000).

T. F. Wunsch, J. R. Kinard, R. P. Manginell, O. M. Solomon, and T. E. Lipe, "A New Fabrication Process for Planar Thin-Film Multijunction Thermal Converters," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2000), May 14-19, 2000, Sydney, Australia, pp. 387-388 (May 2000).

C. D. Reintsema, J. R. Kinard, and T. E. Lipe, "A High Temperature Superconducting Transmission Line for Cryogenic Electrical Metrology Applications," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2000), May 14-19, 2000, Sydney, Australia, pp. 488-489 (May 2000).

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J. R. Kinard, T. E. Lipe, C. B. Childers, O. B. Laug, and R. H. Palm, "Broadband Ac-dc Difference Calibrations of Current Shunts up to 100 A at NIST," Proc. 2000 Natl. Conf. of Standards Laboratories Intl. Workshop and Symp. (NCSL), Jul 16-20, 2000, Toronto, ON, Canada (Jul 2000).

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.

Martin Misakian connects a high voltage dc divider to a 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.

MILESTONE: By 2003, complete construction of automated sampling test system and begin use for customer calibrations up to 100 A and 600 V.

International comparisons are essential for the validation of measurement techniques used at National Metrology Institutes. 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.

MILESTONE: By 2002, complete SIM power and energy measurement intercomparison.

High-current transformers (CT) are key devices for the measuring of bulk power flow. There is an increasing need for the calibration of current transformers at frequencies greater than 400 Hz for use with wideband watthour meters. The existing NIST CT calibration system is capable of performing such calibrations with only moderate uncertainties (0.6 %).

MILESTONE: By 2002, a new test system including the test set, current comparator, and reference CT will be constructed that will allow calibrations up to 3000 Hz to be performed with an uncertainty of 600 ppm.

The effects of human exposure to electric and magnetic fields have been an area of significant interest to many industries, particularly the electric power industry. Recently, the interaction of personal medical devices (PMDs) with magnetic fields (MF) generated by metal detectors has been raised as an issue. A standard method of testing potential interactions of PMDs with MF is required to improve safety.

MILESTONE: By 2002, develop an affordable system to emulate the magnetic fields produced by metal detectors for testing of PMD suseptibility.

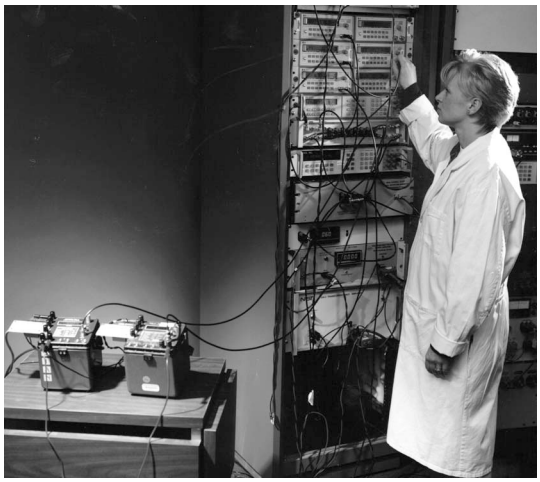
Technical Contact:
Thomas L. Nelson

Staff-Years:
4.0 professionals
0.5 guest scientist
0.5 technician

Funding Sources:
NIST (65 %)
Calibrations (20 %)
OLES (15 %)

Parent Program:
Power

Accomplishments



Lisa Snider calibrating watthour meters.

- NIST participated in an extensive comparison of power and energy measurements with the national measurement laboratory of Canada. The comparison consisted of 75 test points at voltages from 120 V to 600 V and currents from 5 A to 100 A. This comparison was a precursor to a full NORAMET intercomparison. The agreement between the laboratories was good with all measurements agreeing to better than 20 ppm. This agreement confirms the extended calibration capabilities of both labs, and the results were presented at CPEM2000.

- NIST participated in a round robin of impulse voltage divider calibrations sponsored by the International Conference on Large High-Voltage Electric Systems (CIGRE). Thirty laboratories from around the world will participate in this intercomparison which will be completed in 2001. This is the first international intercomparison of a high voltage impulse measurement system including a high voltage divider, digital recorder, and pc for control and analysis. In the past, only the divider was circulated.

- Equations were derived which predict the magnetic flux density for two or more rectangular coils positioned in the same plane. These equations can be used in the design of magnetic field generators for the emulation of the fields generated by metal detectors. A manuscript describing the derivation has been published in the NIST Journal of Research.

- The Interagency Committee created by the Research and Public Information Dissemination (RAPID) Program completed its report to Congress on the possibility of health effects from exposure to power frequency magnetic and electric fields. Representatives from NIST played a key role in developing the consensus required to finalize this document. The report confirms the lack of reproducible evidence supporting significant health risks from exposure. After final approval, the report will be presented to Congress as the final requirement for the completion of the RAPID program.

- Direct and alternating currents were measured through transmembrane ion channels formed by staphylococcus aureus -hemolysin proteins to determine the appropriateness of an equivalent circuit commonly used to model electrical interactions at the surface of cells. A novel method was used to distinguish the alternating current through one or more channels from the current coupled capacitively through the membrane. The results of the study verify an equivalent circuit that models the membrane as a capacitor in parallel with one or more resistors representing the channels over the frequency range 30 Hz to 120 Hz.

FY Deliverables

Calibrations

Calibrations were performed for 46 companies and government agencies with approximately $140,000 income received. (October 1, 1999 to September 30, 2000)

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 FY00.

IEC Technical Committee 85/ Working Group 11: M. Misakian served as Chair and was in charge of preparing the IEC Standard on Measurement of Low-Frequency Magnetic and Electric Fields with Regard to Exposure of Human Beings.

IEEE Standards Coordinating Committee 28/Subcommittee 1 (Instrumentation): M. Misakian served as a member of this committee in charge of standards for the measurement of electromagnetic fields.

Publications

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), CPEM200, Sydney, Australia, (May, 2000)

E. So, D. Angelo, T. Nelson, and L. Snider, "NRC - NIST Intercomparison of Power Meter Calibrations at 60 Hz and Ranges up to 600 V, 100 A," CPEM200, Sydney, Australia, (May, 2000)

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).

