EEEL 1996

TECHNICAL ACCOMPLISHMENTS

Advancing Metrology For Electrotechnology To Support The U.S. Economy

UNITED STATES DEPARTMENT OF COMMERCE
TECHNOLOGY ADMINISTRATION
NIST

ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY • NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

As part of the Commerce Department's Technology Administration, the National Institute of Standards and Technology (NIST) works to promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards. NIST carries out its mission through a portfolio of four major programs:

—a rigorously competitive Advanced Technology Program providing cost-shared awards to industry for development of high-risk, enabling technologies with broad economic potential;

—a grassroots Manufacturing Extension Partnership with a nationwide network of local centers offering technical and business assistance to smaller manufacturers;

—a strong laboratory effort providing technical leadership for the nation's measurements and standards infrastructure; and

—a highly visible quality outreach program associated with the Malcolm Baldrige National Quality Award that recognizes continuous improvements in quality management by U.S. manufacturers and service companies.

In fiscal year 1997, NIST is operating with a budget of about $765 million and nearly 3,300 staff members at its sites in Gaithersburg, Maryland, and Boulder, Colorado. News and general information about NIST programs and services are available on the World Wide Web at http://www.nist.gov, or you can call general inquiries at (301) 975-3058 or e-mail: inquiries@nist.gov.

Any mention of commercial products is for information only; it does not imply recommendation or endorsement by the National Institute of Standards and Technology nor does it imply that the products mentioned are necessarily the best available for the purpose.

COVER:

Design element is abstracted from a schematic diagram of the world's first seven-junction electron pump, developed by EEEL researchers at NIST. The pump's very tiny quantum mechanical tunnel junctions enable researchers to count individual electrons with an accuracy of 15 parts per billion. The Laboratory's single-electron work proves, in principle, that single electron counting can be used as the basis for new fundamental standards of electric current and capacitance. When such standards are realized, electrical quantities such as current and capacitance will join voltage and resistance as electrical quantities that can be related to fundamental atomic constants.

EEEL 1996
TECHNICAL ACCOMPLISHMENTS

Advancing Metrology For Electrotechnology To Support The U.S. Economy

NISTIR 5941

U.S. DEPARTMENT OF COMMERCE
Michael Kantor, Secretary

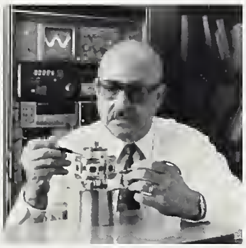
Technology Administration
Mary L. Good, Under Secretary for Technology

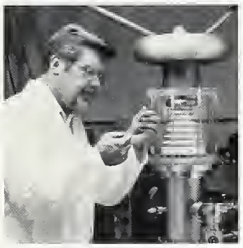
National Institute of Standards and Technology
Arati Prabhakar, Director

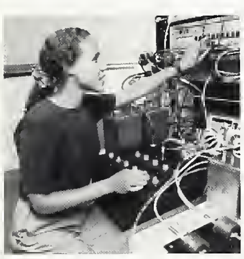
December 1996

TABLE OF CONTENTS

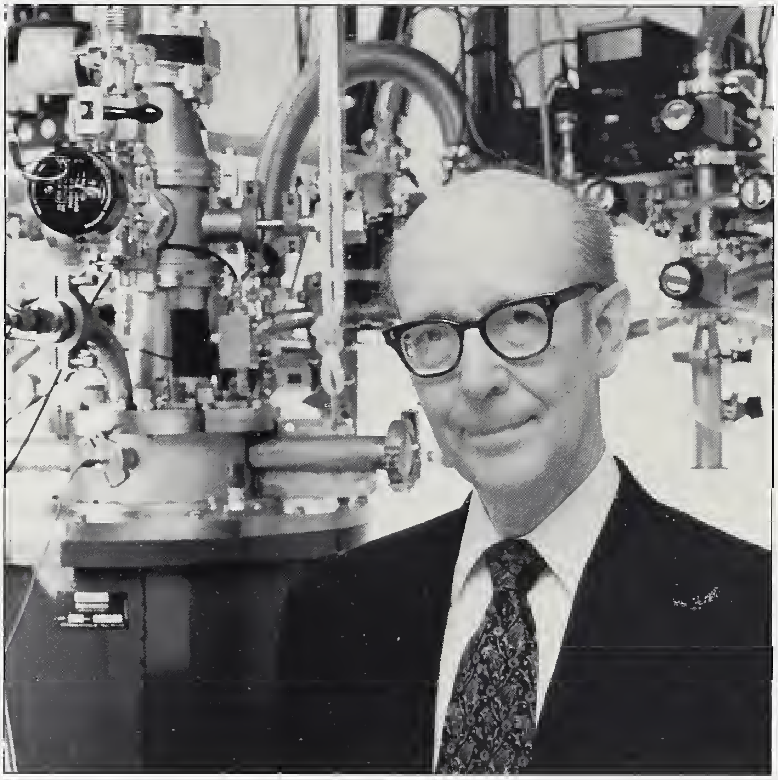
TABLE OF CONTENTS







DIRECTOR'S MESSAGE



Electron Pump Apparatus Containing a Supercooled Microcircuit that Allows Researchers to Count Electrons to an Accuracy of 15 Parts per Billion

J.D. French

We appreciate your interest in our Laboratory and invite you to review some of the fascinating work completed in the past year. You'll find it extends all the way from exciting new developments in semiconductor metrology to a new value of the fine structure constant, developed while determining a new realization of the ohm in the International System of Units. Although it is often difficult to select a limited set of examples that reflect accurately the scope, nature, and impact of our work, it is always satisfying to find that more projects deserve mention than space permits. You will find our selected examples of achievements for FY 1996 listed in the *Technical Accomplishments* section of this report. If you discover you'd like to know more about the technical details on these projects, as I would hope, I suggest that you be sure to look at *EEEL: A Profile*, the first entry in the Appendix, which directs you to other publications.

As you consider the examples of work we chose to present this year, you will recognize the common thread that runs through them. Each in its way reflects EEEL's primary mission: to provide the measurement tools — methods, data, calibrations, standard reference materials, and basic understanding — that industry must have to provide and prove world leadership in performance and quality of its products.

A classic example showing the way the Laboratory's objectives dovetailed with industry's goals occurred this year, 1996. As some of you may recall, EEEL has played an active role in the development of the National Electronics Manufacturing Initiative (NEMI) from its inception under the National Science and Technology Council to the present day. Early this year, leading U.S. electronics firms and government agencies forged the NEMI consortium, which is dedicated to the sustained growth and competitiveness of American electronics manufacturers and suppliers in the global marketplace. NEMI is designed to improve the electronics industry's respective manufacturing technologies and infrastructures, to stimulate creative applications for those technologies, and to establish development and implementation projects between users and suppliers.

From the outset, NEMI has recognized that metrology, including test, inspection, and measurement science (TIM) taken broadly is an important, but often costly, enabler in all aspects of manufacturing from data for design and modeling, through materials, equipment, and manufacturing processes, to final evaluation. As NEMI worked on their roadmap, two general conclusions were reached with respect to metrology: first, that it was essential that TIM be included as a factor in each product sector of the roadmap; and second, that the need to focus on broad TIM issues should transcend the development of the roadmap. So, each of NEMI's technology working groups will address TIM issues in their own technical areas directly. Then, to ensure that important issues that concern more than one group or are outside the responsibility of any one group do not fall through the cracks, a TIM Crosscut working group was established. As Chair of that group, I had the opportunity to see how closely our work supports the consensus achieved at NEMI.

Five crosscut TIM issues were emphasized by the Consortium because each is significant and affects multiple technical areas: small-dimension measurements, software testing, automated optical inspection, high-speed testing, and cost. A glance back at the *Table of Contents* will indicate that at least three of the examples included in this year's selection pertain directly to NEMI's crosscut issues.

In the section describing work in the *Semiconductor* field, EEEL's power circuit modeling effort continues to deliver extraordinary paybacks. In the past year, we were able to provide industry with a simple, easily accessed, testbed circuit that allows users to validate their models with realistic performance measurements before building prototypes. Although it is widely understood that modeling is essential to minimize product-development costs, reliance on inadequate models exacerbates the problem. NIST is successfully working toward a total solution.

Under *Low Frequency*, you can discover how staff developed and transferred to instrument and device manufacturers a means to cut testing costs by very substantial amounts. The technology has now come full circle because we are using a further refinement of that method at NIST to reduce the cost of a critical calibration procedure, which was one of the original goals of the work. In one instance, customers receive better uncertainties for the calibration of an instrument today than we could offer in the past, while saving $20,000 per calibration.

Finally, with respect to the testing of high speed circuits, apart from the fact that EEEL staff are credited with founding the Monolithic Microwave Integrated Circuit (MMIC) Consortium, they also revolutionized the testing methods used to characterize wireless components. If you are interested in this work, it is described in the *Microwaves* section. One of this year's examples is a discussion of NIST MultiCal® software, which implements a unique, NIST-developed calibration process that allows industry to use widely available, less expensive test equipment to characterize high-speed microelectronic components.

Now, it should be noted that just as other NIST laboratories are also contributing expertise in their respective fields to NEMI's initiative, EEEL is working closely on roadmapping with other parallel industry associations. These efforts include the implementation of the semiconductor industry's innovative *National Semiconductor Metrology Program*, participation in the technical committee activities of the Telecommunication Industries Association, and grass-roots leadership in the industry-wide effort being realized by the Optical Industry Development Association. Taken broadly, when you consider the impact of the Laboratory's work just a little further downstream — in terms of the electronics industry's product output — it is apparent that EEEL impacts virtually all of American industry.

Electronic instrumentation guides vehicles on land, in the air, and at sea. Devices we count on at work or play are more durable, reliable, efficient, and pervasive due to the miniaturization enabled by semiconductor electronics. Breakthroughs in medical instrumentation and imaging tools, diagnostic scanners, surgical lasers, and cardiac implants attest to the ubiquitous presence of electronics in our lives. Even the exponential rate of expansion in the communications industry is rooted in the rapidly improving ability to capture and transmit wireless signals, as well as traditional electric signals and fiber-optic signals above- and below-ground. Finally, consider the Laboratory's work in the "traditional" electric industry — an industry which is currently going through massive change.

EEEL provides expert solutions in each of these applications of technology — answers to nuts-and-bolts metrology issues, such as how to measure a value, how to design a protocol, how to test a product. In turn, these solutions lead to improved methods in clean rooms or on factory floors, to improved signals from antennas and receivers on land or in space, to more efficient procedures in power plants and safer protocols in surgical suites. And, ultimately, our solutions stimulate improvements that can be measured in the fabric of our daily lives. We are proud to be so relevant, not to say essential, to our clients. However, lest you think I'm biased in this regard, permit me to share with you a portion of a statement from the Congressional Record for September 30, 1996. The topic was our appropriations bill; the accomplishment referenced in the latter part of the excerpt reflects an external perception of the significance of our work:

"And the National Institute of Standards and Technology [NIST] is doing the work that the Nation's Founders found so essential to our Nation's trade, and economy that they included the responsibility in the Constitution — caring for our Nation's system of weights and measures. NIST's laboratories provide world-class work in a way that the Nation's Founders could never have imagined.

For example, the use of fiber optics in telecommunications would not have occurred as rapidly without NIST's efforts. NIST's work in measures and standards has literally made it possible for fiber optic cables to be connected with each other with simplicity and ease — leading to a world connected by fiber."

Our work is also being noted in a wide range of other publications. This year we received mention in several learned journals captivated by the fact that we were the first in the world to demonstrate that electrons can be counted one by one to an unprecedented precision. You will find a more detailed account of this work under the *Superconductors* field of technology. We reached a broader audience on another topic, the development of the world's smallest hotplate, in the October 1996 issue of *Popular Mechanics*. In collaborations with other NIST Laboratories, we are continuing to develop this work. One such collaboration, noted by *Systems Signals*, a newsletter of the Institute for Systems Research, is the miniaturization of components for "artificial nose technology," noting that its applications could range from ensuring environmentally sound production processes to assisting with medical diagnosis of infections. All told, it has been a productive year.

In closing, I feel we must acknowledge that government organizations underwent a rather unique and disconcerting period early in the year — disconcerting to our conscientious staff and to our clients, certainly. In the long run, I believe we coped with the issues so as to address our clients' concerns effectively. We certainly received a great deal of support and reinforcement from the Administration, from Members of the House and the Senate, and from industry representatives during the past year. I would like to acknowledge our appreciation at this time. We look forward to your continued interest as we go about our work.

JFrench

Judson C. French
Director, Electronics and
Electrical Engineering Laboratory

[Opening Statement, Technology Subcommittee, House Science Committee, U.S. House of Representatives, June 25, 1996] *As the Council on Competitiveness noted in its recent report, "Endless Frontier, Limited Resources," the U.S. research and development enterprise finds itself in a wrenching period of change with the end of the Cold War, the globalization of the world economy, and the drive to eliminate the federal deficit. This environment creates both an unprecedented opportunity and a significant challenge for NIST.*

Today's hearing will focus on the Information Technology Laboratory and the Electronics and Electrical Engineering Laboratory. In many respects, these two laboratories support industrial sectors that are at the forefront of our nation's technological revolution and are defining our global competitiveness. ...The electronics industry is growing rapidly and currently accounts for nearly 11 percent of U.S. GDP [gross domestic product]. For example, the domestic semiconductor industry is recovering from a slump in the mid-1980's, surpassing the Japanese share of the global semiconductor market in 1993 for the first time in eight years. This transformation has been aided by the semiconductor industry's development of a technology roadmap to more efficiently utilize the nation's technology resources, including NIST.

Chairwoman
Technology Subcommittee
House Science Committee

IN A FAST-CHANGING WORLD, BETTER IS NEVER ENOUGH —

We are frequently asked: Why does EEEL need to continuously expand and improve the measurement capabilities it provides? The answer is straightforward: the needs we address are driven by the fast moving world of electronics — an innovative industry that continues to outstrip its own ability to measure and control its materials and processes, and to evaluate its products.

Increasingly of late, industry is recognizing the significance of accurate physical standards, and of the processing and performance standards that depend on them. This came about as industry realized the importance of meeting conformity requirements in the international arena, and cost and quality requirements in its manufacturing plants.

Further, changing technologies, regulatory requirements, and environmental concerns have an impact. It is easy to understand that emerging industries subject to all these factors would create a need for new measurements, but even long-established industries are affected, calling for new and different measurement techniques. All of these needs devolve in some way upon the Laboratory, demanding advances in electrical measurements.

Changing needs in long-established or "mature" industries —

Let's follow an example where changes have occurred in a traditional industry. The U.S. electric power industry could be characterized as a "mature" industry that provides billions of dollars of electricity annually to consumers and employs nearly a half-million people.

Today the industry is undergoing the most profound organizational, economic, and technical changes in a century. As utilities transition from regulated monopolies to competitive entities, they are looking for ways to streamline their operations, address environmental quality and health concerns, and provide reliable, quality power for safety and security. Further, they expect to be able to do it all more cost effectively. It is logical, then, to assume the 100-year-old technology driving the familiar electricity meters, such as those mounted on houses in neighborhoods across the country, needs to be replaced. Remotely-read time-of-service meters, imminent-failure optical sensors, power electronics, and microelectronic controllers are among the technologies now being introduced to meet the industry's new requirements, which in turn give rise to a broad spectrum of new measurement needs.

Changing expectations, technologies, and regulations drive technical changes —

The proliferation of microelectronic devices in everything from personal computers to manufacturing process controllers has radically changed end users' views on the need for quality electric power. Such devices can easily be damaged by disturbances in the source electric power. Today, power disturbances can produce effects ranging from the inconvenience of resetting digital clocks ("blinking clock syndrome") to the loss of an entire batch at a silicon wafer fabricating plant, which requires virtually perfect electric power for its three-week production cycle.

The Public Utilities Regulatory Policies Act of 1978 encouraged the creation of independent power producers, and increasing numbers of them have entered the fray. Until about that time, it had been prohibitively expensive for a private company to generate a moderate amount of electricity as compared to the gigantic power plants of the utilities. However, newly emerging technologies enabled small and moderate-size natural-gas-turbine generators to produce electricity cleanly and safely at a cost equal to or below that of many local utilities, and the markets opened up.

Now, the influx of small-quantity suppliers of electricity into the power grid heightens concerns about the quality of the electric power provided and the stability and reliability of the overall system. At the close of 1990, over 100 environmental laws were in place that affected the U.S. operation of the electric utilities. The industry faces limitations in locating power substations and power line rights-of-way because of concerns about pollution and their proximity to population centers or wildlife. Thus, the utility giants, especially, must pursue ways of increasing the power density of existing systems, methods which often involve higher voltages and currents, giving rise to increased concern for component lifetime and reliability, and for environmental effects from electric and magnetic fields.

New performance requirements translate into technical challenges and new measurement needs —

In addition to the challenges facing generating stations, transmission and distribution systems are also grappling with the effects of new demands. For example, the limitations in the power handling capability of existing transmission and distribution systems are not necessarily established by the thermal limits of the lines and cables, where failure would occur due to overheating, but rather by the electrical stability of the lines where instabilities could trip circuit breakers and produce unexpected shutdowns of parts of the distribution systems.

Current flows through power systems along paths determined by physical laws, the systems network configuration, and dynamic loading of the system. This flow is certainly not based on any contractual obligation between an independent power producer and a designated user. At present, the network cannot be controlled well enough to channel the flow of electricity across specific paths in the most efficient way.

Although much of the technology needed to address these limitations is presently available, there is still a need for numerous low-cost, accurate sensors (whose performance can be verified while in service) to continuously monitor the operation of the system. Given that much of existing power equipment is highly efficient, there is still room for improvement in the efficiencies of generators, cables, and transformers, where the electrical resistance of the conductors produces power losses.

Superconductor technology may yet offer a solution. Early experiments with conventional low-temperature superconductors with minimized power losses demonstrated poor cost effectiveness because of the high cost of refrigeration required to maintain the low temperature. Recently-discovered high-temperature superconductors offer a primary advantage of lower refrigeration costs, but the superconducting materials are ceramics, which are difficult to fabricate into the wires and tapes necessary for electric-power equipment. However, the technology continues to evolve.

Power system reliability is enhanced through the reduction of equipment failures, which can be achieved through predictive maintenance using advanced equipment monitoring technologies. For example, partial discharge is a localized discharge phenomenon that usually occurs in electrical insulation at defect sites such as voids and cracks, and can lead to rapid aging of all types of insulating materials. It is also known that partial discharge is often a precursor to complete electrical breakdown that may result in catastrophic failure of equipment. Even under controlled conditions, these phenomena remain poorly understood. For this very reason, the requirements and standards that specify maximum partial discharge limits for equipment are deliberately conservative. The benefit of this approach is safety; the drawback is that it may well result in the underutilization of high-cost, high-voltage apparatus pending the elucidation of partial-discharge processes.

Since the early 1970s there has been a concern over the possible effects of electric and magnetic fields (EMFs) associated with electric-power equipment and appliances on human health. The accurate measurement of EMFs is of great importance in both epidemiological and laboratory exposure studies. Three-axis magnetic field probes are typically used for determining the field strengths in air, such as in the vicinity of power lines and electrical appliances. However, one study has shown that better measurement techniques are needed. The study determined that when these probes are used for field measurements close to appliances, the error may be close to 20 percent of the actual value!

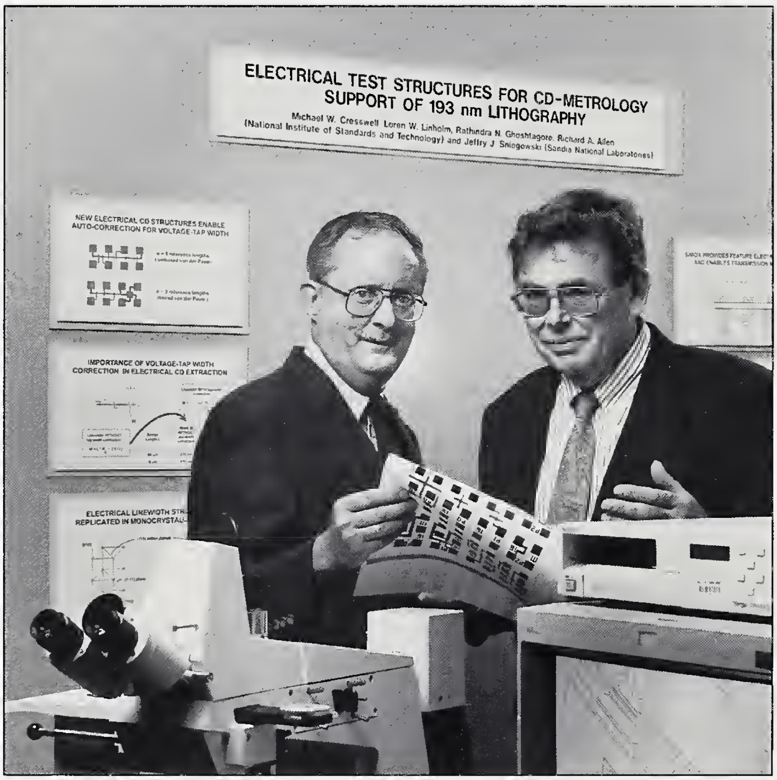
In the last decade, power quality has emerged as a topic of major interest to electric utilities and their customers. Lightning strikes to power transmission and distribution equipment are a major cause of system failures and power interruption in the United States. Transient overvoltages can cause breakdown of electrical insulators or semiconductors, either in the power equipment or in the end user's equipment. Equipment manufacturers are frustrated because making equipment more immune than might be necessary to disturbances is an expense that places them at a competitive disadvantage. The consensus reached by manufacturers of sensitive equipment, electric utilities, and end users is clear: develop test methods and performance criteria for equipment immunity that are appropriate for the intended application. In each instance, NIST is the place where industry looks for solutions.

EEL's *programs address these issues through the development of new metrology and the associated technical research and calibration services —*

When such challenges are within our mission, EEEL responds with help. For example, we have developed standards and calibrations for the optical-fiber sensor industry where few existed; explored the use of high temperature superconductors to expand their applicability beyond standards and research laboratories; provided new understanding and techniques to exploit partial discharge detection as a diagnostic of insulation conditions; developed methods to establish reference electromagnetic fields and measurement techniques; and provided technical input to international standards organizations involved in developing standards for power quality.

