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INTRODUCTION TO FEBRUARY 1990 ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the twenty-eighth issue of a quarterly publication providing information on the technical work of the National Institute of Standards and Technology (formerly the National Bureau of Standards) Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the third quarter of calendar year 1989.

Organization of Bulletin: This issue contains abstracts for all Center papers released for publication by NIST in the quarter and citations and abstracts for Center papers published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication." Papers published in the quarter appear under the subheading "Recently Published." Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Center conferences and workshops planned for calendar year 1990 and a list of sponsors of the work.

Center for Electronics and Electrical Engineering: Center programs provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards.

The metrological products of these programs aid economic growth by promoting equity and efficiency in the marketplace, by removing metrological barriers to improved productivity and innovation, by increasing U. S. competitiveness in international markets through facilitation of compliance with international agreements, and by providing technical bases for the development of voluntary standards for domestic and international trade. These metrological products also aid in the development of rational regulatory policy and promote efficient functioning of technical programs of the Government.

The work of the Center is divided into two major programs: the Semiconductor Technology Program, carried out by the Semiconductor Electronics Division in Gaithersburg, MD, and the Signals and Systems Metrology Program, carried out by the Electricity Division in Gaithersburg and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, CO. Key contacts in the Center are given on the back cover; readers are encouraged to contact any of these individuals for further information. To request a subscription or for more information on the Bulletin, write to CEEE Technical Progress Bulletin, National Institute of Standards and Technology, Metrology Building, Room B-358, Gaithersburg, MD 20899 or call (301) 975-2220.

Center sponsors: The Center Programs are sponsored by the National Institute of Standards and Technology and a number of other organizations, in both the Federal and private sectors; these are identified on page 37.

Note on Publication Lists: Guides to earlier as well as recent work are the publication lists covering the work of each division. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 33.

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SEMICONDUCTOR TECHNOLOGY PROGRAM

Silicon Materials

Released for Publication

Krause, S.J., Visitserngtrakul, S., Cordts, B.F., and Roitman, P., **Effect of Annealing Conditions on Precipitate and Defect Evolution in Oxygen Implanted SOI Material**, to be published in the Proceedings of the 1989 IEEE SOS/SOI Technology Conference, Stateline, Nevada, October 3-5, 1989.

Silicon wafers were implanted with oxygen to a dose of 1.8×10^{18} cm^{-2} at 200 keV at a temperature of 620 °C. The wafers were annealed at temperatures between 1250 and 1350 °C for times between 1 and 6 hours in a nitrogen or argon ambient. The wafers were studied with a scanning electron microscope, a transmission electron microscope, and by secondary ion mass spectrometry. For a given annealing ambient, there is a threshold temperature for the reduction and elimination of precipitates and associated lateral dislocations in the range of 1300 °C to 1325 °C. Nitrogen ambients result in nitrogen pileup at the oxide interfaces.
[Contact: Peter Roitman, (301) 975-2077]

Roitman, P., Simons, D.S., Chi, P.H., Lindstron, R.M., Lux, G.E., Baumann, S., Novak, S.W., Wilson, R.G., Farrington, D., Keenan, J., Stevie, F.A., Moore, J.L., Irwin, R.B., Filo, A.J., Magee, C.W., Alcorn, R., and File, D., **Round-Robin Study of Implants in Si and SiO_2 by SIMS, RBS, and NAA**, to be published in the Proceedings of the Seventh International Conference on Secondary Ion Mass Spectrometry (SIMS VII), Monterey, California, September 4-8, 1989.

A round-robin study of implants of C, Na, Al, Cr, Fe, and Cu into Si and SiO_2 has been conducted. The results are reported.
[Contact: Peter Roitman, (301) 975-2077]

Recently Published

Kopanski, J.J., and Novotny, D.B., **Development and Characterization of Insulating Layers on Silicon Carbide: Annual Report for February 14, 1988 to February 14, 1989**, NISTIR 89-4157 (August 1989).

Processes to fabricate metal-insulator-semiconductor (MIS) capacitors on the cubic (3C) form of silicon carbide (SiC) were studied. The insulating layers were formed from either thermally grown oxide or chemical-vapor-deposited (CVD) silicon dioxide. The effects of wet or dry oxygen and of oxidation temperatures between 1050 and 1200 °C on the electrical properties of devices with thermal oxides were determined. Various post-oxide deposition thermal treatments were investigated for CVD oxide layers. Capacitors with CVD oxide layers that were annealed in nitrogen and subject to a short wet oxidation, and alloyed after metallization, had nearly the same electrical properties as capacitors with thermal oxides. Electrical characterization techniques appropriate for these devices on SiC were developed and applied to the fabricated capacitors. The capacitors were characterized from multiple-frequency capacitance-voltage (C-V) measurements as a function of temperature from room temperature to 300 °C. The apparent interface trap level densities were estimated from the high-frequency C-V curves. The C-V characteristics of SiC MIS capacitors have several distinctive features: (1) the capacitance decreases with increasing negative voltage into deep depletion; (2) at fields of about 2.5×10^6 V/cm, the capacitance recovers from deep depletion to its equilibrium inversion level; and (3) on the reverse sweep, a stagnant inversion layer is seen. From the analysis of the high-frequency C-V curves, the following electrical properties of typical capacitors (both

Silicon Materials (cont'd.)

thermal and CVD oxides) were determined: equivalent fixed charge, N_f, of 5 to 9 x 10^{11} cm^{-2}; interface trap level density at mid-gap, D_{it}, of 0.5 to 2.0 x 10^{11} cm^{-2} eV^{-1}; and oxide breakdown fields, V_{bd}, of 4 to 6 x 10^6 V/cm.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Compound Materials

Released for Publication

Seiler, D.G., Lowney, J.R., Littler, C.L., and Loloee, M.R., **Temperature and Composition Dependence of the Energy Gap of $Hg_{1-x}Cd_xTe$ by Two-Photon Magneto-Absorption Techniques**, to be published in the Proceedings of the Workshop on Physics and Chemistry of HgCdTe, San Diego, California, October 3-5, 1989.

The temperature dependence of the energy gap of $Hg_{1-x}Cd_xTe$ alloys with $0.24 \leq x \leq 0.26$ has been measured by nonlinear optical methods based upon two-photon magneto-absorption (TPMA). The observed nonlinear temperature behavior has been incorporated into a new empirical relationship. The TPMA-determined values of E_g at temperatures of $\approx$4.2 K in alloys with $0.24 \leq x \leq 0.30$ are shown to verify the use of the Hansen-Schmit-Casselman (HSC) relationship for the low temperature x dependence between $0 \leq x \leq 0.3$. The maximum deviation from the HSC relation occurs at 15 K, and for samples with $0.30 \leq x \leq 0.25$, the above new relationship gives values of E_g 3 to 4 meV smaller.
[Contact: David G. Seiler, (301) 975-2074]

Dimensional Metrology

Released for Publication

Postek, M.T., Larrabee, R.D., and Keery, W.J., **A New Approach to Accurate X-Ray Mask Measurements in a Scanning Electron Microscope.**

This paper presents the basic concept and some preliminary experimental data on a new method for measuring critical dimensions on masks used for X-ray lithography. The method uses a scanning electron microscope in a transmitted-electron imaging mode and can achieve nanometer precision. Use of this technique in conjunction with measurement algorithms derived from electron beam interaction modeling may ultimately enable measurements of these masks to be made to nanometer accuracy. Furthermore, since a high contrast image results, this technique lends itself well to automated mask defect recognition and inspection.
[Contact: Beverly M. Wright, (301) 975-2166]

Recently Published

Postek, M.T., and Evans, C.J., **Inspection of Single-Point Diamond Turning Tools at Low Accelerating Voltage in a Scanning Electron Microscope**, Scanning Microscopy, Vol. 3, No. 2, pp. 435-442 (1989).

Single-crystal diamond tools used in the machining process have been inspected in both the optical microscope and scanning electron microscope. Attention was focused on surface characteristics related to the specific polishing process and its relationship to cutting-edge structure. The need for tool inspection is discussed as well as the drawbacks with the inspection techniques presently used. Low accelerating voltage (<2.5 keV) inspection of uncoated diamond tools for machining is shown to be a viable method for the determination of polishing flaws that grossly reflect in the surface quality of the finished part.
[Contact: Beverly M. Wright, (301) 975-2166]

Analysis Techniques

Recently Published

Baghdadi, A., Bullis, W.M., Croarkin,

Analysis Techniques (cont'd.)

M.C., Yue-zhen, L., Scace, R.I., Series, R.W., Stallhofer, P., and Watanabe, M., **Interlaboratory Determination of the Calibration Factor for the Measurement of the Interstitial Oxygen Content of Silicon by Infrared Absorption**, J. Electrochem. Soc., Vol. 136, No. 7, pp. 2015-2024 (July 1989).

We report a worldwide interlaboratory experiment to determine the calibration factor used to calculate the interstitial oxygen content of silicon from room temperature infrared absorption measurements. We conducted a round-robin for both the infrared and the absolute measurements on the same or equivalent specimens. The conversion coefficient for computing the oxygen content of silicon in parts per million atomic (ppma) from a room temperature measurement of the absorption coefficient at 1107 cm^{-1} was determined to be 6.28 ± 0.18 ppma/cm^{-1}.
[Contact: Brian G. Rennex, (301) 975-2108]

Baghdadi, A., Scace, R.I., and Walters, E.J., **Semiconductor Measurement Technology: Database for and Statistical Analysis of the Interlaboratory Determination of the Conversion Coefficient for the Measurement of the Interstitial Oxygen Content of Silicon by Infrared Absorption**, NIST Special Publication 400-82 (July 1989).

This Special Publication contains the data collected for the worldwide, double-round-robin determination of the conversion coefficient used to calculate the interstitial oxygen content of silicon from infrared absorption measurements. It also contains detailed statistical analyses of those data. A paper describing the results of this study has been accepted for publication by the Journal of the Electrochemical Society. It should be considered the official result of the study. The approach taken to determine the conversion coefficient was to conduct interlaboratory round robins for both the infrared measurements and the absolute measurements. The infrared measurements were carried out at 18 laboratories in China, Europe, Japan, and the United States, using either dispersive infrared or Fourier transform infrared spectrometers. The absolute measurements were carried out at eight laboratories in Europe, Japan, and the United States, using either charged-particle activation analysis, photon activation analysis, or inert gas fusion analysis.
[Contact: Robert I. Scace, (301) 975-2220]

Photodetectors

Recently Published

Geist, J., and Baltes, H., **High Accuracy Modeling of Photodiode Quantum Efficiency**, Applied Optics, Vol. 28, No. 18, pp. 3929-3939 (15 September 1989).

We propose a new silicon photodiode model that is optimized for high accuracy measurement applications. The new model differs from previous models in that the contribution from the diode front-region to the quantum efficiency is described by an integral transform of the equilibrium minority carrier concentration. This description is accurate provided that the recombination of excess minority carriers in the front region occurs only at the front surface and that the diode is operating in the linear response region.
[Contact: Jon Geist, (301) 975-2066]

Device Physics and Modeling

Released for Publication

Bennett, H.S., and Lowney, J.R., **Physics for Numerical Simulation of Silicon and Gallium Arsenide Transistors.**

The motivation for using computers to simulate the electrical characteristics of transistors is discussed. Our work

Device Physics and Modeling (cont'd.)

and that of others in the area of device physics and modeling is described. We compare conventional device physics with an alternative approach to device physics that is more directly traceable to quantum mechanical concepts. We then apply this new approach to quasi-neutral regions, space-charge regions, and regions with high levels of carrier injection. The limits for using theoretical results from uniform media in numerical simulations of devices with large concentration gradients are discussed. New calculations of the effective intrinsic carrier concentrations for gallium arsenide and silicon are also given. We conclude with examples of applying quantum-mechanically-based device physics to energy band diagrams for heterojunction bipolar transistors, MOS capacitors, and unirradiated and irradiated homojunction bipolar transistors.
[Contact: Herbert S. Bennett, (301) 975-2053]

Gaitan, M., Enlow, E.W., and Russell, T.J., **Accuracy of the Charge Pumping Technique for Small Geometry MOSFETs.**

The channel length dependence of the charge pumping current for MOSFETs is investigated using a two-dimensional simulation technique. The dependence of charge pumping current on signal offset voltage for various MOSFET channel lengths is studied using energy-dependent interface trap distributions. Simulations are compared to experimental charge pumping measurements on irradiated MOSFETs with different gate lengths with good agreement for the shape of the curves. It is found that as the effective channel length decreases, the accepted charge pumping model has decreasing accuracy that results in an underestimation of the mean interface trap density. The loss in accuracy is due to the nonuniformity of surface potential across the channel caused by source/drain proximity. Using the charge pumping technique to measure interface trap densities on advanced devices with an effective channel length less than 1 μm may result in unacceptable errors.
[Contact: Michael Gaitan, (301) 975-2070]

Gaitan, M., and Roitman, P., **Small Signal Modeling of the MOSOS Capacitor**, to be published in the Proceedings of the 1989 IEEE SOS/SOI Technology Conference, Stateline, Nevada, October 3-5, 1989.

The high frequency and quasi-static capacitance of an MOS capacitor on a layer of insulator (MOSOS) has been modeled using numerical solution by perturbation analysis of the basic semiconductor equations.
[Contact: Michael Gaitan, (301) 975-2070]

Lowney, J.R., **Physical Basis for Bandgap Narrowing: Roles of Carriers and Dopant Ions**, to be published in the Proceedings of the 5th International Workshop on the Physics of Semiconductor Devices, December 11-16, 1989, New Delhi, India.