O. Petersons, T. L. Nelson, N. M. Oldham, G. J. FitzPatrick, "Extension of Voltage Range for Power and Energy Calibrations," IEEE Trans. Instrum. and Meas., **48**, No. 2, pp. 439-443 (Apr 1999).

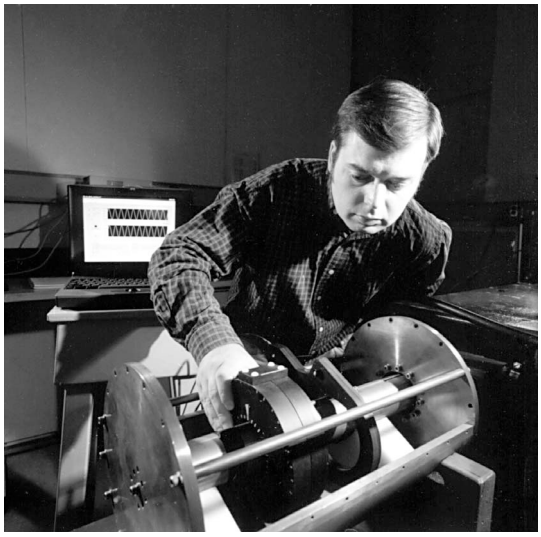
M. Misakian, "Extremely Low Frequency Electric and Magnetic Field Measurement Methods," *Gaseous Dielectrics VIII*, Kluwer Academic/Plenum Press, NY, pp. 451-457 (Dec 1998).

M. Misakian, "Exposure Systems," *Proc. EMF Engineering Review Symposium*, U.S. Dept. of Energy (DOE), Charleston, SC, pp. 5.1-5.6 (Nov 1998).

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 installing an optical current sensor 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. 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 reliably utilize new cost-saving measurement technologies related to the transmission, distribution, and use of electric power.

Technical Strategy

Partial discharges are often a precursor to more serious electrical breakdown failures in electrical power equipment, such as high-voltage transformers, motors, and flywheels. A diagnostic system capable of performing advanced field monitoring and analysis of partial discharge signals in electrical equipment is required for use in predicting future equipment failure.

MILESTONE: By 2003, develop a portable, optically-based, partial discharge detection unit for use on HV transformers and/or rotating machines.

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.

MILESTONE: By 2002, contribute to completion of IEC standard on low frequency disturbances.

In an effort to reduce the consumption of electric power, the U.S. Department of Energy (DOE) designates minimum efficiencies of electrical equipment. Distribution voltage 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.

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

MILESTONE: By 2004, contribute to DOE final rule for the efficiency of fractional horse power 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 to NIST would advance the use of these devices by U.S. utilities.

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

Technical Contact:
Gerald J. FitzPatrick

Staff-Years:
3.5 professionals
0.5 technician
0.5 guest scientist

Funding Sources:
NIST (85 %)
Other Government Agencies (15 %)

Parent Program:
Power

Accomplishments

- A second-generation optical current transducer (OCT) from NxtPhase Corporation was tested for short and long term stability as a power frequency current transformer. The collaborative testing of this device allowed NIST to develop the testing procedures necessary for the calibration of this class of equipment, and assisted NxtPhase in the development of their commercial product. The newly developed testing methods were prepared for archival publication.

- The NIST partial discharge (PD) detection system, which was originally designed for use in fixed line-frequency applications, was redesigned for use at high (up to 6 kHz) variable frequencies. This enables the NIST system to be used for detecting PD in rotating machines, such as energy storage flywheels and variable frequency motors. Detection of PD in these systems is usually limited by high background noise levels caused by the moving parts, but the probability distribution analysis utilized by the NIST system should allow the PD signal to be extracted and analyzed.

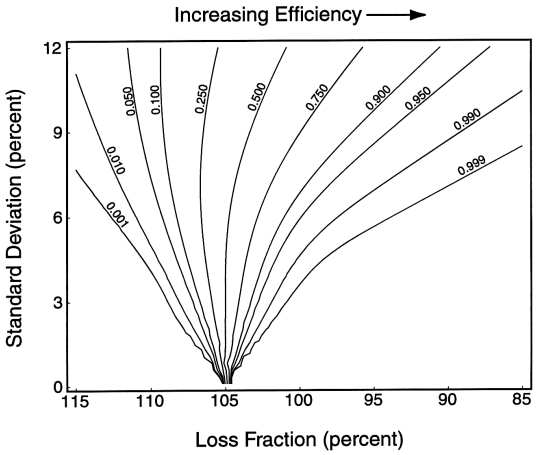
- A new "Power Quality Guide on Transients" was written for the International Union for Electricity Applications (UIE) by an international working group lead by a NIST research engineer. The report has received final approval and has been published. This comprehensive report draws on parallel contributions made by NIST to IEEE and IEC standards on surge protection, thus ensuring harmonization among the three major standards-writing organizations. Ranging from a description of the transient (surge) environment in ac power systems to their mitigation, the report will provide guidance to industry on cost-effective characterization of and protection against surges.

- NIST personnel served as editor for the restructuring of IEEE standards C62.41 and C62.45 into a trilogy of IEEE Guides related to recommended practices for surge protection. The three documents, totaling over 250 pages in length, address the description of the surge environment, the characterization of surges, and appropriate test procedures. Final IEEE approval has been obtained for these documents, and they will form the basis of several IEEE standards on surge protection being developed for U.S. industry.

"On behalf of NEMA and the electrical industry I would like to congratulate NIST on a very successful workshop. We hope to see such programs being held more frequently"

Khaled Masri Program Manager, NEMA National Electrical Manufacturers Association

- NIST Technical Note 1432, entitled "Test Procedures for Electric Motors under 10 CFR Part 431," was published in June of 2000. This accompanies a final rule on electric motor efficiency testing published in the Federal Register that was developed with technical support from NIST. The Technical Note provides guidance to manufacturers on the interpretation of the sampling and testing procedures specified in the final rule.



The operating characteristics of the sampling plan for compliance testing established under 10 CFR Part 431 for electric motors.

