Center for Electronics and Electrical Engineering

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INTRODUCTION TO OCTOBER 1987 ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the nineteenth issue of a quarterly publication providing information on the technical work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the second quarter of calendar year 1987.

Organization of Bulletin: This issue contains abstracts for all Center papers released for publication by NBS 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 Unpublished papers appear under the subheading "Released for Publication".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 1987, some preliminary announcements for calendar year 1988, 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 Electrosystems 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 Bureau of Standards, Metrology Building, Room B-358, Gaithersburg, MD 20899 or call (301) 975-2220.

Center sponsors: The Center Programs are sponsored by the National Bureau of Standards and a number of other organizations, in both the Federal and private sectors; these are identified on page 39.

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 36.

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SEMICONDUCTOR TECHNOLOGY

Silicon Materials

Released for Publication

Robertson, P.J., Dumin, D.J., Carver, G.P., and Novotny, D.B., **Examination of Epitaxial Silicon Quality Versus Silicon Thickness on Boron Phosphide Layers**, to be published in the Proceedings of the 1987 Spring Meeting of the Materials Research Society, Anaheim, California, April 21-25, 1987.

It has been shown that (100) boron phosphide can be grown on (100) silicon substrates and that device quality silicon can be grown on the BP layer. Si-BP-Si structures have been proposed as candidates for three-dimensional integration and novel SOI structures. High resistivity ($=10^6$ Ω-cm) BP has been grown on silicon substrates without heat treatments. Results are reported for a single-temperature Si-BP-Si process which utilizes 0.2 and 0.4 μm of high resistivity BP and a single 1- to 5-μm silicon epitaxial layer on which p-channel MOS devices were manufactured. Threshold voltage, subthreshold slope, subthreshold current, effective linear and saturation surface mobilities, surface doping concentration, and drain-to-source reverse breakdown voltage data are presented to characterize the epitaxial films. Electron channeling patterns are presented to show high-quality silicon crystal growth on all BP layers. The 1- and 2-μm silicon layers were doped as high as 3×10^{17} cm^{-3}, and devices manufactured on these layers did not work properly. Device characteristics improved on thicker silicon layers. Linear and saturation mobilities remained virtually unchanged with 5-μm values as high as 250 and 160 cm^2/V-s, respectively. These values were lower than bulk silicon mobilities at the same doping concentrations. Reverse breakdown voltage was shown to be a function of silicon thickness reaching a maximum of 35 V on the 5-μm silicon layer. The subthreshold slope had an average value of 90 mV/dec. The subthreshold current decreased with increasing silicon thickness to a minimum of 10^{-11} A on the 5-μm silicon layers which was comparable to bulk silicon results.
[Contact: Gary P. Carver, (301) 975-2091]

Recently Published

Hyland, S.L., Ast, P.G., and Baghdadi, A., **Oxygen Measurements in Thin Ribbon Silicon**, Journal of Crystal Growth (Proceedings of the First International Symposium on Shaped Crystal Growth, Budapest, Hungary, July 22-25, 1986), Vol. 82, Nos. (1/2), pp. 191-196 (North Holland, Amsterdam, 1987).

The oxygen content of thin silicon ribbons grown by the dendritic web technique was measured using a modification of the ASTM method based on Fourier transform infrared spectroscopy. Web silicon was found to have a high oxygen content, ranging from 13 to 19 ppma, calculated using the new ASTM conversion coefficient. The oxygen concentration changed by about 10% along the growth direction of the ribbon. In some samples, a shoulder was detected on the absorption peak associated with interstitial oxygen. A similar shoulder in Czochralski-grown material has been variously interpreted in the literature as due to a complex of silicon, oxygen, and vacancies, or to a phase of SiO_2 developed along dislocations in the material. In the case of web silicon, it is not clear which is the correct interpretation of this peak.
[Contact: Aslan Baghdadi, (301) 975-2062]

Mayo, S., and Lowney, J.R., **Photoionization Cross-Section Studies of the Platinum-Donor Center in Silicon**, Journal of Applied Physics, Vol. 61, No. 7, pp. 2626-2632 (1 April 1987).

The relative photoionization cross section of the platinum donor center in silicon was measured over the wavelength range of 2.4 to 3.9 μm by electrical

Silicon Materials (cont'd.)

deep-level optical spectroscopy (DLOS) on a n^+p junction at 80 K. The data were analyzed in terms of the lattice-coupling model proposed by Ridley and Amato, which was modified for valence band nonparabolicity. Good agreement was obtained between the experimental results and the model calculations of the cross section with the energy level of the donor at 0.320 ± 0.005 eV above the valence band edge and a Huang-Rhys factor S of approximately 1.4. This S-value corresponds to a Franck-Condon energy shift of 70 meV with a phonon energy of 50 meV. Previously reported photoionization data of the gold donor were also fit by the same model yielding $S \simeq 0.4$, a surprisingly small value. Estimates were made of the majority carrier capture cross section for these two levels and for the platinum acceptor center in silicon which was measured previously. These estimates, based on Ridley's quantum defect model and our measured S-values, are several orders of magnitude smaller than the corresponding measured values, indicative of the complex nature of these 5d-transition elements in silicon. More elaborate models, perhaps including anharmonicity of the defect vibrations, are required to understand these large capture cross sections.
[Contact: Santos Mayo, (301) 975-2045]

Gallium Arsenide Materials

Released for Publication

Forman, R.A., Hill, J.R., Bell, M.I., White, G.S., Freiman, S.W., and Ford, W., **Strain Patterns in Gallium Arsenide Wafers: Origins and Effects**, to be published in the Proceedings of the International Symposium on Defect Recognition and Image Processing in III-V Compounds (DRIP 1987), Monterey, California, April 27-29, 1987.