Bandgap narrowing, which occurs in electronic devices as a result of heavy doping or large carrier densities, is explicitly a function of both the dopant and carrier densities. This is an important consideration in heavily injected or depleted regions, where quasi-neutrality is violated. This work shows what effects occur in such regions and demonstrates the need to revise device models so that bandgap narrowing is treated as an explicit function of both dopant and carrier density.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Recently Published

Seiler, D.G., Ward, G.B., Justice, R.J., Koestner, R.J., Goodwin, M.W., Kinch, M.A., and Meyer, J.R., **Shubnikov-de Haas Measurements on n-type and p-type**

Device Physics and Modeling (cont'd.)

HgTe-CdTe Superlattices, Journal of Applied Physics, Vol. 66, No. 1, pp. 303-307 (1 July 1989).

Oscillatory magnetoresistance (Shubnikov-de Haas) measurements have been used to determine free carrier effective masses in HgTe-CdTe superlattices. Measurements on an n-type superlattice yield an electron mass which is in excellent agreement with theoretical results from a tight-binding band structure calculation. The p-type data are more complex, showing evidence for a light hole mass at low magnetic fields and a much heavier mass at fields above 20 kG. This finding is also in agreement with the predictions of band structure theory.
[Contact: David G. Seiler, (301) 975-2074]

Insulators and Interfaces

Recently Published

Dumin, D.J., Dabral, S., Freytag, M., Robertson, P.J., Carver, G.P., and Novotny, D.B., **Growth Properties of High-Quality Very-Thin SOS Films**, Journal of Electronic Materials, Vol. 18, No. 1 (1989).

The increased emphasis on submicron geometry CMOS/SOS devices has created a need for high-quality silicon-on-sapphire films with thicknesses of the order of 0.1 to 0.2 μm. To date, the only viable way of producing high-quality SOS films with these thicknesses has been through the application of recrystallization and regrowth techniques. The need for as-grown, high-quality, very-thin SOS films has prompted a study of film quality versus growth rate for films with thicknesses in the 0.1- to 0.2-μm range as a possible way of producing thin high-quality SOS films. It has been found that film quality increased as the growth rate increased. It was possible to produce films as thin as 0.1 μm with mobilities nearly as high as 1-μm films, if the film growth rate was higher than 4 μm/min.
[Contact: Donald B. Novotny, (301) 975-2699]

Marchiando, J.F., **Semiconductor Measurement Technology: A Software Program for Aiding the Analysis of Ellipsometric Measurements, Simple Models**, NIST Special Publication 400-83 (July 1989).

MAIN1 is a software program for aiding the analysis of ellipsometric measurements. MAIN1 consists of a suite of routines written in FORTRAN that are used to invert the standard reflection ellipsometric equations for simple systems. A system is said to be simple if the solid material sample may be adequately characterized by models which assume at least the following: 1) materials which are nonmagnetic; 2) samples which exhibit depth-dependent optical properties, such as layered or laminar structures atop a substrate that behaves like a semi-infinite half-space; 3) layers which are flat and of uniform thickness; and 4) a dielectric function within each layer/substrate which is isotropic, homogeneous, local, and linear. Each layer is characterized in part by a thickness (z), while the optical properties for a given material and wavelength are expressed in terms of a refractive index (n) and extinction coefficient (k). The ellipsometric equations are formulated as a standard damped nonlinear least-squares problem and then solved by an interactive method when possible. Estimates of the uncertainties associated with assigning numerical values to the model parameters are calculated as well.
[Contact: Jay F. Marchiando, (301) 975-2088]

Packaging

Released for Publication

Harman, G.G., **Reliability and Yield Problems of Wire Bonding in Microelec-**

Packaging (cont'd.)

tronics, The Application of Materials and Interface Science, to be published as an ISHM Monograph (International Society for Hybrid Microelectronics, Reston, Virginia).

This book describes the conditions for making reliable wire bonds with a high yield by describing all potential sources of failures, from the final stages of wafer processing, through handling, bonding, testing and screening. Sources of contamination are identified that adversely affect the reliability of wire bonds. In addition, the degrading effects of temperature, temperature cycling, and mechanical forces such as ultrasonic cleaning are described. Bonding machine setup parameters also play a critical role. In addition, the severity of the above problems may depend on the ambient atmosphere, the metallurgy of the wire, and/or the morphology of the bonding pad metallization. Wafer sawing and die attach can also adversely affect bond quality.

Basic concepts of bonding methods, wire metallurgy and aging, and cleaning techniques (UV and/or ozone, solvent, plasma, and burnishing) are described. Classical plague failure, its metallurgy, and the effect of corrosion and impurities are extensively treated. All bond testing methods are described and compared. Problems with electroplating, various metal systems, and machines and setup are described. Thermal and ultrasonic effects on wire fatigue are discussed. Mechanical problems such as cratering, cracks in wedge bonds, and the effect of acceleration and vibration are extensively discussed.
[Contact: George G. Harman, (301) 975-2097]

Recently Published

Harman, G.G., **The Silicon and Gallium Arsenide Cratering Problem**, Book of Abstracts, IEEE/CHMT VLSI & GaAs Chip Packaging Workshop, Santa Clara, California, September 12-14, 1988, pp. 65-70.

The complex synergistic cratering effects of the VLSI era involve not only bonding parameters, but also Au-Al compound-induced stress, silicon nodules in the metallization, plastic package stress, and surface mount stress. The situation is even worse in GaAs.
[Contact: George G. Harman, (301) 975-2097]

Harman, G.G., and Wilson, C.L., **Materials Problems Affecting Reliability and Yield of Wire Bonding in VLSI Devices**, Proceedings of the Materials Research Society Symposium, Electronic Packaging Materials Science IV, San Diego, California, April 24-29, 1989, Vol. 154, pp. 401-413 (1989).

Materials problems have always been a significant cause of wire bond failures in microelectronics. However, modern VLSI materials, processing, and packaging methods combined often result in new or masked versions of old failure mechanisms. This paper describes the classical Au-Al intermetallic compound problem as described by a new two-dimensional finite element diffusion model and demonstrates that diffusion in poor welds is more rapid than in bulk couples. Failures resulting from modern bonding material couples (e.g., Cu-Au, Al-Ag, etc.) can result in bond failures superficially resembling Au-Al type failures. Failures resulting from bonds made to contaminated gold electroplated films are described, and a new failure model resulting from hydrogen in these films is shown.
[Contact: George G. Harman, (301) 975-2097]

Other Semiconductor Metrology Topics

Released for Publication

Lee, K.C., **The Fabrication of Thin, Free Standing, Single Crystal, Semiconductor**

Other Semiconductor Topics (cont'd.)

Membranes.

Free-standing, single-crystal, semiconductor membranes with thicknesses in the range of a few tens of nanometers to tens of microns are of increasing technological interest today. Their applications range from high-speed electronic devices to electromechanical devices and pressure sensors. This review paper identifies two general classes of techniques for producing such thin membranes: dissolution of single-crystal wafers and direct growth of single-crystal membranes. Numerous specific techniques in each general class are discussed. The discussion of each technique includes a brief explanation of the reason why it works, a description of the actual experimental implementation, an analysis of the range of thicknesses that can be produced, and the crystalline and electrical quality of the membranes. Unusual difficulties with implementing a technique or special advantages of a technique are also noted. Since this review is intended to aid in the selection of a technique for producing thin semiconductor membranes when one has a particular application in mind, note is made of those applications for which the membranes produced with each technique are particularly well suited.
[Contact: Kevin C. Lee, (301) 975-4326]

SIGNALS & SYSTEMS METROLOGY PROGRAM

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Recently Published

Zhang, Y.X., McKnight, R.H., and Fenimore, C., **A Method for Fitting and Smoothing Digital Data**, Proceedings of the Sixth International Symposium on High Voltage Engineering, New Orleans, Louisiana, August 28-September 1, 1989, Paper 50.06 (1989).

A method has been developed and evaluated to fit and smooth digital data using cubic splines. Most high-voltage waveforms cannot be fit by a simple analytic expression. Therefore, piecewise fitting is needed. Calculation shows that the fitting algorithm is suitable for the full-lightning and chopped lightning waveforms and the step response. A criterion for selecting the principal free parameter in the fitting process is given with an example.
[Contact: Charles Fenimore, (301) 975-2428]

DC & Low Frequency Metrology

Recently Published

Kinard, J.R., and Cai, T-X., **Determination of AC-DC Difference in the 0.1-100 MHz Frequency Range**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 360-367 (April 1989). [Also to be published in the Proceedings of the CPEM-88 Conference, Tsukuba Science City, Japan, June 7-10, 1988.]

Thermal voltage converter structures have been modeled theoretically and studied experimentally to determine their ac-dc differences in the 0.1- to 100-MHz frequency range. Estimated uncertainties for these ac-dc differences vary from 30 ppm at 1 MHz to 2000 ppm at 100 MHz.
[Contact: Joseph R. Kinard, (301) 975-4250]

Kinard, J.R., Hastings, J.R., Lipe, T.E., and Childers, C.B., **AC-DC Difference Calibrations**, NIST Special Publication 250-27 (May 1989).

The NIST (Gaithersburg) calibration service for thermal voltage and current converters relies on a group of primary multijunction thermal converters and sets of reference and working standards for extending their ranges and frequencies. The converter sets that con-

DC & Low Frequency Metrology (cont'd.)

stitute the NIST standards -- primary, reference, and working -- as well as the build-up and bootstrap techniques used in their characterization over the full ranges of voltage, current, and frequency are described briefly. The upper voltage and current limits and the uncertainties of the ac-dc difference calibrations are given as a function of frequency.
[Contact: Joseph R. Kinard, (301) 975-4250]

Kinard, J.R., and Lipe, T.E., **Recharacterization of Thermal Voltage Converters After Thermoelement Replacement**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 351-356 (April 1989).

The relationship between the characteristics of various thermoelements (TEs) as voltage or current converters and the overall ac-dc differences of a voltage range in a coaxial thermal voltage converter (TVC) set is described. An algorithm to predict the relationships between the ac-dc differences of individual voltage ranges with different TEs is presented, and a method for recharacterizing a thermal voltage converter containing a replacement TE is given. The measured results show that for most applications, a complete recharacterization of the TVC set is unnecessary.
[Contact: Joseph R. Kinard, (301) 975-4250]

Fundamental Electrical Measurements

Released for Publication

Cage, M.E., Marullo Reedtz, G., and Yu, D., **Quantized Dissipative States at Breakdown of the Quantum Hall Effect.**

We report the breakdown of the nearly dissipationless quantum Hall effect into a set of distinct, quantized dissipative states in a wide, high-quality GaAs/AlGaAs sample. We found 35 dissipative states accurately quantized in fractional units of volts/tesla to within our typical ±0.6% measurement uncertainly on the i = 2 plateau, and 9 are quantized on the i = 4 plateau. The phenomena show characteristics consistent with an extension of the quasi-elastic inter-Landau level scattering model of Eaves and Sheard.
[Contact: Marvin E. Cage, (301) 975-4248]

Cryoelectronic Metrology

Released for Publication

McDonald, D.G., **Superconductivity and the Quantization of Energy.**

Ideas about quantized energy levels originated in atomic physics, but superconductivity provides energy levels with unparalleled precision: 3 parts in 10^{19} at an energy of 0.0003 eV, in recent work by Jain, Lukens, and Tsai. The fact that the myriad of interactions of 10^{12} particles in a macroscopic body, a Josephson junction, can produce sharply defined energy levels suggests a dynamical state effectively divorced from the complexities of its environment. The existence of this state, the macroscopic quantum state of superconductors, is well established, but its isolation from intrinsic perturbations has recently been shown to be extraordinary. These new results, with an improved accuracy of about 10 orders of magnitude, are discussed in the context of highly accurate results from quantum electrodynamics, atomic spectroscopy, and the standards of metrology. Further refinements in accuracy may be achievable at higher energy levels, about 12 eV, as they become available from a new series array of 18992 Josephson junctions.
[Contact: Donald G. McDonald, (303) 497-5113]

Pulse Power Metrology

Released for Publication

Pulse Power Metrology (cont'd.)

Van Brunt, R.J., **Research for Electric Energy Systems - An Annual Report**, to be published as NISTIR 89-4167.

This is a report of technical progress in four investigations conducted at the National Institute of Standards and Technology and supported by the U.S. Department of Energy under Task Order Number 137. The first investigation is concerned with the measurements of electric fields and ions in the vicinity of high-voltage transmission lines and biological exposure facilities. For this investigation, results are reported on evaluations of two methods for measuring ion mobilities at atmospheric pressure and an aspiratory-type ion counter for measuring monopolar charge densities in air. The second investigation is concerned with development of advanced diagnostics for compressed gas-insulated power systems. For this investigation, results are reported on measurements of collisional electron detachment and negative ion conversion reactions in SF_6 and on a new technique for measuring the stochastic behavior of partial discharges. The third investigation is concerned with measurement of prebreakdown phenomena at solid-liquid dielectric interfaces. Results are presented here from optical observations of the influence of hydrostatic pressure on prebreakdown partial discharge development and measurement of nanosecond impulse breakdown at liquid-solid interfaces. The fourth area of research is concerned with electrical measurement of fast transient phenomena. Results are presented from an investigation into the interactions between two dividers used simultaneously to measure fast impulse voltages.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Antenna Metrology

Released for Publication

Francis, M.H., **Antenna Far-Field Pattern Accuracies at Millimeter Wave Frequencies Using the Planar Near-Field Technique**, to be published in the Proceedings of the Eleventh Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Monterey, California, October 9-13, 1989.

In recent years there has been an increasing demand for antenna calibrations at millimeter-wave frequencies. Because of this, the National Institute of Standards and Technology (NIST) has been developing measurement capabilities at millimeter-wave frequencies. The development of gain and polarization measurement capabilities has been previously reported. This paper reports the development of an antenna pattern measurement capability which has been achieved during the last year. Measurement accuracies of better than 4 dB have been achieved for sidelobes which are 40 dB below the mainbeam peak. NIST is now providing a new measurement service for antenna patterns in the 30- to 50-GHz frequency range.
[Contact: Michael H. Francis, (303) 497-5873]

Guerrieri, J.R., and Kremer, D.P., **Automated Multi-Axis Motor Controller and Data Acquisition System for Near-Field Scanners**, to be published in the Proceedings of the Eleventh Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Monterey, California, October 9-13, 1989.

