NISTIR 90-4296

## Center for Electronics and Electrical Engineering

# Technical Publication Announcements

Covering Center Programs,
July to September 1989,
with 1990 CEEE Events Calendar

22

April 1990

U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
National Engineering Laboratory
Gaithersburg, Maryland 20899

# INTRODUCTION TO THE CEEE TECHNICAL PUBLICATION ANNOUNCEMENTS

This is the twenty-second 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 Publication Announcements covers the third quarter of calendar year 1989.

Organization of Bulletin: This issue contains citations and abstracts for Center publications published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author within each topic. 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.

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 22.

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 18.

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## SEMICONDUCTOR TECHNOLOGY PROGRAM

### Silicon Materials

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 x $10^6$ 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 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]

### Dimensional Metrology

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

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

Analysis Techniques (cont'd.)

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 $6.28 \pm 0.18$ 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

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

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 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

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 $\mu$m. 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-$\mu$m 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 $\mu$m with mobilities nearly as high as 1-$\mu$m films, if the film growth rate was higher than 4 $\mu$m/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

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 (cont'd.)

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]

**SIGNALS & SYSTEMS METROLOGY PROGRAM**

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

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

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 constitute 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).

DC & Low Frequency Metrology (cont'd.)

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]

Antenna Metrology

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. 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

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 Metrology (cont'd.)

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

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).

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

Microwave & Millimeter-Wave (cont'd.)

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 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

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.

Optical Fiber Metrology (cont'd.)

[Contact: Douglas L. Franzen, (303) 497-3346/-5342]

Electromagnetic Properties

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

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

Other Fast Signal Topics (cont'd.)

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 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

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**

Power Systems Metrology (cont'd.)

**Pressure on the Development of Pre-breakdown Streamers--Collapse and 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 $SF_3^+$,

Power Systems Metrology (cont'd.)

the two most prominent ions from $S_2F_{10}$, are significantly lower than the 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

Power Systems Metrology (cont'd.)

principal free parameter in the fitting process is given with an example.
[Contact: Charles Fenimore, (301) 975-2428]

Superconductors

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 hysteresis 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 $\Delta M$ 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]

Superconductors (cont'd.)

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 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]

ELECTROMAGNETIC INTERFERENCE

Radiated Electromagnetic Interference

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-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

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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 $\lambda$, where $\lambda$ = wavelength, for measuring the input impedance of 0.25-$\lambda$ 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 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

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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.

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

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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 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

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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 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 1962-1989] (March 1990).

This bibliography contains reports of work performed at the National Institute of Standards and Technology in the field of Semiconductor Measurement Technology

Additional Information (cont'd.)

in the period from 1962 through December 1989. 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 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.

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

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

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

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 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), 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

[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.)

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
$9999.9591 \approx 9999.959\ \Omega$

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 standards 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 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**

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

1990 CEEE Calendar (cont'd.)

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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NIST-114A
(REV. 3-89)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

# BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NUMBER
NISTIR 90-4296

2. PERFORMING ORGANIZATION REPORT NUMBER

3. PUBLICATION DATE
APRIL 90-4296

4. TITLE AND SUBTITLE
Center for Electronics and Electrical Engineering Technical Publication Announcements Covering Center Programs, July to September 1989, with 1990 CEEE Events Calendar

5. AUTHOR(S)
E. J. Walters, compiler

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)
U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899

7. CONTRACT/GRANT NUMBER

8. TYPE OF REPORT AND PERIOD COVERED
July-September 1989

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)
U.S. Department of Commerce
National Institute of Standards and Technology
National Engineering Laboratory
Center for Electronics and Electrical Engineering

10. SUPPLEMENTARY NOTES

[ ] DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This is the twenty-second 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 Center for Electronics and Electrical Engineering Technical Publication Announcements covers the third quarter of calendar year 1989. Abstracts are provided by technical area for papers published this quarter.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)
antennas; electrical engineering; electrical power; electromagnetic interference; electronics; instrumentation; laser; magnetics; microwave; optical fibers; semiconductors; superconductors

13. AVAILABILITY

[X] UNLIMITED

[ ] FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS).

[ ] ORDER FROM SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, DC 20402.

[X] ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.

14. NUMBER OF PRINTED PAGES
26

15. PRICE
A03

ELECTRONIC FORM

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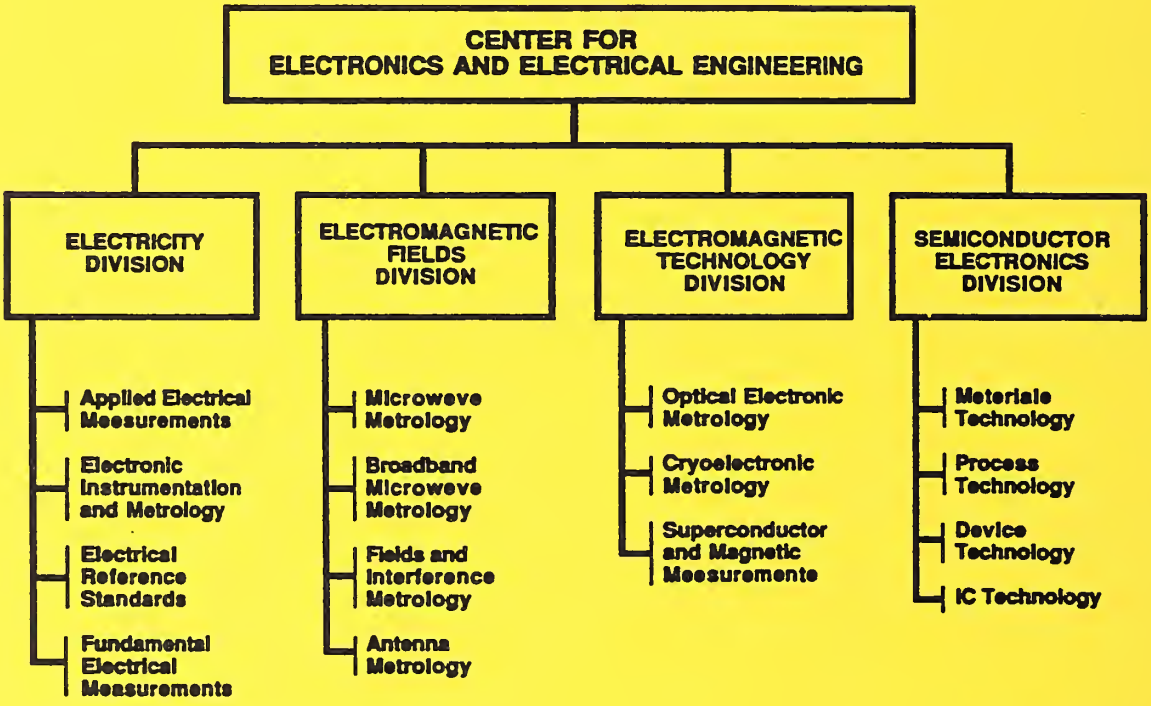


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