Using the rapid x-ray topographic system described earlier (in DRIP I), we have examined a large number of LEC GaAs wafers, both commercial and research, and have been able to identify the sources of some of the observed patterns. We have also studied the effects of the inhomogeneous strain on the fracture properties of the wafers. The high gradients of strain cause deviations from expected crack growth behavior in fracture tests. These deviations include crack velocity variations, and crack tip deflections. The grown-in defects cause point-to-point irreproducibility in hardness and toughness values for this material. Sequential wafers exhibit closely related topographs and similar fracture properties. Inclusions have been identified in indium-doped wafers and produce a characteristic topographic pattern when the inclusion lies in the wafer under study. A characteristic strain pattern propagates away from the inclusion and produces annular rings in later wafers. The relaxation of the bow-tie strain pattern surrounding the inclusion to the annular ring pattern is likely related to the thermoelastic stress patterns described by Jordan et al.
[Contact: Richard A. Forman, (301) 975-2047]

Analysis Techniques

Released for Publication

Bouldin, C.E., Forman, R.A., and Bell, M.I., **Silicon Photodiode for Fluorescence EXAFS.**

A large-area silicon diode is used as a fluorescence detector for extended x-ray absorption fine structure (EXAFS) measurements. A direct comparison of this diode detector relative to a gas ionization fluorescence detector is made. Advantages of the diode detector include: higher signal for a given photon flux (due to higher quantum efficiency), vacuum and cryogenic compatibility, freedom from microphonic noise, good linearity, extremely wide dynamic range, operation without high voltage or gas connections, very simple electronics, and low cost. A brief

Analysis Techniques (cont'd.)

comparison with other detection methods for fluorescence EXAFS is given. Use of photodiodes for transmission EXAFS is discussed.
[Contact: Charles E. Bouldin, (301) 975-2046]

Dimensional Metrology

Recently Published

Postek, M.T., **Non-Destructive Submicron Dimensional Metrology Using the Scanning Electron Microscope**, Review of Progress in NDE, Vol. 6B, D.O. Thompson and D.E. Chimenti, eds. (Plenum Publishing Corporation, 1987), pp. 1327-1338.

The increasing evolution of microelectronics into the submicron region necessitates non-destructive examination of these structures both for linewidth measurement and defect inspection by systems other than the optical microscope. The scanning electron microscope operated in the low beam-voltage mode has been recently employed in this work due to its potentially high spatial resolution and depth of field. This paper discusses realistic applications of the scanning electron microscope to non-destructive microelectronics inspection and metrology in light of the present instrument specifications and capabilities and relates them to the processing controls required for submicron metrology.
[Contact: Michael T. Postek, (301) 975-2299]

Postek, M.T., and Joy, D.C., **Submicrometer Microelectronics Dimensional Metrology: Scanning Electron Microscopy**, NBS Journal of Research, Vol. 92, No. 3, pp. 205-228 (May-June 1987).

The increasing integration of microelectronics into the submicron region for VHSIC and VLSI applications necessitates the examination of these structures both for linewidth measurement and defect inspection by systems other than the optical microscope. The low beam-voltage scanning electron microscope has been recently employed in this work due to its potentially high spatial resolution and large depth of field. This paper discusses applications of the scanning electron microscope to microelectronics inspection and metrology in light of the present instrument specifications and capabilities, and relates them to the processing controls required for submicron processing.
[Contact: Michael T. Postek, (301) 975-2299]

Packaging

Released for Publication

Kane, D., Moore, B.A., and Walters, E.J., **RADC/NBS International Workshop on Moisture Measurement and Control for Microelectronics (IV)**, to be published as NBSIR 87-3588.

This fourth Workshop on Moisture Measurement and Control for Microelectronics served as a forum on moisture and/or materials reliability problems and on ways to control them or measure their extent. Twenty-two presentations are included which contain detailed information on hermeticity measurement and definition; development of standard packages for mass spectrometric calibrations; moisture interaction with various materials; and techniques that can be used to measure moisture in microelectronics. It was clear from several presentations in this workshop that a very systematic approach is needed when organic materials are involved; all the variables must be identified and studied one at a time. This is the key to lot-to-lot reproducibility, materials selection, and control; hence a better reliability at the design phase will decrease this need for testing, hence the cost, thus resulting in a greater satisfaction to the customer.
[Contact: E. Jane Walters, (301) 975-2050]

Integrated Circuit Test Structures

Released for Publication

Linholm, L.W., and Radack, D.J., **On-Chip Propagation Delay Measurement**, to be published in the Proceedings of the 1987 IEEE VLSI Multilevel Conference, Santa Clara, California, June 14-17, 1987.