The National Institute of Standards and Technology (NIST) has developed a multi-axis controller and software data acquisition system that has improved position accuracies. This extends the usefulness of the NIST planar near-field scanner to higher frequencies. This system integrates programmable power supplies into an existing planar measurement system with new software that controls the power supplies and the data acquisition. It yields higher

Antenna Metrology (cont'd.)

positioning accuracy required for millimeter-wave measurements at a reasonable cost.

This system uses the NIST planar near-field scanner's existing dc motors, computer, and laser interferometer measurement system. The programmable power supplies are connected to the motors, with a separate power supply for each motor's armature and a common power supply for each of the motor's field windings. This allows for concurrent movement in each axis and eliminates delays in switching between axis. Directional control, motor protection, and special software features are implemented via control logic.
[Contact: Jeffrey R. Guerrieri, (303) 497-3863]

Muth, L.A., and Lewis, R.L., **An Iterative Technique to Correct Probe Position Errors in Planar Near-Field to Far-Field Transformations**, to be published in the Proceedings of the 1989 International Symposium on Antennas and Propagation, Tokyo, Japan, August 22-25, 1989. [Also published as NIST Technical Note 1323 (October 1988)].

We have developed a general theoretical procedure to take into account probe position errors when planar near-field data are transformed to the far field. If the probe position errors are known, we can represent the measured data as a Taylor series, whose terms contain the error function and the ideal spectrum of the antenna. Then we can solve for the ideal spectrum in terms of the measured data and the measured position errors by inverting the Taylor series. This is complicated by the fact that the derivatives of the ideal data are unknown; that is, they can only be approximated by the derivatives of the measured data. This introduces additional computational errors, which must be properly taken into account. We have shown that the first few terms of the inversion can be easily obtained by simple approximation techniques, where the order of the approximation is easily specified. A more general solution can also be written by formulating the problem as an integral equation and using the method of successive approximations to obtain a general solution. An important criterion that emerges from the condition of convergence of the solution to the integral equation is that the total averaged position error must be less than some fraction of the sampling criterion for the antenna under test.
[Contact: Lorant A. Muth, (303) 497-3703]

Muth, L.A., and Lewis, R.L., An **Iterative Technique to Correct Probe Position Errors in Planar Near-Field Measurements.**

We present a general theoretical procedure to remove known probe position errors when planar near-field data are transformed to the far field. We represent the measured data as a Taylor series, whose terms contain the error function and the ideal spectrum of the antenna. This representation is then assumed to be an actual near field existing on an error-free, regularly spaced, two-dimensional scan plane. Then by inverting the Taylor series, we obtain the ideal spectrum in terms of the measured data and the position errors. The solution is given in terms of an error operator that acts on the measured data (incorporating measurement errors). This error operator is the Taylor series without the zeroth order term. The nth-order approximation to the ideal near field of the antenna can be explicitly constructed by inspection of the structure of the error operator. Since we have an infinite series of a differential operator, the question of convergence is addressed. Computer simulations using periodic error functions show that we are dealing with a convergent series, and the error correction technique is seen to be highly successful. This is demonstrated

Antenna Metrology (cont'd.)

for a triple periodic error function. The root-mean-square values of the far fields as functions of the radius in k (wavenumber) space are calculated and compared for the error-free, error-contaminated, and error-corrected far fields. Appropriate graphical representation of the error fields, the error-contaminated, and error-free fields are presented to enhance understanding of the results.
[Contact: Lorant A. Muth, (303) 497-3603]

Newell, A.C., Guerrieri, J.R., Persinger, R.R., Stiles, J.A., Hughes, A.C., and McFarlane, E.J., **Comparison of Antenna Boresight Measurements Between Near-Field and Far-Field Ranges**, to be published in the Proceedings of the Eleventh Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Monterey, California, October 9-13, 1989.

This paper describes the results of electrical boresight measurement comparisons between one far-field and two near-field ranges. Details are given about the near-field alignment procedures and the near-field error analysis. Details of the far-field measurements and its associated errors are not described here since the near-field technique is of primary interest. The coordinate systems of the antenna under test and the measurement ranges were carefully defined, and extreme care was taken in the angular alignment of each. The electrical boresight direction of the main beam was determined at a number of frequencies for two antenna ports with orthogonal polarizations. Results demonstrated a maximum uncertainty between the different ranges of 0.018 degrees. An analytical error analysis was also performed that predicted a similar level of uncertainty. This error analysis can serve as the basis for estimating uncertainty in other near-field measurements of antenna boresight.
[Contact: Allen C. Newell, (303) 497-3743]

Newell, A.C., Kremer, D.P., and Guerrieri, J.R., **Improvements in Polarization Measurements of Circularly Polarized Antennas**, to be published in the Proceedings of the Eleventh Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Monterey, California, October 9-13, 1989.

A new measurement technique is described that is used to measure the polarization properties of dual-polarized, circularly polarized antennas. A three-antenna technique is used, and high-accuracy results are obtained for all three antennas without assuming ideal or identical properties. This technique eliminates the need for a rotating linear antenna, reduces the setup time when gain measurements are also performed, and reduces error for antennas with low axial ratios.
[Contact: Allen C. Newell, (303) 497-3743]

Recently Published

Francis, M.H., **X-Band Atmospheric Attenuation for an Earth Terminal Measurement System**, NISTIR 89-3918 (July 1989).

The National Institute of Standards and Technology has developed an Earth Terminal Measurement System to be used by the Camp Parks Communications Annex in determining satellite effective isotropic radiated power and antenna gain. In determining these quantities, the effects of atmospheric attenuation must be taken into account. This paper provides an overview of the methods used for determining atmospheric attenuation, with emphasis on a tipping-curve method. An error analysis is also provided.
[Contact: Michael H. Francis, (303) 497-5873]

Jesch, R.L., **Mobile Antennas**, U.S.

Antenna Metrology (cont'd.)

Department of Justice, Technology Assessment Program, NIJ Standard-0205.01 (May 1989).

This document establishes minimum performance requirements and methods of test for mobile antennas mounted on vehicles used by law enforcement agencies, and deals with antenna characteristics that determine the suitability and effectiveness of antennas for law enforcement use. As a result, only the following four frequency bands are considered: 25 to 50 MHz, 150 to 174 MHz, 400 to 512 MHz, and 806 to 866 MHz. This standard supersedes NILECJ-STD-0205.00, Mobile Antennas dated May 1974. This revision has been written to include mobile antennas operating in the 806- to 866-MHz frequency band, and it also provides a substantially improved standard radiation test site that uses an elevated metal ground plane. In addition, the relative antenna gain requirement and test method have been replaced by a gain-transfer requirement and test method.
[Contact: Ramon L. Jesch, (303) 497-3496]

Wittmann, R.C., review of book, Antenna Spherical Near-Field Antenna Measurements, edited by J.E. Hansen, column, "Reviews and Abstracts," IEEE Antennas and Propagation Society Newsletter, June 1989.

The general plan of the book is presented, with brief descriptions of the content of the seven chapters. The reviewer found the appendices particularly noteworthy in that they provide a collection of spherical-wave formulas in a "uniform, concise notation."
[Contact: Ronald C. Wittmann, (303) 497-3326]

Noise Metrology

Recently Published

Daywitt, W.C., **Radiometer Equation and Analysis of Systematic Errors for the NIST Automated Radiometers**, NIST Technical Note 1327 (March 1989).

Equations used in the NIST coaxial and waveguide automated radiometers to estimate the noise temperature and associated errors of a single-port noise source are derived in this report. These equations form the foundation upon which the microwave and millimeter-wave noise calibration and special test services are performed. Results from the 1- to 12-GHz coaxial radiometer are presented.
[Contact: William C. Daywitt, (303) 497-3720]

Francis, M.H., **X-Band Atmospheric Attenuation for an Earth Terminal Measurement System**, NISTIR 89-3918 (July 1989).

The National Institute of Standards and Technology has developed an Earth Terminal Measurement System to be used by the Camp Parks Communications Annex in determining satellite effective isotropic radiated power and antenna gain. In determining these quantities, the effects of atmospheric attenuation must be taken into account. This paper provides an overview of the methods used for determining atmospheric attenuation, with emphasis on a tipping-curve method. An error analysis is also provided.
[Contact: Michael H. Francis, (303) 497-5873]

Microwave & Millimeter-Wave Metrology

Released for Publication

Adair, R.T., and Livingston, E.M., **Coaxial "Intrinsic" Impedance Standards**, to be published as NISTIR 89-3924.

This paper discusses how impedance standards are derived from the basic definition of impedance, constructed, and used in metrology with coaxial airline systems. Basic transmission line

Microwave & Millimeter-Wave (cont'd.)

equations are reviewed, with emphasis given to intrinsic or derived standards for obtaining the impedance in low-loss transmission line systems. A brief description of how impedance standards are used to calibrate the vector automatic network analyzer and, in particular, the dual six-port system automatic network analyzer which is used at the National Institute of Standards and Technology (NIST) for calibration services in the radio-frequency, microwave, and millimeter-wave areas is given. Measurement uncertainties are given for 7-mm coaxial devices measured with the NIST six-port system. The resolution of our six-port system is several orders more precise than that of the present impedance standards from which it is calibrated. Required improvements in the physical dimensions of air-line standards are identified which would permit the automatic network analyzer's capability to be utilized more fully.
[Contact: Eleanor M. Livingston, (303) 497-5339]

Daywitt, W.C., and Counas, G.J., **Measuring Adapter Efficiency Using a Sliding Short Circuit.**

This paper describes a simple technique for measuring the efficiency of low-loss adapters that is useful in microwave applications where a few hundredths of a decibel error is acceptable. An expression for the efficiency error is given.
[Contact: William C. Daywitt, (303) 497-3720]

Hoer, C.A., **Systematic Errors in Power Measurements Made With a Dual Six-Port ANA**, to be published as NIST Technical Note 1332.

The purpose of this report is to determine the systematic error in measuring power with a dual six-port automatic network analyzer. Most of the report concentrates on developing equations for estimating systematic errors due to imperfections in the test port connector, imperfections in the connector on the power standard, and imperfections in the impedance standards used to calibrate the six-port for measuring reflection coefficient. These are the largest sources of error associated with the six-port. For 7-mm connectors, all systematic errors which are associated with the six-port add up to a worst case uncertainty of ±0.00084 in measuring the ratio of the effective efficiency of a bolometric power sensor relative to that of a standard power sensor.
[Contact: David H. Russell, (303) 497-3148]

Weil, C.M., Marler, F.E., Major, J.R., Weidman, M.P., and Russell, D.H., **Development of Waveguide Dual Six-Port Systems for Measurements in the Range 18 - 50 GHz**, to be published in the Digest of the 33rd ARFTG Conference, Long Beach, California, June 15-16, 1989.

The development and evaluation of three waveguide dual six-port reflectometer systems, covering the frequency range 18 to 50 GHz, are discussed. These are capable of automated or semi-automated operation and will provide complex scattering parameter data for customer waveguide components, as well as effective efficiency data for power sensors. Some representative measurement data are presented which demonstrate that these systems yield results that do not differ significantly from those obtained using older measurement systems. Some discussion of measurement uncertainties is also included.
[Contact: Claude M. Weil, (303) 497-5305]

Recently Published

Hill, D.A., **Reflection Coefficient of a Waveguide with Slightly Uneven Walls**, IEEE Transactions on Microwave Theory and Techniques, Vol. 37, No. 1, pp. 244-252 (January 1989).

Microwave & Millimeter-Wave (cont'd.)

First-order results are derived for the reflection coefficient of a waveguide with slightly uneven walls. Specific analytical and numerical results are given for rectangular waveguides and coaxial transmission lines. Simple upper bounds are given for reflection coefficients in terms of the maximum deviation of the waveguide. For typical tolerances, the reflection coefficients are very small ($<10^{-3}$), but the results are important in precise six-port measurements.
[Contact: David A. Hill, (303) 497-3472]

Holt, D.R., **Scattering Parameters Representing Imperfections in Precision Coaxial Air Lines**, Journal of Research of the National Institute of Standards and Technology, Vol. 94, No. 2, pp. 117-133 (March-April 1989).

Scattering parameter expressions are developed for the principal mode of a coaxial air line. The model allows for skin-effect loss and dimensional variations in the inner and outer conductors. Small deviations from conductor circular cross sections are conformally mapped by the Bergman-Kernel Technique. Numerical results are illustrated for a 7-mm air line. An error analysis reveals that the accuracy of the determination of the scattering parameters is primarily dependent on the precision of the measurement of the conductor radii.
[Contact: Donald R. Holt, (303) 497-3574]

Juroshek, J.R., Hoer, C.A., and Kaiser, R.F., **Calibrating Network Analyzers with Imperfect Test Ports**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 4, pp. 898-901 (August 1989).

The test ports on automatic network analyzers are generally built with an impedance that matches the impedance of the calibration standards. Any impedance discontinuity at the test port interface is discouraged since unwanted modes can be produced. There has been concern that if unwanted modes exist at the test port interface, there is no assurance that they remain constant throughout the calibration process. Thus, a calibration and subsequent measurement error is possible. This report gives experimental evidence that substantial impedance discontinuities can be tolerated at the test port interface if proper calibration procedures are observed. The 50-Ω test port on one of the six ports in a dual six-port network analyzer was replaced with a 75-Ω test port. This test port was then calibrated to look like a 50-Ω test port. Measurements on various devices showed that indeed it was possible to make a 75-Ω test port indistinguishable from a 50-Ω test port.
[Contact: John R. Juroshek, (303) 497-5362]

Livingston, E.M., and Adair, R.T., **Performance Evaluation of Radiofrequency, Microwave, and Millimeter Wave Power Meters**, NIST Technical Note 1310 (December 1988).