- NIST sponsored a workshop in December 1999 entitled "Challenges for Measurements and Standards in a Deregulated Electric Power Industry." The workshop was attended by 100 participants, and featured an introductory speech by the Deputy Under Secretary for Technology, U.S. Department of Commerce, on the overwhelming need for U.S. industry to be involved in the international standards process. Specific technical areas that were identified by workshop speakers that require additional measurements and standards in order to promote the full benefits of electricity deregulation included: standardization of information availability requirements; expanded measurement and communication capabilities for system control and transaction verification; expanded measurement, communication, and control of distributed generation systems; and security standards for information and control systems.

- An economic-impact study of the changing impact of measurements and standards due to deregulation of the U. S. electric power industry was sponsored by NIST. The aggregate annual economic impact estimated by the report is between $3.1 billion and $6.5 billion. This is a prospective annual cost estimate of not having

adequate measurement and standards in place to capture the full economic benefits of deregulation. Within this estimate, the impact of measurements and standards on the reliability of the U.S. electric power system is the largest impact category. Power quality issues for end-users, generation costs, and ancillary service costs each represent other areas of significant economic impact.

FY Deliverables

Collaborations

Performance validation testing was performed on a metering quality optical current sensor in collaboration with the manufacturer, NxtPhase, Phoenix, AZ and the Optoelectronics Division, NIST-Boulder.

Collaborations involving the development of power quality test protocols and standards continue with the Electric Power Research Institute (EPRI) Power Electronics Application Center, Knoxville, TN.

Standards Committee Participation

IEEE Industrial Applications Society, Electric Machines Committee: K. L. Stricklett is the member of this committee in charge of 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 77 on Electromagnetic Compatability: F. D. Martzloff served on the working group on Terminations.

IEEE Power Engineering Society Power Systems Instrumentation and Measurement Committee: G. J. FitzPatrick served on the High Voltage Test Techniques Subcommittee and the Emerging Technologies Subcommittee.

IEEE Power Engineering Society Power Systems Instrumentation and Measurement Committee: Y. Wang served on the High-Voltage Test Techniques Subcommittee.

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

Publications

T.S. Key, D. Nastasi, K. Phipps, and F.D. Martzloff, "Some Enlightening Case Histories on Lightning Damage", Proc. of 25th Intl. Conf. on Lightning Protection, Rhodes, Rion, Greece, (Sept. 2000)

F.D. Martzloff, "The Trilogy Update of IEEE Std. C62.41", Proc. of 25th Intl. Conf. on Lightning Protection, Rhodes, spon. High Voltage Laboratory, Univ. of Patras, Rion, Greece, (Sept. 2000)

F.D. Martzloff, "On the Dispersion of Lightning Current after a Direct Flash to a Building", Proc. of 25th Intl. Conf. on Lightning Protection, Rhodes, Univ. of Patras, Rion, Greece, (Sept. 2000)

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

F.D. Marzloff and K. Phipps, "A Novel Transducer for Monitoring Surge in AC Mains: Expectations and Reality", Proc. EMC Europe 2000 Symposium, Brugge, Belgium, (Sept. 2000)

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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).

J. Horwath, D.L. Schweickart, and Y. Wang, "Analysis of the Degradation of Polyethylene in Air Using Electrical and Physical Data," *Gaseous Dielectrics VIII*, Kluwer Academic/Plenum Press, NY, pp. 313-318 (Dec 1998).

X. Han, Y. Wang, L. G. Christophorou, and R. J. Van Brunt, "Characteristics of Partial Discharges on a Dielectric Surface in SF_6-N_2 Mixtures," *Gaseous Dielectrics VIII*, Kluwer Academic/Plenum Press, NY, pp. 307-312 (Dec. 1998).

A. Mansoor, F. D. Martzloff, and K. O. Phipps, "Gapped Arresters Revisited: A Solution to Cascade Coordination," IEEE Trans. on Power Quality, **13**, No. 4, pp. 1174-1180 (Oct 1998).

X. Han, N. A. Heckert, J. J. Filliben, and Y. Wang, "Statistical Analysis of Partial Discharge Phenomena - Time of Occurrence Distributions," *1998 Annual Report, Conf. on Electrical Insulation and Dielectric Phenomena (CEIDP)*, II, IEEE Dielectrics and Electrical Insulation Soc., Oct 25-28, 1998, Atlanta, GA, pp. 407-411 (Oct 1998).

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.

John Libert installs a photo detecter in the Display Measurement Assessment Transfer Standards (DMATS) prototype.

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.

MILESTONE: By 2001, publish second public version of the VESA Flat Panel Display Metrology Standard.

MILESTONE: 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.

MILESTONE: 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.

MILESTONE: By 2001, 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.

MILESTONE: By 2001, 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.

MILESTONE: By 2001, investigate a second-generation eyeball-like camera and report progress at an industry Conference.

Accomplishments

- Display Measurement Assessment Transfer Standards (DMATS) prototype built and demonstrated to Council for Optical Radiation Measurements (CORM) 2000. DMATS will serve to determine the worldwide color measurement capabilities and methods, and

Technical Contact:
Edward F. Kelley

Staff-Years:
3 professionals

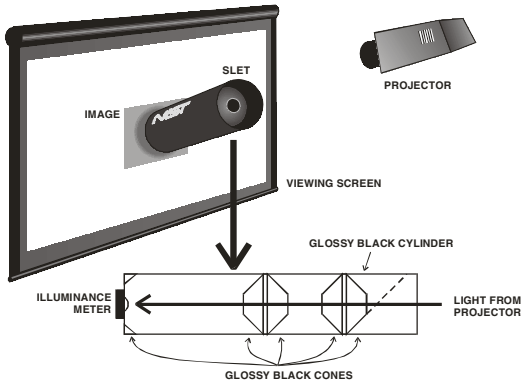
Funding Sources:
NIST (100 %)

Parent Program:
Video

"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

industry is anxious for its implementation. The DMATS solution is essential to resolving issues of color transportability in E-commerce.



The stray light elimination tube (SLET) can be used to minimize the effects of stray light in projection display measurements.

"This document [FPDM] has been extraordinary in its detail, quality, and application for our use. It addresses an enormous need that has gone unattended for some time. Please continue these efforts as the technology continues to evolve further."