The accurate measurement of gate propagation delay is needed for increasing the accuracy of simulators and for comparing device designs and evaluating fabrication technologies. A digital circuit is presented which can be used to determine propagation delay of any unclocked circuit element. The circuit contains on-chip logic which allows propagation delay measurement using a low-frequency parametric test system.
[Contact: Loren W. Linholm, (301) 975-2052]

Radack, D.J., Swartz, T.C., Linholm, L.W., and Cresswell, M.W., **A Comprehensive Test Chip for the Characterization of Multi-Level Interconnect Processes**, to be published in the Proceedings of the 1987 IEEE VLSI Multilevel Interconnect Conference, Santa Clara, California, June 14-17, 1987.

A test chip for the evaluation and characterization of multi-level interconnect processes has been developed. The test chip contains test structures which allow a process engineer to make comparative, quantitative measurements for evaluating the performance of selected processes and equipment. This paper describes the design and testing of selected test structures and presents initial test results.
[Contact: Loren W. Linholm, (301) 975-2052]

Recently Published

Linholm, L.W., Radack, D.J., Reeve, C.P., Cresswell, M.W., Lowry, L.R., and Pessall, N., **Test Structures and Expert Systems for Process Control**, Proceedings of SEMICON/West '87, San Mateo, California, May 19-21, 1987, pp. 54-64.

This paper describes the test structures, test results, data analysis algorithms, and a developmental expert system which can be used as a means of improving selected aspects of process control. A prototype expert system has been developed to allow rapid evaluation of selected portions of a 1-μm fabrication process. Test results from custom designed test chips containing a variety of structures comprise the input to the expert system. The output is an English-language process diagnosis. Examples of a diagnosis provided by the expert system for selected portions of a VLSI process are presented.
[Contact: Loren W. Linholm, (301) 975-2052]

Schafft, H.A., **STATUS: Interlaboratory Electromigration Experiment**, Proceedings of the 1985 Wafer Reliability Assessment Workshop, Lake Tahoe, California, October 21-23, 1985, O.D. Trapp, ed., pp. 213-216 (1986).

An update is presented of an interlaboratory electromigration experiment now underway. The purpose of the experiment is to assess the reproducibility of electromigration characterizations and to develop guidelines for the design of test structures, for methods to measure t_{50}, and for reporting characterization results. Fourteen laboratories, including two universities, are participating in the experiment.
[Contact: Harry A. Schafft, (301) 975-2234]

Power Devices

Recently Published

Blackburn, D.L., **Turn-Off Failure of Power MOSFET's**, IEEE Transactions on Power Electronics, Vol. PE-2, No. 2, pp. 136-142 (April 1987). [Identical paper appeared in PESC '85, Proceedings of the Power Electronics Specialists

Power Devices (cont'd.)

Conference, Toulouse, France, June 24-28, 1985, pp. 429-435].

Experimental results of the failure of power MOSFET's during inductive turn-off are discussed. The electrical characteristics of these devices during failure are shown to be identical to those of a bipolar transistor undergoing second breakdown. Other comparisons of the power MOSFET failure and bipolar second breakdown are made. A nondestructive measurement system is used that allows repeated measurements of the failure characteristics as a function of various parameters to be made on a single device. It is shown that commercially available power MOSFETs do not fail as a result of dV/dt currents. Drain voltage slew rates up to 22 V/ns were studied. Other measurements show that the drain voltage at which failure occurs increases with temperature, the critical current above which failure occurs decreases with temperature, and the magnitude of the load inductance has no effect on the failure. The results of this study are consistent with the theory that activation of the parasitic bipolar transistor initiates the power MOSFET failure during turn-off.
[Contact: David L. Blackburn, (301) 975-2053]

Device Physics and Modeling

Released for Publication

Bennett, H.S., **Numerical Simulations on Neutron Effects on Bipolar Transistors.**

A detailed device model that has been verified by comparisons with experimental measurements on unirradiated, state-of-the-art bipolar devices has been modified to include the effects of neutron radiation on carrier lifetimes, concentrations, and mobilities. Numerical experiments on the degradation due to neutron fluences in the dc common emitter gains for bipolar transistors with submicrometer emitter and base widths are given and compared in general terms with the few published measurements.
[Contact: Herbert S. Bennett, (301) 975-2079]

Lowney, J.R., and Bennett, H.S., **Limitations of Isotropic Theory of Band-Gap Narrowing in Si and GaAs Devices,** to be published in the Proceedings of the IEEE Bipolar Circuits and Technology Meeting, Minneapolis, Minnesota, September 21-22, 1987.

The theory of band-gap narrowing based on uniform material is shown to be invalid for devices with very large doping gradients. Calculations also show that enhanced narrowing results from the built-in field.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Wilson, C.L., **Hydrodynamic Carrier Transport in Semiconductors with Multiple Band Minimums.**

Carrier transport equations for analysis of semiconductor devices fabricated in materials with multiple band minimums, such as GaAs, are presented. This revised formulation has several advantages over previous models. Separation of the carrier transport into central and satellite components improves numerical stability in numerical simulations and allows the physical processes associated with each band to be modeled in greater physical detail. This permits processes previously neglected in hydrodynamic models, such as electron injection into insulating substrate material and deep electron traps in GaAs transistors, to be included. A model of a GaAs MESFET, which illustrates the importance of the new physical effects and achieves reasonable agreement with experiment without use of adjustable parameters, is presented as an example.
[Contact: Charles L. Wilson, (301) 975-2080]

Radiation Effects

Released for Publication

Singh, G., Galloway, K.F., and Russell, T.J., **Observation of Rebound in Power MOSFETs**, to be published in the Proceedings of the Natural Space Radiation and VLSI Conference, Houston, Texas, January 20-21, 1987.