EEEL has also provided long-standing assistance through reliable, high-quality calibration services for electric power metering equipment, including wattmeter and watthour meters and support apparatus, such as voltage and current transformers, high voltage dividers, ac/dc converters, and phase meters.

In closing, I feel obligated to note that a study of the social rate of return (a payoff measure like the interest in your bank account) of our calibration work has shown an unusually high rate of over 400%. You might think we could rest on our laurels, but in this fast-changing world, we can't. There's more to be done already visible on the horizon.



L.W. Linholm, M.W. Cresswell

Structures for Lithography

In collaboration with Sandia and SEMATECH, single crystal test structures with vertical sidewalls have been developed to improve the critical dimension (CD) measurement for advanced semiconductor metrology tool characterization.

This is just a brief note acknowledging the value of the Semiconductor Characterization Conference...I am still getting feedback from industry participants, including those from Intel, on the benefit of the information sharing which occurred. The outstanding published proceedings are also receiving excellent feedback as an ongoing reference resource.

Manager,
Materials Technology Department
Intel Corporation

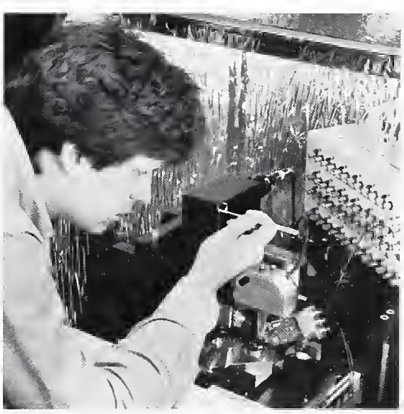
1.1 The Scanning Capacitance Microscope—A New Nanoscale Dopant Profiler

A metrology infrastructure has been developed that helps make the Scanning Capacitance Microscope (SCM) a practical and accurate metrology tool for two-dimensional dopant profiling of silicon. A new approach to feedback instrumentation has increased the dynamic range of the Semiconductor Electronics Division's SCM by a factor of 1000 over previous practice. A physically accurate model of the SCM measurements has been developed at NIST and integrated into a data conversion formalism which can extract the dopant profile from the SCM image in seconds.

The work accomplished in this project answers a need articulated in the National Technology Roadmap for Semiconductors, specifically, an ability to create two-dimensional dopant profiles at nanoscale spatial resolution. Deemed critical to the development of new generations of semiconductor circuits, the ability to accurately measure two-dimensional dopant profiles can be used to improve the predictive capability of technology computer-aided design (TCAD), which in turn reduces process development cost.

Joseph Kopanski and Jay Marchiando addressed the remaining technical barriers to bring the SCM technique's transition from a qualitative imaging technique to a quantitative two-dimensional dopant profiling metrology by extracting dopant profiles from SCM images.

Prior to their investigation, theoretical modeling predicted a nearly proportional change in SCM signal with dopant, implying that existing SCMs did not have the dynamic range to see the complete dopant concentration range of interest. Kopanski, along with David Berning, built an amplitude modulation circuit and a feedback differential amplifier which increased the dynamic range of the constant capacitance SCM by a factor of 1000.



J.J. Kopanski

Scanning Capacitance Microscope

SCM Image of a Self-aligned Implant, Field Effect Transistor Test Structure with a Nominal Polysilicon Gate Width of 0.355 Micrometers

Marchiando developed software to calculate the capacitance measured by the SCM in both two dimensions and three dimensions. The two-dimensional analysis is based on a multi-grid finite-element analysis. This finite-element-based model of the SCM has been demonstrated to be a better predictor of SCM performance than simple methods based on a one-dimensional analytical solution. The three-dimensional analysis is based on an innovative application of the method of collocation inside the semiconductor and finite-element analysis outside.

For industrial applications, the measured SCM images need to be converted to quantitative dopant profiles in a way that is accurate, quick, and convenient. A full analysis is too time-consuming for commonly available computing platforms. Thus, a conversion formalism is being developed that achieves both very fast and accurate data conversion by interpolating to a specific solution of SCM response from a database of general solutions calculated off-line with the finite element model.

The researchers are working with several major semiconductor manufacturers to help them bring SCM on-line as a practical two-dimensional dopant profiling technique. In May 1996, NIST hosted a review of the SEMATECH-sponsored development of a commercial SCM by a major instrument manufacturer. Invited papers on the work were presented this year and have also been scheduled for 1997.

1.2 NIST Test Bed Yields Circuit to Validate IGBT- Model Predictions Under Realistic Conditions

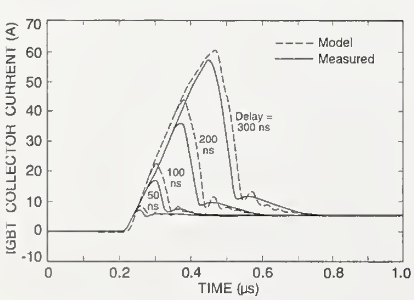
Power circuit modeling is an economic necessity. The high cost of medium- and high-power circuit components as well as the cost of the load itself requires that the risk of system failure during prototyping be reduced to an absolute minimum. Circuit simulation, which is the best means of eliminating system failure during prototyping, does not meet this demand unless the device models used are accurate and reliable at their greatest extremes, that is, when the devices experience their greatest stress.

Allen Hefner, who founded the NIST/IEEE Working Group on Model Validation in 1993, is well versed in the intricacies of circuit simulation and model design. The Group's 190 members are drawn from some 75 U.S. companies and 30 universities. His prior work with insulated-gate bipolar transistors (IGBT) device modeling led to the formation of an IGBT task group that is now developing an IEEE Recommended Practice Standard on IGBT Model Validation. This will provide a means to test the validity of a model's predictions under a full range of realistic behavioral conditions. Working with the task group, Hefner and David Berning created a testbed circuit at NIST for model-verification measurements of a popular half-bridge configuration for IGBTs.

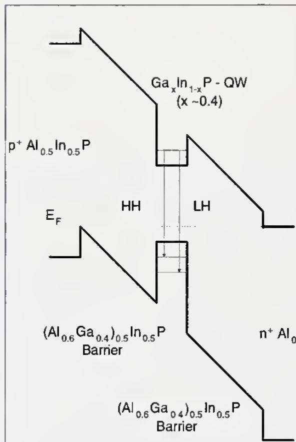
The IGBT has become the power switch of choice for many power applications, particularly in the field of motor and motion control. In recent years, efforts to model the switching behavior of IGBTs has greatly expanded. The testbed and procedures developed at NIST stress the IGBT under realistic "fault" conditions (shoot-through) as well as the usual "diode-recovery" conditions.

The relative simplicity of the well-characterized testbed permits realistic simulations to be made for verifying model predictions versus the measurements. The testbed has been used to develop a validation procedure for the model of an ultra-fast IGBT that employs a buffer-layer to optimize a trade-off between switching speed and on-state losses. Current densities exceeding 1000 A/cm^2 were studied, which are near the pulsed-current limit of presently available devices.

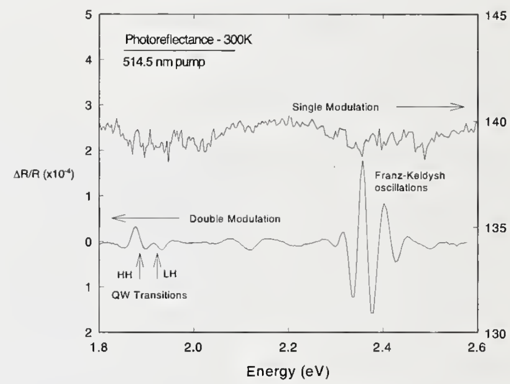
The ability of the model to predict the shoot-through current is shown in the figure for different "delay" or fault times. The "no fault" condition has the device turning on to a level of 5 A. The extreme stress that the actual device undergoes in shoot-through operation is evident in the peak current of almost 60 A for the 300 ns delay case. The model, also being stressed near its extremes, predicts this value quite well. Using validated models will allow circuit designers to reliably test their systems' behavior even before hardware prototyping.



IGBT Shoot-through Current as a Function of Delay Time



Band-Edge Schematic for QW Laser Structure



Single-Versus-Double Modulation PR Spectra from the QW Laser Structure

1.3 Non-Invasive Double-Modulation Photoreflectance System Provides Superior Means to Characterize Compound Semiconductors

Photoreflectance (PR), a contactless and nondestructive technique capable of probing interband electronic transitions and built-in electric fields in the surface and interface regions in semiconductor materials or structures, is widely used as a characterization tool in the semiconductor industry. Until now, its application to microstructures has been limited because it was very difficult to minimize the interference from the luminescence on the measured spectrum.

To address the problem, NIST developed a double-modulation-photoreflectance (DMPR) system to harness the potential of the powerful technique for the study of highly luminescent systems, such as quantum-well (QW) semiconductor laser structures and high-speed electronic devices, including high electron-mobility transistors (HEMT). Such devices require complex multilayer microstructures and complex and expensive processing steps.

Being able to perform detailed characterization of the wafers before processing devices makes it possible to fine tune the epitaxial growth pattern, which, in turn, improves device yields and reduces processing costs. Further, being able to quickly analyze a wafer soon after growth is invaluable to the growers and device designers for optimizing device operation. Pre-processing screening can also prevent out-of-specification wafers from being processed in the manufacturing area.

Paul Amirtharaj and Deane Chandler-Horowitz, the developers of DMPR, demonstrated the usefulness of the double-modulation procedure by comparing the QW laser structure spectra using single-versus-double modulation methods. The accurate measurement of the energy position and the splitting between the light-hole and heavy-hole states made it possible to accurately deduce the electronic state of the pseudomorphic QW, including the degree of tetragonal strain present. Also, the intense Franz-Keldysh oscillations from the barrier regions yielded the interface electric field strengths. The measurements were performed in a non-invasive fashion after growth, but before expensive processing, and revealed detailed information regarding the active electronic states of both laser and HEMT structures.

"The contents of Semiconductor Characterization demonstrate the extent to which instrumentation and techniques have been developed to meet those and many other challenges [higher purities and crystal perfection, push for ever-smaller geometries, greater yields and higher reliability]. The emphasis throughout is on the semiconductor industry. ... The comprehensive nature of the volume comes from the 180 authors - experts all - some from overseas, many from industry and industry-related organizations such as SEMATECH, and government laboratories such as NIST. ... The combination of knowledgeable authors, conscientious editors, and a handsome production job by the publisher (including an effective index, critically needed for books with such broad coverage) makes this volume a must for those in the field."

Book Review – L.W. Rubin
Physics Today, February 1997
an American Institute of Physics publication

1.4 Semiconductor Reference Book Leads into 21st Century

"Semiconductors and their applications are one of the greatest scientific and technological breakthroughs of this century," declared Craig Barrett, Chief Operating Officer at Intel, and Arati Prabhakar, Director of NIST, in the foreword of the recently published book *Semiconductor Characterization: Present Status and Future Needs* (AIP Press, 1996). David G. Seiler, Chief of NIST's Semiconductor Electronics Division, along with W. Murray Bullis of Materials and Metrology, and Alain C. Diebold, SEMATECH, were co-editors.

The book is based on papers delivered at an international workshop on semiconductor characterization held at NIST/Gaithersburg in 1995. The workshop was dedicated to summarizing major issues and giving critical reviews of important semiconductor characterization techniques that are useful to the semiconductor industry. Speakers were leaders in the industry invited to present up-to-date reviews of the major issues and characterization techniques for semiconductor device research, development, and manufacturing. Contributed papers included new developments and improvements in characterization technology.

Semiconductor technology is critical to state-of-the-art computers, entertainment equipment, automotive electronics, medical instrumentation, telecommunications, space technology, television, radio, and manufacturing technologies. Semiconductor characterization, then, is an essential component of the Nation's well-being from both an economic and a competitive standpoint.

The text covers the unique characterization requirements of silicon integrated circuit development and manufacturing, compound semiconductor materials and devices, and others given in the National Technology Roadmap for Semiconductors. Additional sections discuss technology trends and future requirements for compound semiconductor applications. Recent developments in characterization, including in-situ, in-FAB, and off-line analysis methods, are also highlighted. The publisher expects the book to serve as a long-term, base-line, reference in this field for the next decade.

a[Statement before the Subcommittee on Technology of the Committee on Science, U.S. House of Representatives, June 25, 1996]

More importantly to our industry, EEEL is leading the NIST interlaboratory effort to develop metrology to meet the needs of the semiconductor industry as identified in the Roadmap. ...The Director of EEEL also serves as a member of the Roadmap Coordination Group. ...Technology is the driver for economic growth in the world market to an unprecedented degree...it is essential that industry and government work together as partners so that the Roadmap can be implemented in a way that benefits our nation from both an economic and security standpoint.

Vice President, Technology Programs
Semiconductor Industry Association

2

MAGNETICS

J.M. Moreland

Magnetic Force Resonator Microscope

A read/write head from a computer data storage device is loaded into the Magnetic Force Resonator Microscope in preparation for mapping of the magnetic field around the device.

2.1 Reference Sample Developed for Magnetic Force Microscopy Instrumentation

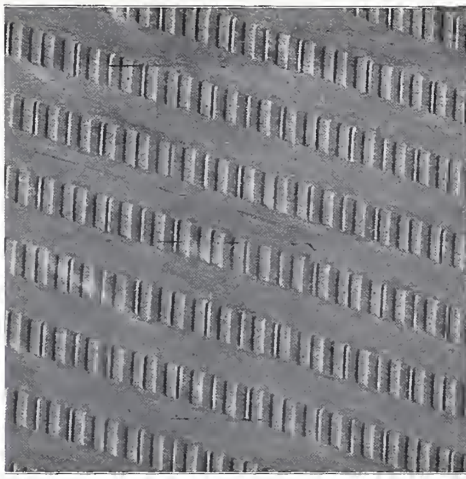
An imaging reference sample optimized for magnetic force microscopy (MFM) instrumentation has been fabricated and tested. The reference samples will be used as a tool to analyze the performance of MFM instrumentation and will allow qualitative correlations between various magnetic-imaging methods.

MFM is used widely in the data storage industry for high resolution imaging of drive components because it is easier to implement on a production line. However, the MFM image depends on the specific instrument detection mode and the magnetic nature of the scanning tip. If there is uncertainty about the scanning tip's magnetic state, MFM images can be difficult to interpret.

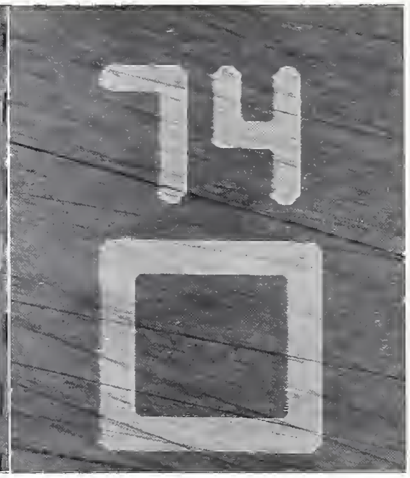
The NIST imaging reference sample is a well characterized artifact that is helpful in determining the magnetic state of scanning tips. It is also used to gauge the performance of MFM instruments with regard to force sensitivity, resolution, and image interpretation.

NIST scientists, Paul Rice and Stephen Russek, collaborated with staff from a magnetic disk drive manufacturer to develop the imaging reference sample. The industry researchers wrote magnetic bit transitions onto a hard disk mounted in a precision spin stand. When they were done, Russek deposited a thin-film pattern of numbered squares on the surface of the disk so that the position of the bit transitions could be located. Rice imaged a number of the squares with his MFM instrument. A few squares were provided to scientist Michael Kelly in the Physics Laboratory for scanning electron microscope with polarization analysis (SEMPA) measurements on the exact same transitions imaged by MFM.

SEMPA provides images of the vector magnetization inside the magnetic media of the disks. These images can be used to calculate the fields and field gradients sampled by MFM above the media. This helps to quantify the MFM instrument response and allows for contrast and comparison of these two fundamentally different, but complementary techniques.



MFM Image: 65 nm by 65 nm



Surface Topography from the Same Scan

2.2 Micromagnetic Simulator Software

In response to the needs of the magnetic data storage industry, NIST developed micromagnetic models of the magnetic sensors used in magnetic recording heads and magnetoresistive random access memory. The models, originally implemented on the NIST supercomputer, often required several hours of calculation. Although these results were welcomed by experts in magnetic modeling, more work was needed to effectively transfer this technology to industry designers.

NIST scientists, John Oti and Stephen Russek, set out to make these modeling techniques accessible to nonspecialists. Their premise was simple: when more scientists and engineers could easily model magnetic devices, significant improvements could be expected at every stage of the manufacturing process from initial design to actual production.

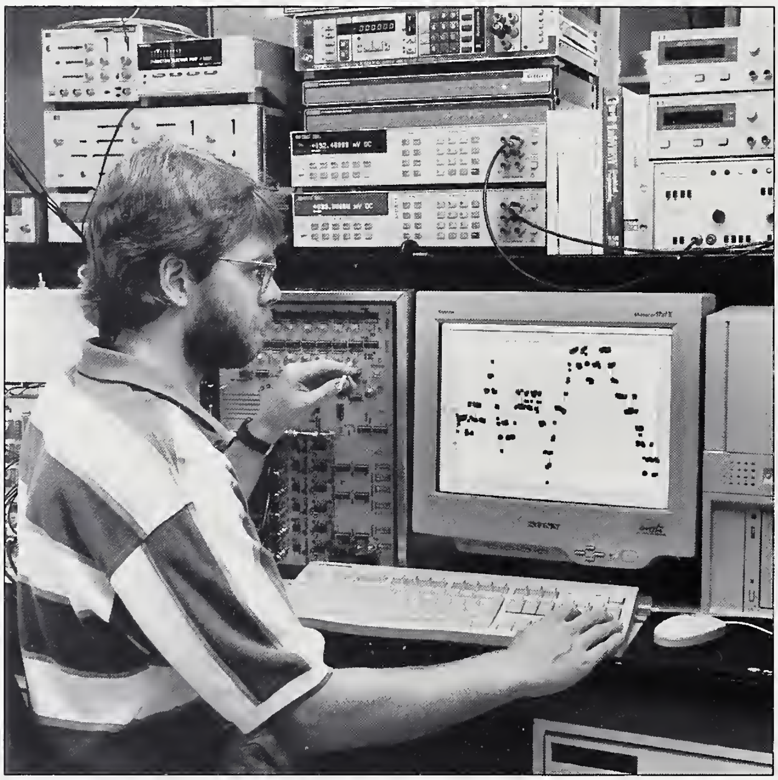
So, working in collaboration with a leading manufacturer, they developed a new software package, the *Micromagnetic Simulator*, that provides an easy graphical interface to the original program. The *Micromagnetic Simulator* is user-friendly and simple to implement. It is written in a common language, runs on standard personal computers, and is available in 16- and 32-bit versions, which run on widely popular operating systems.

The package allows easy access to the simplest NIST modeling code which simulates the magnetic devices used in magnetic recording and magnetic data storage. Code from the NIST supercomputer will be added this year. Further, by providing nonspecialists an easy means to build up multilayer magnetic devices and calculate their magnetic and magnetoresistive response using a variety of models, it enables magnetic data storage companies to compare their in-house modeling results with open NIST modeling packages and standards.

The simplest model maps the device onto a set of interacting single domain particles. This model includes magnetostatic interactions, exchange interactions, device geometry effects, field angle effects, and high current density effects. On a state-of-the-art personal computer, the model completes its calculations in a matter of seconds or minutes, and also displays calculated magnetization and magnetoresistance as well as an animated movie of the device responding to an external magnetic field.

The most complicated model that can be accessed by this front end package is a full micromagnetic model originally implemented on the NIST supercomputer. The full model is conveniently run in the background in the new application. A beta version of the Micromagnetic Simulator software package has been delivered to scientists and engineers at NIST and at selected universities. Once the beta tests have been completed, the model accuracy is quantified, and the manuals are prepared, general distribution will follow. The target date is June 1998.

SUPERCONDUCTORS



M.W. Keller

Electron Pump Measurement and Control Equipment

Graphical display of the electron counting accuracy of the 7-junction pump. A change in step level represents an error of one electron.

NIST Develops Super High Frequency Oscillator Circuit

Researchers at NIST have built one of the most complex, high-temperature superconducting circuits ever designed. The device, a high frequency oscillator, eventually could be used in receivers operating in the millimeter-wave to far-infrared (terahertz frequency) region. Tunable frequency sources have not been readily available in this region and are needed for applications such as observation of atmospheric gases, astronomy, and advanced communication systems.

CAL LAB The International Journal of Metrology
March - April, 1996

3.1 Electron Pump Sets World Record for Counting Accuracy

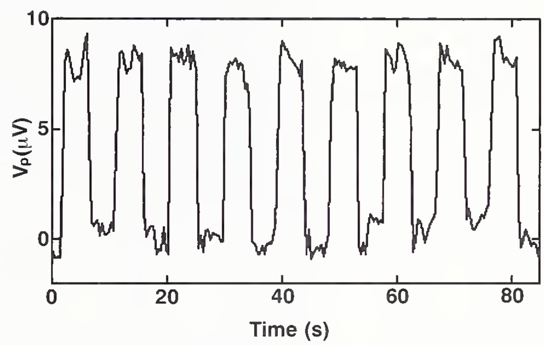
Using a microcircuit cooled to near absolute zero, NIST scientists have demonstrated that electrons can be counted one by one with an accuracy of 15 parts per billion. This experiment proves in principle that electron counting can be used as the basis for new fundamental standards of electric current and capacitance with a potential for greater accuracy than existing standards. If such standards are realized, current and capacitance will join voltage and resistance as electrical quantities that can be related to fundamental atomic constants. In addition, electron counting may lead to a more accurate evaluation of the fine-structure constant and contribute to refined tests of quantum electrodynamics.

At NIST, electrons are counted using a circuit called the electron pump, which consists of several micrometer-sized metallic islands connected in series by sub-micrometer tunnel junctions. To obtain the required junction size, approximately 30 nanometers, the circuit is fabricated by electron-beam lithography. When cooled to a temperature of 30 mK in a dilution refrigerator, the electron pump can be operated as a turnstile, allowing a single electron to pass each time it is activated by appropriate bias voltages.