Dr. William Pavlicek, Asst. Professor of Radiological Physics, Mayo Clinic Scottsdale

- Developed a flying-spot temporal diagnostic measurement for laser displays and associated light-measuring devices. These diagnostics provide a means to determine the suitability of instrumentation in measuring light from the new laser displays capable of painting wall-sized images at airports, etc.

- Presented an invited "Applications Seminar" on Flat Panel Display Measurements and Standards at the Society for Information Display (SID) 2000 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 that currently envisioned by the display industry.

- Developed a color-inversion test pattern used in the SID 2000 Display Technology Showcase. The display industry now has a single target that will reveal color-inversions and shifts and how they change across the screen. Its inclusion in the Showcase was requested by the organizers, and an article about its use has appeared in Information Display Magazine.

- Developed a metrology outline for the grand revision of ISO 9241 series and 13406 series all dealing with display metrology. Correlating the metrology of various display standards is key to guiding the revision of the new ISO standards for displays.

- Provided data reduction and statistical analysis for the Video Quality Experts Group (VQEG) study on the Validation of Objective Measures of Video Quality and co-authored the official VQEG Final Report of the study and two conference papers summarizing the study and results. NIST served as primary analyst of the data, and as one of four author/editors of the final report including the VQEG recommendations to the relevant working groups of the International Telecommunication Union relative to standards for video quality measurement. This was a major international effort, involving participants from the US, Europe, Japan, and South America in which valuable data on objective measurement model performance was obtained via a controlled, and refereed test of unprecedented scope. The final report yielded two conference papers in year 2000, which were translated for distribution in Japan, and Springer-Verlag has expressed an interest in publishing the VQEG final report in book form.

FY Deliverables

Collaborations

In addition to the collaborations that naturally precipitate 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 National Information Display Laboratory (at David Sarnoff Research Center, Princeton, NJ), on projection and reflection measurements**.**

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

Evaluation of the reflection measurement procedures in the ISO display standards is being performed through a round-robin effort with the Display Measurement Group (an international group of display measurement equipment manufacturers and users).

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 at 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)

Publications

P. A. Boynton, E. F. Kelley, S. Highnote, and R. Hurtado, "Diagnostics for Light Measuring Devices in Flying-spot Display Measurements," Projection Displays 2000, San Jose, CA, **3954**, pp. 42-51 (Jan 2000).

E. F. Kelley, "Electronic Display and Imaging Metrology at NIST," Photonics West 2000 Conf., IS&T/SPIE 12th Intl. Symposium on Electronic Imaging, Jan 26, 2000, San Jose, CA, pp. 1-38 (Jan 2000).

J. M. Libert, L. Stanger, A. B. Watson, and A. M. Rohaly, "Toward Developing a Unit of Measure and Scale of Digital Video Quality: IEEE Broadcast Technology Society Subcommittee on Video Compression Measurements," Proc. Intl. Soc. for Optical Engineering (SPIE), Conf. on Human Vision and Electronic Imaging V, **3959**, Jan 24-27, 2000, San Jose, CA, pp. 160-165 (2000).

C. Fenimore, J. Libert, and P. Roitman, "Mosquito Noise in MPEG-compressed Video: Test Patterns and Metrics," Proc. Intl. Soc. for Optical Engineering (SPIE) Conf. on Human Vision and Electronic Imaging V, **3959**, Jan 24-27, 2000, San Jose, CA, pp. 604-612 (Jan 2000).

C. Fenimore, J. Libert, and M. Brill, "Algebraic Constraints Implying Monotonicity for Cubics," NISTIR 6453, Natl. Inst. Stand. Technol. (U.S.), 8 pages (Jan 2000).

P. Corriveau, A. Webster, A. M. Rohaly, and J. Libert, "Video Quality Experts Group: The Quest for Valid Objective Methods," Proc. Intl. Soc. for Optical Engineering (SPIE) Conf. on Human Vision and Electronic Imaging V, **3959**, Jan 24-27, 2000, San Jose, CA, pp. 129-139 (Jan 2000).

E. F. Kelley, "Flat-Panel-Display Measurements and Standards," Tutorial, Applications Seminars at Society for Information Display Intl. Symp. and Seminar 2000, May 16-18, 2000, Long Beach, CA, pp. A-41-52 (May 2000).

E. F. Kelley, "Flat Panel Display Metrology -- Less than Meets the Eye," National Conference of Standards Laboratories, Charlotte, North Carolina, July 11-15, 1999.

E. F. Kelley, "Polystyrene Box Uniform Light Sources," Council for Optical Radiation Measurements, May 4-6, 1999.

P. A. Boynton, “Evaluation of Light-Measuring Devices for Flying-Spot Display Measurements,” Council for Optical Radiation Measurements, May 4-6, 1999.

E. F. Kelley, "Flat Panel Display Measurements and Standards," Applications Seminar, 1999-SID International Symposium, Society for Information Display, San Jose, CA, May 17-21, 1999.

E. F. Kelley, "Simulated-Eye-Design Camera for High-Contrast Measurements," International Society for Optical Engineering (SPIE) Electronic Imaging Conference, San Jose, CA, January 29, 1999, Proceedings of SPIE, Flat Panel Display Technology and Display Metrology, Vol. 3636, pp. 184-190, 1999.

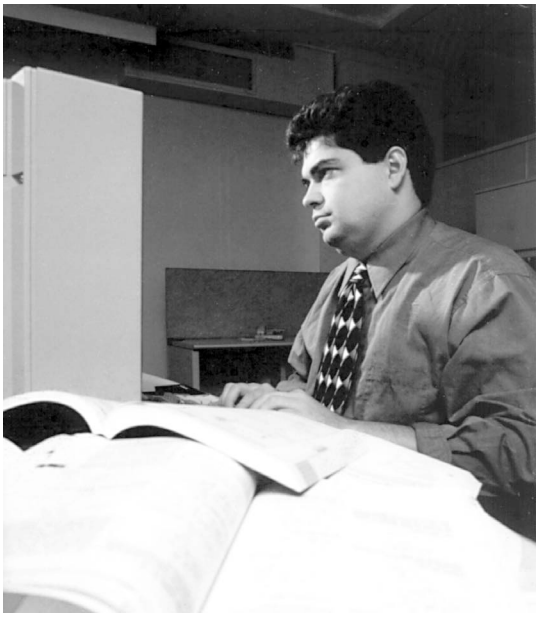
P. A. Boynton and E. F. Kelley, "Stray Light Elimination in Making Projection Display Measurements," International Society for Optical Engineering (SPIE) Electronic Imaging Conference, San Jose, CA, January 29, 1999.