Nonradiation-hardened n-channel power MOSFETs were irradiated under a positive gate bias. The irradiated transistors were thermally annealed at different temperatures with all terminals shorted, and under positive gate bias, with source and drain shorted. Threshold voltage rebound was observed for some transistor types under certain experimental conditions.
[Contact: Thomas J. Russell, (301) 975-2073]

Insulators and Interfaces

Released for Publication

Carver, G.P., Kopanski, J.J., Novotny, D.B., and Forman, R.A., **Specific Contact Resistivity of Metal-Semiconductor Contacts -- A New, Accurate Method Linked to Spreading Resistance.**

A new method to deduce the specific contact resistivity of metal-semiconductor contacts has been developed that allows separation of the components contributing to the total series resistance between two contacts. The principle of the method is the subtraction of the semiconductor spreading resistance, deduced from a four-contact resistivity measurement, from the total two-contact resistance. This procedure requires geometrically well-defined small contacts that are accurately fabricated by lithographic methods. Using the method, accurate values were obtained for the specific contact resistivity of an aluminum-1.5% silicon alloy to p-type silicon wafers having dopant densities from 5×10^{14} to 2×10^{20} cm^{-3}. The specific contact resistivity values are lower than previously published values obtained using earlier methods in which parasitic and nonideal effects could not be quantified or eliminated. The lower values indicate that contact resistance has a less limiting effect on the performance of integrated circuits than presently believed.
[Contact: Gary P. Carver, (301) 975-2091]

Carver, G.P., Novotny, D.B., and Kopanski, J.J., **An Innovative Measurement of Specific Contact Resistivity Confirms Lower Aluminum-Silicon Contact Resistance**, to be published in the 1987 IEEE VLSI Multilevel Interconnect Conference, Santa Clara, California, June 14-17, 1987.

New accurate data prove that the value of the aluminum-silicon specific contact resistivity is much smaller than the value determined previously by two-level planar contact resistor structures. The new data were obtained using an innovative method based upon small, geometrically well-defined contacts, for which the silicon spreading resistance can be calculated self-consistently. In this method, the total series resistance is measured at a contact window in an oxide layer to a silicon wafer. Unlike two-level planar structures, lateral and vertical current crowding effects in the metal layer are measured separately and are not involved directly in modeling the contact resistance. Using this new method, values of the specific contact resistivity between an aluminum alloy containing 1.5% silicon and silicon wafers were measured for p-type silicon resistivities in the range from 0.006 to 25 Ω-cm and for n-type silicon resistivities in the range from 0.0014 to 0.0026 Ω-cm. The specific contact resistivity values we obtained are about five times smaller than values reported from two-level planar structures, suggesting that aluminum may be useful for contact dimensions as small as 0.5 μm on a side. With the new results, multilevel conductor systems can be designed

Insulators and Interfaces (cont'd.)

tor optimal performance.
[Contact: Gary P. Carver, (301) 975-2091]

Robertson, P.J., Dumin, D.J., Carver, G.P., and Novotny, D.B., **Examination of Epitaxial Silicon Quality Versus Silicon Thickness on Boron Phosphide Layers**, to be published in the Proceedings of the 1987 Spring Meeting of the Materials Research Society, Anaheim, California, April 21-25, 1987.

It has been shown that (100) boron phosphide can be grown on (100) silicon substrates and that device quality silicon can be grown on the BP layer. Si-BP-Si structures have been proposed as candidates for three-dimensional integration and novel SOI structures. High resistivity ($=10^6$ Ω-cm) BP has been grown on silicon substrates without heat treatments. Results are reported for a single-temperature Si-BP-Si process which utilizes 0.2 and 0.4 µm of high resistivity BP and a single 1- to 5-µm silicon epitaxial layer on which p-channel MOS devices were manufactured. Threshold voltage, subthreshold slope, subthreshold current, effective linear and saturation surface mobilities, surface doping concentration, and drain-to-source reverse breakdown voltage data are presented to characterize the epitaxial films. Electron channeling patterns are presented to show high-quality silicon crystal growth on all BP layers. The 1- and 2-µm silicon layers were doped as high as 3×10^{17} cm^{-3}, and devices manufactured on these layers did not work properly. Device characteristics improved on thicker silicon layers. Linear and saturation mobilities remained virtually unchanged with 5-µm values as high as 250 and 160 cm^2/V-s, respectively. These values were lower than bulk silicon mobilities at the same doping concentrations. Reverse breakdown voltage was shown to be a function of silicon thickness reaching a maximum of 35 V on the 5-µm silicon layer. The subthreshold slope had an average value of 90 mV/dec. The subthreshold current decreased with increasing silicon thickness to a minimum of 10^{-11} A on the 5-µm silicon layers which was comparable to bulk silicon results.
[Contact: Gary P. Carver, (301) 975-2091]

Recently Published

Carver, G.P., Novotny, D.B., Hershey, R., and Luther, J.E., **Double-Level Metallization: Annual Report for October 1, 1985 to September 30, 1986**, NBSIR 87-3579 (June 1987).