In the latest work, carried out by Mark Keller, John Martinis, Neil Zimmerman and Andrew Steinbach, a pump with six islands was designed, fabricated, and subjected to rigorous tests. In one test, the pump is used to repeatedly move one electron onto and off of a capacitor, while the capacitor's voltage is monitored with a sensitive electrometer.

As shown in the figure, the resulting voltage change is large enough that an error of one electron is easily detected. When continued over billions of pump cycles, this test established an accuracy of 15 parts per billion for the six-island pump. As a result, charge is now one of the most accurately measurable electrical quantities, and the applicability of electron counting to metrology is assured.

The pump's control over individual electrons, which is far beyond the capabilities of conventional circuits, is achieved by making the capacitance of each island so small that the presence of one extra electron increases the island's potential enough to block other electrons from tunneling onto the island. Thus, in the absence of thermal noise, one and only one extra electron moves through the pump at a time.



Capacitor Voltage as a Function of Time When One Electron Is Repeatedly Moved On and Off the Capacitor Using an Electron Pump

3.2 Major Stumbling Block Eliminated in Quest to Characterize Commercial High-Temperature Superconducting (HTS) Devices

The microwave industry is focusing on the development of high-temperature superconducting devices that can be incorporated into a variety of microwave systems, including cellular telephone base stations, personal communication systems, and military communication networks. For example, cellular telephone providers are currently testing a variety of new base station filters based on HTS thin films.

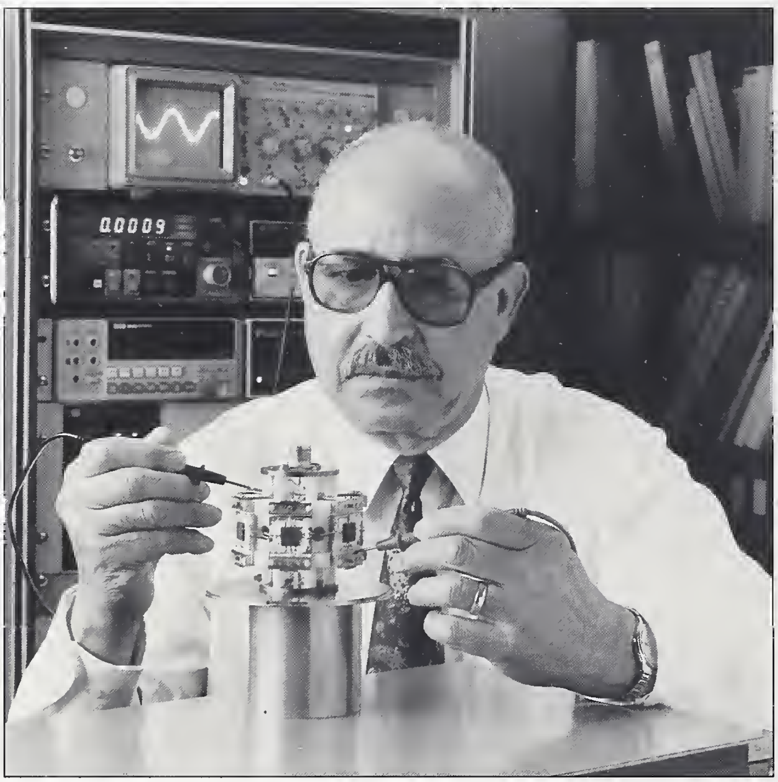
To remain competitive in this area, the industry needs better methods to characterize both the unpatterned thin films and the finished devices. Up to now, the need to calibrate microwave measurements at cryogenic temperatures posed major difficulties.

In the past year, NIST has developed both the facilities and methods needed to characterize the microwave performance of these devices. Using a dielectric-loaded cavity resonator, James Beall, Ronald Ono, James Booth, Frans Stork, and David Rudman of the HTS Electronics Project, have been able to measure the microwave surface resistance of HTS films down to 3 milliohms at 25GHz and 76 K.

Calibrated measurements of thin film devices are also being made using a recently acquired cryogenic microwave probe station. Working with Donald DeGroot of the Microwave Metrology Group, the NIST room-temperature approach for probe station calibration has been adapted to this new system. To date, it has been used to measure attenuation constants in HTS coplanar transmission lines as small as 0.03 dB/cm at 9.3 GHz and 50 K.

Armed with this kind of feedback, industry will be able to optimize film deposition parameters. A perfect solution is not likely, however. As film quality improves, even lower surface resistances will need to be measured, so there will always be a gap between what is desired and what is possible. Meanwhile, the probe station is being used to compare different approaches to patterning HTS devices.

4 LOW FREQUENCY

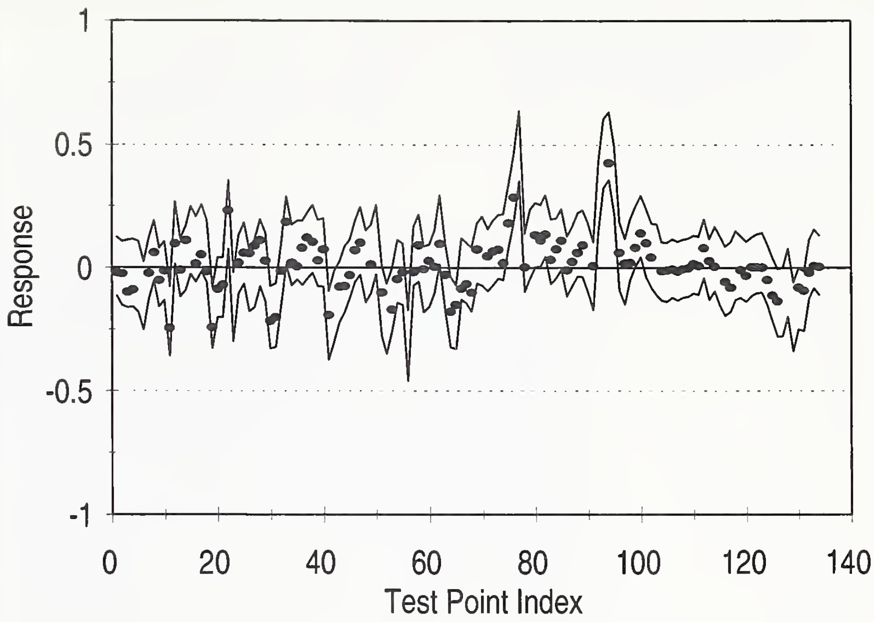


C.B. Childers

Prototype 5-A AC-DC Difference Standard Using EEEL-Developed High-Current Multijunction Thermal Converter

...[High-frequency circuit] board fabricators must account for frequency effects by using empirical corrections to the reported dielectric constants. This is often inaccurate, particularly with new materials. The result is errors in predicting impedance, leading to costly scrap and time-consuming delays as the board fabricator adjusts design parameters to achieve specified impedances. Nick Paulter of NIST *has...developed a measurement system that...allows board fabricators to easily measure the high frequency dielectric constant of a substrate.* His *goal is to develop a* TDR *method that can serve as an industry standard for measuring the dielectric constant of printed circuit substrates. ...up to 20% of all telecommunication products* [$62 B *market] need controlled impedance...* This *fraction is growing rapidly as operating frequencies go up and cellular telephones become common consumer items.*

Scientist
DMTS, AT&T Bell Labs



Typical 95% Uncertainty Intervals

Plot of response predictions for a multirange ac meter at 104 points, along with the 95% prediction intervals computed based on known response values at 30 points. The plot has been normalized to the 90-day uncertainty specifications for the instrument.

4.1 NIST Reduces Customer Cost for Calibration Service Through Application of New Complex Testing Methodology

To be competitive in the field of electronic manufacturing, you must be able to test your products efficiently. In some cases, a product's testing cost, including calibration, can approach or even exceed its original manufacturing cost.

As part of an Electricity Division program "Testing Strategies for Complex Electronic Systems," T. Michael Souders and Gerard Stenbakken began investigating this problem. Stenbakken and Souders focused on finding the most efficient generic testing strategy for linear, multirange electronic instrument standards. Working in collaboration with staff from Cornell and Georgetown Universities, and staff from the NIST Statistical Engineering Division, they developed the Empirical Linear Prediction (ELP) process.

The ELP method allowed the performance of the device or instrument under test to be predicted from an empirical model determined from extensive measurement data taken on a statistically representative number of instruments. This data is then used to establish a mathematically reduced matrix model representing the underlying behavior of the instrument, from which an optimal (minimum) set of test points can be established, and which will provide an accurate prediction of the instrument behavior at all test points.

Recently, Stenbakken and Souders greatly enhanced ELP by making it possible to calculate uncertainty intervals for the predictions produced by the process. Based only on measurements made at the reduced number of test points, they incorporated procedures to estimate the amount of nonmodel error present in a device.

Another member of the Division, Andrew Koffman, verified these procedures in two demonstration projects using extensive data obtained from the Department of Defense and a major instrument manufacturer. In particular, Koffman applied the new ELP approach to create and evaluate uncertainty intervals for calibrating commercial ac voltage thermal transfer standards.

The experimental results were outstanding. In both cases, Koffman found that 95% uncertainty intervals (based only on measurements taken at the reduced set of test points) actually bounded slightly more than 95% of the measurements at all test points. His results left no doubt that the newly enhanced ELP process can be used effectively and accurately to test production-line electronic instruments. To facilitate the transfer of this technology, Koffman has developed software in the form of a NIST ELP Toolbox together with a user-friendly interface, which is currently being beta-tested.

...During a recent R&D cycle, we developed new features requiring advanced deconvolution capabilities. The leading algorithms in this area have been developed at NIST. ...previous research work at NIST was reviewed, updated, and adapted to address the application area at hand. The outcome was an extension of the state-of-the-art in the area. Stable, optimal deconvolution serves as the basis for advanced signal analysis. These analysis algorithms fundamentally advance the capabilities of the test instruments, allowing for significant cost reductions to end users. In general, direct market impact for all [our] company's products may well approach $10 M over the next few years.

President
Signal Integrity Solutions, Inc.

4.1 Continued

Another outcome of Koffman's results is that NIST is now able to apply this research to the NIST calibration service for thermal transfer instruments. The first calibration using ELP was recently completed, and the customer reaped a windfall. With exacting ac-dc difference measurements carried out by EEEL staff Thomas Lipe and Mark Parker, NIST was able to meet the customer's tight uncertainty requirements at all 309 specified test points, based on measurements made at only 108 test points. The cost savings to the customer was approximately $20 K per instrument tested at NIST.

4.2 World's First Thin-Film, Higher-Current AC-DC Difference Standard Developed at NIST

Many won't argue the point "...if it ain't broke, don't fix it" but what are the options when a critical instrument is broken, and it can neither be repaired nor replaced? This was the problem NIST faced this past year with regard to their stock of Weston current converters. A vintage standard developed more than 30 years ago, Weston converters were used at NIST for the measurement of currents ranging from several milliamps to 20 amperes. When several of these standards failed, staff had to look elsewhere for a solution.

Initially, Joseph Kinard, Thomas Lipe, Donald Novotny, Clifton Childers, and Guest Scientist De-Xiang Huang chose a solution based on thin-film fabrication technology, which is commonly used in the semiconductor industry. Within a relatively short time, the team had developed special film multijunction thermal converters that performed very well. Lipe and Childers then focused on the next step: finding a means to enable the converters to serve as replacements for the higher current Weston elements. Their solution was to mount groups of the converters in parallel, and the outcome was first rate. The new element is a novel, hexagonal structure in which six converters are placed in parallel to achieve a 6 A capability. Preliminary data show that the ac-dc characteristics of individual chips rival those of comparable Weston elements, and that the process of ganging numbers of them will lead to viable current standards.

The latest effort has not only replaced the obsolete broadband ac current standard, it has upgraded the support NIST provides to activities of national importance. These activities cover a broad range of applications, such as energy metering in the power industry, maintenance on the radar systems used for national defense and air traffic safety, and evaluations of electrical power regulation devices, nuclear detonation- and blast-effects research, and high-energy physics.

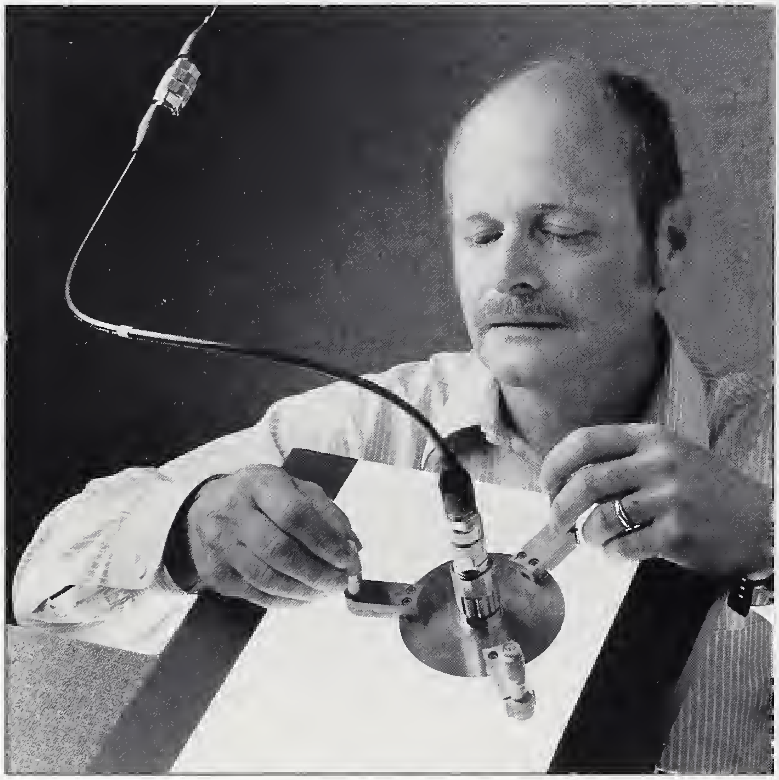
Improved electronics and ac generation techniques have led to steady improvements in the instrumentation used by industry. The direct consequence of these improvements is that industry must then look to NIST for greater accuracy in laboratory standards. This phenomenon is generally described as upgrading the metrology of an industry or a nation. To ensure the dissemination and widespread acceptance of this breakthrough, EEEL has signed cooperative research and development agreements with four U.S. instrumentation companies.

O.B. Laug, R.H. Palm, Jr.

Transconductance Amplifier Used to Calibrate Current Transformer

EEEL-developed 100 ampere wideband transconductance amplifier is used as an accurate current source to calibrate current measuring devices such as shunts and current transformers.

5 MICROWAVES

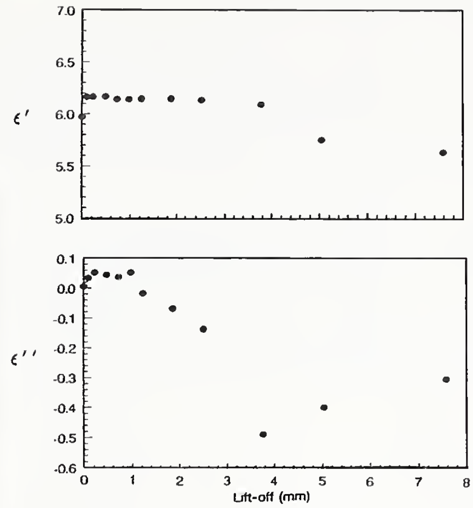


J.R. Baker-Jarvis

Open-Ended Coaxial Probe for Non-Destructive Permittivity Measurements Placed on the Dielectric Material to be Characterized

[E-mail to Robert M. Judish]
I want to personally thank you and your staff for the excellent calibration turn around on our model 8478B Thermistor Mount. Without your attention and quick response, our Power Measurement Production Hybrid Lab would have been impacted by $500,000 in shipments. Thank you again for your excellent service and prompt handling of this order.

Director of Quality
Giga-tronics Inc.



Measured Permittivity Versus Lift-off

Measured permittivity at 1.0 GHz versus lift-off for a glass sample whose ε′ = 6.15 and whose ε″ = 0.03. Acceptable lift-off range = 0 to 2.5 mm.

5.1 Accuracy of Nondestructive Technique for Measuring Dielectric and Magnetic Properties of Materials at RF/Microwave Frequencies Improved

Applications of newly-emerging microwave technologies include satellite remote sensing and radar imaging of the earth for geological, agricultural and oceanographic purposes as well as automobile anti-collision radars and aircraft landing systems that enable commercial planes to land in zero visibility. Another important application involves the hyperthermic treatment of human cancers using sophisticated RF applicators. All of these technologies necessarily require that the microwave energy be very accurately focused, directed, and processed using specialized circuitry and phased array antennas that are generally mounted on a thin layer of polymer or ceramic dielectric, termed a substrate.

Usually, the efficient and cost-effective design of such high-performance systems requires that the dielectric properties of the substrate materials be known to better than ±3%. However, most of the characterization techniques involve preparing a machined sample of the material under test; i.e. they are destructive and unsuitable for use in production line settings. A very widely-used nondestructive and broadband measurement method involves placing an open-ended coaxial probe in contact with the material under test, and deriving its dielectric parameters by measuring the probe admittance using an automatic network analyzer. A major U.S. instrument manufacturer currently markets such a measurement system.

However, measurements performed by NIST and others on thin substrates have consistently shown that such measurements are accurate to within no better than ±10% and generally degrade further with increasing relative permittivity, ε'_r of the material under test. The reasons for this primarily relate to inadequacies in the electromagnetic model used to define this measurement problem and oversimplified solutions to this model.

The most significant of these problems is neglect of the "lift-off" factor, defined as the unavoidable presence of an air gap between probe face and material surface. Even where the probe appears to be in good contact with a polished material surface, NIST has shown that the unavoidable air gap of 50-100 µm has a very significant influence on probe admittance. Furthermore, for some specialized applications, such as use of the probe for process control in moving assembly lines, inclusion of lift-off is obviously essential.

In efforts to significantly improve the measurement accuracy of the open-ended coaxial probe, James Baker-Jarvis and Michael Janezic of NIST have developed full-field solutions (the most accurate) to a much improved model that includes a) the air gap lift-off, b) finite layer thickness, where the material may now have both dielectric and magnetic properties and c) optional conductor backing (for measuring copper-clad substrates). By deliberately including a small and known probe lift-off in the measurement process and using micrometer-equipped probes, improved measurement accuracies down to ±3% or better have now been routinely demonstrated. In addition to being significantly more accurate, the newly developed NIST coaxial probe software contains many more measurement options than previously available and can now be operated in a convenient PC environment.

5.2 MultiCal® Software Provides Low-Cost Network Analysis

MultiCal® software, a popular program developed by NIST for the microwave and radio frequency industries, has been extensively improved by Roger Marks, Donald DeGroot, Jeffery Jargon, and Dylan Williams. At the request of industry, the team created a new software version that implements a variety of advanced algorithms, and interfaces with a number of test instruments used to measure microwave network parameters. These improvements will provide convenient implementations of sophisticated microwave measurement algorithms.

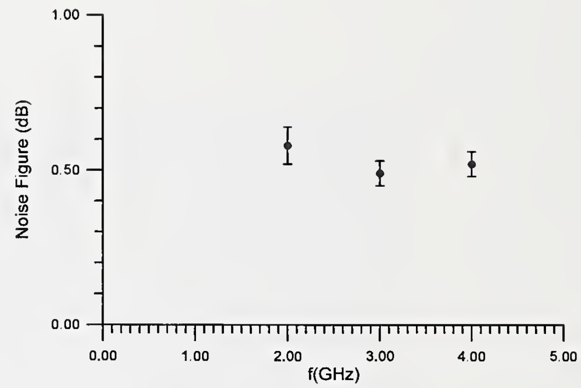
MultiCal® was developed with the support of the NIST Industrial MMIC Consortium, and the Consortium has exclusive use of the software in its first year of availability. With a ready industrial audience, it directly impacts the design and manufacture of high-speed microelectronic components, including monolithic radio frequency, microwave, and millimeter-wave integrated circuits. These components are vital to the growth of civilian telecommunications industries, including personal communications systems (PCS), advanced cable and wireless television distribution networks, automotive radar, and ground positioning by satellite.

The new MultiCal® not only implements the NIST-developed "multiline TRL" calibration procedure, the most accurate yet developed for integrated circuits, it also supports a multitude of other calibration procedures and a variety of test instruments. While traditional TRL calibration procedures are accurate only over narrow frequency ranges, the use of "multiline" standards provides redundancy for verifiable accuracy over several decades of bandwidth.

A major new feature in MultiCal® is its implementation of a new, practical, and accurate "two-tier" version of the multiline TRL calibration. This feature enables industry to use more widely-available RF network analyzers for many measurements that previously required more expensive microwave network analyzers.

Another related feature is the software's ability to interface with a digital sampling oscilloscope. NIST studies of "time domain network analysis" have shown that by carefully optimizing the measurement parameters, a digital sampling oscilloscope can replace a much more expensive microwave network analyzer for many applications.

The overall advantage of MultiCal® is that it provides test engineers with a known and tested implementation of advanced microwave measurement techniques and analysis. Its ability to interface with less costly instruments more typically found in industrial settings ensures that desired precisions and accuracies will be more easily affordable and attainable.



Measured Noise Figure of Amplifier with Adaptor

J.L. Rice

Characterization of Low-Noise Amplifier

5.3 New Measurements on Low-Noise Amplifiers Confirm Measurement Methods

John Rice, David Wait, and Robert Billinger recently completed measurements of the noise characteristics of two state-of-the-art, commercial, low-noise amplifiers. Using carefully characterized NIST standards and thorough error analyses, the researchers were able to achieve accuracies near the limit of NIST's primary noise standards, a factor of ten better than typical industry measurements.

The availability of inexpensive, very-low-noise amplifiers has contributed greatly to the boom in the communications industries, particularly in the production of cellular telephones and personal receivers for satellite television. However, a crucial factor in the successful commercialization of low noise amplifiers, is an accurate knowledge of their noise properties. In order to accurately determine overall system performance, engineers need to know and rely on the noise figure specifications.