Measurement techniques are described for the evaluation of the electrical performance of commercially available radiofrequency (rf), microwave (mw) and millimeter-wave (mmw) power meters which use bolometric power sensors and which typically operate from 10 MHz to 26.5 GHz for an average power range of 10 μW to 10 mW, with appropriate attenuation for higher power ranges.

Power measurements at dc and low frequencies are relatively straightforward since voltage, current, and impedance are discrete entities from which values of power may be calculated through the use of Ohm's law. For radio, microwave, and millimeter-wave frequencies, however, these become complex, interactive, distributed parameters. Impedance mismatch, leakage, and nonlinear responses must also be considered. The principle of

Microwave & Millimeter-Wave (cont'd.)

the bolometric method of measurement of rf, mw, and mmw power is presented.

Techniques are described for analysis of: ranges of frequency and power, operating temperature, stability, response time, calibration factor, extended power measurement, overload protection, and characteristics of the internal power reference source. Some automated methods are discussed. Block diagrams of test setups are presented.

Sources of uncertainty in the bolometric method are analyzed.
[Contact: Eleanor M. Livingston, (303) 497-5339]

Optical Fiber Metrology

Recently Published

Drapela, T.J., Franzen, D.L., Cherin, A.H., and Smith, R.J., **A Comparison of Far-Field Methods for Determining Mode Field Diameter of Single-Mode Fibers Using Both Gaussian and Petermann Definitions**, IEEE/OSA Journal of Lightwave Technology, Vol. 7, No. 8, pp. 1153-1157 (August 1989).

An interlaboratory comparison of far-field measurement methods to determine mode field diameter of single-mode fibers was conducted among members of the Electronic Industries Association. Measurements were made on dispersion-unshifted and -shifted fibers at 1300 and 1550 nm. Results were calculated using both Petermann and Gaussian definitions. The Petermann definition gave better agreement than the Gaussian in all cases. A systematic offset of 0.52 μm was observed between methods when applied to dispersion-shifted fibers. Such an offset may be caused by limited angular collection.
[Contact: Timothy J. Drapela, (303) 497-5858]

Franzen, D.L., Young, M., Cherin, A., Head, E., Hackert, M., Raine, K., and Baines, J., **Numerical Aperture of Multimode Fibers by Several Methods: Resolving Differences**, IEEE/OSA Journal of Lightwave Technology, Vol. 7, No. 6, pp. 896-901 (June 1989).

An industry-wide study among members of the Electronic Industries Association was conducted to document differences between three numerical aperture measurement methods. Results on twelve multimode graded index fibers indicate that systematic differences exist among commonly used far-field and index profile techniques. Differences can be explained by a wavelength-dependent factor and choice of definitions. Conversion factors may be used to relate the various methods.
[Contact: Douglas L. Franzen, (303) 497-3346/-5342]

Electro-Optic Metrology

Released for Publication

Day, G.W., **Recent Advances in Faraday Effect Sensors**, to be published in the Proceedings of the International Conference on Optical Fiber Sensors, Paris, France, September 18-20, 1989.

This paper reviews recent developments in the application of the Faraday effect to electric current and magnetic field sensing. Progress toward smaller, faster, more sensitive, and more stable devices is emphasized.
[Contact: Gordon W. Day, (303) 497-5204]

Schlager, J.B., Yamabayashi, Y., and Franzen, D.L., **Soliton-Like Compression of Pulses from Erbium-Fiber Lasers**, to be published in the Proceedings of the European Conference on Optical Communications, Gotenburg, Sweden, September 11-14, 1989.

Erbium-fiber lasers with cavity lengths of 5 to 5000 m are mode-locked at the fundamental cavity frequency. Pulse durations vary from 13 to 80 ps; shorter cavity lengths yield transform-limited

Electro-Optic Metrology (cont'd.)

pulses which can be soliton-compressed by further propagation in external fibers.
[Contact: John B. Schlager, (303) 497-3542]

Yamabayashi, Y., Schlager, J.B., and Franzen, D.L., **Single-Mode Short-Pulse Operation of Fabry-Perot Laser Diodes for Erbium Fiber Amplification.**

A mode-selection and wavelength tuning technique for pulsed, pigtailed Fabry-Perot laser diodes is demonstrated. A grating and fiber coupler is used to provide feedback to the diode through a delay fiber whose round-trip time is equal to an integral multiple of the pulse period. Single-mode, 80- to 300-ps pulses with a wavelength tuning range of 14 to 25 nm and repetition rates of 1 to 500 MHz are obtained using typical commercial Fabry-Perot laser diodes. This technique yields a convenient short pulse source that can be tuned to the center of the narrow 1536-nm gain transition of erbium-doped amplifiers; a small-signal gain of 21 dB and a peak power of 122 mW at 10 MHz are achieved with an erbium fiber amplifier pumped by an ion laser.
[Contact: Yoshiaki Yamabayashi, (303) 497-5952]

Electromagnetic Properties

Released for Publication

Baker-Jarvis, J., Vanzura, E.J., and Kissick, W.A., **An Improved Technique for Determining Complex Permittivity with the Transmission/Reflection Method.**

The transmission/reflection dielectric constant measurement procedure is examined for complex permeability and permittivity. The special case of permittivity measurement is examined in detail. A robust algorithm is presented for the transmission/reflection permittivity measurement technique which eliminates the divergent nature of the commonly-used procedures at frequencies corresponding to integer multiples of one-half wavelength in the sample. In light of the new solution procedure, an error analysis is presented which yields estimates for the errors incurred due to the uncertainty in scattering parameters, length measurement, and reference plane position. In addition, new equations are derived for determining the complex permittivity parameters which are independent of measurement reference planes and sample length.
[Contact: James R. Baker-Jarvis, (303) 497-5621]

Gans, W.L., Geyer, R.G., and Klemperer, W.K., **Suggested Methods and Standards for Testing and Verification of Electromagnetic Buried-Object Detectors**, to be published as an NISTIR.

This is an interim report to the sponsor on work performed by the National Institute of Standards and Technology personnel from January 1, 1985 to September 30, 1988. A brief overview of the theory of the electromagnetic properties of soils is presented, followed by an equally brief review of existing technologies for the detection of buried objects using electromagnetic methods. Suggested methods are then presented for realizing adequate target and soil standards and for testing procedures for buried-object detectors utilizing these standards. Suggested instrumentation methodologies for verifying (calibrating) the target and soil standards are also presented, along with an appendix containing reprints of selected relevant papers and an extensive bibliography.
[Contact: William L. Gans, (303) 497-3538]

Kremer, D.P., and Newell, A.C., **Absorber Characterization**, to be published in the Proceedings of the Eleventh Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Monterey, California, October 9-13, 1989.

Electromagnetic Properties (cont'd.)

When a laboratory considers replacing an old microwave absorber or a new installation, it needs a method that makes possible quick, inexpensive, and accurate measurements on individual absorber samples. Different types and sizes of absorber need to be quickly analyzed at multiple frequencies to determine which type best maintains or improves the facility's radio-frequency characteristics. In response to this need, the National Institute of Standards and Technology has devised an improved version of the Doppler-shift method to measure the scattering levels of different sizes and types of microwave absorber. This technique is useful as an inexpensive and simple method for measuring individual absorber pieces with good accuracy and sensitivity. The system described does not require a large anechoic facility or a sophisticated measurement system for minimizing the effects of background scattering. Using this method, reflectivity levels on the order of -80 dB can be measured and relative changes of 1 dB can be detected. Sample results for an absorber with and without fire retardant salts and different sizes are presented.
[Contact: Douglas P. Kremer, (303) 497-3732]

Recently Published

Vanzura, E.J., and Kissick, W.A., **Advances in NIST Dielectric Measurement Capability Using a Mode-Filtered Cylindrical Cavity**, Proceedings of the 1989 IEEE MTT-S Conference, Long Beach, California, June 13-15, 1989, Volume 1, pp. 901-904.

A 60-mm diameter cylindrical cavity resonator has been constructed for performing high-accuracy permittivity measurements on low-loss materials at microwave frequencies. The cavity's design and evaluation are described. Estimated errors in seven parameters result in approximately 0.2% uncertainty in permittivity and 6% uncertainty in loss tangent for a fused silica measurement.
[Contact: Eric J. Vanzura, (303) 497-5752]

Other Fast Signal Topics

Released for Publication

Goyal, I.C., Gallawa, R.L., and Ghatak, A.K., **An Approximate Solution to Second Order Linear Homogeneous Differential Equations.**

We give here an approximate method for solving an equation of the type $d^2\psi/dx^2 + k^2(x)\psi(X) = 0$. The method of derivation is reminiscent of the WKB methodology, but our solution, although approximate, is much more accurate than the traditional WKB solutions and can be used with almost as much ease. This new method is applicable to all problems where the WKB method has hitherto been used. Furthermore, these solutions are valid in regions where the WKB method fails. (WKB refers to the initials of three independent workers - Wentzel, Kramers, Brillouin - who first used the approximation procedure to solve the Schrodinger wave equation in one dimension.)
[Contact: Robert L. Gallawa, (303) 497-3761]

Young, M., **The Scratch Standard is Only a Cosmetic Standard**, to be published in the Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227), Surface Characterization and Testing II, San Diego, California, August 10-11, 1989.

In this paper, I present a history of the scratch-and-dig standard for optical surface quality and show that this standard has since its inception been recognized as a cosmetic standard and not as an objective or performance standard. In addition, I attempt to dispel the myth that the scratch standard was changed during the 1960s

Other Fast Signal Topics (cont'd.)

and show that scratch number cannot be related to scratch width. Finally, I describe a preliminary aging experiment that suggests that the scratch standards have not aged with time and are, in fact, extremely stable.
[Contact: Matt Young, (303) 497-3223]

Recently Published

Capobianco, T.E., Ciciora, S.J., and Moulder, J.C., **Standard Flaws for Eddy Current Probe Characterization**, Review of Progress in Quantitative Nondestructive Evaluation, Vol. 8A, D.O. Thompson and D.E. Chimenti, Eds. (Plenum Publishing Corp., New York, NY, 1989), pp. 985-989.

We report the development of a new technique for making artifact standards used in eddy current probe characterization measurements. The specimen is a slot in a rectangular plate of aluminum alloy, one centimeter or more thick. The slot is made by pressing a thin tool into the annealed aluminum plate. The tool is made from shim stock with the end formed to the desired shape, in this case a circular segment. The slot width is regulated by controlled compressive deformation of the block. The block is reannealed after yielding to remove the damage caused by the fabrication procedure. Preliminary eddy current measurements show that the phase of the eddy current signal is closer to that of an actual fatigue crack than a conventional saw cut or electric-discharge machined (EDM) notch. The phase of the eddy current response can be regulated by controlling the slot width during yielding of the specimen. The notch size appears to be easily reproducible. Results are presented for measurements made with both single-coil, absolute probes and uniform-field eddy current probes on fatigue cracks, EDM notches, and the new simulated flaws. This technique appears to offer the advantages of ease of manufacture, reproducible results, and eddy current signals more closely approximating those from true fatigue cracks.
[Contact: Thomas E. Capobianco, (303) 497-3141]

Capobianco, T.E., and Dulcie, L.L., **Characterization of Eddy Current Probes: Results of an Interlaboratory Intercomparison**, Proceedings of the 37th Defense Conference on Nondestructive Testing, Jacksonville, Florida, November 1-3, 1988, pp. 211-216.

NIST recently conducted a round robin involving potential users of a proposed new military standard. This draft standard attempts to establish a test method for characterizing eddy current probe performance. The three objectives of the study were: 1) to assess the ability of potential standard users to implement the specified test, 2) to introduce potential users to the technique, and 3) to expose any shortcomings in the test method documentation. The round robin involved eleven participants representing a spectrum covering military labs to repair depots. Preliminary results from this study were incorporated in the second draft of the standard as a result of meeting the second and third objectives. This paper concentrates on the fact that the round-robin results show that a significant problem exists with the test method implementation.
[Contact: Thomas E. Capobianco, (303) 497-3141]

Hill, D.A., **Clutter Models for Subsurface Electromagnetic Applications**, NISTIR 89-3909 (February 1989).

Clutter models for subsurface electromagnetic applications are discussed with emphasis on the detection of tunnels. Random medium models are more versatile and require less detailed information than deterministic models. The Born approximation is used to derive expressions for the incoherent field, and electric and magnetic dipoles are treated in detail. When random inhomogeneities are located in the near

Other Fast Signal Topics (cont'd.)

field of the dipole source, an electric dipole radiates a larger incoherent field than a magnetic dipole because of its larger reactive electric field.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., **Near-Field Detection of Buried Dielectric Objects**, IEEE Transactions on Geoscience and Remote Sensing, Vol. 27, No. 4, pp. 364-368 (July 1989).

The plane-wave, scattering-matrix method is used to compute the response of a detector to a buried dielectric scatterer. Specific numerical results are generated for a UHF dipole detector swept over a buried dielectric cube. The maximum response is obtained when the detector is located at the air-earth interface, and the response decays rapidly with detector height. The sweep curves are symmetrical in the horizontal direction and have a null for the detector directly over the object. An experimental curve for a free-space environment has the same qualitative features.
[Contact: David A. Hill, (303) 497-3472]

Vanzura, E.J., **Creating CSUBs Written in FORTRAN That Run in BASIC**, Proceedings of the 1988 Conference of HP Technical Computer Users, Orlando, Florida, August 7-12, 1988, Paper 20. [Also published as: **Creating CSUBs in BASIC**, HP Design and Automation Magazine, pp. 18-21 (October 1988) and p. 25 (November 1988).]