P. A. Boynton and E. F. Kelley, "*Is the Measurement of Front-Projector Characteristics an Impossible Task?,*" Information Display, Vol. 14, No. 10, pp. 34-37, December 1998.

Infrastructure for Integrated Electronic Design

Project Goals

To actively contribute to the technical development of neutral product data exchange specifications and component information infrastructure for the electronics industry by assisting in the development of a standards-based, industry consensus methodology and infrastructure for exchanging component information. The project provides an impartial forum to resolve conflicts among competing and conflicting standardization efforts within the electronics industry. In addition, the project testbed at NIST is used to test and validate various Electronic Commerce of Component Information (ECCI) related standards.



John Messina using the NIST developed QuickData reference implementation which can replace all the parts manuals surrounding him.

Customer Needs

To reduce the time to market and improve communication between separated business units, manufacturers are, and will be, using the Internet to distribute and find information about electronic components. To make this happen industry must adopt a unified set of common standards to support such an exchange of information. 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. Original Equipment Manufacturers (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.

Technical Strategy

This project is working on various aspects of the infrastructure necessary to make ECCI a reality. Some of the technical areas addressed by this project 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 in 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.

This project will explore ways of making existing tools and interoperability information regarding electrical product data standards available to the U.S. electronics industry. NIST has a great deal of experience in conformance testing and certification. The product data representation and exchange community has been very involved in conformance and certification programs for mechanical-based application programs, but the electrical community is lacking in this area. Because this type of work requires an in-depth technical understanding of the intent of the electrical product exchange standards, NIST is an ideal organization to coordinate such an effort. This project will be concerned with defining methodologies for conformance and certification testing of applications with reference to a given electrical product data exchange standard.

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

Discussions with various industry representatives have highlighted the need for on-line traceable dictionaries of terminology in order to effectively

Technical Contact:
Jim St.Pierre

Staff-Years:
4.1 professionals

Funding Sources:
NIST (100 %) (SIMA)

Parent Program:
Electronic Data Exchange

distribute electronic component data via the Internet. The dictionaries must include search tools as well as tools to provide parametric searches of part libraries which use these definitions. Also, there must be tools that allow for the expansion of definitions and the creation of a hierarchical structure to allow various countries and organizations to maintain dictionaries, and to be able to submit new terms for consideration.

MILESTONE: 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.

"ECIX has the right vision, HP is counting on it!"

Dave Kleinke, Manager - Hewlett Packard, Responsible for Corporate Component and Supplier Management System (CSMS)

The Silicon Integration Initiative (Si2) is an organization of industry-leading silicon systems and tool companies focused on improving productivity and reducing cost in creating and producing integrated silicon systems. In collaboration with Si2, this project has helped develop a Quick Data standard as part of the Si2 Electronic Component Information Exchange (ECIX) suite of protocols for the electronics industry. The standard provides the infrastructure required to share component information using the Extensible Markup Language (XML) using existing Internet web technologies. The standard allows the electronics industry to share electronic component information between electronic equipment suppliers and customers. This web-based standard is an initial effort that will need to be expanded and refined to allow customers to convey enough information to suppliers to limit the response to a manageable number of candidate components. Each of the components will also have enough accompanying information (e.g., simulation files, data sheets, timing diagrams) to allow an engineer to make an informed choice on the component selection. We have incorporated tools which we developed into a demonstration example, such as dictionary translation tools, so that components described using differing electronic dictionaries can be compared using a single common electronic dictionary format.

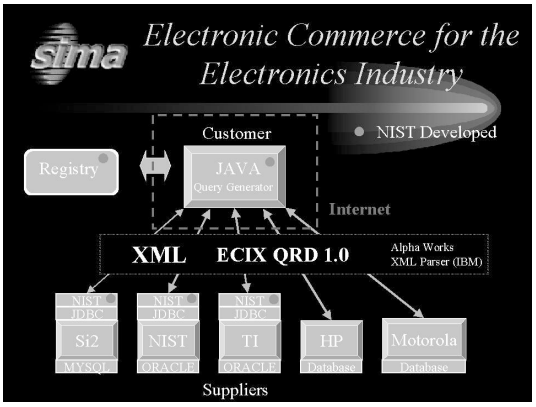
"The DictionaryBuilder is an ongoing open-source development project, being developed by RosettaNet and PTC, with assistance from Si2 and NIST."

RosettaNet announcement

MILESTONE: By 2003, expand ECCI Quick Data work to include advanced engineering information (e.g., thermal/geometry), and expand the to support Intellectual Property Cores (Virtual Components).

Accomplishments

- NIST continues to provide technical support for the Si2 QuickData Standard, and development of reference implementation software: 1) The software is now configurable to any XML dictionary, Document Type Definition (DTD), available in QuickData format. This allows the tool to be used with new versions of QuickData (such as Virtual Components) as soon as the DTD is created; 2) NIST researchers presented at a 2-day seminar on QuickData and the Si2 toolkit to a group of about 80 industry representatives from over 30 companies. The seminar was an in-depth tutorial of the NIST reference software and a presentation on the different types of access control and authentication mechanisms for QuickData security; and 3) NIST implemented a sample version of SSL (Secure Socket Layer) protection to the reference implementation.



The QuickData architecture – customers contact the registry to obtain a list of available supliers; supliers are then contacted directly.

- NIST provided significant technical support to Si2 for their QuickData VC and EC demonstrations at the Design, Automation, and Test Conference in Europe 2000 (DATE) and the Design Automation Conference 2000 (DAC). DATE focused on demonstrating the newest version of the QuickData Query Generator software developed from the new QuickData for Virtual Component (VC) specification. The DAC convention had both QuickData EC and QuickData VC demonstrated at the Si2 booth based on NIST's reference Implementation software.
- NIST developed a prototype dictionary maintenance backend system to support RosettaNet's electronic component technical dictionary (ECTD). This prototype was demonstrated at NIST's 2-day eDictionary for eCommerce workshop, held in July of 2000.