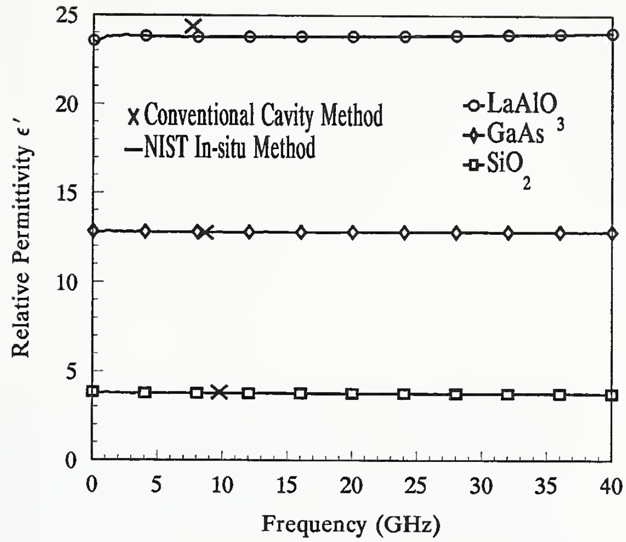
Measurement of low noise figures is a very difficult task. Special techniques are required because of the low noise powers involved, and because the noise figure varies dramatically with the impedance of the source. Noise figure measurements in industry are often conducted with noise figure meters having uncertainties of 0.1 to 0.5 dB, that is, on the same order of magnitude as the noise figure of the amplifier being measured.

This is unacceptable for several reasons. First, it is often impossible for manufacturers to verify their performance claims. Second, inaccurate noise figures can result in claims that offer unfair competitive advantage to those less hesitant to assert better performance data than can be consistently proven. Finally, inaccurate noise figures can lead to performance failures in systems using the amplifiers.

The team's work this year confirmed the validity of the methods to be used in the new measurement service for low noise amplifiers. They were able to measure amplifiers at 2, 3, and 4 GHz, and the noise figures obtained were near 0.4 dB, with uncertainties (95% confidence level) as low as 0.04 dB for amplifiers whose connectors match those of NIST's primary standards (0.08 dB if an adapter was required). This accuracy is near the limit set by the uncertainty in the primary noise standards and was achieved, in part, by modeling and correcting for the effects of reflections.

[Letter to Dr. James Randa] *We wish to extend our heartfelt thanks to the* Broadband Microwave Metrology Laboratory*...specifically to* Mr. Andy Terrell, Dr. David Wait, Mr. Bob Judish, *and yourself. Significant and unselfish contributions were made to our collaborative research effort...it is a rare occasion when a researcher can get the encouragement and necessary tools to perform critical measurements on a project such as this. Your lab, measurement capabilities, and technical personnel are truly a national treasure.*

Section Head
Microwave Remote Sensing Engineering
ECI Division
E-Systems, a Raytheon Company
and
Associate Professor, Microwave and Wireless Program
University of South Florida



Plot Showing Measurement Results

The relative permittivity of lanthanum aluminate, gallium arsenide, and fused silica substrates measured using broadband NIST in-situ methods. Conventional single frequency cavity results are shown for comparison.

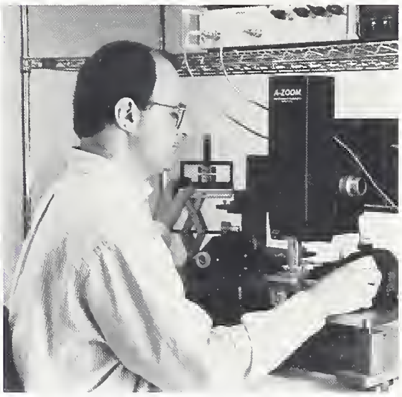
5.4 Successful NIST/Industry Collaboration Improves Ability to Characterize Manufacturing Materials for Wireless Communication Components

Metrologists Michael Janezic and Dylan Williams have developed methods that will accelerate the wireless industry's ability to accurately characterize the electrical properties of thin dielectric films and substrates. Because these materials play a crucial role in both modern microelectronics packaging and integrated circuits, the lack of satisfactory characterization techniques has been one of the major stumbling blocks to the development of higher performance circuits.

Traditionally, characterization efforts involved testing materials machined from bulk samples, but time and again it appeared that the properties of the material were different when tested on the chip. So, Janezic and Williams focused on the development of in-situ measurement methods for determining the frequency-dependent dielectric properties of new materials.

Using the printed transmission lines integrated into microelectronic circuits, a new technique allowed them to test the actual materials used in the fabrication of an integrated circuit, including substrates, thin metal and dielectric films, and protective coatings. These techniques combined conventional methods for measuring a transmission line's propagation constant with new methods for measuring its characteristic impedance. The additional information on impedance is used to differentiate between the effects of the dielectrics and the metals on the propagation of electrical signals in the lines; it is essential to characterize them separately.

The researchers tested the new methods on printed transmission lines already characterized with conventional techniques and typical of those currently used in industry. The results proved that transmission lines can be used to measure permittivity within a few percent. Collaborations with major industrial players have been initiated to apply the new methods to the characterization of materials under development for state-of-the-art packaging and circuitry.



M.D. Janezic

Dielectric Characterization Probe Station

Connection to transmission lines printed on the dielectric materials of microelectronic circuits permits accurate characterizaton of their dielectric properties.

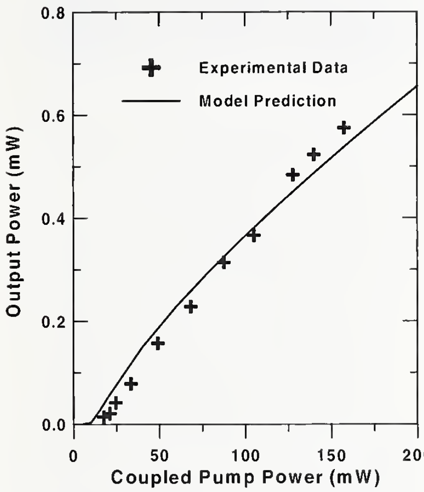
6 LIGHTWAVES

D.L. Veasey

Prism Coupling System for Measuring the Optical Characteristics of Prototype Waveguides for Waveguide Lasers

6.1 Rare-Earth Doped Optoelectronic Devices: Metrology and Manufacturing

NIST scientists, in collaboration with a glass manufacturer and a device manufacturer, are developing metrology and manufacturing processes for waveguide lasers in rare-earth doped glasses and lithium niobate. Recent efforts have resulted in the development and demonstration of several new or improved devices: optically pumped erbium-doped glass waveguide lasers with thresholds of less than 2.5 mW of absorbed pump power at 980 nm; a ytterbium/erbium co-doped glass waveguide laser with a threshold of less than 18 mW of absorbed pump power; and what is believed to be the first stable, 980-nm-pumped, lithium niobate waveguide laser.



Experimental and Theoretical Laser Output

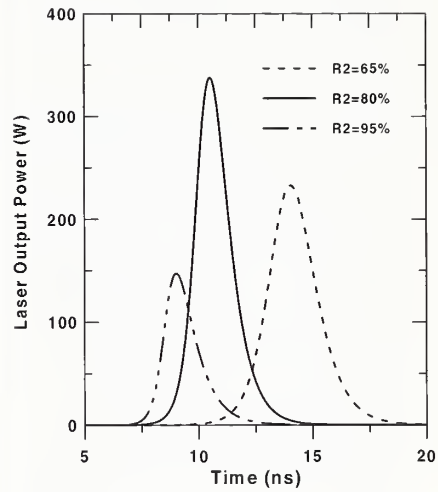
Output laser power at 1442 nm wavelength as a function of coupled pump power at 980 nm wavelength for a 2-cm Yb/Er co-doped waveguide laser in silicate glass with theoretical predictions derived from the waveguide laser model.

Rare-earth-doped glass integrated optical devices are attractive for multiple wavelength communication and sensor systems because they have large spectral emission bandwidths, permitting several wavelengths to be used simultaneously. Channel waveguide components also offer a much higher gain-per-unit-length than their fiber counterparts, which opens up the possibility of transparent signal processing devices such as add-drop filters or modulators. Waveguide laser sources offer better coupling efficiency to optical fibers than diode lasers because their mode characteristics are more closely matched. They are also inherently more stable and less susceptible to outside interference than semiconductor lasers because they are dielectric materials with high energy storage capacity.

NIST scientists David Veasey, Norman Sanford, and J. Andrew Aust, and Guest Scientist Jaymin Amin, have employed spectroscopic measurements, improved waveguide fabrication and testing techniques, and laser characterization and modeling to optimize the waveguide lasers. All of this is necessary to develop the highest quality laser host materials and manufacturing processes, and to achieve new levels in laser performance.

Working through industrial partnerships such as these, NIST is applying its expertise in metrology toward more efficient manufacturing and serves as a link between materials manufacturing and systems manufacturing.

As a result of this work, one of NIST's industrial collaborators is producing and selling new high efficiency laser glasses, for the manufacture of waveguide lasers and amplifiers. The other is expanding its work on the development of new sensor products using waveguide laser technology.



Predicted Q-Switched Laser Pulses

Predictions for Q-switched optical pulses in a 2-cm Yb/Er co-doped waveguide laser operating at 1542 nm wavelength. R2 is the reflectivity of the laser output coupler. The R2=80% curve represents the optimum design for this laser and shows an output power approaching 350 W peak power and a pulse width (FWHM) of 1.7 ns.

6.2 Growth in Optoelectronic Source and Detector Calibration Services

Calibration services are one of the most direct methods of providing industry and other government laboratories with traceability to national standards. NIST has been offering calibration services for the characterization of lasers since the late 1960s. However, the recent growth of the industry and its changing requirements have nearly doubled the demand for calibration services over the last few years.

These services support manufacturers and their customers in diverse fields, including telecommunications, materials processing, semiconductor integrated circuit manufacturing, laser printing, optical data storage, military systems, and medicine. Shifting customer needs have required NIST staff to adapt existing capabilities and develop new services. Key scientists include Christopher Cromer, Rodney Leonhardt, Igor Vayshenker, Paul Hale, John Lehman, Xiaoyu Li, Richard Jones, David Livigni, and Donald Larson. Many of the calibrations are carried out by Iris Tobias and Darryl Keenan.

One new development in the optical telecommunications industry that has required some adjustments is the proliferation of optical power meters designed to measure the power exiting an optical fiber. Unlike prior instruments, these receive the power to be measured through any one of several types of optical fiber connecters. The connectors make the calibration process much more difficult, as the mating of connectors is not a perfectly reproducible process and can lead to wavelength-

I. L. Tobias

Laser Power Meter Calibration Standard

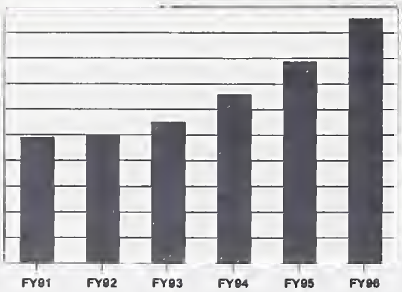
On behalf of the members of **the Optoelectronics Industry Development Association (OIDA),** *I want to express our support and concern for the vital role which the* **National Institute of Standards and Technology (NIST)** *plays in promoting the competitiveness of* **U.S.** *industry. ...The programs of* **NIST** *are essential in the development of emerging technologies, such as electronics, that will drive future economic growth. The vital importance to the national economy must be highlighted in this era of cost-cutting, so that key decision makers in the government can make informed decisions about maintaining this crucial national resource.*

President
Optoelectronics Industry
Development Association

6.2 Continued

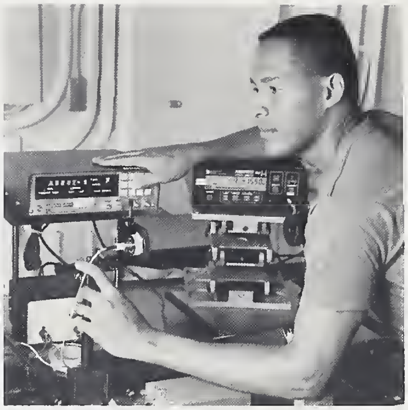
dependent errors. Further, optical power meters need to be calibrated over a wide range of power levels to establish their linearity, and because they may be used over a range of wavelengths, they must be calibrated versus wavelength, as well.

Communications engineers need to know the speed at which optical detectors, and the receivers in which they are used, can be operated. New services have been established to allow measurement of detector frequency response at frequencies to 50 GHz, and are being improved to increase their accuracy and to reach yet higher speeds.



Calibration Work: Optoelectronics Division

The growing use of lasers in medicine for such operations as retinal welding, coronary angioplasty, and general surgery requires careful monitoring of laser power and frequent calibration of power measuring instruments. Meeting the needs of companies producing ultraviolet lasers for ophthalmic operations such as photorefractive keratotomy has required adaptations of existing standards.



D.A. Keenan

Optical Fiber Power Meter Calibration System

The use of ultraviolet lasers in the production of semiconductor integrated circuits, such as computer processors and memories, is also requiring further adaptations of NIST calibration capabilities. The need for ever-increasing component densities requires shorter and shorter wavelength lithography. Calibration services at the wavelength of the KrF laser (248 nm) have already been added. The next target wavelength is 193 nm, followed by 157 nm. At these wavelengths, many optical materials are damaged by the radiation, making calibration difficult.

6.3 Standard Reference Materials for Optoelectronics

Several new Standard Reference Materials (SRMs) have been developed at the request of standards groups and manufacturers of optical instrumentation. These devices will serve as artifact standards for the calibration of commercial instrumentation. Optical instrumentation used in the development and maintenance of optical communications systems is a $400M worldwide market growing at 10% annually.

SRMs 2521, 2522, and 2523 are for parameters associated with high performance fiber connectors — fiber coating diameter and the inside and outside diameters of connector ferrules. They were developed by Matt Young in collaboration with the NIST Manufacturing Engineering Laboratory, and supplement SRM 2520 for fiber cladding diameter, developed several years ago. Connecting optical fibers with low optical loss requires tight control of the dimensions of the fiber, the fiber coating, and the ferrule which holds the fiber in the connector.

The velocity of light in optical fiber depends slightly on the wavelength of the light, an effect known as chromatic dispersion. This can limit the maximum rate at which information can be transmitted over the fiber. Fortunately, there is a wavelength at which the chromatic dispersion is zero and designers of high capacity systems often choose an operating wavelength as close as possible to that wavelength. SRM 2524, developed by Steven Mechels, consists of 10 kilometers of optical fiber with the wavelength of zero chromatic dispersion known to within ±0.08 nm. With it, fiber manufacturers will be able to specify this parameter much more accurately than in the past.

Many new high capacity systems use several laser transmitters, operating at slightly different wavelengths, to increase the transmission capacity of a single fiber, a technique known as wavelength division multiplexing (WDM). This requires that the wavelengths of the individual lasers be well known and controlled. SRM 2519, developed by Sarah Gilbert, is a fiber-connected gas absorption cell that permits quick wavelength calibration of instruments, such as optical spectrum analyzers, used in

[Letter to Douglas Franzen] *As a manufacturer of optical fiber in the United States...* AT&T *places high priority on fiber measurement standards activities. The ability to succeed in trade and commerce many times depends on the ability to specify and test fiber as well as having good agreement with customers.* NIST *has played an important role in the fiber optic industry by working with manufacturers in the* TIA/EIA *groups, sponsoring measurement round robins, and providing* SRMs. *...*AT&T *would like to encourage support from* NIST *for new* SRMs. *The tightening of specification tolerances caused by competitive and system performance pressures increases the need for better calibration methods and better agreement among members of the fiber optic industry.*

Member, Technical Staff
Fiber Measurements
AT&T

the development of WDM systems in the 1550 nm spectral region.

Two new SRMs will be used to calibrate instruments for polarization measurements. SRM 2525, developed by a team headed by Kent Rochford, is for optical retardance. Retardance is a property of devices commonly known as waveplates, which are used for polarization control. The retardance of the SRM is much less dependent on temperature, wavelength, and angle of incidence than previously available devices. Not only will it be useful for instrument calibration, but it should help waveplate manufacturers specify their products more accurately.

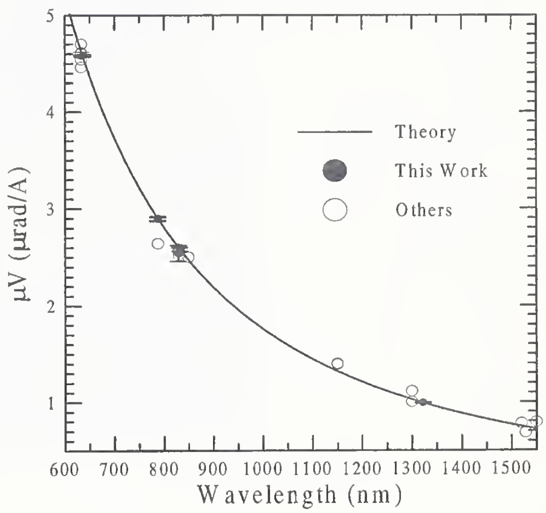
The velocity of light in a fiber is also slightly dependent on the polarization state; this can limit capacity much as chromatic dispersion does. An SRM being developed by Paul Williams will permit more accurate calibration of instruments designed to measure this parameter, known as polarization mode dispersion.

6.4 Improved Determination of Verdet Constant in Optical Fiber

Allen Rose has completed a series of Verdet constant measurements on annealed optical fiber, which demonstrates improved accuracy and provides better knowledge of the Verdet constant's variation with wavelength. The accuracy of these measurements, about ±0.6%, is a factor of eight improvement over previous work. Rose measured the Verdet constant at five different wavelengths between 633 and 1300 nm.

Optical fiber current sensors use the Faraday effect, in which the polarization state of light is rotated in a current-induced magnetic field. The Verdet constant is a fundamental property of the fiber material and quantifies the rotation per unit magnetic field or current. Optical fiber current sensors are being used for applications in electric power transmission metering and switching, and for electric motor control to improve efficiency.

An important factor in Rose's ability to make these measurements was the development of improved methods of annealing optical fiber to remove linear birefringence. Linear birefringence in the fiber can interfere with the current sensing capability of optical sensors. Although annealing the fiber eliminates stress-induced birefringence, a residual birefringence, resulting from the imperfect circularity of the core, can still limit the quality of annealed fiber coils. Twisting the fiber prior to annealing greatly decreases this residual birefringence. This new annealing technique allows high yields from almost any ordinary fiber and provides an alternative to fiber current sensing with more expensive specialty fiber. A full theoretical and experimental evaluation of twisted and annealed fiber has recently been published.



Silica-Based Fibers

7 VIDEO

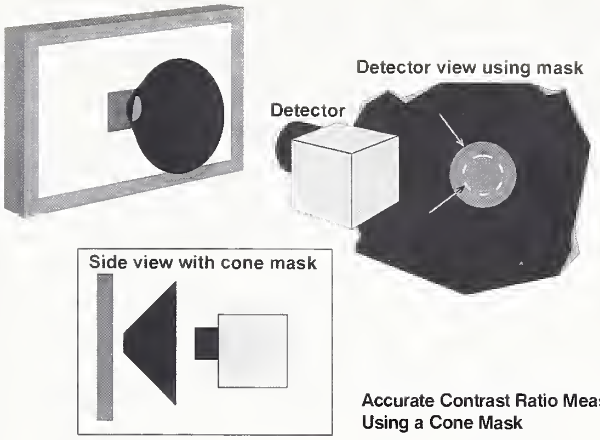
P.A. Boynton

Display Contrast Ratio Measurement Apparatus with Cone Aperture

Manufacturing: The Noble Calling

Paul Boynton and Ed Kelley of the U.S. National Institute of Standards and Technology (NIST) verify what many members of the display community have long felt: standard methods of measurement often grossly understate the contrast ratio (CR) of displays. Even better, Boynton and Kelley provide a straightforward technique for making accurate, reliable, and consistent CR measurements.

Editorial
Information Display
Publication of the Society for Information Display
November, 1996



Accurate Contrast Ratio Measurements Using a Cone Mask

7.1 Accurate Contrast Ratio Measurements for Flat Panel Displays Eliminate Guesswork

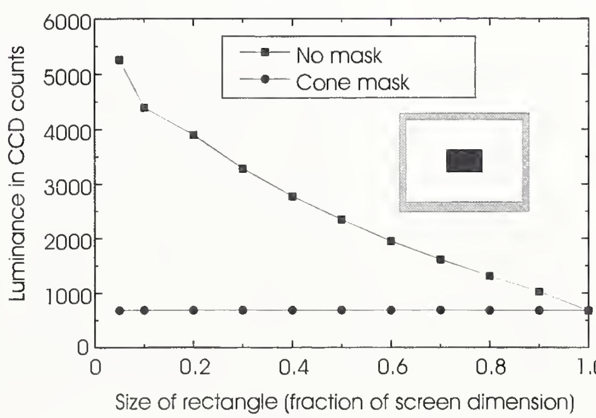
Up to now, industry has been up against a wall with regard to measuring the contrast ratio of high-contrast devices, such as flat panel displays. Contrast ratio, the ratio of the luminance of a white area to a black area on a display, is a critical performance parameter that strongly influences the perceived quality of a display.

With the conventional techniques available to them, industry leaders recognized that they could not accurately measure contrast ratio nor could they recognize when the measurements they made were in error. In sum, U.S. manufacturers of products that used flat panel displays could neither accurately characterize nor compare competing displays, that is, they had no grounds on which to base a sound decision.

Edward Kelley conducted research to provide a diagnostic method and a simple-to-implement, but accurate, measurement technique to eliminate the problem. He determined that when measuring black regions of a flat-panel display, the surrounding white regions introduced unavoidable reflections (glare) in the lens of the measuring instrument. The problem is severely exacerbated with newer displays that use contrast-enhancing techniques, such as anti-reflection coatings or black pixel-surrounds.