CSUBs are compiled subprograms created using the PASCAL operating system which run in the BASIC environment. A new technique is described in which programs written in FORTRAN can be turned into CSUBs. Thus, powerful, well-documented FORTRAN routines become accessible to the BASIC-language programmer. I/O and variable interfacing are discussed, and a comprehensive example is provided.
[Contact: Eric J. Vanzura, (303) 497-5752]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Misakian, M., and Kaune, Sr., W.T., **An Optimum Experimental Design for In Vitro Studies Using ELF Magnetic Fields**.

An experimental arrangement is described which maximizes the amount of dosimetric information that can be obtained during in-vitro studies with ELF (extremely-low-frequency) magnetic fields. The arrangement enables researchers to distinguish between a purely magnetic field effect and one that also involves the electric field and current density induced by the magnetic field.
[Contact: Martin Misakian, (301) 975-2426]

Olthoff, J.K., Van Brunt, R.J., Wang, Y., Doverspike, L.D., and Champion, R.L., **Collisional Electron-Detachment and Ion-Conversion Processes in SF_6**, to be published in the Proceedings of the Sixth International Swarm Seminar, Glen Cove, New York, August 2-5, 1989.

In this report we summarize results from the first direct measurements of absolute cross sections for electron-detachment and ion-conversion processes involving interactions of SF_6^-, SF_5^-, and F^- with SF_6. These cross sections are used to calculate electron-detachment and ion-conversion reaction coefficients as functions of electric field-to-gas density ratios (E/N) for various reactions. We then discuss the relevance of these results to the interpretation of data from uniform-field drift-tube measurements and measurements of electrical-discharge initiation processes.
[Contact: James K. Olthoff, (301) 975-2431]

Power Systems Metrology (cont'd.)

Pace, M.O., Wintenberg, A.L., Blalack, T.V., Kelley, E.F., FitzPatrick, G.J., Fenimore, C., and Yamashita, H., **Pressure Effects on Partial Discharges in Hexane Under DC Voltage**, to be published in the 1989 Annual Report, Conference on Electrical Insulation and Dielectric Phenomena, Leesburg, Virginia, October 29-November 1, 1989.

The pressure dependencies of the early partial discharges (PD) have been experimentally investigated at a needle in hexane from subatmospheric pressure (near hexane vapor pressure) to several atmospheres. Each PD is photographed in synchronism with a characteristic pattern of current pulses. An image-preserving optical delay allows photography to commence just before or at inception. Individual current pulses comprising a characteristic pattern are resolved.
[Contact: Gerald J. FitzPatrick, (301) 975-2737]

Van Brunt, R.J., **Research for Electric Energy Systems - An Annual Report**, to be published as NISTIR 89-4167.

This is a report of technical progress in four investigations conducted at the National Institute of Standards and Technology and supported by the U.S. Department of Energy under Task Order Number 137. The first investigation is concerned with the measurements of electric fields and ions in the vicinity of high-voltage transmission lines and biological exposure facilities. For this investigation, results are reported on evaluations of two methods for measuring ion mobilities at atmospheric pressure and an aspiratory-type ion counter for measuring monopolar charge densities in air. The second investigation is concerned with development of advanced diagnostics for compressed gas-insulated power systems. For this investigation, results are reported on measurements of collisional electron detachment and negative ion conversion reactions in SF_6 and on a new technique for measuring the stochastic behavior of partial discharges. The third investigation is concerned with measurement of prebreakdown phenomena at solid-liquid dielectric interfaces. Results are presented here from optical observations of the influence of hydrostatic pressure on prebreakdown partial discharge development and measurement of nanosecond impulse breakdown at liquid-solid interfaces. The fourth area of research is concerned with electrical measurement of fast transient phenomena. Results are presented from an investigation into the interactions between two dividers used simultaneously to measure fast impulse voltages.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Recently Published

Martzloff, F.D., **Lightning and Surge Protection of Photovoltaic Installations, Two Case Histories: Vulcano and Kythnos**, NISTIR 89-4113 (June 1989).

Two installations of photovoltaic power-supply systems were damaged during lightning storms. The two sites were visited and the damaged equipment that was still available on the site was examined for analysis of the suspected occurrence. The evidence, however, is insufficient to conclude that all the observed damage was caused by the direct effect of lightning. A possible scenario may be that lightning-induced overvoltages caused insulation breakdown at the edges of the photovoltaic modules, with subsequent damage done by the dc current of the array. Surge protection considerations are addressed, and suggestions presented for further investigations.
[Contact: Francois D. Martzloff, (301) 975-2409]

McKenny, P.J., Forster, E.O., Kelley, E.F., and Hebner, R.E., **Effect of Pressure on the Development of Pre-breakdown Streamers--Collapse** and

Power Systems Metrology (cont'd.)

Reversal, 1988 Annual Report, Conference on Electrical Insulation and Dielectric Phenomena, Ottawa, Canada, October 16-20, 1988, pp. 263-268.

The initiation of streamers in a liquid under the application of impulse voltages applied to a needle-sphere gap was investigated. A square pulse was applied having a peak voltage so that the streamer would not grow to breakdown before the pulse was chopped to zero. With the application of pressure, the initial streamer was observed to collapse and disappear while the voltage remained on the tip. When the voltage was chopped, a new streamer appeared which resembled the structure of the anode streamers, the branches of which did not strictly follow the previous branches of the cathode tree which injected the charge in the liquid. Using a simple model, approximately 11 nC is estimated to be injected into the liquid for a charge density of 49 $\mu C/cm^3$.
[Contact: Edward F. Kelley, (301) 975-5826]

Misakian, M., **AC Electric and Magnetic Field Measurement Fundamentals** [original title: AC Electric and Magnetic Field Meter Fundamentals], Proceedings of the Sixth International Symposium on High Voltage Engineering, New Orleans, Louisiana, August 28-September 1, 1989, Paper 40.01. [Also published in the Proceedings of the EPRI Utility Seminar on Power Frequency and Magnetic Field Exposure Assessment, Colorado Springs, Colorado, October 12-14, 1988, pp. 1-23.]

Questions raised in the early 1970s regarding possible adverse environmental effects due to high-voltage ac transmission line fields focused attention on the need for accurate measurements of the power-frequency electric and magnetic fields. Following a brief description of the fields near ac power lines, this paper surveys the instrumentation, calibration procedures, measurement techniques and standards that have been developed since the early 1970s to characterize the electric and magnetic fields near ac power lines.
[Contact: Martin Misakian, (301) 975-2426]

Misakian, M., Anderson, W.E., and Laug, O., **Drift Tubes for Characterizing Atmospheric Ion Mobility Spectra**, Proceedings of the Sixth International Symposium on High Voltage Engineering, New Orleans, Louisiana, August 28-September 1, 1989, Paper 44.01 (1989).

Two drift tubes constructed of insulating cylinders with conductive guard rings on the inside walls were examined to determine their suitability for measuring ion mobility spectra at atmospheric pressure. One drift tube is of the pulse time-of-flight (TOF) type with adjustable drift distance, and the other is an ac-TOF drift tube similar in principle to a device reported by Van de Graaff. The latter tube was evaluated using sinusoidal and alternating-polarity pulse-voltage waveforms for gating the shutters.
[Contact: Martin Misakian, (301) 975-2426]

Olthoff, J.K., Van Brunt, R.J., and Sauers, I., **Electron Energy Dependence of the S_2F_{10} Mass Spectrum**, Journal of Physics D: Applied Physics, Vol. 22, pp. 1399-1401 (1989).

The positive ion mass spectrum of S_2F_{10} has been measured as a function of electron-impact energy in the range 20 to 70 eV using a quadrupole mass spectrometer. Contrary to recent results reported by Farber and coworkers (1989) from mass spectrometric analysis of arc-decomposed SF_6, there was no evidence of $S_2F_9^+$ or $S_2F_{10}^+$ ion formation from S_2F_{10} at any energy. The largest ion observed at all electron energies is SF_5^+. It was found, however, that the appearance potentials for SF_5^+ and SF_3^+, the two most prominent ions from S_2F_{10}, are significantly lower than the

Power Systems Metrology (cont'd.)

appearance potentials of these same ions from SF_6. The differences between the mass spectra of S_2F_{10} and SF_6 are delineated, and the implications for detection of S_2F_{10} in the presence of SF_6 are discussed.
[Contact: James K. Olthoff, (301) 975-2431]

Olthoff, J.K., Van Brunt, R.J., Wang, Y., Champion, R.L., and Doverspike, L.D., **Collisional Electron Detachment and Decomposition Cross Sections for SF_6^-, SF_5^-, and F^- on SF_6 and Rare Gas Targets**, Journal of Chemical Physics, Vol. 91, No. 4, pp. 2254-2260 (15 August 1989).

Absolute cross sections for collisional electron detachment of SF_6^-, SF_5^-, and F^- on SF_6 and rare gas targets are presented for center-of-mass collision energies ranging from a few eV to several hundred eV. Onsets of collisional detachment cross sections are found to be higher than previously anticipated. Cross sections are also measured for collision-induced dissociation processes of SF_6^-, SF_5^-, and F^- in SF_6 and rare gases.
[Contact: James K. Olthoff, (301) 975-2431]

Olthoff, J.K., Van Brunt, R.J., Wang, Y., Champion, R.L., and Doverspike, L.D., **Collisional Electron Detachment and Decomposition Rates of SF_6^-, SF_5^-, and F^- in SF_6: Implications for Ion Transport and Electrical Discharges**, Journal of Chemical Physics, Vol. 91, No. 4, pp. 2261-2268 (15 August 1989).

Measured cross sections for prompt collisional detachment and decomposition of SF_6^-, SF_5^-, and F^- on SF_6 reported in a companion paper [See Olthoff, J.K., Van Brunt, R.J., Wang, Y., Champion, R.L., and Doverspike, L.D., **Collisional Electron Detachment and Decomposition Cross Sections for SF_6^-, SF_5^-, and F^- on SF_6 and Rare Gas Targets**] are used to calculate detachment coefficients and ion-conversion reaction coefficients as functions of electric field-to-gas density ratio for ion drift in SF_6. The calculated detachment coefficients indicate that prompt electron detachment from SF_6^- and SF_5^- in SF_6 are insignificant processes. Calculated rates for ion-conversion processes indicate the necessity to re-examine the previously measured rates in SF_6 from drift-tube experiments, and indicate the necessity of using ion kinetic energy distributions with larger high-energy tails than the standard distributions assumed in earlier calculations. The calculated detachment and reaction coefficients are used in a theoretical model which invokes detachment from long-lived energetically unstable states of collisionally excited SF_6^- to explain the pressure dependence of previously measured detachment coefficients and the high detachment thresholds implied by analysis of electrical breakdown-probability data for SF_6. Consistent with interpretation of results from earlier work, the model indicates that at high pressure, measured detachment coefficients depend primarily upon rates for ion-conversion and prompt collisional detachment from F^-.
[Contact: James K. Olthoff, (301) 975-2431]

Zhang, Y.X., McKnight, R.H., and Fenimore, C., **A Method for Fitting and Smoothing Digital Data**, Proceedings of the Sixth International Symposium on High Voltage Engineering, New Orleans, Louisiana, August 28-September 1, 1989, Paper 50.06 (1989).

A method has been developed and evaluated to fit and smooth digital data using cubic splines. Most high-voltage waveforms cannot be fit by a simple analytic expression. Therefore, piecewise fitting is needed. Calculation shows that the fitting algorithm is suitable for the full-lightning and chopped lightning waveforms and the step response. A criterion for selecting the principal free parameter in the fitting process is given with an example.

Power Systems Metrology (cont'd.)

[Contact: Charles Fenimore, (301) 975-2428]

Superconductors

Released for Publication

Collings, E.W., Marken, Jr., K.R., Sumption, M.D., Goldfarb, R.B., and Loughran, R.J., **AC Loss Measurements of Two Multifilamentary NbTi Composite Strands.**

As part of an interlaboratory comparative testing program conducted in support of the Versailles Agreement on Advanced Materials and Standards (VAMAS), transverse-field dc hysteresis loss measurements were made at liquid-helium temperatures at fields of up to 3 T (30 kG) on two samples of multifilamentary NbTi composite. The strands differed widely in filament number, were comparable in filament diameter, and one of them was provided with a Cu-Ni barrier between the filaments. The results have been analyzed, and magnetically deduced critical current density values obtained (for comparison with directly measured transport data) using various standard techniques. Based on these studies, a figure-of-merit for ac loss is recommended. The Cu-matrix strand, with its interfilamentary spacing of less than 1 μm, exhibited pronounced proximity-effect-induced coupling losses: this was not observed in the mixed-matrix strand which possessed not only a Cu-Ni barrier but also an interfilamentary spacing of typically 4 μm.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Goldfarb, R.B., and Spomer, R.L., **Magnetic Characteristics and Measurements of Filamentary Nb-Ti Wire for the Superconducting Super Collider.**

In synchrotron accelerator applications, such as the superconducting super collider (SSC), superconducting magnets are cycled in magnetic field. Desirable properties of the magnets include field uniformity, field stability with time, small residual field, and fairly small energy losses upon cycling. This paper discusses potential sources of problems in achieving these goals, describes important magnetic characteristics to be considered, and reviews measurement techniques for magnetic evaluation of candidate SSC wires. Instrumentation that might be practical for use in a wire-fabrication environment is described. We report on magnetic measurements of prototype SSC wires and cables and speculate on causes for instability in multipole fields of dipole magnets constructed with such cables.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Goodrich, L.F., and Bray, S.L., **Integrity Tests for High-T_c and Conventional Critical-Current Measurement Systems.**

Critical-current measurement systems must be extremely sensitive to the small differential voltage that is present across the test specimen as it transitions from the zero-resistance state to the flux-flow resistance state. Consequently, these measurement systems are also sensitive to interfering voltages, such as those arising from the presence of ground loops and common-mode signals. Specific methods for testing the sensitivity of critical-current measurement systems and for detecting the presence of interfering voltages are discussed. These include a simple procedure that simulates the zero-resistance state and a simple electronic circuit that simulates the flux-flow resistance state.
[Contact: Loren F. Goodrich, (303) 497-3143]

Goodrich, L.F., Bray, S.L., and Stauffer, T.C., **Thermal Contraction of Fiberglass-Epoxy Sample Holders Used for Nb_3Sn Critical-Current Measurements.**

Superconductors (cont'd.)