FY Deliverables

Collaborations

We are working with the 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

Standards Committee Participation

IEC/TC93/WG5 Test Validation,

Conformance and Qualification for Standards: Jim St.Pierre 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: Jim St. Pierre 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 Jim St.Pierre have been working with RosettaNet to develop technical standards for B2B E-commerce transactions for electronic components, and technical dictionaries for describing electronic components

Publications

J. V. Messina, J. A. St. Pierre, and M. R. McCaleb, "Design and Development of a Dictionary Translator," National Institute for Standards & Technology. (U.S.) NISTIR 6219, 12 pages (Jan 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 for Standards & Technology. (U.S.), 104, No. 3, pp. 291-297 (May/June 1999).

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 for Standards & Technology, Gaithersburg, MD, 12 pages (Oct 1998).

Infrastructure for Integrated Electronic Manufacturing

Project Goals

To create an environment where small manufacturers of mechanical and electronic components may participate competitively in virtual enterprises that manufacture printed circuit assemblies (PCAs). In particular, this project will identify and overcome some of the manufacturing information technology problems that exist at the intersection of manufacturing and electronic commerce systems.

Michael McLay and Tom Rhodes discuss the design and production of Linux Advanced Radio Terminal (LART) boards as a test of the GenCAM standard.

Customer Needs

North American Original Equipment Manufacturers (OEMs) are relying more heavily on their subcontractors and contract manufacturers for a greater breadth and volume of production functions. This increased outsourcing makes efficient cross-company communication an even more critical business success factor. Industry needs reliable standards in this domain and a neutral test-bed to help reduce the risks associated with technology adoption.

Technical Strategy

The project will gather and document industry requirements and current practice through a series of scenario development/strategy workshops. This information will be used to evaluate and refine an activity model to guide the project, and to guide the creation of a business case to document the economic motivation for migrating towards Internet commerce in the printed circuit assemblies industry. The team is also modeling business processes to assist in the development of standards.

The project has established an Internet Commerce for Manufacturing (ICM) Testbed at NIST. The testbed is used to validate new technology and the ability of industry to use standards identified in the standards roadmap to address the industrial needs identified in the business case and scenario document. Using an overview of current research in electronic commerce frameworks, demonstration components have been acquired to establish a baseline technical information exchange demonstration.

MILESTONE: By 2003, complete IPC/NEMI standard for Bill of Material and quotation information.

The project will identify and support development of needed standards. A web-based standards roadmap has been published and will be updated to reflect the availability and status of standards for the exchange of both technical and business information. Team members will participate in the development and testing of those standards identified as critical to the migration towards Internet commerce. The technical interchange standard GenCAM has been identified as critical, by the Institute for the Packaging of Electronic Circuits (IPC), and project resources have been used to develop both the standard and a conformance test module. The project is assisting the development of other new standards, such as the IPC-2570 series for supply chain communication.

MILESTONE: By, 2002, verify the GenCAM standard can convey all needed information to PCA board manufactures by producing test boards with Georgia Tech.

This project also is 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 Electronics Manufacturing Initiative (NEMI), and CommerceNet. The business case, standards

Technical Contact:
Kevin Brady

Staff-Years:
4.5 professionals

Funding Sources:
NIST (100 %) (SIMA & AMI)

Parent Program:
Electronic Data Exchange

roadmap, and proceedings from all workshops will be published and disseminated through the project website. Opportunities for increasing industry involvement, through organizations such as NEMI or RosettaNet, are being investigated.

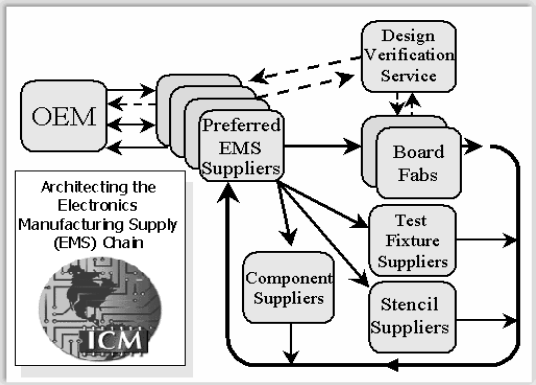
MILESTONE: By 2006, complete IPC/NEMI Plug & Play Factory standard and provide technical support for implementation by equipment and software vendors.

"Intel Corporation announced today the adoption of the GenCAM* IPC 2510 data format as its standard for exchange of Printed Circuit Board (PCB) design information among its departments and manufacturing facilities and with external vendors."

Intel Press release, Oct. 16, 2000

Accomplishments

- The ICM Activity Model, developed in FY99 based on the IPC/ECCE Activity Model, was used to develop a "Data Staging Process Model," or ICM "Flow Model," that shows 23 key business-to-business transactions and data exchanges occurring among major trading-partners involved in manufacturing of printed circuit boards and assemblies.



Architecture for the ICM project, used to identify key interfaces for standardization.

"Full support of the GenCAM format will be a key component when making equipment and software tool decisions starting April 2001"

Bill Bader, General Manager, Intel Systems Manufacturing

- The Electricity Division led the multi-OU Internet Commerce for Manufacturing (ICM) project which demonstrated the use of standards-based supply chain operations to a variety of internal and external audiences. The ICM project manufactured two separate circuit board designs using a web-based product data package and published an Electronic Commerce Business Case Document.

- IPC recognized NIST as providing significant assistance in maintaining and enhancing the GenCAM Conformance Test Module (see http://www.gencam.org/).

- ICM Agent Testbed accomplishments: 1) established an agent infrastructure that is open, distributed, component-based, scalable, and extensible, and able to support other e-manufacturing acivities; and 2) implemented and demonstrated five agents (agent-name server, broker-agent, gateway-agent, GenCAM-specialist agent, and Web-assistant agent) comprising a "GenCAM Multi-Agent System", to support OEM-EMS business processes.