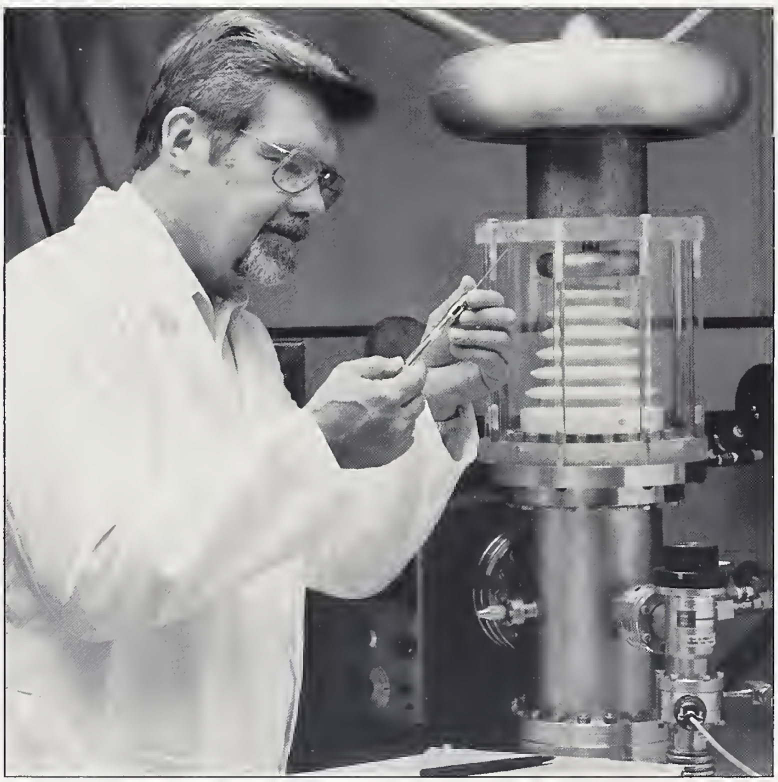
Kelley established the scope of the problem by comparing the results using both new and old measurement methods. First, Kelley and Boynton measured a display using the conventional techniques, which resulted in a contrast ratio value of 50:1. They then employed the newly developed NIST technique, which revealed a more accurate contrast ratio value of 250:1.

The NIST method involves inserting specially designed gloss-black cone apertures between the display and the measurement device. The cone apertures are designed to substantially reduce the glare introduced into the lens system without interfering with the measurement. Multiple apertures can be inserted to reduce the glare to an arbitrarily small (insignificant) value.



Measurement of the Luminance of Black Rectangle of Various Sizes on a White Screen With and Without a Mask

8 POWER



R.J. Van Brunt

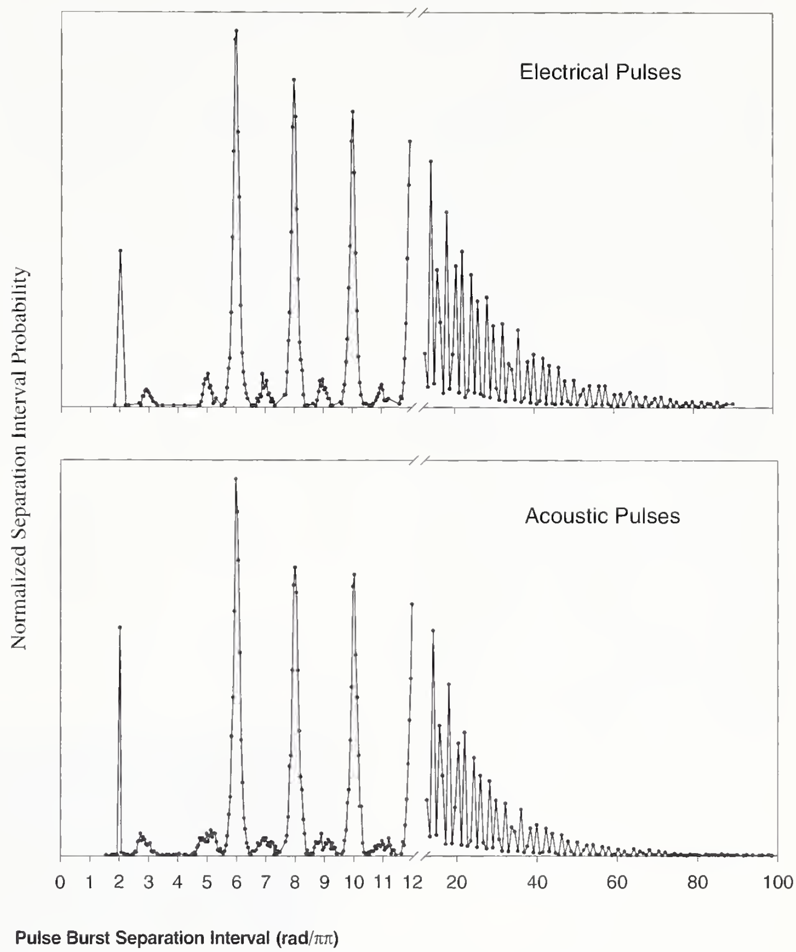
Corona Discharge Cell

Decomposed gaseous insulating material (SF_6) is extracted from corona discharge cell for analysis

NIST Helps Power Grids Make "Lightning Saves"

A NIST technique has been incorporated into the latest version of an electrical standard used to test the ability of electric power grid high-voltage equipment to survive lightning strikes. ...The technique improves the measurement of specific high-voltage impulse waveforms that simulate lightning. Such test waveforms subject the equipment to up to 10 times its normal operating voltage. To certify that power grid equipment is lightning proof, engineers must evaluate the strength of the waveform. They use a "high-voltage divider" device to scale the voltage down to levels that can be measured. However, the process can produce a distorted reading. The NIST technique improves the measurement process by enabling testers to mathematically estimate the distortion.

RF DESIGN
April, 1996



8.1 Acoustical Sensors May Be Viable for Monitoring Partial Discharge Signals in Oil-Insulated Power-System Components

A partial-discharge signal digitizer and computer-based data recorder system recently developed at NIST was successfully adapted for simultaneous recording of both acoustical and electrical partial discharge signals. The signals were generated by applying a high alternating voltage at low frequencies to electrodes immersed in transformer oil.

These measurements demonstrated the possibility of using the electrical signals to calibrate the discharge intensity as measured by the acoustical signals. The measurements also showed that detailed information about the complex properties of the partial discharge is contained in both the recorded electrical and acoustical data.

Acoustical methods for partial-discharge monitoring offer certain advantages over other measurement methods. In particular, acoustical methods are immune to electrical noise which can be problematic in substation or power-plant environments. These methods can also provide information about the location of the discharge site that cannot be extracted readily from electrical signals.

The work clearly shows that some of the same statistical information, such as partial-discharge pulse-amplitude and phase distributions can be extracted from the acoustical data as well as from the electrical data. By using the electrical/acoustical correlations from this work, acoustical sensors can be used to monitor the occurrence of partial-discharge in oil-insulated power-system components, such as high voltage substations. Doing so provides the advantage of having continuous, permanent records of all partial-discharge events that occur in the systems, and allows the records to be subjected to detailed off-line analysis.

This project was carried out as part of a CRADA involving engineers from a manufacturer of acoustical partial-discharge detectors currently being used for monitoring transformers and other power-system components. The experiments were performed at NIST by Richard Van Brunt, Peter von Glahn and Kenneth Stricklett, in collaboration with Luiz Cheim, a Guest Researcher from CEPEL, Rio de Janeiro, Brazil.

Because partial-discharge phenomena exhibit unique statistical signatures, the team's findings can also be used to distinguish partial-discharge signals from noise. This will help overcome serious existing problems associated with the calibration of the partial-discharge signal amplitudes in terms of absolute discharge intensity. The results also indicate that partial discharge in liquids depends significantly on the polarity of the applied voltage and can exhibit nontrivial temporal behavior that has not previously been seen.

K.L. Stricklett

Partial Discharge Cell

8.2 Better, Cheaper High-Voltage Divider Design will Support Electric Power Equipment Industry

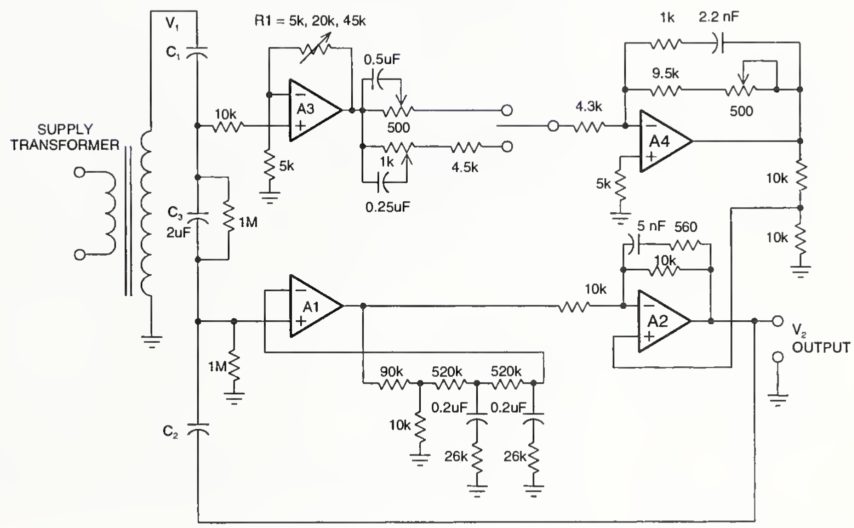
Accurate measurements of ac high voltages are necessary for quality control testing of transformers, capacitors, surge arrestors, and other power equipment to ensure their reliability. The failure of such equipment while in service can lead to costly and dangerous power outages.

At NIST, an active divider was designed and built for the measurement of 60 Hz high voltage with relative uncertainties of 20 μV/V or less. The divider design, devised by Oskars Petersons, a Guest Scientist, incorporates inexpensive electronic circuitry that can be used with a compressed-gas high-voltage capacitor and a multimeter for precision measurements of ac high voltages.

The only expensive component required for the apparatus is the high-voltage capacitor, but these are routinely available in the high-voltage test laboratories of many electric utilities and electric-power equipment manufacturers. Staff members, Gerald Fitzpatrick and Eric Simmon, built the active divider and verified its performance.

The active device has a measurement accuracy that is an order of magnitude better than that of most passive ac devices, such as resistive ac dividers. The team was able to reduce the measurement uncertainties to the 20 μV/V level through the use of high-stability low-voltage capacitors and a controlled voltage source. The design also allows significant cost savings. Previously, this measurement required two expensive high-voltage capacitors: one for the high-voltage arm of the divider and one for the controlled source. Instead, a low-voltage capacitor has been substituted in the controlled source, eliminating the need for the second more expensive component.

U.S. electric-power equipment firms should be able to capitalize on this opportunity to save dollars and enhance their competitiveness. By adapting their existing equipment for a modest cost rather than purchasing new equipment, such as laboratory-grade voltage transformers, at considerably greater expense, significant cost savings can be realized. Electric utilities can also benefit from this development by the improved reliability testing measurements available for their own equipment. At NIST, the new circuit will be used as a calibration reference in test equipment applications for measuring ac high voltage and transformer power losses.



Active High-Voltage Divider Schematic

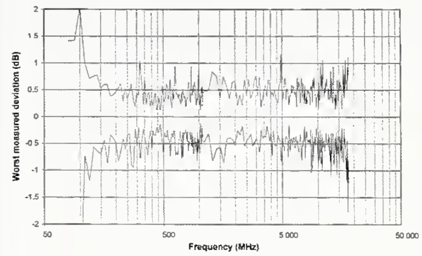
9 ELECTROMAGNETIC COMPATIBILITY

K.D. Masterson

Aligning Standard Dipole to Characterize Electromagnetic Test Field

[Letter to Dr. Martin Misakian, Convenor TC 85/WG11: Definitions and methods of measurement of low frequency magnetic and electric fields with particular regard to effects on human beings]
I am impressed by the amount of work that you have accomplished [re: preparing a new publication taking into account existing national documents as basis for the work] and I would like to thank you, on behalf of the IEC and TC85, for the thoroughly professional manner in which you have tackled the project.

Chairman IEC TC85, Measuring Equipment for Electromagnetic Quantities
Chief Engineer - Instruments
GEC ALSTHOM



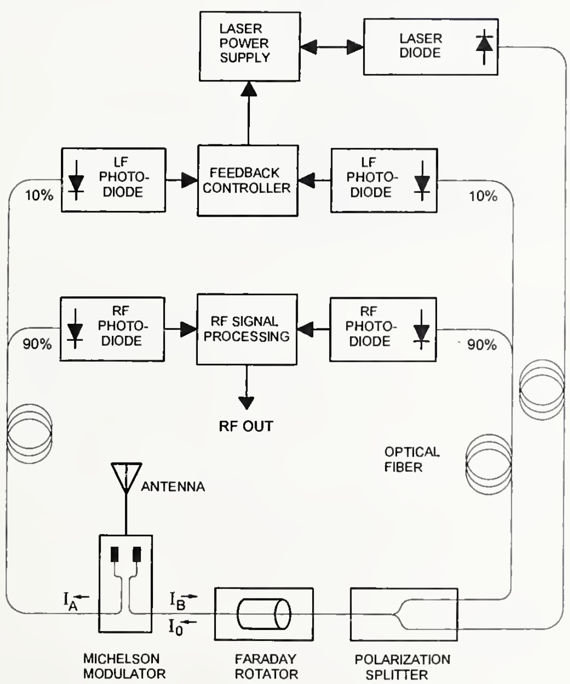
Worst Measured Deviation (dB) in Estimate of Chamber Gain, Based on Six Independent Measurements

9.1 Unique Reference Antenna Reduces Calibration Errors Due to Ambient Electromagnetic Fields

Antenna performance is critical for all wireless applications, including microwave communication links and cellular telephones. If manufacturers know exact antenna performance parameters, they can determine optimum locations for the devices. Optimum location is what makes the difference between enjoying excellent coverage on your cellular phone and not getting your calls through.

The increasing use of wireless communication products demands ever higher levels of calibration accuracy. Manufacturers must be able to precisely delineate the performance characteristics of the antennas they use and those they design into their products. The problem with determining these characteristics is that, up to now, it has been very difficult to obtain a pure signal out of traditional broadband reference antennas used at outdoor calibration test ranges. The signal output contains contributions from the ambient electromagnetic fields of all frequencies at the antenna site.

To address this problem, NIST researcher Keith Masterson developed an improved RF standard antenna for the NIST calibration system. He devised a means to discriminate against the out-of-band interference while maintaining the integrity of the signal. The key element of the NIST system is the development of a unique RF electro-optic modulator that converts the RF signal from the antenna to a lightwave signal that can be piped to the measuring instrumentation via a nonconducting optical fiber. Using the nonconducting fiber provides a twofold advantage: it preserves the integrity of the signal, and it does not interfere with the electromagnetic field the antenna is measuring. Working to his specifications, Masterson collaborated with a private company to design and fabricate the modulator, which required extremely tight dimensional constraints.



Electronic and Optical Components of the RF-Standard Antenna System

9.2 Improved Methods for Radiated Immunity and Emissions Measurements

Reverberation chambers, or mode-stirred chambers, are becoming the industry's preferred means to obtain radiated immunity and emissions measurements. In response, NIST has developed improved methods to further reduce the uncertainties and to improve the reliability of this metrology.

EEEL researchers Galen Koepke, John Ladbury, and Dennis Camell have introduced network analyzer measurement techniques that separate antenna impedance and efficiency effects from reverberation chamber wall loss when measuring the chamber quality factor. Improvements have also been made in the modeling and statistical analysis of the chamber fields. This is the first step in a new analysis of the measurement uncertainties associated with reverberation chamber measurements. Preliminary results of this work have indicated a significant improvement in the quality of these measurements when the antenna and other system effects are properly considered.

NIST has used these new techniques to characterize three new reverberation chambers at NASA Langley, ensuring traceability to the NIST chamber. The new chambers are a major component of NASA's High Intensity Radiation Laboratory in the Electromagnetic Research Branch of the Flight Electronics and Technology Division. The unique High Intensity Radiated Fields capability of this facility allows NASA to conduct aircraft Electromagnetic Compatibility and Interference (EMC/EMI) research not currently achievable in U.S. industry. This research is aiding the Federal Aviation Administration and the aerospace community in developing cost-effective test methodology for high intensity radiated field certification of 21st century aircraft.

10 ELECTRONIC DATA EXCHANGE

K.G. Brady

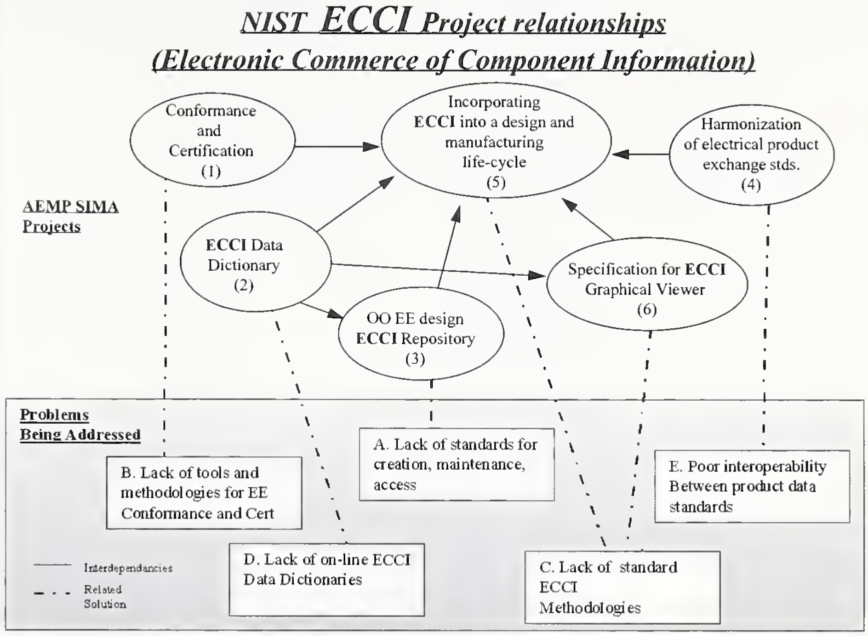
Comparing a Hardware Implementation of a Printed Circuit Board with a Computerized Representation of the Board and Its Component Information

While many IC vendors are putting component data on the Web...each supplier determines his own terminology, and the same terms may be used to describe different parametric information...The Component Information Dictionary Standard (CIDS) will address that issue.

Staff Reporter
Electronic Engineering Times
August 19, 1996

"I applaud NIST's insight into the need for this research."

Principal Engineer
Rockwell Collins Avionics and Communications Division



NIST Electronic Commerce Component Information (ECCI) Project Relationships

10.1 Easy Access to Electronic Dictionary Possible Using Prototype Object-Oriented Software

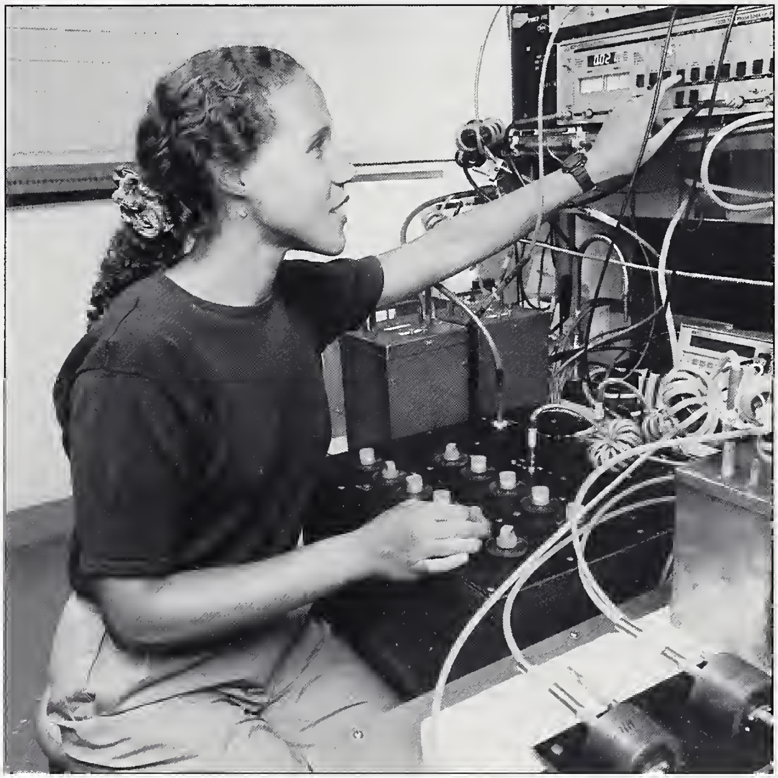
Efficient engineering disciplines require several types of electronics component data in computer-accessible digital formats. To implement total-quality management, flexible manufacturing, cooperative development, or concurrent engineering, manufacturers need to share data among themselves and between themselves and their suppliers. One requirement for achieving electronic data sharing is the use of a set of common specifications, or dictionary, of electronic terminology. Otherwise problems abound.

One such problem is the classic "apples to oranges" comparison. Manufacturer A's specification for the rise time of an electronic component may or may not correspond to the specification provided by Manufacturer B, making it impossible to do a meaningful comparison of the values. Another problem occurs when it is desirable to search the Internet for component information — one needs a consistent or traceable terminology. If dictionary definitions were electronically embedded within component data, accurate information would be readily accessible to all parties.

Toward this end, NIST researcher Michael McLay has collaborated with members of Subcommittee 3D of the International Electrotechnical Commission (IEC), to develop a prototype object oriented software version of the IEC 1360 dictionary. To date, he has developed a part of the infrastructure that allows software "objects" to be incorporated and transmitted with component information. This is done by converting each dictionary definition into a software object. The dictionary, which runs on a variety of popular computer platforms, will be distributed to industry for review and comment.

McLay is also developing a dictionary browser to provide direct access to the terms, permit the editing of a "local" dictionary, and facilitate the submission of new terms to appropriate standards bodies. Both the object oriented software version of the 1360 dictionary and the browser are being developed in response to industry requests for a method to include standard electronic terminology in existing on-line component information systems.

NATIONAL ELECTRICAL STANDARDS



A. Jeffery

Precision Capacitance Bridge

Step-up comparison of capacitors using NIST-developed four-terminal-pair AC transformer bridge

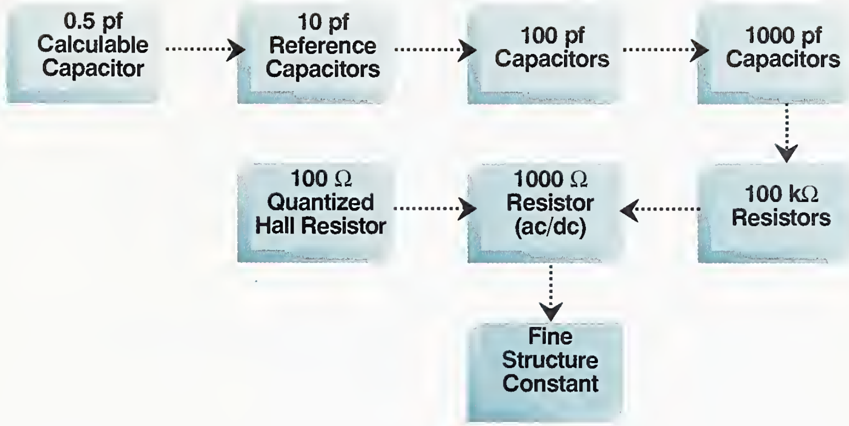
11.1 New Determination of the SI Ohm Yields a New Value of the Fine Structure Constant

Using the NIST calculable capacitor, a team of scientists, which includes Anne-Marie Jeffery, Randolph Elmquist, Lai Lee, John Shields and Ronald Dziuba, has recently completed a new determination of the basic unit of electrical resistance. As the figure indicates, the unit is the ohm.