It is typical for Nb_3Sn superconductor specimens to be wound into coils on tubular specimen holders for critical-current measurements. If the thermal contraction of the holder is different from that of the specimen, axial strain may be applied to the specimen upon cooling from room to liquid-helium temperature. This strain can affect the measured critical current. The thermal contractions of several different specimen holders, all of which were made from fiberglass-epoxy composites, were measured. The measurements were made using an electrical-resistance strain-gage technique, and they were confirmed by direct mechanical measurements. The tubes varied in diameter, wall thickness, and fabrication technique. Some of the tubes were made directly from tube stock, while others were machined from plate stock. The results of these measurements show that the thermal contraction of tube stock depends on the ratio of its wall thickness to its radius, while the contraction of tubes machined from plate stock is relatively independent of these dimensions. Critical-current measurements of Nb_3Sn specimens mounted on these various holders show that the presence of differential thermal contraction between the specimen and its holder can affect the measured critical current.
[Contact: Loren F. Goodrich, (303) 497-3143]

Moreland, J., Li, Y., Ekin, J.W., and Goodrich, L.F., **Possible "Proximity Matrix" Route to High Current Conductors.**

The conductance of point contacts between the surfaces of superconducting $YBa_2Cu_3O_{7-\delta}$ thin films is very low. This is probably due to a native insulating surface layer. The conductance of these point contacts can be markedly increased by vacuum depositing and subsequently annealing a thin layer of Ag into the surface of the films. We believe that what might be described as a normal metal superconducting "proximity matrix" is formed at the surface of the Ag-coated $YBa_2Cu_3O_x$ films. In this paper, we describe our efforts to adapt this method to $YBa_2Cu_3O_x$ powder. In particular, we have developed a procedure for vacuum deposition of very thin Ag coatings onto the surface of $YBa_2Cu_3O_x$ powder grains. The Ag-treated powder is then pelletized, sintered, annealed, and cut to form small conducting bars for electrical transport testing.
[Contact: John Moreland, (303) 497-3641]

Roshko, A., Moodera, J.S., and Chiang, Y-M., **Field and Temperature Dependence of Transport J_c in $La_{1.85}Sr_{0.15}CuO_{4-y}$**, to be published in the Proceedings of the International Conference of Materials and Mechanisms of High Temperature Superconductivity (M2S-HTSC Conference), Stanford, California, July 23-28, 1989.

The transport critical-current density in polycrystalline $La_{1.85}Sr_{0.15}CuO_{4-y}$ samples, in which the microstructure has been well characterized and with densities greater than 95% of theoretical, has been measured in fields from 4×10^{-5} to 15 T, at temperatures varing from 13 K to just below T_c. The dependence of critical current on the temperature and magnetic field in zero and low fields, close to T_c, is consistent with superconductor-normal-superconductor behavior, as expected from analyses of grain boundary composition.
[Contact: Alexana Roshko, (303) 497-5420]

Recently Published

Chen, D-X., and Goldfarb, R.B., **Kim Model for Magnetization of Type-II Superconductors**, Journal of Applied Physics, Vol. 66, No. 6, pp. 2489-2500 (15 September 1989).

We have calculated the initial magnetization curves and complete hystere-

Superconductors (cont'd.)

sis loops for hard type-II superconductors. The critical-current density J_c is assumed to be a function of the internal magnetic field H_i according to Kim's model, $J_c(H_i) = k/(H_0 + |H_i|)$, where k and H_0 are constants. As is the case for other critical-state models, additional assumptions are that bulk supercurrent densities are equal to J_c, and that the lower critical field is zero. Our analytic solution is for an infinite orthorhombic specimen with finite rectangular cross section, 2a x 2b (a < b), in which a uniform field H is applied parallel to the infinite axis. Assuming equal flux penetration from the sides, we reduced the two-dimensional problem to a one-dimensional calculation. The calculated curves are functions of b/a, a dimensionless parameter $p = (2ka)^{1/2}/H_0$, and maximum applied field H_m. The field for full penetration is $H_p = H_0[(1 + p^2)^{1/2} - 1]$. A related parameter is $H_m^* = H_o[(1 + 2p^2)^{1/2} - '1]$. Hysteresis loops were calculated for the different ranges of H_m: $H_m < H_p$, $H_p < H_m < H_m^*$, and $H_m^* < H_m$. The equations for an infinite cylindrical specimen of radius a are the same as those for a specimen with square cross section, a = b. In the limit $p \ll 1$ and a = b, our results reduce to those of the Bean model (J_c independent of H_i) for cylindrical geometry. Similarly, in the limit $p \ll 1$ and $b \to \infty$, the results are the same as those for a slab in the Bean model. For $H > 1.5\ H_p$, or $H > 0$ when $p \ll 1$, the width of the hysteresis loop ΔM may be used to deduce J_c as a function of H: $J_c(H) = \Delta M(H)/[a(1-a/3b)]$.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Ekin, J.W., **Offset Criterion for Determining Superconductor Critical Current**, Applied Physics Letters, Vol. 55, No. 9, pp. 905-907 (28 August 1989).

Critical-current criteria based on electric field or resistivity can present a number of problems in defining critical current, especially for high-T_c superconductors in the vicinity of the critical temperature or upper critical field. The resulting critical-current density, J_c, can be quite arbitrary, since it depends strongly on criterion level at high fields and temperatures. These J_c definitions also create problems in distinguishing between superconductors and high-conductivity normal metals such as copper. They can also strongly bias J_c data when comparing superconductors with significantly different values of normal-state resistivity. To overcome these problems, a criterion is proposed based on the long-standing concept of a flux-flow resistivity. J_c is defined as the value on the current-density axis where an extrapolation of the tangent to the plotted curve of electric field (E) as a function of current density (J) at a point determined by a given electric-field level intersects the axis (extrapolation to zero electric field). This definition determines an offset J_c that has none of the above problems and, in addition, is independent of any flux creep voltages that may be present, since it depends entirely on the E-J characteristic in the high-current flux-flow regime. The offset J_c is shown to correspond physically to the average critical current of the critical-current distribution in the superconductor.
[Contact: Jack W. Ekin, (303) 497-5448]

Goodrich, L.F., and Bray, S.L., **Critical-Current Measurements of Nb_3Sn Superconductors: NBS Contribution to the VAMAS Round Robin,** Cryogenics, Vol. 29, pp. 699-709 (July 1989).

Critical-current measurements on several NB_3Sn superconductors were made. These were round-robin measurements (inter-laboratory comparison) made in conjunction with twenty-five laboratories from the European Economic Community, Japan, and the USA as part of the Versailles Agreement on Advanced Materials and Standards (VAMAS). The results of the

Superconductors (cont'd.)

NIST (formerly NBS) measurements, including the effect of sample mounting techniques on the measured critical current, are given. A systematic study of the effect of the measurement mandrel (tubular sample holder made from G-10 fiberglass-epoxy composite) geometry revealed that a seemingly small change in that geometry can result in a 40% change in the measured critical current at a magnetic field of 12 T. Specifically, the radial thermal contraction of the measurement mandrel depends on its wall thickness and, thus, so do the conductor prestrain (at 4 K) and, ultimately, the measured critical current. Techniques for reducing this and other measurement variables are suggested.
[Contact: Loren F. Goodrich, (303) 497-3143]

Magnetic Materials & Measurements

Released for Publication

Fickett, F.R., and Thompson, C.A., **Anomalous Magnetoresistance in Al/Al-Alloy Composite Conductors.**

The transverse magnetoresistance of several composite conductors containing a large single filament of pure aluminum in a matrix of AlFeCe has been measured at 4 K to fields of 10 T. The magnetoresistance ($\Delta R/R$) of the composite is very large, rising to 55 in the "worst" case. Previous measurements on polycrystalline pure aluminum have always shown a rapidly saturating behavior with a very small linear component: $\Delta R/R$ rarely exceeding a value of 5 to 6. In addition, the rotational behavior at 10 T shows a structure in the magnetoresistance measured on these square cross-section samples.
[Contact: Frederick R. Fickett, (303) 497-3785]

Goldberg, I.B., Mitchell, M.R., Murphy, A.R., Goldfarb, R.B., and Loughran, R.J., **Magnetic Susceptibility of Inconels 718, 625, and 600 at Cryogenic Temperatures.**

In June 1988, the Discovery Space Shuttle mission was delayed because of a malfunctioning hydrogen fuel bleed valve system. The problem was traced to the linear variable differential transformer (LVDT) which produced erroneous readings for the valve position. Near liquid-hydrogen temperatures, the inconel used in the armature of the LVDT became magnetic. The alternating current magnetic susceptibility of three samples of inconel 718, that differed slightly in composition, and one sample of inconel 625 were measured as a function of temperature. Inconel 718 behaves as a spin glass. Its susceptibility reaches a maximum between 15 and 19 K near the liquid hydrogen boiling point, 20 K. The magnitude of the susceptibility changed by an order of magnitude with decreases of 1.2% in iron and 1.5% in nickel. The nominal composition is 12 to 20% iron and 50 to 55% nickel. Inconel 625, which contains about 4% iron, was paramagnetic. The qualitative behavior of these materials follows trends indicated by Chauvenard (1928) and Jackson and Russell (1938).
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Thompson, C.A., and Fickett, F.R., **Magnetoresistance of Multifilament Al/Al-Alloy Conductors.**

Previously, we have shown that composite monofilament conductors consisting of very pure aluminum confined in an AlFeCe alloy sheath show an anomalously high magnetoresistance compared to pure aluminum. Some monofilament conductors showed values of $\Delta R/R$ (the change in resistivity divided by the intrinsic resistivity) in excess of 50 at 4 K in fields of 10 T, whereas pure aluminum values are usually an order of magnitude smaller. Concerns that similar anomalous behavior might occur in multifilament wires of the same materials prompted this study. Multifilamentary conductors with pure

Magnetic Matls. & Meas. (cont'd.)

aluminum filaments contained in an AlFeCe matrix have been investigated. [Contact: Curtis A. Thompson, (303) 497-5206]

ELECTROMAGNETIC INTERFERENCE

Radiated Electromagnetic Interference

Released for Publication

Crawford, M.L., and Ladbury, J.M., **Mode-Stirred Chamber for Measuring Shielding Effectiveness of Cables and Connectors: An Assessment of MIL-STD-1344A Method 3008.**

The mode-stirred method for measuring the shielding effectiveness (SE) of cables and connectors as specified in MIL-STD-1344A Method 3008 is examined. Problems encountered in applying the method are identified, and recommendations to improve the measurement results are provided. These include chamber design, type and placement of transmitting and reference receiving antenna, determination and correction for voltage standing-wave ratio of the reference antenna and equipment under test (EUT), and the measurement approach to use at specified test frequencies. Design and measurement setups for a small mode-stirred chamber suitable for performing SE measurements in the frequency range 1 to 18 GHz with dynamic ranges up to 130 dB are given along with SE measurement results of some sample EUTs. [Contact: Myron L. Crawford, (303) 497-5497]

Hill, D.A., **Magnetic Dipole Excitation of an Insulated Conductor of Finite Length.**

Excitation of currents on an insulated conductor of finite length with arbitrary terminations is studied for a magnetic dipole source. For matched terminations, the results agree closely with previous results for an infinitely long conductor, but other terminations produce end reflections that cause standing waves. Specific calculations are presented for a vertical magnetic dipole source because this source produces the appropriate horizontal electric field and could be used in a borehole-to-borehole configuration. Numerical results for the induced current and secondary magnetic field indicate that long conductors produce a strong anomaly over a broad frequency range for any type of termination. [Contact: David A. Hill, (303) 497-3472]

Hill, D.A., and Anderson, L.R., **Propagation Along a Two-Wire Line Located at the Air-Earth Interface.**

A simple quasi-static expression has been derived for the propagation constant of a two-wire transmission line located at the air-earth interface. A numerical solution of the mode equation shows that the quasi-static approximation is valid when the wire separation is much less than a free-space wavelength. The quasi-static approximation can be used to determine the complex dielectric constant of the earth from measurements of either the propagation constant or the characteristic impedance of the transmission line. [Contact: David A. Hill, (303) 497-3472]

Kanda, M., **A Microstrip Patch Antenna as a Standard Transmitting and Receiving Antenna**, to be published in the Digest, International Symposium on Electromagnetic Metrology (ISEM '89), Beijing, China, August 16-19, 1989.

This paper discusses the possibility of employing a microstrip patch antenna as a standard transmitting antenna. The intrinsic properties of the substrate used for the antenna are determined by careful impedance measurements. The experimental results indicate that the transmitting characteristics of a microstrip antenna can be theoretically determined from its geometry. The microstrip patch antenna discussed here

Radiated EMI (cont'd.)

is physically small (20-cm square for 450 MHz) and can be well matched to a power delivery system (standing-wave ratio = 1.17).
[Contact: Motohisa Kanda, (303) 497-5320]

Ma, M.T., **Electromagnetic Fields Radiated by Electrostatic Discharges**, to be published in the Digest, International Symposium on Electromagnetic Metrology (ISEM '89), Beijing, China, August 16-19, 1989.