- Virtual OEM/EMS Testbed accomplishments: 1) developed web-interfaces for an OEM and EMS that supports Quote submission and Bid response; 2) implemented e-business registration capability based on CommerceNet eCo Framework that allows trading-partners to publicly register information about their company and it's capabilities; 3) integrated the NIST developed ECIX/Quick Data software, used for selecting electronic components from supplier catalogs over the Web, will be into the ICM testbed demonstrations.

- ICM held two Industry-Scenario Workshops in FY00 to identify current PC manufacturing requirements and trends and to obtain feedback on ICM efforts.

FY Deliverables

Collaborations

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.

External Recognition

The IPC, an electronic interconnection industry trade association, presented its President's Award to Michael McLay for his contribution to the IPC GenCAM standard.

The National Electronics Manufacturing Initiative presented its NEMI Award to Barbara Goldstein in recognition of significant progress in the Factory Information Systems Technical Implementation Group.

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).

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

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Standards Committee Participation

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

NEMI Factory Information Systems: Barbara Goldstein co-chairs this working group

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 spend on producing the necessary calibration forms and associated reports.

Jennifer Lindeman demonstrates the use of iButton technology to attach calibration data to equipment, for tracking purposes.

Customer Needs

The administrative tasks of the calibration process at NIST have been a paper intensive and manual process for most of the calibration staff. A new automated process that decreases the administrative requirements of the technical staff was needed. Income and workflow information were not readily available to management, and the current system provided no means for forecasting current income or projecting future income. The total experience of the customer needed improvement along with decreasing the turn around time of the calibration process. With the growing Internet presence of most companies, providing 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 web-based (structured query language (SQL)) database that provides access to over two hundred users at NIST. The web-based system allows access from a plethora of different machines and operating systems used by research personnel at NIST. The ISSC has reduced the time to complete the required paperwork by automating the entire workflow process.

MILESTONE: By 2002, expand the ISSC to use the latest web technologies as they occur (e.g., XML), this will greatly extend the capabilities and useful life of the system.

The ISSC supports both the administrative and technical requirements of the fourteen divisions at NIST that perform calibrations, through fourteen separate implementations of the ISSC. The Calibration Program and the Chief Financial Officer have access to each implementation to provide NIST-wide statistics and billing functions. The ISSC provides a nearly paperless environment for the technical staff, replacing a paper intensive process with a web-based database system. Customers of the calibration services are provided access to status information via secure web pages.

MILESTONE: By 2003, 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 monthly to resolve problems encountered with the software and to determine enhancements to the software.

Each division at NIST that performs calibrations has been given access to the ISSC. Fiscal Year 2000 will be the first year all calibration divisions will be using the system. This project is responsible for correcting any problems in a timely fashion so as to not delay the calibration process. A custom interface has been developed for the Calibration Program 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 actually print customer invoices directly from the system.

Technical Contact:
Kevin G. Brady

Staff-Years:
1.0 professionals

Funding Sources:
NIST (100 %)

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. Each division will be given the opportunity to have a template of their calibration report entered into the system for their specific use in printing calibration reports.

MILESTONE: By 2002, add extensive reporting capabilities to allow users to build adhoc, custom reports.

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 will be 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).

MILESTONE: By 2002, develop a security implementation plan and disaster recovery plan.

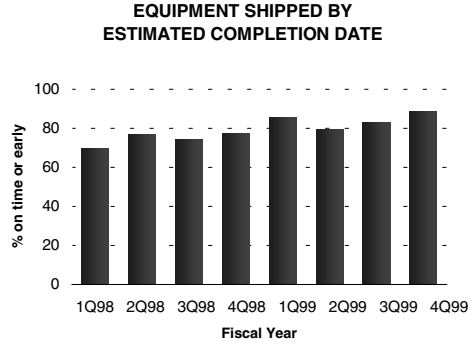
MILESTONE: By 2002, implement increased security for the calibration customer's status web pages using Secure Socket Layers (SSL) technology.

Providing as much information to customers as possible will always be a goal of the calibration program. Electronic copies of calibration results and the actual calibration report in a standard format would be beneficial to both the customer and the NIST calibration staff. In addition, calibration data can be physically attached to equipment or artifacts by using iButton technology which is approximately the size of a nickel. The data can be read/written to/from the device using a simple tool attached to a PC serial port. A custom designed application can display the data on the PC or electronically transfer it into the ISSC (e.g., model number, serial number) circumventing any transposition or typographical errors.

MILESTONE: By 2003, provide capability for tracking and storage of calibration data using iButton or some comparable technology.

Accomplishments

- ISSC has been deployed NIST wide to 14 divisions, the CFO's office, and the Calibration Program, with little-to-no interruption in day-to-day activities. The ISSC is now used by all calibration personnel at both the Boulder and Gaithersburg NIST campuses. 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.
- 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 technical staff, and administrative officers. Development of training manuals is under way.
- 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 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.



Typical statistic that can be tracked by the ISSC. These data are for all Electricity Division calibrations conducted during the specified time periods.

FY Deliverables

Collaborations

We are working with the Manufacturing Engineering Laboratory on the iButton technology to store calibration information physically with the calibrated item.

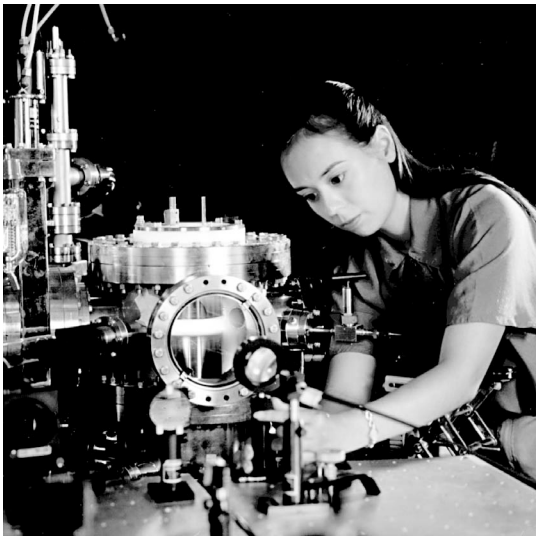
Publications

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. However, the presence of a semiconductor wafer in the reactor chamber can change completely the ion chemistry occurring within the discharge. Mass spectrometry will be applied to inductively-coupled plasmas exposed to semiconductor wafers to determine the effect on the composition of the ion flux.