Determining the ohm in the International System of Units (SI) involved a long chain of painstaking measurements, which started with a measurement of the specially constructed 0.5 pF capacitor. The capacitance value was accurately calculated from interferometric measurements directly referred to the unit of length, the SI meter. The chain ends with a comparison against the quantum Hall resistance. In-depth evaluations of sources of possible systematic errors in both the ac and dc parts of the experiment were also performed. The fine structure constant is a fundamental measure of the interaction between nuclear and atomic electromagnetic fields. Its value can also be calculated with precision using quantum electrodynamic (QED) theory. Each new, more precise experimental determination helps to test fundamental theories underlying what is known of basic atomic structure.

Fundamental constants are used widely throughout all of physics at the most precise values available. The latest NIST value for the fine structure constant α^{-1} is 137.036 003 7 ±0.000 003 3, which compares favorably with another new experimental determination at the National Measurement Laboratory in Australia, and a new QED theoretical calculation at Cornell University.

The new NIST value is based on a series of consistent measurements over the past three years; the prior NIST value (1988) was based on a single measurement. The team will use the new value to provide data for the least-squares adjustment of fundamental constants in 1997.



Measurement Chain

The chain of measurements, which starts with the 0.5 pF calculable capacitor, is illustrated here. The SI value is transferred to a series of three capacitance standards with values of 10-, 100-, and 1000-picofarads. From this point, the value is transferred to a series of three resistance standards, beginning with a value of 100 k Ω. All measurements are made using AC transformer bridges. An AC-DC conversion is then made to obtain the DC value of the resistor. The comparison of the QHR with the realization of the ohm through the calculable capacitor is made through the DC measurement of the 1000 Ω transportable resistor.

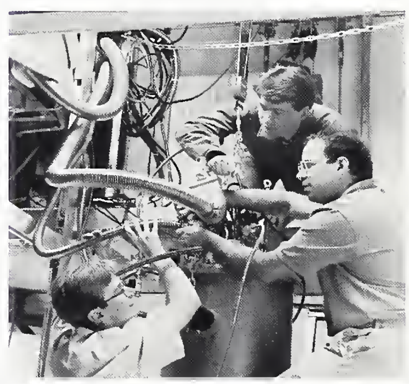
11.2 Calibration of Multimegohm Resistors is Automated and Improved

NIST scientists Dean Jarrett and Ronald Dziuba have developed an automated system for the calibration of multimegohm standard resistors. The team also extended the range of calibration services from the previous limit of one teraohm (10^{12} ohms) to a new limit of 100 teraohms.

The new system will prove especially helpful to the semiconductor industry, which relies heavily on this type of service. Calibrations at this order of magnitude, the measurement of very small currents, are critical to the characterization of semiconductor materials and associated processes, such as determinations of the purity status of the cleansing water in semiconductor and circuit-board processing. Scientists working in the field of nuclear research and instrumentation are also dependent on this type of calibration, particularly when ion current measurements are involved.

Very-small-current measurements are typically made using current-sensing electrometers or picoammeters, both of which require periodic recalibration. The need for calibrated multimegohm standard resistors arises from the fact that there are no phenomena readily available for use as current standards. Hence, the precise measurement of current for calibration purposes is done by measuring the voltage drop across known resistances.

To create the automated system, the team developed an active-armed bridge designed specifically for high resistances. They also collaborated with a small instrument manufacturing company to develop a guarded programmable switch. Each are critical components. The bridge design offers two improvements over traditional designs: stray currents in the bridge are negligible, thus improving its accuracy; and the linearity of the bridge affords a continuum of ratios (unlike conventional bridges) and high accuracies even at 100:1 and 1000:1 ratios. This wide range of available ratios facilitates calibration of resistor values far removed from nominal standards, as well as permitting redundant measurements for improved uncertainty assessment.



L.M. Head, J.L. Cobb, N.M. Zimmerman

Preparing Dilution Refrigerator to Measure Single-Electron Devices

PROGRAMS—MATRIX MANAGED BY EEEL

The Electronics and Electrical Engineering Laboratory administers NIST-wide laboratory programs in law enforcement and microelectronics as well as the programs sponsored by our own Laboratory. You will find descriptions of matrix-managed programs which are conducted within EEEL in the Accomplishments section of this document. Additionally, to offer a sense of the significance, quality, and impact of the matrix-managed work performed by other cooperating laboratories within NIST, we have provided the following examples.

Office of Microelectronics Programs

Technical Support for MIT Lincoln Laboratory

Lincoln Laboratory, in cooperation with SEMATECH, is developing new technology needed for patterning integrated circuit chips with linewidths of 180 nanometers and smaller. As these chips will be manufactured within the next five years, the technology and tools must be available for development work before that time. To support the task of creating images as small as required, NIST is measuring the optical properties of silicon dioxide (fused quartz) and calcium fluoride, which are the only two materials suitable for making lenses using 193-nanometer wavelengths of light. NIST's efforts are being coordinated by the Physics Laboratory, in which the majority of work is being done, although this work also draws on the expertise of EEEL and the Chemical Science and Technology Laboratory. In addition to NIST, the overall Lincoln Laboratory program involves other government laboratories, such as Sandia National Laboratories and several universities. The materials being measured come from Europe and Japan as well as from the United States, and will be used in manufacturing tools at all of these locales. This broad scope is necessary because the U.S. semiconductor industry will need to purchase the best of these tools without regard to where they are made.

Improved Radiation Thermometry for Rapid Thermal Processing (RTP) Control Using Multispectral Thermal Imaging

Rapid thermal processing is widely used to anneal crystal damage from ion implantation, and for depositing thin films on silicon wafers by thermally-driven chemical vapor deposition. The extremely small geometries of the wafer features could be destroyed by thermal diffusion if the wafers were exposed to high temperatures for too long a period. An RTP apparatus can heat a wafer from room temperature to over 1000 ΩC and cool it down almost to room temperature again in less than a minute, while maintaining a uniform temperature over the entire wafer. Although this process can be done repeatably, only limited success has been achieved using RTP for accurate wafer temperature control. NIST is obtaining a specially-designed RTP test bed and will be working on new approaches to address this significant problem. The work is being coordinated by the Chemical Science and Technology Laboratory, with its expertise in thermometry and thin-film thermocouple technology, and involves significant contributions in spectral radiation metrology from the Physics Laboratory.

Dimensional Metrology at the Nanometer Level

Measurement of the dimensions of physical features on silicon wafers is a continuing metrological challenge. NIST is developing new techniques and continuing to refine existing ones. As an example, the scanning electron microscope (SEM) is widely used in the industry to see these small features, but the interactions of electrons with the structures being viewed have not been known sufficiently well to allow accurate dimensional measurements to be made. Monte Carlo modeling of these interactions has now been completed by EEEL using NIST's supercomputer facilities. The results have been reduced to a form that allows fast lookup by much less expensive work stations, allowing the information to be used directly in the SEM to make linewidth measurements possible. To verify the accuracy of this advancement, a high-resolution field emission SEM in NIST's Manufacturing Engineering Laboratory has been instrumented with a compact commercial scanning probe tool. This combination will be used with the Monte Carlo results to assess the accuracy of this new approach.

Optical Critical Dimension and Overlay Metrology

Knowing the dimensions of small features on a wafer is not sufficient — it is also essential to know the positions of such features in relation to those in neighboring layers. Further, the allowable uncertainty in this measurement is only a tenth of that permitted in linewidth. Compounding the problem is the fact that linewidth measurements are one-dimensional, while overlay measurements are two-dimensional. Researchers in the Manufacturing Engineering Laboratory have constructed a new optical instrument designed specifically to meet this need. This tool is constructed on a Stewart platform. The platform is a kinematic structure which provides much improved rigidity and resistance to vibration in comparison with the performance of conventional microscope structures, while offering work spaces large enough to accommodate whole wafers. The instrument is now being tested to assess its performance.

Thin Film Profile Measurement Methods and Reference Materials

Using their Standard Reference Material for boron in silicon (SRM 2137), the Chemical Science and Technology Laboratory scientist who led the SRM development work has been employed in an inter-laboratory evaluation of the uncertainties of the measurement by secondary ion mass spectrometry (SIMS). This experiment was conducted under the auspices of the International Organization for Standards (ISO). The result shows that this analytical technique, calibrated by use of the SRM, has an uncertainty of about eight percent (2σ). The uncertainty without such calibration can easily be three times larger.

Office of Law Enforcement Standards

Procedure for Analysis of Smokeless Powder Residues by Capillary Electrophoresis Published

This publication documents a procedure for the analysis of residues generated by the combustion of ammunition and explosives prepared with smokeless powder. The bases of the test are the qualitative and quantitative identification of characteristic organic components present in the post-combustion residues. The residues are collected by adhesive film lift and/or alcohol swabbing of hands, clothing, spent shell casings and explosive debris, and analyzed using micellar electrokinetic capillary electrophoresis (MECE). The MECE technique provides identification of organic additives in the smokeless powder, and thereby may provide positive identification of the use of materials containing smokeless powder.

NIST Contribution to New Class of Body Armor Recognized by ARPA

The Defense Department's Advanced Research Projects Agency (ARPA) recently reported the first order for a new class of personal armor protection, concealable body armor (CBA), in an accomplishment memorandum for the Secretary of Defense and credited the Office of Law Enforcement Standards (OLES) as one of the three collaborators who made this achievement possible. OLES has a national reputation for its work on characterizing body armor performance and developing test methods used by others to evaluate armor. OLES's collaborators were the U.S. Army Research Laboratory and the Natick Research, Development, and Engineering Center. The work was carried out as an objective of the Body Armor Program, sponsored by the Joint (the Departments of Defense and Justice) Program Steering Group at ARPA.

Concealable body armor provides military and law-enforcement personnel with much greater protection than soft body armor — high-velocity handgun protection to the torso and rifle protection at typical firing distances to vital organs. Further, CBA is designed to be user friendly as an undergarment and, as the name implies, its presence is very difficult to detect when worn. The system, which employs ballistic inserts over the heart and spine that defeat 7.62 mm ball munition at a range of 175 meters, weighs about 3.5 kg, and costs about $2,000 per vest. Prototypes are being evaluated by several law enforcement agencies and Special-Operations Command-affiliated organizations. U.S. forces in Bosnia have identified a need for prototypes, and U.S. Forces in Korea have requested prototypes for evaluation.

Development of Standard for Nickel-Cadmium Secondary Batteries

Users of personal/portable transceivers and others who purchase or use nickel-cadmium secondary batteries may be interested in a performance standard developed by the Office of Law Enforcement Standards as part of the National Institute of Justice Law Enforcement and Corrections Standards and Testing Program. NIJ Standard-0211.01, Rechargeable Batteries for Personal/Portable Transceivers, establishes performance requirements and test methods for nickel-cadmium batteries used in hand-held radios by law enforcement agencies. Such batteries are classified into two types: those for which the manufacturer specifies only the nominal capacity, usually in milliamperehours; and those for which the manufacturer specifies a duty cycle. For either type, the standard specifies a test cycle for service life/capacity determinations based on the battery being worked 10% in the transmit mode, 10% in the receive mode, and 80% in the standby mode. The current drains for each mode are specified according to whether the battery capacity is less than or greater than 700 mAh.

Automated Traffic Speed Measurement Systems Model Performance Specification Prepared by OLES

A model performance specification for automated across-the-road Doppler radar systems has been prepared by the Office of Law Enforcement Standards for a number of audiences interested in speed measuring devices. Those interested include law enforcement agencies that use police traffic radar and other devices to enforce speed laws; these agencies depend on equipment accuracy and reliability to produce credible evidence to support speeding citations. Other organizations include the legal community and the speed measuring device manufacturing community. This publication provides information obtained from the research and testing of automated across-the-road Doppler radar devices by the National Institute of Standards and Technology. The material contained herein is expected to assist law enforcement administrators and others in making more informed purchasing decisions.

A Digital Intercept System for Integrated Services Digital Networks (ISDN)

Requirements for an ISDN Digital Intercept System (DIS) have been drafted by OLES and are currently undergoing review by experts from the communications industry. ISDN enables ordinary twisted-pair telephone cables to carry digitized information at very high transmission rates. Before the end of 1998, over one million telephone subscribers will be using ISDN technology. The DIS is a high technology system for covert surveillance of criminal and foreign espionage communications over ISDN lines. The ISDN/DIS requirements were developed in a collaborative effort between the Office of Law Enforcement Standards and the Federal Bureau of Investigation, with continuing support by the National Institute of Justice.

Ballistic Imaging Interoperability

To facilitate interoperability between existing ballistic imaging systems, the Office of the National Drug Control Policy, the Federal Bureau of Investigation, and the Bureau of Alcohol, Tobacco, and Firearms executed a memorandum of understanding recognizing that the two ballistic image systems currently in use be interoperable. Under this memorandum, NIST, as a neutral third party, was charged to develop a standard for interoperability and to develop and oversee interoperability conformance tests. The purpose of ballistic imaging systems is to permit forensic evidence (cartridge cases and bullets) recovered at a crime scene to be imaged and compared to an existing database of thousands of images to identify possible links between crimes previously unsuspected as being related. However, due to differences in software, image acquisition, and networking capabilities, the images captured on either one of the two systems cannot be used on the other, thus denying crime laboratories full access to all image databases. NIST has developed and published a specification for interoperability for cartridge cases (NIST Interagency Report 5855) and the system vendors are presently modifying their systems to become compliant with the specification.

EEEL STAFF: AWARDS AND RECOGNITION

Dr. Marvin E. Cage

was elected Fellow of the American Physical Society, "for excellence in measurement research that led to an accurate experimental determination of the quantized Hall resistance and adoption of the quantum Hall effect as the new international standard for resistance."

Dr. Alan H. Cookson

received the 1996 Eric O. Forster Distinguished Service Award of the IEEE Dielectrics and Electrical Insulation Society for sustained leadership excellence evinced in first the development of Society goals and then the effective promotion of those goals, for inspiring Society members to excel by example, and for materially advancing the field of dielectrics and electrical insulation, including the authorship or co-authorship of some sixty papers and inventions resulting in thirty-two patents.

Mr. John W. Ekin

was elected Fellow of the American Physical Society, "for his discovery of the superconductor strain scaling law, and his development of low specific resistivity interfaces for oxide superconductors and a superconducting dc transformer."

Dr. Douglas L. Franzen

was elected Fellow of the Optical Society of America for "technical contributions and leadership in optical fiber measurements." Dr. Franzen, Leader of the Fiber and Integrated Optics Group of the Optoelectronics Division, previously received the Department's Bronze, Silver, and Gold Medals, the NIST Applied Research Award, the Telecommunications Industry Association's Distinguished Contribution Award, and the Nippon Telegraph and Telephone Corporation's Director's Award.

Mr. George G. Harman

was selected by the IEEE United States Activity Board to receive the 1996 Harry Diamond Memorial Award for "contributions to microelectronics." Mr. Harman's work has brought engineering rigor and innovation to microelectronic bonding and packaging technology. His research and development on wire and other bonding technologies has provided new metallurgical and process understanding and new test methods leading to numerous benefits. As a result of his work, reliability of electronic systems has increased. In early examples, two major defense systems reported no field failures; previously, bond failures had made the systems unreliable; new bonding technologies arising from the work enabled the first-ever production of hybrid circuits having over 500 bonds each. As a result of his work, manufacturing equipment was redesigned to improve effectiveness, and production yield of high reliability devices was increased by factors of 2 to 35 in various companies.

Dr. Allen R. Hefner, Jr.

received the NIST Applied Research Award for "developing a methodology for modeling power semiconductor devices that enables a new collaborative approach for industry to design circuits using these devices and a significant reduction in the time between initial design and introduction of the final product." In this process, a manufacturer of power devices provides a model, based on Dr. Hefner's work, of a device design to a prospective customer before the device is actually fabricated. Through modeling the customer evaluates the device in a proposed circuit. Device and circuit are then tailored to the intended use. These procedures have been applied by the automobile industry in the design of circuits for conventional and electric/hybrid-electric cars.

Dr. Jeremiah R. Lowney and Dr. Michael T. Postek

of the Manufacturing Engineering Laboratory, received the Department of Commerce Silver Medal for "modeling and validation of the first-ever scanning electron microscope linewidth measurements, needed for special integrated-circuit devices now and for the future as the mainstream semiconductor industry moves to technologies beyond the capabilities of optical lithography." Specifically, they have determined the location of an edge in a patterned silicon target to an uncertainty of less than 6 nanometers as a result of making comparisons between simulated and measured backscattered-electron and secondary-electron signals.

Dr. John M. Martinis

was recognized with a Department of Commerce Silver Medal and also by the NIST Samuel Wesley Stratton Award for "applying his experimental skills in cryoelectronics and theoretical insights into quantum physical phenomena, especially as related to single-electron tunneling (SET), to spearhead research that has established the accuracy of Coulomb-blockade electron counting circuits for fundamental standards." This work, culminating in an experiment that demonstrated acounting accuracy of 15 parts per billion, with an average leakage rate of one electron in ten minutes, has been recognized as leading the world by the major laboratories engaged in SET research. Confirming that metrological levels of accuracy can be achieved in a SET experiment, the work is a key step towards a needed new basic standard of capacitance.

Mr. John F. Mayo-Wells

was recognized with the Department of Commerce Bronze Medal for his contribution "in a wide variety of sensitive key assignments, including planning and analyses of technical programs, development of program initiatives, evaluations of significance and potential impact of new technologies, and presentations to special clients. His extensive knowledge of technology and industry has enabled him to make unique contributions in communicating output from NIST programs to clients in industry, Congress, and government and maintaining very high standards of excellence."

Mr. Allen C. Newell

was recognized by the Department's highest award — its Gold Medal — and by the IEEE United States Activities Board with its Electrotechnology Transfer Award, for "personal technical contributions and leadership essential to the development of antenna near-field scanning into a practical measurement tool and for spearheading the transfer of this NIST-invented technology to industry and the technical community so that it has become the preferred method for testing advanced complex antennas, such as those used for satellite communications." Mr. Newell was first to reduce the theoretical concept to experiments demonstrating the method's technical feasibility. Recognizing its inherent potential, he then showed the method's practicality for characterizing real-world antennas, in the process designing and operating the world's first near-field scanning range. This work has had major impact on the U.S. communications industry.

Mr. Norman Sanford

was elected Fellow of the Optical Society of America, in recognition of his "development of innovative glass and ferroelectric integrated optical devices." Mr. Sanford is leader of the Dielectric Materials and Devices Project in the Optoelectronics Manufacturing Group; he has led efforts in the development of measurements for dielectric materials used in integrated optics, and has been a pioneer in the development of rare-earth-doped waveguide devices.

Mr. Thomas R. Scott

received a Department of Commerce Bronze Medal for "technical leadership, contributions to international standardization, and the development of measurement services responsive to industry needs in the field of laser radiometry." As a result of his work, NIST has had a large impact on the industrial and medical laser communities. His development of a calibration service, now in high demand, for optical fiber power meters has provided key support to the optical communications community. Mr. Scott's efforts have also resulted in new methods for determining laser beam profile and for characterizing an important emerging device class, vertical-cavity surface-emitting lasers.

EEEL: A PROFILE

Customers

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. To realize the range and diversity of our customers, the term "electronics industry" must be understood in the broadest sense.

The capability provided by our programs supports entities ranging from giant electric utilities and large aerospace and communication companies with thousands of workers to specialized instrument manufacturers employing fewer than ten individuals — all engaged in a broad spectrum of technologies. EEEL also provides support to the federal government as needed to improve efficiency in technical operations and cooperates with academia in development and utilization of measurement methods and scientific data.

Measurement Technology

The measurement technology provided by the Laboratory is essential for industrial research and development, for improvements in the design and manufacturing of quality products, for proof of performance, for marketplace transactions including the acceptance of U.S. products into international markets, and for product applications. In countries throughout the world, all measurements must ultimately be referred back to national reference standards to provide consistency and accuracy. EEEL is the linchpin of this process for electrical measurements in the United States.

Functions

Two of the Laboratory's major functions are to maintain the national reference standards for electricity for the Nation, and to disseminate these standards through appropriate calibration services, calibrated artifacts, and measurement methods to private industry and other clientele. Further, EEEL/NIST must realize national reference standards in terms of their internationally agreed-upon definitions to provide equity in international trade. All of these processes are technically difficult and require a dedicated laboratory capability.

The activities necessary to provide full measurement capability range from the timely development of new measurement technology to the maintenance and realization of electrical standards. Dissemination of these standards is the key, however. Suitable, appropriate, and meaningful measurement methods must be made available and accessible to users across the country. Only then will specialists and nonspecialists alike be able to correctly use available instrumentation and standards to perform measurements at their required accuracies.

Industry Interactions

EEEL staff continuously interacts closely with industry personnel to define and validate our work. By maintaining a presence in the industrial community, we are well-positioned to determine client needs, plan appropriate responses, and evaluate our effectiveness. An illustration of the way we determine client needs is easily drawn from our outreach efforts in the past two years.

During that period, the Laboratory sponsored or cosponsored nine major workshops and participated in several national technical roadmapping activities all of which are particularly useful in identifying industry needs. Staff also actively participated in conferences, visited industry laboratories, and maintained consultative dialogues using media ranging from one-to-one telephone contacts to multiparty videoconferencing facilities and e-mail. Altogether, staff members have collaborated with, or served in some substantial way, over 2000 different organizations in the past two years.

Further, EEEL periodically contracts for impartial impact analyses on our programs to assure that we are, in fact, targeting and effectively responding to highly important client needs. More detailed information on customer interactions for FY 1996 is provided elsewhere in the Appendix.