Accurate estimation of the electromagnetic fields radiated by electrostatic discharges (ESD) is of importance to users of systems affected by these fields. Analytical and experimental results, based on a simple theoretical model and specific measurement system, are presented to provide such information. The ESD spark is modeled as an electrically short, time-dependent, linear dipole situated above an infinite ground plane. The measurement system consists of a newly developed broadband, time-domain horn antenna, a wideband digitizing oscilloscope, and a desktop computer.
[Contact: Mark T. Ma, (303) 497-3800]

Randa, J.P., and Kanda, M., **Standard Field Generation for Microwaves and Millimeter Waves**, to be published in the Proceedings of the 1989 Navy Metrology R&D Requirements Conference, Corona, California, April 4-6, 1989.

The requirements for electromagnetic field measurements at microwave and millimeter-wave frequencies in both the laboratory and the field are discussed. Current National Institute of Standards and Technology (NIST) capabilities and intended extensions are presented. The NIST anechoic-chamber facility can generate calibrated fields up to 18 GHz and will soon be extended to 40 GHz. Future extensions will be 2-GHz bands centered at 60 GHz and 95 GHz. Transfer-standard probes developed by NIST are available up to 18 GHz, and work is in progress to develop probes which would operate to 110 GHz. It is not clear whether these probes (if successfully developed) would be suitable for field use, as hazard meters, for example. For measurements in the field, electric-field probes which are claimed to operate to 40 GHz are available commercially. Small, transportable facilities for calibration of probes in the field are not readily available. This paper discusses the present situation in these areas, presents current NIST work to extend our relevant capabilities, and notes present and probable future deficiencies.
[Contact: James P. Randa, (303) 497-3150]

Recently Published

Crawford, M.L., **TEM Driven Reverberating Chamber Design Concept Study: A Single Facility for Large System Radiated EMC Testing, 10 kHz - 40 GHz**, Proceedings of the EMC EXPO 89 International Conference on Electromagnetic Compatibility, Washington, D.C., August 1-3, 1989, pp. B6.22-B6.29.

This paper describes work in progress at the National Institute of Standards and Technology to develop a single, integrated facility using a large shielded enclosure configured as a TEM (transverse electromagnetic) transmission line-driven reverberating chamber. TEM test fields are generated at frequencies below multimode cutoff, and mode-stirred test fields are generated at frequencies above multimode cutoff. The paper discusses a proposed design, advantages and limitations, the theoretical basis for the concept, and the proposed experimental approach for evaluating a 1/10 scale model of a large enclosure having a test volume of 8 m x 16 m x 30 m.
[Contact: Myron L. Crawford, (303) 497-5497]

Cruz, J.E., and Larsen, E.B., **Alternative Techniques for Some Typical MIL-**

Radiated EMI (cont'd.)

STD-461/462 **Types of Measurements**, NIST Technical Note 1320 (March 1989).

Most testing for MIL-STD-461/462 is performed in a shielded enclosure (screenroom) which leads to uncertainty in the measurement of emissions from electronic equipment, or the susceptibility of equipment to electromagnetic radiation. Possible alternative techniques for improved measurements in a screenroom have been developed by the National Institute of Standards and Technology. These techniques are covered in this report.

This report presents antenna factors determined in a screenroom which was partially loaded with radio-frequency absorbing material, using the two-antenna insertion-loss technique. These antenna factors are compared with the antenna factors obtained in an unloaded screenroom, a fully loaded screenroom (anechoic chamber), and at an open-field site. In addition, measurements at the eight corners of a cube were made in the partially loaded and fully loaded screenrooms to determine the field deviation at the eight corners of the cube with respect to its center. Also, measurement improvements are quantified for the electric-field strength beneath a single-wire transmission line, in a partially loaded screenroom. Finally, electric-field measurements were made on top of the grounded table in a partially loaded screenroom to determine the field strength variation above the table.
[Contact: Jose E. Cruz, (303) 497-3763]

FitzGerrell, R.G., **Monopole Impedance and Gain Measurements of Finite Ground Planes**, U.S. Department of Justice, Technology Assessment Program, NIJ Report 200-87 (May 1989).

The purpose of the work described in this report is to determine if it is possible to make acceptable accurate input impedance and gain measurements of monopoles on a reduced-size ground plane. Ideally, monopoles are measured with the antenna located on an infinite, perfectly conducting, ground plane. Practically, measurements are made on a test site with dimensions largely determined by the cost and availability of the space occupied by the site. Theoretical calculations show that the radius of a highly conducting ground plane should be at least 2 λ, where λ = wavelength, for measuring the input impedance of 0.25-λ monopoles. At 25 MHz, the lowest frequency considered here, such a ground plane would require a space at least 48 m (157 ft) in diameter. Model impedance measurements and calculations presented in this report imply that a space on the order of 10 by 11 m (33 by 36 ft) may be sufficient if the researcher uses 16 resistively-loaded wire radials to extend a 3.66 by 4.88 m (12 by 16 ft) solid metal ground plane. Measured insertion loss data acquired using a 1:5 scale model ground plane with resistively-loaded radials indicate that this area is sufficiently large for gain measurements as well. Measured and calculated monopole standing-wave ratio and insertion loss on a full-scale ground plane verify the results of the model measurements.
[Contact: Richard G. FitzGerrell, (303) 497-3737]

Hill, D.A., **Electromagnetic Detection of Long Conductors in Tunnels**, Proceedings of the Third Technical Symposium on Tunnel Detections, Golden, Colorado, January 12-15, 1988, pp. 518-537.

Formulations for the excitation of currents on an infinitely long conductor by electric or magnetic dipoles of arbitrary orientation are presented. The conductor can be either insulated or bare to model ungrounded or grounded conductors. Specific calculations are presented for a vertical magnetic dipole source because this source produces the appropriate horizontal polarization and could be used in a borehole-to-borehole configuration. Numerical results for the induced current and secondary

Radiated EMI (cont'd.)

magnetic field indicate that long conductors produce a strong anomaly over a broad frequency range. The secondary magnetic field decays slowly in the direction of the conductor and eventually becomes larger than the dipole source field.
[Contact: David A. Hill, (303) 497-3472]

Koepke, G.H., Ma, M.T., and Bensema, W.D., **Implementation of an Automated System for Measuring Radiated Emissions Using a TEM Cell**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 473-479 (April 1989).

The transverse electromagnetic (TEM) cell is widely used to evaluate the electromagnetic characteristics of electrically small devices. This paper reviews the theoretical basis for a technique to quantify the radiated emissions from any such device in the cell. The technique is well suited to an automated test system provided that the mechanical motions required can be controlled by a computer. The difficulties associated with these mechanical motions are discussed and possible solutions are proposed. The measurement technique is also expanded to include multiple-frequency sources in addition to single-frequency sources.
[Contact: Galen H. Koepke, (303) 497-5766]

Koepke, G.H., Ma, M.T., and Bensema, W.D., **Theory and Measurements of Radiated Emissions Using a TEM Cell**, NIST Technical Note 1326 (January 1989).

The transverse electromagnetic (TEM) cell is widely used to evaluate the electromagnetic characteristics of electrically small devices. This paper reviews the theoretical basis for a technique to quantify the radiated emissions from any such device in the cell. The technique is well suited to an automated test system provided that the mechanical motions required can be controlled by a computer. The difficulties associated with these mechanical motions are discussed, and possible solutions are proposed. The measurement technique is also expanded to include multiple-frequency sources in addition to single-frequency sources.
[Contact: Galen H. Koepke, (303) 497-5766]

Larsen, E.B., Ehret, R.L., Camell, D.G., and Koepke, G.H., **Calibration of Antenna Factor at a Ground Screen Field Site Using an Automatic Network Analyzer**, Proceedings of the IEEE 1989 National Symposium on Electromagnetic Compatibility, Denver, Colorado, May 23-25, 1989, pp. 19-24.

The technique now employed at the National Institute of Standards and Technology for calibrating antenna factor at frequencies from 25 to 1000 MHz uses a standard "open-circuit" half-wave receiving dipole to measure the electric field strength. Unfortunately, the dipole responds to ambient fields over a large frequency range. This approach is compared with a three-antenna method which uses an accurate automatic network analyzer with 120-dB dynamic range to measure insertion loss between the transmitting and receiving antennas. A field site having a 30 m x 60 m ground screen which acts as a good reflector is used. Thus, the effects of ground reflection can be calculated and compensated for. The new insertion loss technique permits faster measurements with greater repeatability and reduction in calibration uncertainty, especially at frequencies above 75 MHz.
[Contact: Ezra B. Larsen, (303) 497-3540]

Ma, M.T., **How High is the Level of Electromagnetic Fields Radiated by an ESD?**, Proceedings of the 8th International Zurich Symposium and Technical Exhibition on Electromagnetic Compatibility, Zurich, Switzerland, March 7-9, 1989, pp. 361-365.

Radiated EMI (cont'd.)

Quantitative estimation of the electromagnetic fields radiated by electrostatic discharges (ESD) is of importance to the users and to the computer industry. Analytical and experimental results, based on a new theoretical model and specific measurement system, are presented.
[Contact: Mark T. Ma, (303) 497-3800]

Masterson, K.D., and Driver, L.D., **A Broadband, Isotropic, Photonic Electric-Field Meter for Measurements from 10 kHz to Above 1 GHz**, Proceedings of SPIE (The International Society for Optical Engineers, P.O. Box 10, Bellingham, Washington 98227), High Bandwidth Analog Application of Photonics II, Vol. 987, pp. 107-118 (1989).

An isotropic, photonic electric-field meter (PEFM-15) having 15-cm resistively tapered dipole sensing elements and Pockels-effect electro-optic modulators is used to measure electromagnetic fields of 10 to 100 V/m from 10 kHz to beyond 1 GHz. The probe's frequency response is flat to within ±3 dB from 30 kHz to 100 MHz except for a region between 1 and 10 MHz where acoustic resonances occur in the $LiNbO_3$ modulator crystals. Using a 3-kHz detection bandwidth, the noise equivalent field is approximately 7 V/m, thereby giving a calculated linear dynamic range of 68 dB in field power density. The isotropic response is flat to within ±2 dB, and each individual dipole follows the theoretically predicted angular response. An optical beam switch that connects the individual dipoles to a laser source and optical receiver is also described.
[Contact: Keith D. Masterson, (303) 497-3756]

Masterson, K.D., Driver, L.D., and Kanda, M., **Photonic Probes for the Measurement of Electromagnetic Fields Over Broad Bandwidths**, Proceedings of the IEEE 1989 National Symposium on Electromagnetic Compatibility, Denver, Colorado, May 23-25, 1989, pp. 1-6.

The characteristics of photonic systems which make them especially well suited for use as broadband electromagnetic field sensors are discussed. Transfer functions are given for the individual components of such a measurement system, with special emphasis given to those of Pockels-cell and modified-directional-coupler optical modulators. An isotropic electric-field meter having 15-cm resistively tapered dipole elements combined with bulk crystal, Pockels-cell modulators is described. The meter's frequency response is flat between 30 kHz and 100 MHz, except for resonances in the modulator crystals that occur between 1 and 10 MHz. For a 3-kHz detection bandwidth, the noise floor is equivalent to a field of about 7 V/m, and the calculated linear dynamic range is 70 dB in electromagnetic-field power density. The response is within ±2 dB of the ideal isotropic response. A photonic probe that uses a modified directional-coupler modulator is also briefly described.
[Contact: Keith D. Masterson, (303) 497-3756]

Randa, J.P., Kanda, M., Melquist, D.G., and Orr, R.D., **Thermo-Optic Designs for Microwave and Millimeter-Wave Electric-Field Probes**, Proceedings of the IEEE 1989 National Symposium on Electromagnetic Compatibility, Denver, Colorado, May 23-25, 1989, pp. 7-11.

We have considered various thermo-optic designs for electric-field probes for the approximate frequency range of 1 to 110 GHz. The designs are all based on using an optically sensed thermometer to measure the temperature rise of a resistive material in an electric field. This paper presents calculations of the sensitivities of the different designs, measurement results for the most easily fabricated design, and a discussion of possible improvements. Our results indicate that a probe based on this design could detect a minimum electric

Radiated EMI (cont'd.)

field of about 30 to 50 V/m.
[Contact: James P. Randa, (303) 497-3150]

Wu, D.I., and Chang, D.C., **The Effect of an Electrically Large Stirrer in a Mode-Stirred Chamber**, IEEE Transactions on Electromagnetic Compatibility, Vol. 31, No. 2, pp. 164-169 (May 1989). [A more comprehensive discussion has been published as NBS Technical Note 1317 (March 1988).]

In a mode-stirred chamber, the field in the cavity is perturbed with a stirrer or rotating scatterer so that the time-averaged field is constant. In this paper, we investigate the key factor that governs the effectiveness of a stirrer. By examining the fundamental properties associated with a perturbing body in a cavity, we find that the key to effective field perturbation lies in shifting the eigenmode frequencies. We illustrate this phenomenon by examining a 2-D cavity with a 1-D perturbing body. Using the transmission-line-matrix method, we compute the shifting of eigenfrequencies and examine the variation on the magnitude of the fields for different stirrer sizes. From this analysis, we draw useful insights that include an analogy between the action of a large stirrer and a frequency modulator.
[Contact: Motohisa Kanda, (303) 497-5320]

Wu, D.I., and Chang, D.C., **A Hybrid Representation of the Green's Function in an Over-Moded Rectangular Cavity**, IEEE Transactions on Microwave Theory and Techniques, Vol. 36, No. 9, pp. 1334-1342 (September 1988).

A hybrid ray-mode representation for the Green's function in a rectangular cavity is developed using the finite Poisson summation formula. In order to obtain a numerically efficient scheme for computing the field generated by a point source in a large rectangular cavity, the conventional modal representation of the Green's function is modified in such a way that all the modes near resonance are retained, while the truncated remainder of the mode series is expressed in terms of a weighted contribution of rays. For a large cavity, the contribution of rays from far-away images becomes small; therefore, the ray sum can be approximated by one or two dominant terms without a loss of numerical accuracy. To illustrate the accuracy and the computational simplification of this ray-mode representation, numerical examples are included with conventional mode series (summed at the expense of long computation time) serving as a reference.
[Contact: Motohisa Kanda, (303) 497-5320]

ADDITIONAL INFORMATION

Lists of Publications

Lyons, R.M., and Gibson, K.A., **A Bibliography of the NIST Electromagnetic Fields Division Publications**, NISTIR 89-3920 (September 1989).