An outline for a double-level metal process for the fabrication of circuits having a minimum linewidth of 3 µm is described. The process is designed to be implemented in the Microelectronics Processing Facility at Fort Meade, Maryland, where single-level metallization circuits are already in production. A summary is included of the related research performed in the Semiconductor Processing Research Laboratory at the National Bureau of Standards.
[Contact: Gary P. Carver, (301) 975-2091]

Chandler-Horowitz, D., and Candela, G.A., **Ellipsometric Instrumentation for Optical Metrology in Thin Films**, Proceedings of SEMICON/West '87, San Mateo, California, May 19-21, 1987, pp. 126-132.

Nondestructive optical characterization of thin-film structures on substrates by ellipsometry is a precise measurement technique which may lead to accurate metrology. In order to study problems important to semiconductor technology, we have built a spectroscopic, multi-angle of incidence, rotating-analyzer ellipsometer. The primary metrological requirement for accuracy is to obtain the uncertainties in the instrumental data for a particular sample surface. These data are the ellipsometric values for Δ, ψ, the angle of incidence ϕ, and the wavelength λ. Then a mathematical analysis involving surface modeling is

Insulators and Interfaces (cont'd.)

performed to find both the best values of the film parameters and their uncertainties. In practice there are conditions which can optimize both the uncertainties in Δ and ψ, and the resulting uncertainties in the film parameters. Both the angles of incidence and of the polarizer can be adjusted for optimum accuracy in determining the values for Δ and ψ when the instrument is used in the rotating-analyzer mode. The ability of this instrument with its increased accuracy can lead to a better understanding of complex multilayered samples, such as proposed semiconductor device starting materials, e.g., SIMOX.
[Contact: Deane Chandler-Horowitz, (301) 975-2084]

Mountain, D.J., Galloway, K.F., and Russell, T.J., **The Effect of Post-Oxidation Anneal on the Electrical Characteristics of Thin Oxides**, Journal of the Electrochemical Society, Vol. 134, No. 3, pp. 747-479 (March 1987).

In this study, the effects of pre- and post-oxidation treatments on thin ($\sim$20-nm) gate oxide properties have been evaluated. Pre-oxidation cleans and post-oxidation anneal (POA) times and ambients were compared. Flatband voltage, oxide field breakdown, and average density of interface trap measurements were used to evaluate the different sequences. The data indicate that an optimum oxidation sequence for thin gate oxides can be designed. A sacrificial oxidation cleaning procedure and a long (120-min) POA in nitrogen gave the oxide with the best electrical characteristics.
[Contact: Thomas J. Russell, (301) 975-2073]

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Released for Publication

Lagnese, J., and McKnight, R.H., **Calculation of Confidence Intervals for High Voltage Impulse Reconstruction.**

A recently described algorithm designed to calculate confidence intervals for solutions to ill-posed problems subject to inequality constraints is applied to the calculation of confidence intervals for a high-voltage impulse distorted by a divider system. Applications of the method to measurements made with resistive and capacitive dividers illustrate its value for obtaining useful stochastic error bounds for high voltage impulse restoration.
[Contact: Ronald H. McKnight, (301) 975-2431]

Lagnese, J., and McKnight, R.H., **Estimates of Confidence Intervals for Divider Distorted Waveforms**, to be published in the Proceedings of the 5th International High Voltage Symposium, Braunschweig, West Germany, August 20-21, 1987.

This paper describes a method for computing confidence intervals for a high-voltage impulse distorted by a divider system. The technique is based on a recent algorithm designed to calculate confidence intervals for solutions to ill-posed problems subject to inequality constraints. Applications of the method to measurements made with a resistive divider illustrate its value for obtaining useful stochastic error bounds for high-voltage impulse restoration.
[Contact: Ronald H. McKnight, (301) 975-2431]

Lawton, R.A., and Anderson, W.T., **Two Layer Dielectric Stripline Structure Modeling and Measurement.**

Further development of the modeling of the two-layer dielectric stripline structure is reported by computing the scattering parameter S_{21} derived from the model and comparing the computed value with the measured value over the frequency range from 45 MHz to 25 GHz. The sensitivity of S_{21} to various

Waveform Metrology (cont'd.)

parameters of the structure is also discussed. Examples of measurement and modeling of the silicon dioxide on silicon system and modeling of the gallium arsenide on silicon system are given.
[Contact: William L. Gans, (303) 497-3538]

Oldham, N.M., and Parker, M.E., **NBS Calibration System for AC Voltage**, to be published in the Proceedings of the 1987 National Conference of Standards Laboratories Workshop and Symposium, Denver, Colorado, July 12-16, 1987.

A semi-automatic system for calibrating high-accuracy ac voltmeters and calibrators is described. The system relies on measurements using coaxial thermal voltage converters to achieve uncertainties of 5 to 150 ppm over the frequency range of 10 Hz to 1 MHz. Specialized hardware and measurement techniques make it possible to achieve these uncertainties in test periods of approximately one minute. Random errors introduced by the system are typically less than 2 ppm (one standard deviation).
[Contact: N. Michael Oldham, (301) 975-2408]

Oldham, N.M., Parker, M.E., Young, A., and Smith, A.G., **A High Accuracy, 10 Hz - 1 MHz Automatic AC Voltage Calibration System**, to be published in IEEE I&M Transactions, Conference Record, Boston, Massachusetts, April 27-29, 1987.