Solutions for Industry

Examples abound to illustrate the impact of our technical solutions. Two that fairly represent the Laboratory's efforts include the following for the optoelectronics industry and the microwave industry.

Over the years, EEEL's work with the optical fiber manufacturers has provided the technical basis for over two dozen Telecommunications Industry Association (TIA) standards, leading the President of the TIA to say, "Without the NIST assistance and leadership, the U.S. fiber optics industry would not be in the competitive position it is today."

More recently, when U.S. manufacturers encountered difficulty competing with overseas manufacturers, who were able to make optical fibers having circular cross sections with submicrometer tolerances, the TIA asked EEEL for help. In a nutshell, the competitors' fibers were able to avoid large signal losses in multiple connections, and ours might not.

The industry needed a practical, timely, response. EEEL undertook the research needed to solve the problem, and provided U.S. manufacturers with improved measurement methods and a standard reference material (SRM) that enabled them to manufacture competitive fiber. From that point forward, all the fiber drawing towers of the major U.S. manufacturers continue to use these SRMs for production control.

The microwave industry's awareness of a metrology-based problem was triggered by frustrated design efforts and accompanying reductions in semiconductor-wafer productivity. In response, staff of EEEL's microwave program identified the source of the problem, and introduced new measurement methods based on transmission line test structures formed directly on the semiconductor wafers. Eminent scientists in the field acknowledged and praised this work; one characterized it as "the greatest advance in microwave circuit theory in 50 years."

The initial application of these new methods disclosed large errors (greater than 30% in some cases) in traditional industrial measurements. As a consequence, EEEL's measurement methods have been incorporated in commercial test instruments and adopted by major U.S. companies.

Calibration Services

In EEEL the term "calibration services" covers a broad span of activities: extending from the development of a metrology to the internalization and realization of that metrology to the offering and provision of services to our customers. In fact, it is really through our calibration services that much of the practical transfer of metrology standards occurs. As our calibration capabilities improve, these improvements are transferred to customers industry-wide, upgrading the metrology on a national level.

To look at the role of calibrations in the overall picture of EEEL activities, let's trace the initiation and development of a calibration service using very broad strokes. The tale begins in the 1960s when a British scientist, Brian David Josephson, theorized that electron-tunneling in superconductors could be quantized. Scientists in laboratories around the world began to work on the development of such a device, that is to say, a Josephson junction. Initially, researchers used one device, certainly not more than a few, to achieve the necessary units. The process was tedious, and required ratio systems to go from millivolts of Josephson junctions to useful values of voltage.

Ultimately, NIST's research led to a breakthrough that improved the process by several orders of magnitude. Using a circuit design developed in collaboration with a visiting scientist, EEEL staff found a means to permit thousands of devices to be connected in series, enabling the convenient development of a one-volt and, later, a ten-volt device. The NIST device provided an unprecedented accuracy, and this work immediately became the basis for the national standard and new calibration services. For industry, it meant a means to demonstrate world leadership in electronic multimeter linearity and control multimeter production. Some nations also chose to adapt the NIST one-volt chip to implement their own national standards.

Today, EEEL provides the largest share, more than 40 percent, of all of NIST's calibration services. Our effort serves 380 customers and yields $2 M in calibration-fee income. People come to NIST because of our special characteristics: our world-class measurement capability, expertise in a wide range of measurement areas, and direct access to national standards.

Calibration Infrastructure

EEEL's calibrations support many millions of dollars worth of secondary calibration business in the United States and billions of dollars of industrial business. For example, through our calibration services, we provide microwave antenna measurements used by every major U.S. aerospace company, supporting a U.S. microwave industry which supplies about one half of the world-wide $60 B microwave equipment market. EEEL also provides the national reference standards needed to assure the accuracy of the electric power meters in every home and business in the United States. This service entails supporting the metering of over $200 B per year of electricity.

These examples only touch on the nearly 200 unique calibrations that we offer on 32 different types of standards. The bottom line is that through its focus on measurement research and services, EEEL really makes a difference to the electronics industry. Over and over, our services have been shown to improve productivity and profitability, stimulate new product commercialization and new company start-ups, change industry-wide practices, and influence technical and policy actions — all to the benefit of our wide-ranging clientele.

EEEL PROGRAMS AND THEIR PROJECTS

PROGRAMS	PROJECTS
SEMICONDUCTORS	NIST-Wide Semiconductor Programs Metrology for Nanoelectronics Optical Characterization Metrology Electrical Characterization Metrology Thin-Film Process Metrology Metrology for Simulation and Computer-Aided Design Metrology for Devices and Packages Silicon on Insulator Metrology Metrology for Process and Tool Control Interconnect Reliability Metrology Dielectric Reliability Metrology MicroElectroMechanical Systems (MEMS) Plasma Chemistry-Plasma Processing
MAGNETICS	Nanoprobe Imaging for Magnetic Technology Magnetic Instruments and Materials Characterization Magnetic Recording Technology
SUPERCONDUCTORS	Superconductor Interfaces and Measurement Techniques High Performance Sensors, Converters, and Mixers Josephson Array Development Nanoscale Cryoelectronics High-T_c Electronics Superconductor Standards and Technology
LOW FREQUENCY	AC-DC Difference Standards and Measurement Techniques Waveform Acquisition Devices and Standards Waveform Synthesis and Impedance Metrology Measurement for Complex Systems
MICROWAVES	High Speed Microelectronics Metrology Power Standards and Measurements Impedance, Voltage Standards and Measurements Network Analysis and Measurement Noise Standards and Measurements Antenna Measurement Theory and Application Metrology for Antenna, Radar Cross Section and Space Systems
LIGHTWAVES	Dielectric Materials and Devices Semiconductor Materials and Devices Fiber and Discrete Components Integrated Optics Metrology Optical Fiber Sensors Optical Fiber Metrology High Speed Source and Detector Measurements Laser Radiometry
VIDEO	Video Technology
POWER	Dielectrics Research Metrology for Electric Power Systems
NATIONAL ELECTRICAL STANDARDS	Quantum Resistance and Capacitance Quantum Voltage and Current
ELECTROMAGNETIC COMPATIBILITY	Standard EM Fields and Transfer Probe Standards Emission and Immunity Metrology Electromagnetic Properties of Materials
ELECTRONIC DATA EXCHANGE	Automated Electronics Manufacturing
OFFICE OF LAW ENFORCEMENT STANDARDS	Enabling Technologies for Criminal Justice Practitioners

EEEL ORGANIZATIONS AND THEIR PROJECTS

OFFICES AND DIVISIONS:	PROJECTS
SEMICONDUCTOR ELECTRONICS DIVISION	Metrology for Nanoelectronics Optical Characterization Metrology Electrical Characterization Metrology Thin-Film Process Metrology Metrology for Simulation and Computer-Aided Design Metrology for Devices and Packages Silicon on Insulator Metrology Metrology for Process and Tool Control Interconnect Reliability Metrology Dielectric Reliability Metrology MicroElectroMechanical Systems (MEMS)
OFFICE OF MICROELECTRONICS PROGRAMS	NIST-Wide Semiconductor Programs
ELECTRICITY DIVISION	Plasma Chemistry-Plasma Processing AC-DC Difference Standards and Measurement Techniques Waveform Acquisition Devices and Standards Waveform Synthesis and Impedance Metrology Measurements for Complex Electronic Systems Video Technology Dielectrics Research Quantum Resistance and Capacitance Quantum Voltage and Current Automated Electronics Manufacturing
ELECTROMAGNETIC FIELDS DIVISION	High Speed Microelectronics Metrology Power Standards and Measurements Impedance, Voltage Standards and Measurements Network Analysis and Measurement Noise Standards and Measurement Antenna Measurement Theory and Application Metrology for Antenna, Radar Cross Section and Space Systems Standard Electromagnetic Fields and Transfer Probe Standards Emission and Immunity Metrology Electromagnetic Properties of Materials
ELECTROMAGNETIC TECHNOLOGY DIVISION	Nanoprobe Imaging for Magnetic Metrology Magnetic Instruments and Materials Characterization Magnetic Recording Metrology Superconductor Interfaces and Electrical Transport High-Performance Sensors, Converters, and Mixers Josephson Array Development Nanoscale Cryoelectronics High-T_c Electronics Superconductor Standards and Technology
OPTOELECTRONICS DIVISION	Dielectric Materials and Devices Semiconductor Materials and Devices Fiber and Discrete Components Integrated Optics Metrology Optical Fiber Sensors Optical Fiber Metrology High Speed Source and Detector Measurements Laser Radiometry
OFFICE OF LAW ENFORCEMENT STANDARDS	Enabling Technologies for Criminal Justice Practitioners

CUSTOMER INTERACTIONS

Communications

Publications	243
Software Packages Distributed	280
Talks	309
Consultations	2,990
Staff Visits	480
Technical Visitors	440
Meetings	
Attendees	1,730
Contributors	91

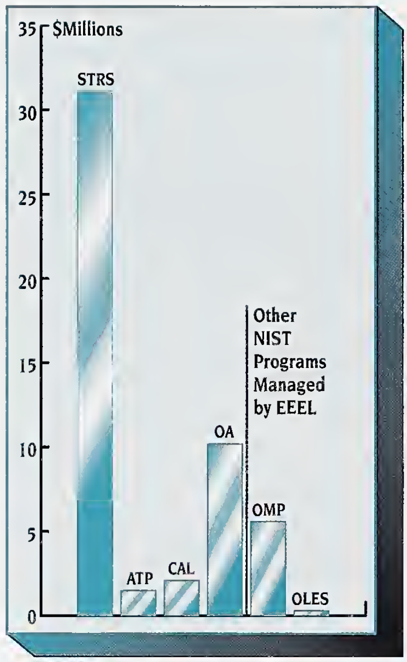
Joint Activities

Standards Organizations	
Staff Participating	34
Memberships	61
Professional Societies	
Memberships	180
Cooperative Research Projects	140
Consortia	6
Guest Scientists	96

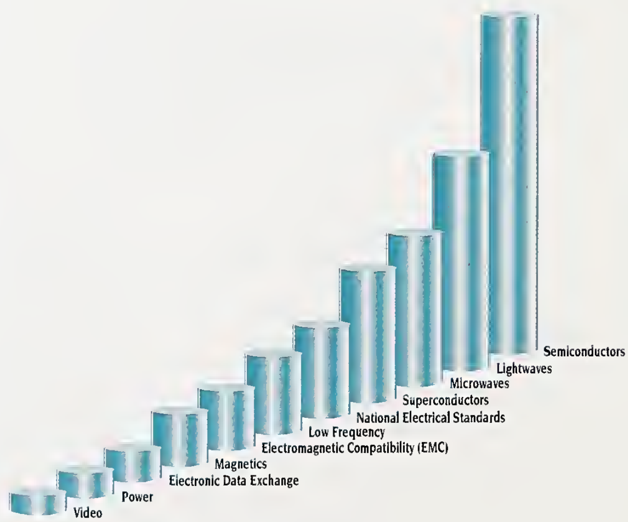
Paid Services

Custom Measurement Development	110
No. of Standard Reference Materials Sold	90
No. of Calibration Customers	310
Training Courses and Workshops Administered	39

RESOURCES FY 1996



FY 1996 Resources



FY 1996 Resources by Technology Field

CRADAs

EEEL participated in 27 cooperative research and development agreements (CRADAs) with industry during FY 1996. CRADA Participants included large and small companies across the nation. EEEL actively seeks industrial, academic, and non-profit partners to work collaboratively on projects of mutual benefit. Special efforts are made to tailor cooperative programs to the individual needs of research partners. CRADAs typically cover joint research efforts in which both NIST and the cooperating company provide staff, equipment, facilities, and/or funds, in any number of possible combinations for a project of mutual interest. Under a CRADA, NIST can protect confidential or proprietary information exchanged during the project, keep research results confidential, and provide exclusive rights for intellectual property developed. EEEL welcomes industry to collaborate on projects of mutual interest through the CRADA format. A detailed directory of research areas available for cooperative research, entitled Guide to NIST, can be obtained at no cost using fax number: (301) 926-1630.

Analogy, Incorporated: Power Semiconductor Devices in Electronic Circuits

Bio-Rad Laboratories, Incorporated, Semiconductor Division: Test Structures to Enable Referencing of Measurements Made by Commercial Optical-Metrology Overlay Systems

Bio-Rad Laboratories, Incorporated, Semiconductor Division: Scanning Capacitance and Electromagnetic Consortium

Cascade Microtech, Incorporated: Monolithic Microwave Integrated Circuit Consortium

Digital Instruments, Incorporated: Scanning Capacitance and Electromagnetic Consortium

EMAG Technologies, Incorporated: High-Frequency Characterization Using Time Domain Instrumentation

General Electric CRD: Parameter Extraction for High Power IGBTs

Honeywell, Incorporated: Optical Fiber Sensors

IMRA America, Incorporated: Rare-Earth Doped Waveguide DBR Lasers and Polarization Discriminating Receivers

IBM Corporation: Thin Film for Magnetic Storage Media

KLA Instruments: Scanning Capacitance and Electromagnetic Consortium

Optical E.T.C., Incorporated: Integrated Dynamic Thermal Emitter Arrays

Optical Specialties, Incorporated: Scanning Capacitance and Electromagnetic Consortium

Quantum Design: Improved SQUID Magnetometer Measurement Testing

Quantum Magnetics, Incorporated: Magnetic Imaging

RF Microsystems, Incorporated: Microwave CMOS Micromachined Power Systems

SEMATECH: Scanning Capacitance and Electromagnetic Consortium

SEMATECH: Semiconductor Technology and Processes

Tektronix Federal Systems Incorporated: Transmission Line Characterization Using Time Domain Instrumentation

Texas Instruments: Monolithic Microwave Integrated Circuit Consortium

The Regents of the University of Colorado: General Agreement for Collaborative Research in Optical Electronics

TRW, Incorporated: Monolithic Microwave Integrated Circuit Consortium

U.S. Air Force Base, Newark AFB, Aerospace Guidance and Metrology Center: Monolithic Microwave Integrated Circuit Consortium

University of Maryland, Department of Materials and Nuclear Engineering: In-Situ Determination of Temperature and Stress of Thin-Films during Decomposition

VLSI Standards, Incorporated: Thin Film Standard Reference Materials Development

VLSI Standards, Incorporated: Feasibility of Electrical Certification of Reference Materials for Lithography-Reticle Metrology

Vitesse Semiconductor Corporation: Test Chip for High Density Multilevel Interconnect for GaAs IC Fabrication

EEEL EXECUTIVE STRUCTURE AND MANAGEMENT STAFF

EEEL Laboratory Headquarters

Judson C. French, Director
Robert E. Hebner, Deputy Director*
Alan H. Cookson, Act. Deputy Director
Bruce F. Field, Act. Associate Director
B358 Metrology Building, NIST
Gaithersburg, MD 20899-0001
(301) 975-2220
e-mail: judson.french @nist.gov
e-mail: robert.hebner@nist.gov
e-mail: alan.cookson@nist.gov
e-mail: bruce.field@nist.gov

Office of Microelectronics Programs

Robert I. Scace, Director
A323 Technology Building, NIST
(301) 975-4400
e-mail: scace@nist.gov

Office of Law Enforcement Standards

Kathleen M. Higgins, Director
A323 Technology Building, NIST
(301) 975-2757
e-mail: kathleen.higgins@nist.gov

811 Electricity Divison

William E. Anderson, Chief
B164 Metrology Building, NIST
(301) 975-2400
e-mail:
william.anderson@nist.gov

812 Semiconductor Electronics Division

David G. Seiler, Chief
B344 Technology Building, NIST
(301) 975-2054
e-mail: david.seiler@nist.gov

813 Electromagnetic Fields Division

Dennis S. Friday, Act. Chief
Division 813.00, NIST
325 Broadway
Boulder, CO 80303-3328
(303) 497-3131
e-mail: dennis.friday@nist.gov

814 Electromagnetic Technology Division

Richard E. Harris, Chief
Division 814.00, NIST
325 Broadway, Boulder, CO
80303-3328
(303) 497-3678
e-mail: richard.harris@nist.gov

815 Optoelectronics Division

Gordon W. Day, Chief
Division 815.00, NIST
325 Broadway
Boulder, CO 80303-3328
(303) 497-5204
e-mail: gordon.day@nist.gov

*EEEL's Deputy Director, Dr. Robert E. Hebner, was selected to serve as Acting Deputy Director of NIST during the greater part of FY 1996.

The Electronics and Electrical Engineering Laboratory comprises five divisions and two offices. Laboratory Headquarters, the Electricity Division, the Semiconductor Electronics Division, the Office of Microelectronics Programs, and the Office of Law Enforcement Standards are located in Gaithersburg, Maryland. The Electromagnetic Fields Division, the Electromagnetic Technology Division, and the Optoelectronics Division, which was formed in FY 1994, are located in Boulder, Colorado.

810 Laboratory Headquarters

2220 FRENCH, Judson C., Director
2220 PALLA, Jenilie C., Secretary
2220 HEBNER, Robert E., Deputy Director
2220 COOKSON, Alan H., Acting Dep. Director
2220 SACCHET, Linda L., Secretary
4230 FIELD, Bruce F., Act. Assoc. Director
2220 GONZALEZ, Josephine A., Secretary
2220 MAYO-WELLS, J. Franklin, Staff Assoc.
2220 POWELL, Ronald M., Scientific Asst.
2665 RUSSELL, Thomas J., Mgr., Optical Computing Coop. Prog.
5267 SURETTE, JoAnne M., Information Specialist
2228 HORMUTH, James A., Exec. Officer

Administrative Support—Gaithersburg

2227 HAMILTON, Darlene, Admin. Ofr.
2229 JOHNSON, Margie I., Admin. Ofr.
2230 THOMAS, S. Michael, Admin. Ofr.

Administrative Support—Boulder

3812 SCHUMP, Jeanne, Admin. Ofr.
3813 ANDRUSKO, Gaynel K., Admin. Ofr.
5342 McCOLSKEY, Kathy, Admin. Ofr.
3811 QUARTEMONT, Heidi, Admin. Asst.
3514 GLAZE, Terry L., Admin. Clerk

Office Of Microelectronics Programs

4400 SCACE, Robert I., Director
4400 SETTLE-RASKIN, Alice, Secretary

Office Of Law Enforcement Standards

2757 HIGGINS, Kathleen M., Director
4258 LIEBERMAN, A. George
2757 LYLES, Sharon E., Secretary
2757 FATAH, Alim
5128 WATERS, Nathaniel E.
3396 WORTHEY, James A.
2756 LEACH, Marilyn, Secretary

The Office of Microelectronics Programs (OMP) provides integrated circuit manufacturers, materials suppliers, and makers of semiconductor manufacturing equipment with a clear window on the EEEL/NIST organization. OMP offers direct access to an enormously varied range of scientific and technical expertise.

In addition, OMP manages NIST's strong working relationship with SEMATECH, the consortium of U.S. semiconductor manufacturers, and with many of its member firms. Research priorities are established on the basis of industry input and the Office's participation in U.S. and international conferences and planning activities.

The National Semiconductor Metrology Program, which was established in 1994 draws on the full range of NIST expertise in semiconductor electronics, manufacturing engineering, chemical and materials science engineering, and fundamental science, is managed by OMP.

The Office of Law Enforcement Standards (OLES) supports law enforcement agencies through the development of measurement methods and techniques for testing devices used in such applications as tracking vehicles, speed monitoring, surveillance, and communications. The Office develops minimum performance standards for issuance by the National Institute of Justice as voluntary national standards. The areas of research investigated by this Office include clothing, communication systems, emergency equipment, investigative aids, protective equipment, security systems, vehicles, weapons, and analytical techniques and standard reference materials used by the forensic science community.

Its mission is to assist federal, state, and local law enforcement agencies to apply new technology efficiently, effectively, and safely. OLES draws on the technical expertise and resources of all of NIST in its support missions for the National Institute of Justice (NIJ), which is the research arm of the Department of Justice, and the National Highway Traffic Safety Administration, which is part of the Department of Transportation.

ELECTRICITY DIVISION

811.00—Electricity Division

2400 ANDERSON, William E., Chief
2400 SCHMEIT, Ruth Ann, Secretary
4361 CUMMINGS, Roberta K., Secretary
2439 GREENBERG, Joseph, Spec. Assistant
2868 CHANDLER, Joseph W., Computer Network Supp.
4223 BELECKI, Norman B.
4221 PRATHER, Denise D., Calibration Serv. Admin.
4222 FROMM, Sharon L., Admin. Supp. Asst.

.02 Electronic Instrumentation And Metrology

2419 BELL, Barry A. (GL)
2402 MAGRUDER, Kathy H., Secretary

Automated Measurements for Voltage, Current, Phase, Power, and Impedance

2408 OLDHAM, Nile M. (PL)
2412 LAUG, Owen B.
4237 CHANG, Y. May
2438 WALTRIP, Bryan C.
2413 PARKER, Mark E.
2441 PALM, Robert H., Jr.
4244 TILLETT, Summerfield B.