This bibliography lists publications by the staff of the National Institute of Standards and Technology's Electromagnetic Fields Division for the period from January 1970 through August 1989. Selected earlier publications from the Division's predecessor organizations are included.
[Contact: Kathryn A. Gibson, (303) 497-3132]

DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NIST Publications**, NISTIR 89-3921 (August 1989).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NIST in the period from January 1970 through publication of this report. A few earlier references that are directly related to the present work of the

Additional Information (cont'd.)

Division are included.
[Contact: Sarabeth Moynihan, (303) 497-3678]

Palla, J.C., and Meiselman, B., **Electrical and Electronic Metrology: A Bibliography of NIST Electricity Division's Publications, NIST List of Publications 94** (January 1990).

This bibliography covers publications of the Electricity Division, Center for Electronics and Electrical Engineering, NIST, and of its predecessor sections for the period January 1968 to December 1989. A brief description of the Division's technical program is given in the introduction.
[Contact: Jenny C. Palla, (301) 975-2220]

Walters, E.J., **Semiconductor Measurement Technology, NBS List of Publications 72** [a bibliography of NBS publications concerning semiconductor measurement technology for the years 1962-1988] (March 1989).

This bibliography contains reports of work performed at the National Institute of Standards and Technology in the field of Semiconductor Measurement Technology in the period from 1962 through December 1988. An index by topic area and a list of authors are provided.
[Contact: E. Jane Walters, (301) 975-2050]

NEW CALIBRATION SERVICES OFFERED

The explosive growth of optical fiber use in the communications industry has resulted in a demand for calibration services. NIST's Boulder, Colorado, laboratory now offers **measurements of optical laser power and energy at wavelengths and power levels of interest to fiber optic producers and users.** Measurements are based on a standard reference instrument called the C-series calorimeter. An electrically calibrated pyroelectric radiometer (ECPR) is calibrated against the calorimeter and is then used to calibrate optical power meters at wavelengths of 850, 1300, and 1550 nm. To improve calibration capabilities, NIST is preparing test measurement systems for detector linearity, detector uniformity, and detector spectral responsivity. These systems should be available in 6 months. For a paper outlining NIST's optical power measurement capabilities, contact Fred McGehan, Div. 360, NIST, 325 Broadway, Boulder, Colorado 80303. For more information on calibration services, contact Thomas R. Scott, Div. 724, same address, or phone (303) 497-3651.

NEW NIST RESEARCH MATERIAL

NIST has announced the availability of **Research Material 8458**, a well-characterized artificial flaw used as an **artifact standard in eddy current nondestructive evaluation (NDE).** The new Research Material (RM) is the outcome of work carried out by the Division to address the need for calibration standards for eddy-current NDE, for example, as used to detect fatigue cracks in aircraft structures. The RM flaw is produced in an annealed aluminum alloy block by first indenting the block and then compressively deforming the resulting notch until it is tightly closed. The next operation is to restore a flat finish to the block face, after which the block is heat treated to the original temper. The controlled flaw has been named the "CDF notch," after its inventors (listed on patent application) Thomas E. Capobianco (Electromagnetic Technology Division), William P. Dube (Division 583), and Ken Fizer (Naval Aviation Depot, NAS Norfolk, Virginia).

In the past, the challenge has been to manufacture artificial flaws that closely simulate the mechanical properties of fatigue cracks. Currently used artifacts include electrical-discharge-machined and saw-cut notches, both of which are relatively poor

New NIST Research Material (cont'd.)

representations of fatigue cracks as their widths are too great. The Division-developed method provides notches that can be made controllably in a variety of geometries, have known dimensions, with widths that are narrow enough to provide an acceptable representation of fatigue cracks.

An NIST Research Material is not certified by NIST, but meets the International Standards Organization definition of "a material or substance one or more properties of which are sufficiently well established to be used in the calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials." The documentation issued with RM 8458 is a "Report of Investigation." Contact: technical information -- Fred Fickett, (303) 497-3785; order information-- Office of Standard Reference Materials, (301) 975-6776.

JAN. 1, 1990 CHANGES IN THE U.S. ELECTRICAL UNITS

Effective January 1, 1990, the U.S. as-maintained (i.e., "practical") units of voltage and resistance were increased by 9.264 ppm and 1.69 ppm, respectively. The increases in the U.S. legal units of current and of electrical power will be about 7.57 ppm and 16.84 ppm, respectively. These changes result from efforts by the major national standardizing laboratories, including the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards (NBS), to re-evaluate their as-maintained units in terms of the International System of Units (SI). The consequence of this activity has been the introduction of standards representing the SI units of voltage and resistance by the International Committee of Weights and Measures, an international body created by the Treaty of the Meter.[1] The use of these standards world-wide beginning January 1, 1990, will result in international consistency of electrical measurement as well as coherence among the practical units of length, mass, electricity, time, etc., inherent in the definitions of the SI.

Implementation of Changes at NIST

These changes have been instituted in the U.S. by NIST using the new, internationally-adopted constants K_{J-90} = 483597.9 GHz/V exactly and R_{K-90} = 25812.807 Ω exactly with the Josephson and quantum Hall effects to establish representations of the SI volt and ohm, respectively. The representation of the SI volt is attained by using K_{J-90} in the formula

$$U_J(n) = \frac{f}{K_J} \qquad n = 1,2,3,...$$

to give the voltages $U_J(n)$ of the steps produced by the ac Josephson effect at a frequency f. The past value, K_{J-72}, was 483593.42 GHz/V(NBS-72), thus leading to the 9.264 ppm change. Likewise, R_{K-90} is used in the following formula for the resistance of the i^{th} plateau of a quantum Hall effect device,

$$R_H(i) = \frac{R_K}{i} \qquad (R_K = R_H(1))$$

to realize a representation of the SI ohm. The most recent past national unit of resistance, $\Omega(\text{NBS-48})_t$, was based on a group of five Thomas one-ohm standards and had an uncompensated drift rate of approximately -0.053 ppm per year. Since the quantum Hall effect is used as the national standard, the U.S. representation of the ohm has no drift. (The past unit of voltage, V(NBS-72),

[1] **Note that the SI Units have not been redefined; rather, they have been realized more accurately and a quantum physics representation of the ohm has been introduced, thus leading to the changes in magnitude of the practical or as-maintained units.**

Changes in U.S. Elec. Units (cont'd.)

was based on the Josephson effect since 1972, and accordingly had a zero drift rate.)

Reassignments to Non-adjustable Standards

Since the U.S. practical volt and ohm units increased on January 1, 1990, the changes must be implemented in non-adjustable standards calibrated in terms of V(NBS-72) and/or Ω(NBS-48) only by **reducing** the values assigned to them proportionally. The examples given below show how to do this for a standard cell and a standard resistor.

Sample Adjustments of Values of Standards

Standard cell:

"Old" emf 1.0180564 V(NBS-72)

Multiply "Old" emf by 0.999990736 to get emf in terms of the present volt representation 1.01804697 ≈ 1.0180470 V

Standard resistor:

"Old" resistance value
9999.976 $\Omega(\text{NBS-48})_{01/01/90}$

Multiply "Old" resistance by 0.99999831 to get the resistance in terms of the present ohm representation
9999.9591 ≈ 9999.959 Ω

In the above, "Old" refers to the value of the standard which would have been in use on January 1, 1990, had the changes not been made; i.e., if a correction curve based on its past assigned values has been employed to obtain the currently-used value for a standard, the above represents a downward shift of the curve starting January 1, 1990. For resistance, the slope of the curve also changed (slightly) since Ω(NBS-48) has a drift rate and Ω(NIST-90) does not.

Do not send your standrds to NIST for special recalibration solely because of these changes in the U.S. electrical units. The changes are accurately known and corrections to existing standards may be applied.

Adjustment of Instrumentation

An assigned or calibrated value of a standard is merely a label giving the magnitude of the parameter embodied in the standard. The actual emf or resistance of a standard did not change on January 1, 1990; only what it is called should have changed. In the same sense, meter readings are labels giving the magnitudes of the parameters being measured. **Readings taken after January 1, 1990 using unadjusted meters will be too large in magnitude.** Adjustments to meters must have the effect of reducing the amplitudes of readings for fixed emf's or resistances.

Adjustable voltage and current sources or adjustable resistors for which nominal output is desired, on the other hand, must have their outputs **increased** proportionally by the above amounts. DVM calibrators are probably the largest class of this type of instrument.

Guidelines

The National Conference of Standards Laboratories (NCSL) and NIST have formed NCSL ad hoc Committee 91.4, Changes in the Volt and Ohm, to assist industry and government laboratories in coming into compliance with the changes. A major responsibility of the committee is the generation and publication of a set of guidelines which describes unambiguous methods for adjusting standards and instruments, or their values, and delineates other types of problems which may arise, e.g., voltage values called out explicitly in maintenance procedures, values imbedded in software, and the like. These guidelines have been published as NIST Technical Note 1263, "Guidelines for Implementing the New Representations of the Volt and Ohm Effective January 1, 1990." This

Changes in U.S. Elec. Units (cont'd.)

document is available at no charge through the NIST Electricity Division. To receive a copy, contact Sharon Fromm at 301-975-4222.

For further information, contact Norman B. Belecki (301-975-4223), Ronald F. Dziuba (301-975-4239), Bruce F. Field (301-975-4230) or Barry N. Taylor (301-975-4220).

1990 CEEE CALENDAR

February 6-8, 1990 (Phoenix, AZ)

IEEE Semiconductor Thermal and Temperature Measurements Symposium. This sixth annual **SEMI-THERM** symposium is sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE in cooperation with NIST and constitutes an international forum for the presentation of new developments relating to generation and removal of heat within semiconductor devices, measurement of device temperatures, and the simulation of device and system thermal behavior. Major SEMI-THERM topic areas include thermal measurements; thermal characterization; applications; and simulation, computation, and software.

The program includes keynote speakers, technical presentations, tutorial sessions, workshops, and an exhibit. In addition, the Semiconductor Equipment and Materials Institute (SEMI) and the Joint Electron Devices Engineering Council (JEDEC) have scheduled in conjunction with SEMI-THERM several Standards Committee Task Force meetings, to which attendees are invited.
[Contact: David L. Blackburn, (301) 975-2068]

September 17-19, 1990 (Boston, MA)

VLSI and GaAs Chip Packaging Workshop. The IEEE CHMT Society and the National Institute of Standards and Technology are co-sponsoring the Ninth VLSI packaging Workshop. Topics to be discussed include VLSI package design; multichip module design; WSI packaging; package thermal design; package electrical design; GaAs IC packaging; VLSI package interconnection options; VLSI package materials and die-attach solutions; and failure mechanism and quality of VLSI packages. All attendees are expected to be specialists working in the field and to participate in discussions.
[Contact: George G. Harman, (301) 975-2097]

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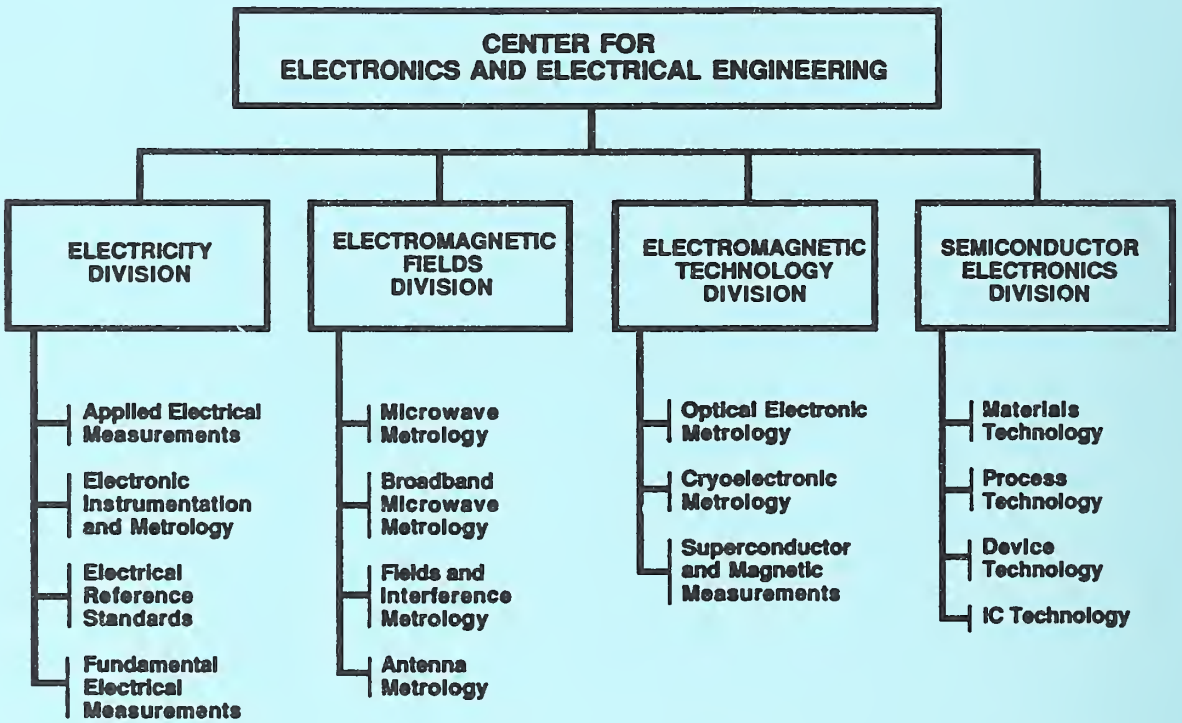

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