An automatic system for calibrating high-accuracy ac voltmeters and calibrators is described. The system is based on traditional coaxial thermal voltage converters to provide ac voltage measurement uncertainties of 5 to 20 ppm in the audio frequency range and 5 to 250 ppm over the full range from 10 Hz to 1 MHz at voltages between 0.5 to 600 V. Lower levels (0.01 to 0.5 V) are realized using wideband inductive dividers. Specialized hardware and measure-

ment techniques make it possible to achieve these uncertainties in test periods of approximately one minute. Random errors introduced by the measurement system are typically less than 2 ppm (one standard deviation).
[Contact: N. Michael Oldham, (301) 975-2408]

Recently Published

Sorrells, J.R., **A Survey of Electronic Measurement Needs Below 10 MHz**, NBSIR 87-3549 (June 1987).

The results of a survey to assess the electronic measurement needs from dc to 10 MHz are presented. The questionnaire used in the survey covered three broad areas of measurement need: 1) basic electrical quantities and related precision instruments, 2) automatic test equipment and other complex measurement systems, and 3) conducted electromagnetic interference. The data provided by 527 respondents are summarized, and the results of various analyses are described. Several conclusions, suggested by the analyses, are also discussed.
[Contact: Barry A. Bell, (301) 975-2402]

Souders, T.M., Schoenwetter, H.K., and Hetrick, P.S., **Characterization of a Sampling Voltage Tracker for Measuring Fast, Repetitive Signals**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, IMTC/87, Boston, Massachusetts, April 27-29, 1987, pp. 240-243.

An equivalent time-sampling and digitizing system is described, together with test methods for characterizing its dynamic performance. Time-base errors, linearity errors, step-response parameters, and frequency response are considered, and typical measurement results are included. The system is capable of state-of-the-art measurements at rf frequencies.
[Contact: T. Michael Souders, (301) 975-2406]

Waveform Metrology (cont'd.)

Stenbakken, G.N., **Characterizing Square and Triangular Waveforms**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, IMTC/87, Boston, Massachusetts, April 27-29, 1987, pp. 9-11.

A method has been developed for determining the parameters and errors of square and triangular waveforms relative to idealized waveforms, even when the waveforms to be characterized are highly distorted. The method is based on measurements obtained by sampling the waveform. Then, an idealized waveform is fitted to the sampled data using a least-squared-error algorithm. The errors in the waveform are defined as the deviations between the data samples and the ideal waveform. Also, the parameters of the measured waveform are defined as the corresponding parameters of the fitted ideal waveform.
[Contact: Gerard N. Stenbakken, (301) 975-2440]

Stenbakken, G.N., Laug, O.B., Kibalo, T.H., Bell, B.A., and Perrey, A.G., **NBS Wideband Sampling Wattmeter**, NBS Technical Note 1221 (May 1987).

The design and operation of a wideband sampling wattmeter capable of measuring distorted power signals with fundamental frequencies from 1 Hz to 10 kHz and harmonics up to 100 kHz is described. The microcomputer-controlled wattmeter uses asynchronous sampling of the voltage and current signals. The errors associated with this type of operation are described, as are various methods of correcting some of these errors. A hardware multiplier-accumulator allows a large number of power signal samples to be integrated for each measurement. Sampling rates are variable up to a maximum of 300 kHz. A direct-memory-access unit is used to capture 4096 samples of both the voltage and current signals. These data are used to calculate the average and rms values of these signals.

A special feature of the sampling wattmeter is the use of programmable time delay circuits to compensate for differential time delays between the two input channels. Performance tests of the wattmeter show that it has a measurement uncertainty of less than ±0.1 percent of full-scale amplitude over the above-described frequency range.

This technical note gives schematic diagrams of the circuits used in this wattmeter and describes their operation. The software is also described, and flow charts and selected program listings are provided for the programs written in PASCAL. The results of calibration of the instrument over the past year are also presented.
[Contact: Gerald N. Stenbakken, (301) 975-2440]

Turgel, R.S., and Vecchia, D.F., **Precision Calibration of Phase Meters**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, IMTC/87, Boston, Massachusetts, April 27-29, 1987, pp. 135-137.

A procedure and statistical analysis for the calibration of precision phase meters has been developed. The method can be applied equally to the calibration of any instrument that has a nominally linear response characteristic. Using statistical tests, the method checks whether the calibration data fit a linear model and then determines the linear equation from which the corrected calibration values are computed. Because random fluctuations tend to mask the limiting mean of the instrument response, the corrections are based on the values computed from the calibration curve, rather than on the actual calibration data.

To obtain the data, test points are chosen to cover the range to be calibrated, and several sets of calibration readings are taken by comparing the instrument under test to a standard. The replication of the data at the selected test points serves to charac-

Waveform Metrology (cont'd.)

terize the repeatability and to decide whether the linear model is appropriate. If the assumption of a linear model is correct, the data are fitted to a straight line (calibration curve), and statistical tests are used to determine if the slope and intercept of the calibration curve are significantly different from their ideal values.