Waveform Acquisition Device Standards and Test Methods

2406 SOUDERS, T. Michael (PL)
2437 DEYST, John P.
2412 LAUG, Owen B.
2441 PALM, Robert H., Jr.

Thermal Transfer Standards and Measurements

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

Calibration and Testing Strategies

2406 SOUDERS, T. Michael (PL)
2440 STENBAKKEN, Gerard N.
4518 KOFFMAN, Andrew D.
2402 ENGLER, Hans (GR)

Optoelectronic Technology

2405 PAULTER, Nicholas G., Jr. (PL)
2441 PALM, Robert H., Jr.

.04 Fundamental Electrical Measurements

2139 CLARK, Alan F. (GL)
4219 LIVINGSTONE, Sharon D., Secretary

Resistance Standards and Quantum Hall Effect

6591 ELMQUIST, Randolph E. (PL)
4249 CAGE, Marvin E.
4239 DZIUBA, Ronald F.
4236 LEE, Kevin C.
4240 JARRETT, Dean G.
4245 MOORE, Theodore P.
4243 SECULA, Andrew J.
4241 KILE, Lisa L. (S)

Voltage Standards and Josephson Effect

2139 CLARK, Alan F. (PL)
4238 SIMS, June E.
4443 KIM, Jinhee (GR)
3979 SOSSO, Andrea (GR)

Single Electron Tunneling

5887 ZIMMERMAN, Neil M. (PL)
2139 CLARK, Alan F.
4270 COBB, Jonathan (PD)
4219 AMAR, Ajay (GR)
4219 LOBB, Christopher (GR)
4815 SOULEN, Robert (GR)
4219 WELLSTOOD, Frederick (GR)
4056 HEAD, Linda M. (GR)

Capacitance

4246 JEFFERY, Ann-Marie (PL)
4233 SHIELDS, Scott
4231 LEE, Lia H. (GR)
4233 SHIELDS, John Q. (GR)

Watt, Ampere, and Gamma P

4226 STEINER, Richard L. (PL)
4206 WILLIAMS, Edwin R. (PL)
4228 NEWELL, David B.
6555 BOWER, Vincent (GR)

.05 Electrical Systems

2403 OLTHOFF, James K. (GL)
2403 SWANKE, Sylvia M., Secretary

Dielectrics

2425 VAN BRUNT, Richard J. (N/F)
3955 STRICKLETT, Kenneth L.
2427 VON GLAHN, Peter G. (INT)
2432 CHRISTOPHOROU, Loucas (PT)
2436 HAN, Xiaolian (GR)

Power and Energy

2986 NELSON, Thomas L.
3955 STRICKLETT, Kenneth L.
3956 SIMMON, Eric
2418 PETERSONS, Oskars (GR)

Pulse Power Technology

2737 FitzPATRICK, Gerald J.
3956 SIMMON, Eric
6658 PITT, James A.

Electric and Magnetic Fields

2426 MISAKIAN, Martin

Power Quality

2409 MARTZLOFF, Francois D.

Plasma Processing

2403 OLTHOFF, James K.
2425 VAN BRUNT, Richard J.
2432 CHRISTOPHORU, Loucas (PT)
2436 RAO, Mangina (GR)
4278 WANG, Yicheng (IPA)

.06 Electronic Information Technologies

4124 ST. PIERRE, James A. (Act. GL)
2404 MARTUCCI, Robin J., Secretary

Video Technology

2428 FENIMORE, Charles P.
3842 KELLEY, Edward F.
3014 BOYNTON, Paul A.
4225 JONES, George R., Jr.

Automated Electronic Manufacturing Program

4124 ST. PIERRE, James A. (PL)
2304 GOLDSTEIN, Barbara
3644 BRADY, Kevin G.
3517 PARKS, Curtis H.
4099 McLAY, Michael J.
4229 McCALEB, Michael R.
4124 MESSINA, John (S)

LEGEND:

CON = CONSULTANT
CU = CONTRACT WITH UNIVERSITY
CP = COOPERATIVE EDUCATION PROG.
FH = FACULTY HIRE
FTT = FULL TIME TEMP.
GRF = GRADUATE RESEARCH FELLOW
GL = GROUP LEADER
GR = GUEST RESEARCHER
N/F = NIST FELLOW
PD = POSTDOCTORAL APPOINTMENT
PL = PROJECT LEADER
PT = PART TIME
S = STUDENT

The Electricity Division maintains and improves the national standards of electrical measurement, and develops stable standards for the dissemination of the units of electrical measure. Another major responsibility of this Division is to realize the electrical units in terms of the International System (SI) and determine the fundamental constants related to electrical units.

The Division is responsible for providing calibration services, and developing and improving 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, members of this division apply their expertise to selected scientific and technological problems in other areas of NIST research, including research on video technology and electronic product data exchange.

SEMICONDUCTOR ELECTRONICS DIVISION

812.00—Semiconductor Electronics Division

2074 SEILER, David G., Chief
2054 MAIN, Brenda P., Secretary
2097 HARMAN, George G., NIST Fellow
2079 BENNETT, Herbert S., Senior Research Scientist
2056 CROWE, Cheryl D., Secretary (PT)
2055 OETTINGER, Frank F. (GR)
2242 BUCK, Laurence M., Computer Facility Mgr. (Property Officer)
2050 WALTERS, E. Jane, Lead Editorial Assistant
2296 ROHRBAUGH, Janet M., Editorial Assistant

.01 Materials Technology

2054 SEILER, David G., (Act. GL)
2081 ROACH, Ramona K., Secretary
2061 COMAS, James - Detailed to TRP

Metrology for Nanoelectronics

2123 PELLEGRINO, Joseph G. (PL)
2087 MONK, David H.
5291 TSENG, Wen F.
2081 SMIRL, Arthur L. (GR)
3241 DiCAMILLO, Barbara A. (PD)

Optical Characterization Metrology

5974 AMIRTHARAJ, Paul M. (PL)
2081 DHAR, Nibir K. (GR)
2084 CHANDLER-HOROWITZ, Deane (Laser Safety Officer)
2108 RENNEX, Brian G. (PT)
6582 BALCHIN, Gregory A. (PD)

Electrical Characterization Metrology

2089 KOPANSKI, Joseph (PL)
2238 KIM, Jin S.
2088 MARCHIANDO, Jay F.
2067 THURBER, W. Robert

.03 Device Technology

2068 BLACKBURN, David L. (GL)
2053 LAMBERT, Barbara J., Secretary

Semiconductor Processing Laboratory

2699 NOVOTNY, Donald B., Processing Facility Mgr.
2095 KREPPS, Guilford L.
2096 MILLER, Mary Louise (PT)
2094 RUSSELL, Raymond G.

Thin-Film Process Metrology

2060 EHRSTEIN, James R., (PL)
2248 BELZER, Barbara J.
2044 NGUYEN, Nhan Van
2082 RICHTER, Curt A.
2065 RICKS, Donnie R.
4310 YARUSSI, Richard A. (GR)

Silicon-on-Insulator Metrology

2077 ROITMAN, Peter, (PL)
2078 EDELSTEIN, Monica D., Safety Officer

Metrology for Devices and Packages

2071 HEFNER, Allen R., Jr., (PL)
4710 ADAMS, Vance H. (GRF)
2075 ALBERS, John
2079 BENNETT, Herbert S.
2069 BERNING, David W.
4079 JOSHI, Yogendra K. (GR)
5466 ORTEGA, Alfonso (GR)

.04 IC Technology

2052 LINHOLM, Loren W. (GL)
2052 WILKES, Jane M., Secretary
2236 ELLENWOOD, Colleen H., CAD Facility Mgr. (PT)

Metrology for Process & Tool Control

2072 CRESSWELL, Michael W. (PL)
5026 ALLEN, Richard A.
4446 GHOSHTAGORE, Rathindra N. (GR)
5623 OWEN, James C.

Interconnect Reliability Metrology

2234 SCHAFFT, Harry A. (PL)
2045 MAYO, Santos
2241 SCHUSTER, Constance E.

Dielectric Reliability Metrology

2247 SUEHLE, John S. (PL)
2240 TEA, Nim H. (PD)
2111 CHEN, Yuan (GR)
2247 HUA, Yijia (GR)

MicroElectroMechanical Systems

2070 GAITAN, Michael (PL)
2049 MARSHALL, Janet C. (PT)
4706 MILANOVIC, Veljko (GR)
5193 RAMAN, Rajkumar (GR)
2239 ZAGHLOUL, Mona E. (FH)
2073 ZINCKE, Christian A. (GRF)

The Semiconductor Electronics Division (SED) provides leadership and participates in developing the semiconductor measurement infrastructure essential to improving U.S. economic competitiveness by providing necessary measurement methods, physical standards, and supporting data and technology; associated generic technology; and fundamental research results to industry, government, and academia. The primary focus is on mainstream silicon; the Division's programs also respond to industry measurement needs related to compound semiconductors, power devices, and silicon-on-insulator devices. SED plans and implements its programs in cooperation with the semiconductor industry and its suppliers and customers to address critical needs. SED collaborates with industry, academia, other government agencies, and standards organizations, sponsors technical workshops, hosts guest researchers, and serves on numerous semiconductor advisory committees to enhance the Division's effectiveness. It impacts industry through achieving goals such as those outlined in the National Technology Roadmap for Semiconductors, a silicon roadmap SED participated in developing.

SED conducts research in semiconductor materials, processing, devices, and integrated circuits to provide, through both experimental and theoretical work, the necessary basis for understanding measurement-related requirements in semiconductor technology. Program areas include optical and electrical characterization metrology, metrology for nanoelectronics, in-situ metrology, scanning probe metrology, MBE compound semiconductor growth and characterization, focused ion-beam lithography, superlattices and heterostructures, interface properties, quantum nanostructures, model validation for model-based design, power semiconductor devices, device and package electrical and thermal metrology, silicon-on-insulator metrology, silicon integrated circuits, thin-film process metrology, metrology for process and tool control, reliability metrology for interconnects and dielectrics, test structures, and microelectromechanical systems (MEMS).

ELECTROMAGNETIC FIELDS DIVISION

813.00—Electromagnetic Fields Division

3131 FRIDAY, Dennis S., Act. Chief
3132 LYONS, Ruth Marie, Secretary
3557 REEVE, Gerome R.
5284 DeLARA, Puanani L., Property Ofr.
6564 NEWELL, Allan C. (GR)

.06 Microwave Metrology

3380 JUDISH, Robert M. (GL)
5755 RIVERA, Suzie, Secretary

Network Analysis and Measurements

5362 JUROSHEK, John R. (PL)
5491 KAISER, Raian K.F.
3210 LeGOLVAN, Denis X.
5249 MONKE, Ann F.
5231 PACKER, Marilyn E.

Impedance, Attenuation, Voltage Standards and Measurements

3561 REBULDELA, Gregorio (PL)
3609 FREE, George M.
3634 GINLEY, Ronald A.
3149 MAJOR, James R.
5593 PITTMAN, Earle S.
3939 SHERWOOD, Glenn V.
5048 TALLEY, Kenneth E.

Noise Metrology

3150 RANDA, James P. (PL)
5737 BILLINGER, Robert L.
3546 PUCIC, Sunchana
3664 RICE, John L.
3280 TERRELL, L. Andrew
3610 WAIT, David F.

High Speed Microelectronics Metrology

3037 MARKS, Roger B. (PL)
3138 WILLIAMS, Dylan F. (PL)
7212 DeGROOT, Donald C.
3596 JARGON, Jeffery A.
3015 MORGAN, Juanita M.
5490 WALKER, David K.

Power Standards and Measurements

5778 CLAGUE, Fred R. (PL)
5871 ALLEN, J. Wayde
3365 VORIS, Paul G.

Measurement Services

3753 HEWITT, Paula M.
3524 ONDREJKA, Connie L.

.07 Fields & Interference Metrology

5320 KANDA, Motohisa (GL)
3321 HAAKINSON, Edit, Secretary

Standard EM Fields and Transfer Probe Standards

5320 KANDA, Motohisa
3756 MASTERSON, Keith D.
3168 NOVOTNY, David R.
3309 ONDREJKA, Arthur R.
3737 JOHNK, Robert T.

EMI Instrumentation

5766 KOEPKE, Galen H.
3214 CAMELL, Dennis G.
5332 MEDLEY, Herbert W.

EMI Measurements & Standards

3472 HILL, David A.
3995 CAVCEY, Kenneth H.
5372 LADBURY, John M.

.08 Antenna and Materials Metrology

5703 REPJAR, Andrew G. (GL)
3302 SANDERA, Sharon L., Secretary

Near-Field Antenna Techniques

3732 DEAN, David N.
5873 FRANCIS, Michael H.
3302 BASSETT, David N. (PT)
5196 LEWIS, Richard L.
3471 MACREYNOLDS, Katherine
3927 STUBENRAUCH, Carl F.
3694 TAMURA, Douglas T.
3863 GUERRIERI, Jeffrey R.
5702 CANALES, Seturnino, Jr.

Dielectric Materials Properties

5305 WEIL, Claude M.
5852 GEYER, Richard G.
5621 BAKER-JARVIS, James R.
3656 JANEZIC, Michael D.
5533 GROSVENOR, John H., Jr.
5958 JONES, Chriss A.
5752 RIDDLE, Bill F.
5852 KRUPKA, Jerzy (GR)

Theoretical Support

3603 MUTH, Lorant A.
3326 WITTMANN, Ronald E.

The Electromagnetic Fields Division develops and evaluates systems, devices, and methods for the measurement and analysis of radio-frequency electromagnetic fields, signals, noise, and interference. Other areas of investigation within the purview of this Division are the properties of materials for guided and freely propagated fields, including frequency and time domain representation of electromagnetic fields and their interaction with materials and structures. The Division provides essential measurement and calibration services that enable industry and government to solve important national, commercial, industrial, and military problems, such as evaluating the performance of microwave and millimeter systems, components, and materials used in advanced radars, satellite and mobile communications, and automated test systems.

Assistance is also provided to other agencies to solve measurement-related issues, such as determining levels of nonionizing radiation and solving electromagnetic interference problems. The results of the Division's work are disseminated to industry, universities, and other government agencies to foster effective research, development, manufacturing, and marketplace equity. The Division's principal program areas include microwave and millimeter wave metrology for continuous wave transmission line measurements, noise and dielectric measurements, antenna metrology, and fields and interference metrology. These services and associated standards provide a consistent base of measurements to enable contractors in the defense, aerospace, and communications industries to both assemble complete systems and perform the stringent performance assessments which are required.

ELECTROMAGNETIC TECHNOLOGY DIVISION

814.00—Electromagnetic Technology Division

3776 HARRIS, Richard E., Chief
3678 BRADFORD, Ann G., Secretary
3750 PETERSON, Robert L., Staff Assistant
3678 MADRID, Michael, Property Officer
5068 SIMMON, Mary Jo, Cler. Asst.

.01 Magnetic Recording Metrology

5097 RUSSEK, Stephen E. (PL)
5477 CORWIN, Ruth A., Secretary
5477 KIRSCHENBAUM, Leif (CU)
5557 OTI, John
5206 THOMPSON, Curtis A.

.02 Magnetic Instruments & Materials Char.

3650 GOLDFARB, Ronald B. (PL)
5333 KOS, Anthony B.
7826 SILVA, Thomas J.
3701 CRAWFORD, Thomas (PREP)

.03 Nanoprobe Imaging for Magnetic Tech.

3641 MORELAND, John M. (PL)
5615 FIELD, John C.
3841 RICE, Paul S.
3141 THOMSON, Ruth Ellen
5606 DULCIE, Laura
7305 LIOU, Sy-Hwang
7602 RUSKELL, Todd (PD)

.05 Superconductor Standards and Technology

3143 GOODRICH, Loren (PL)
3840 MEDINA, Troy (CU)
3777 STAUFFER, Theodore C.

.06 Superconductor Interfaces and Electrical Transport

5448 EKIN, John W. (PL)
5344 BERGREN, Norman F.
5631 BRAY, Steven L.
5441 CLICKNER, Cameron C.
3722 FISKE, Richard (CU)
5345 KIRKPATRICK, Pete (PREP)
5477 XU, Yizi (PD)

.07 Josephson Array Development

3740 HAMILTON, Clark H. (PL)
5258 BENZ, Samuel P.
3906 BURROUGHS, Charles J.
3988 McCARTHY, Sandra E., Secretary

.08 Nanoscale Cryoelectronics

3391 KAUTZ, Richard L. (PL)
5679 HILTON, Gene C.
5011 IRWIN, Kent D. (PD)
5430 KELLER, Mark W. (PD)
3597 MARTINIS, John M.
5844 STEINBACH, Andy (CU)
3988 WOLLMAN, David A. (PD)

.09 High Performance Sensors, Infrared Detectors, and Mixers

5102 GROSSMAN, Erich N. (PL)
7064 KOCH, Jonathan A.
7549 MacDONALD, Michael (CU)
5052 REINTSEMA, Carl D.

.10 High T_c Integrated Circuits

5081 RUDMAN, David A. (PL)
5989 BEALL, James A.
5049 CREWS, Margaret S.
3340 HARVEY, Todd E.
7705 LI, Hanqing (GR)
3762 ONO, Ronald H.
5121 VALE, Leila R.

The Electromagnetic Technology Division develops and promotes advanced standards and measurement methods for the magnetics, cryogenic electronics, and superconductor industries and their scientific communities. The Division employs phenomena based on magnetics, superconductivity, and cryoelectronics to create new standards, apparatus, and measurement technology, advancing the state-of-the-art by basic research and the development of requisite materials, fabrication techniques, and metrology.

For the magnetics industry, the Division provides new measurements, instrumentation, imaging and characterization tools and standards. In addition, with support from theoretical studies and modeling, the Division develops measurement technology to determine basic properties of magnetic materials and structures. The Division collaborates with the magnetic recording industry in the development of metrology to support future recording heads and media with their ever-increasing data density. For the superconductor industry, the Division uses the unique properties of superconductors to invent and improve measurement methods for electromagnetic signals ranging from static voltages and magnetic fields through audio, microwave, infrared, visible, and x-ray frequencies. This Division leads the international community in setting standards for the measurement of superconductor parameters, and provides the metrology infrastructure needed for the industrial development of both large- and small-scale superconductors.

LEGEND:

CON = CONSULTANT
CU = CONTRACT WITH UNIVERSITY
CP = COOPERATIVE EDUCATION PROG.
FH = FACULTY HIRE
FTT = FULL TIME TEMP.
GRF = GRADUATE RESEARCH FELLOW
GL = GROUP LEADER
GR = GUEST RESEARCHER
N/F = NIST FELLOW
PD = POSTDOCTORAL APPOINTMENT
PL = PROJECT LEADER
PT = PART TIME
S = STUDENT

OPTOELECTRONICS DIVISION

815.00—Optoelectronics Division

5204 DAY, Gordon W., Chief
5342 SMITH, Annie J., Secretary
5342 GALLAWA, Robert L. (GR)
5202 JUNEAU, Robert I.

.01 Sources and Detectors

3651 SCOTT, Thomas R. (GL)
3842 SKINNER, Dorothy L., Secretary

3741 CASE, William (Ctr)
5620 CROMER, Christopher L. (PL)
7455 DOWELL, Marla L. (PREP-CU/PD)
5367 HALE, Paul D. (PL)
7426 ITOH, Hideo (GR)
3439 JONES, Richard D.
5583 KEENAN, Darryl A.
3440 LARSON, Donald R.
3654 LEHMAN, John H.
5162 LEONHARDT, Rodney W.
3621 LI, Xiaoyu
5898 LIVIGNI, David J.
5747 OBARSKI, Gregory E.
3696 PHELAN, Robert J., Jr. (CON)
5253 TOBIAS, Iris L.
3394 VAYSHENKER, Igor
5342 ZHANG, Zhuomin (Ctr)

.02 Fiber and Integrated Optics

3346 FRANZEN, Douglas L. (GL)
5187 DERR, Linda, Secretary

3250 ALLEN, David W. (CU)
5858 DRAPELA, Timothy J.
5409 MECHELS, Steve
3542 SCHLAGER, John B.
3805 WILLIAMS, Paul A.
3223 YOUNG, Matt

.03 Optical Components

3120 GILBERT, Sarah L. (Act. GL)
3842 SKINNER, Dorothy L., Secretary

3359 CRAIG, Rex M.
7463 DYER, Shellee D. (PD)
3287 ETZEL, Shelley M. (PT)
7728 GILL, Erin M. (PREP-CU)
7494 LUX, Olivier (S)
5170/3842 MacCARTHY, Patrick M. (PREP)
6353 MIOC, Silvia L. (PD)
7630 RAWLUK, Kari S. (PREP)
5170 ROCHFORD, Kent B.
5599 ROSE, Allen H.
7381 SWANN, William (Ctr)

.04 Optoelectronic Manufacturing

3455 HICKERNELL, Robert K. (Act. GL)
5187 DERR, Linda, Secretary

3289 AMIN, Jaymin (Ctr)
3942 AUST, Andy J.
5069 BERTNESS, Kristine A.
7281 BUCKLEY, Matt (PREP)
3354 CHRISTENSEN, David H.
3370 HILL, Jim R.
5515 KNOPP, Kevin J. (GS-NASA)
7955 MIRIN, Richard (PREP)
7948 MUNROE, Michael (PD)
7953 PETIT, Frederic (S)
5420 ROSHKO, Alexana
5239 SANFORD, Norman A. (PL)
5952 VEASEY, David L.

LEGEND:
CON = CONSULTANT
CU = CONTRACT WITH UNIVERSITY
CP = COOPERATIVE EDUCATION PROG.
FH = FACULTY HIRE
FTT = FULL TIME TEMP.
GRF = GRADUATE RESEARCH FELLOW
GL = GROUP LEADER
GR = GUEST RESEARCHER
N/F = NIST FELLOW
PD = POSTDOCTORAL APPOINTMENT
PL = PROJECT LEADER
PT = PART TIME
S = STUDENT

The Optoelectronics Division is committed to providing the optoelectronics industry and its suppliers and customers with comprehensive and technically advanced measurement capabilities, standards, and traceability to those standards. The Division achieves these objectives by developing and evaluating measurement techniques, and by developing and disseminating reference data, standard reference materials and components. Providing measurement services and participating in industry-wide efforts toward measurement standardization are also part of this Division's strategy to support the characterzation of materials, equipment and processes as required for design and manufacturing.

In keeping with these activities, the Division conducts basic research, develops new theoretical concepts and models as well as new and advanced devices, components, and associated technology. These actions are designed to further the equitable exchange of products in the marketplace, and the efficient, reliable, and economical application of such products. The Division also provides technical support to other government, industry, and academic organizations.

BIBLIOGRAPHIC INFORMATION

ABSTRACT

The Electronics and Electrical Engineering Laboratory (EEEL), working in concert with other NIST Laboratories, is providing measurement and other generic technology critical to the competitiveness of the U.S. electronics industry and the U.S. electricity-equipment industry. This report summarizes selected technical accomplishments and describes activities conducted by the Laboratory in FY 1996. Also included is a profile of EEEL's organization, its customers' interactions, and the Laboratory's long-term goals.

KEYWORDS

commercialization of technology, electrical-equipment industry, electronics industry, international competitiveness, measurement capability

ORDERING

Copies of this document are available as Order No. PB97-121131 from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161, at (800) 553-6847 or (703) 487-4650.

For additional information, contact NIST/EEEL

TELEPHONE
301 975 2220

FACSIMILE
301 975 4091

E-MAIL
EEEL@nist.gov

WRITER/EDITOR:
JoAnne Surette

PHOTOGRAPHER:
Geoffrey Wheeler

PRINTING COORDINATOR:
Warren Overman

DOCUMENT PRODUCTION:
EPI Communications, Inc.