MILESTONE: By 2001, measure the composition and energies of the ion fluxes generated in reactive plasmas exposed to semiconductor wafers.

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.

MILESTONE: 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.

MILESTONE: By 2001, complete an assessment of the available electron-interaction data for the most commonly used plasma processing etching gases.

MILESTONE: By 2003, complete an assessment of the available electron-interaction data for the most commonly used plasma processing deposition gases.

Technical Contact:
Yicheng Wang

Staff-Years:
2.0 professionals
1.0 postdoc

Funding Sources:
NIST (100 %)

Parent Program:
Semiconductors

Accomplishments

- Absolute, mass-resolved ion fluxes were measured in high density, inductively coupled plasmas generated in a wide range of processing gases, including C_2F_6, C_4F_8, CF_3I, and CF_3CH_2F. The later two gases possess low global warming potentials that make them potential environmentally-friendly processing gases. The results indicate a large number of ions being produced by each gas as evidence of the complex chemistries present in the plasmas. These results have been used to validate and refine reactor modeling codes used in the development of plasma processing methods.

"Many of our model development efforts, including oxide etch and Ta ionized PVD, have benefitted from their [NIST] research ..."

Shahid Rauf
Motorola Semiconductor

Yicheng Wang adjusts electron transport apparatus.

- NIST-recommended data were derived for electron interactions with SF_6, a gas with many industrial applications. This was the largest review of electron interactions with a plasma processing gas to be completed in this project. The review was published in the Journal of Chemical and Physical Reference data, and the resulting data were posted on the Internet. These data were used by industry to improve deep silicon etch processes.

- Electron-interaction data were reviewed for CF_3I, a plasma etching gas being considered for use by the semiconductor industry because of its very low global warming potential. The review revealed extensive data that were previously unavailable to the industry. Recommended data were derived from the review and posted on the Internet.

- Electron drift velocities and effective ionization coefficients were measured 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 Deliverables

Standard Reference Data

In FY00, additions to the "Electron Interactions with Plasma Processing Gases" database (www.eeel.nist.gov/811/refdata) included posting of the recommended data for SF_6 and CF_3I, and modifying the website to make it compliant with new Federal Government requirements. This site experienced over 2000 hits in FY00.

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.

Modeling of electron transport in SF_6 using the NIST standard reference data for electron interactions is being performed in collaboration with researchers from Keio University, Japan.

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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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	Ronald F. Dziuba (301) 975-4239 Randolph E. Elmquist (301) 975-6591
A.2	High-Voltage Standard Resistors	Martin Misakian (301) 975-2426 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 ..... Norman B. Belecki (301) 975-4223
Andrew J. Secula (301) 975-4243

D.2 Resistive Dividers ..... Martin Misakian (301) 975-2426
Gerald J. FitzPatrick (301) 975-2737

D.3 Capacitive Dividers ..... Gerald J. FitzPatrick (301) 975-2737
James K. Olthoff (301) 975-2431

D.4 Mixed Dividers ..... Gerald J. FitzPatrick (301) 975-2737
James K. Olthoff (301) 975-2431

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
Lisa S. Snider (301) 975-4688

I. Pulse Waveform Measurements ..... Donald R. Larson (301) 975-2437

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.

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 us to control electrical flow in units of 1 e in order to accurately measure the electrical current or charge. The Electricity Division studies such effects and their implications for precision metrology of the electrical units. We have two goals. The first one is a collaborative effort with our Boulder location, using the electron pump to charge up a cryogenic capacitor. After comparisons 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 a long-term study of the charge offset and noise problems, which limit any possible industrial applications of SET phenomena. In addition, we pursue any newly discovered phenomena that have potential metrological applications such as the pumping of single electrons with surface acoustic waves in a two-dimensional gas.

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 (Is) with decay and rms noise of less than 10^{-6} Is/s. 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 (70GHz 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 ^{o}C programmable process furnace, cryogenic equipment consisting of dc and radio-frequency SQUID instrumentation, and a 16 T quantum-Hall system with a 3He 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 0.008 ppm uncertainty 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.

Flat Panel Display Metrology

Contact: E. Kelley

More and more products include integrated flat panel displays. The quality of the device used to display the image is very important. Traditional cathode-ray-tubes are rapidly being replaced by flat panel displays for some applications; however, metrological methods for characterizing such displays are undefined.

Our current program focuses on measuring and simulating the performance of a variety of display technologies, under various lighting conditions. In addition, the work involves developing new measurement procedures for flat panel display devices. This work involves using a variety of workstations and an automated laboratory to characterize the optical and electrical performance of complete displays.

Electricity Division Organization

Division Office (811.00)

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4124 ST.PIERRE, James A., Deputy Chief
2400 SCHMEIT, Ruth Ann, Secretary
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Fundamental Electrical Measurements (811.04)

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4224 MATTHEWS, John (GR)
4243 SECULA, Andrew J.

Realization of the SI Farad and Ohm

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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)
4270 HUBER, William H. (PD)
4815 FOGLE, William (GR)
4219 SOULEN, Robert (GR)

The Electronic Kilogram

4226 STEINER, Richard L. (PL)
6556 LIU, Ruimin (GR)
4228 NEWELL, David B.
8129 SCHWARZ, Joshua P. (PD)
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Metrology for Electric Power Systems

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4278 WANG, Yicheng

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2409 MARTZLOFF, Francois D.
6658 PITT, James A.
3956 SIMMON, Eric D.
3955 STRICKLETT, Kenneth L.

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4222 FROMM, Sharon L., Secretary

Flat Panel Display Metrology

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3828 LIBERT, John M.

Infrastructure for Integrated Electronic Design

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4479 GALE, John (S)

Infrastructure for Integrated Electronic Manufacturing

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4284 MESSINA, John V.
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4124 ST. PIERRE, James A.

Information System to Support Calibrations

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4284 MESSINA, John V.

Legend:

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

Telphone numbers are: (301) 975-XXXX, (the four digit extension as indicated)

Permanent staff can generally be contacted by email using the following format: firstname.lastname@nist.gov

January 2001

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