As a next step, the error limits of the readings from the instrument under test are computed for three conditions: no corrections applied, only a constant correction applied, and the full calibration curve used for the corrections. The three error limits are then compared to the instrument specifications to determine which type of calibration correction, if any, is needed.
[Contact: Raymond S. Turgel, (301) 975-2420]

Cryoelectronic Metrology

Released for Publication

Go, D., Hamilton, C.A., Lloyd, F.L., DiIorio, M.S., and Withers, R.S., **Superconducting Analog Track-and-Hold.**

A superconducting analog track-and-hold circuit has been designed and tested. Experimental results report a 1- to 2-GHz bandwidth and a 35-dB dynamic range. Model calculations indicate that within the limits of the fabrication technology, substantially higher bandwidths reaching 20 GHz can be achieved.
[Contact: Diane Go, (303) 497-3770]

Hamilton, C.A., Lloyd, F.L., and Burroughs, C., **Josephson Voltage Array Development at the NBS in Boulder,** to be published in the Proceedings of the 1987 National Conference of Standards Laboratories Workshop and Symposium, Denver, Colorado, July 12-16, 1987.

This paper reviews the principles of

Josephson array voltage standards and discusses the four important goals of array development at the NBS in Boulder. These goals are: 1) the fabrication of more reliable and stable devices, 2) the development of larger arrays to achieve voltages approaching 10 V, 3) the development of an automated system to facilitate a wide variety of calibrations, and 4) the support of a rapidly growing list of standards laboratories using our array devices.
[Contact: Clark A. Hamilton, (303) 497-3740/3988]

Kautz, R.L., **Activation Energy for Thermally Induced Escape from a Basin of Attraction.**

A new method for calculating activation energies in nonequilibrium systems is presented. In the limit of low temperatures, the most probable path for escape from a basin of attraction (a generalization of the classical problem of escape from a potential well) is the path which minimizes the available thermal noise energy required for escape. This minimum energy is the activation energy of escape.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

Lloyd, F.L., Hamilton, C.A., Beall, J.A., Go, D., Ono, R.H., and Harris, R.E., **A Josephson Array Voltage Standard at 10 Volts.**

The technology of Josephson voltage standards has been extended to an array of 14,184 junctions which is capable of generating over 150,000 quantized voltage levels spanning the range from -12 to +12 V. This makes possible the direct calibration of 10-V zener reference standards without the use of a voltage divider.
[Contact: Frances L. Lloyd, (303) 497-3254/3988]

Raisanen, A.V., Crete, D.G., Richards, P.L., and Lloyd, F.L., **A 100 GHz SIS Quasiparticle Mixer With 10 dB Coupled Gain,** to be published in the Proceed-

Cryoelectronic Metrology (cont'd.)

ings of the 1987 IEEE MTT-S International Microwave Symposium, Las Vegas, Nevada, June 9-11, 1987.

We have tested a superconducting quasiparticle mixer for 85 to 110 GHz which gives much larger coupled gain than has been previously observed. When operated with a negative dynamic resistance of about 2000 Ω, the maximum coupled gain was G_M(double sideband [DSB]) = 12.5 ± 2.5 dB [G_M(single sideband) = 9.5 ± 2.5 dB]. The associated mixer noise temperature was 15.9 K (DSB). Large gain was also observed with large positive dynamic resistance, giving the lowest mixer noise temperature of 12.4 K (DSB).
[Contact: Frances L. Lloyd, (303) 497-3254 or -3988]

Zimmerman, J.E., Beall, J.A., Cromar, M.W., and Ono, R.H., **Operation of a YBa$_2$Cu$_3$O$_x$ rf-SQUID at 81 K.**

An rf-SQUID has been made from bulk YBa$_2$Cu$_3$O$_x$. The device displays quantum interference effects and operates with useful signal levels up to 81 K. The SQUID is formed from a ring of YBa$_2$Cu$_3$O$_x$ which is broken in the cryogenic environment and then recontacted. Estimates of the SQUID noise performance are given.
[Contact: James A. Beall, (303) 497-5989]

Recently Published

Cirillo, M., and Lloyd, F.L., **Phase Lock of a Long Josephson Junction to an External Microwave Source,** Journal of Applied Physics, Vol. 61, No. 7, pp. 2581-2585 (April 1987).

A long Josephson junction dc biased on a zero-field singularity and emitting radiation at microwave frequencies is irradiated with external microwave power. This power can be supplied either by a room-temperature oscillator or by another long junction. We find that the oscillations of the junction can lock coherently to the external signal for frequency intervals ranging from 500 kHz to 50 MHz. The dependence of the width of these intervals of coherence on the external microwave power is measured for the case in which the power is generated by a room-temperature oscillator.
[Contact: Frances L. Lloyd, (303) 497-3254 or 3988]

Crete, D.G., McGrath, W.R., Richards, P.L., and Lloyd, F.L., **Performance of Arrays of SIS Junctions in Heterodyne Mixers,** IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-35, No. 4, pp. 435-440 (April 1987).

We have made a systematic experimental study of the performance of millimeter-wave quasiparticle heterodyne mixers which use arrays of superconductor-insulator-superconductor (SIS) tunnel junctions. Sets of arrays with N = 1, 5, 10, 25, and 50 junctions in series were fabricated by photolithography. All of the arrays in a given set were made on a single wafer so that their response time parameters $\omega_S R_N C$ were the same (ω_S = signal frequency; R_N = junction normal-state resistance; C = junction capacitance). Junction areas were scaled so that the total impedance was the same for each array in a set. Sets of arrays from four wafers with values of $\omega_S R_N C$ ranging from 2.6 to 13 were evaluated in mixers at 33 and 36 GHz. These measurements showed that the signal power required to saturate the mixers varies as N^2, and the conversion efficiency is nearly independent of N for all values of $\omega_S R_N C$. The mixer noise temperature is independent of N for large values of $\omega_S R_N C$. Therefore, the dynamic range of an SIS quasiparticle mixer can increase in proportion to N^2. For small values of $\omega_S R_N C$, however, the mixer noise increases systematically with N. This correlation suggests that the junction capacitance affects the coupling between junctions that can contribute to the noise.

Cryoelectronic Metrology (cont'd.)

[Contact: Frances L. Lloyd, (303) 497-3254]

McDonald, D.G., **Novel Superconducting Thermometer for Bolometric Applications**, Applied Physics Letters, Vol. 50, No. 12, pp. 775-777 (March 23, 1987).

The temperature dependence of the magnetic penetration depth in a superconductor is proposed as a basis for a sensitive thermometer. This depth is monitored through the inductance of a microstrip transmission line, which is incorporated into an impedance measuring bridge. The bridge is envisioned as an integrated circuit with all critical components at low temperature. It is estimated that the contribution to the noise equivalent power by the sum of the Josephson noise and the preamplifier noise can be reduced to about 7×10^{-20} watt per root hertz, which is approximately four orders of magnitude below currently realized values. Performance of this device as a bolometer is limited by noise from the thermal conductance of the bolometer mount with the present state of the art.
[Contact: Donald G. McDonald, (303) 497-5113]

Raisanen, A.V., Crete, D.G., Richards, P.L., and Lloyd, F.L., **Low Noise SIS Mixer with Gain for 80-115 GHz**, Proceedings of the ESA Workshop on a Space-Borne Sub-Millimetre Astronomy Mission, Segovia, Spain, June 4-7, 1986, pp. 255-258 (European Space Agency, Paris, France, 1986). [See also a more extensive paper by the same authors published in the International Journal of Infrared and Millimeter Waves, Vol. 7, No. 12, pp. 1835-1852 (1986).]

Several superconductor-superconductor (SIS) quasiparticle mixers have been designed and tested for the frequency range from 80 to 115 GHz. The sliding backshort is the only adjus-

table radiofrequency (RF) tuning element. The RF-filter reactance is used as a fixed RF-matching element. A mixer which uses a single 2×2 μm^2 Pb-alloy junction in a 1/4-height waveguide mount has a coupled conversion gain of G_M(double sideband [DSB]) = 2.6 ± 0.5 dB with an associated noise temperature of T_M(DSB) = 16.4 ± 1.8 K at the best DSB operation point. The receiver noise temperature T_R(DSB) is 27.5 ± 0.8 K. This mixer provides a single-sideband (SSB) receiver noise temperature below 50 K over the frequency range from 91 to 96 GHz, the minimum being T_R(SSB) = 44 ± 4 K.
[Contact: Frances L. Lloyd, (303) 497-3254 or -3988]

Raisanen, A.V., Crete, D.G., Richards, P.L., and Lloyd, F.L., **Wide-Band Low Noise MM-Wave SIS Mixers With a Single Tuning Element**, International Journal of Infrared and Millimeter Waves, Vol. 7, No. 12, pp. 1835-1852 (1986).

Several superconductor-insulator-superconductor (SIS) quasi-particle mixers have been designed and tested for the frequency range from 80 to 115 GHz. The sliding backshort is the only adjustable radiofrequency (RF) tuning element. The RF filter reactance is used as a fixed RF matching element. A mixer which uses a single 2×2 μm^2 Pb-alloy junction in a quarter-height waveguide mount has a coupled conversion gain of G_M(double sideband [DSB]) = 2.6 ± 0.5 dB with an associated noise temperature of T_M(DSB) = 16.4 ± 1.8 K at the best DSB operation point. The receiver noise temperature T_R(DSB) is 27.5 ± 0.8 K for the mixer test apparatus. This mixer provides a single-sideband (SSB) receiver noise temperature below 50 K over the frequency range from 91 to 96 GHz, the minimum being T_R(SSB) = 44 ± 4 K. Another mixer with an array of five 5×5 μm^2 junctions in series in a full-height-waveguide mount has much lower noise temperature T_M(DSB) = 6.6 ± 1.6 K, but less gain G_M(DSB) = -5.1 ± 0.5 dB.
[Contact: Frances L. Lloyd, (303) 497-3254 or -3988]

Antenna Metrology

Released for Publication

Camell, D., Cruz, J.E., and Larsen, E.B, **NBS Calibration Procedures for Horizontal Dipole Antennas (25 to 1000 MHz)**, to be published as NBS Technical Note 1309.

This publication describes the theoretical basis and test procedures for horizontally polarized half wavelength dipole calibration at the National Bureau of Standards. Two different techniques and two different test sites are used. The standard field method is used in the anechoic chamber in the frequency range of 200 MHz to 1000 MHz. The standard antenna method is used at the open-field site in the frequency range of 25 MHz to 1000 MHz. Procedures for both techniques are explained and measurement setups are illustrated. Measurement uncertainties are discussed. Sample reports are included for both methods.
[Contact: Dennis Camell, (303) 497-3214]

FitzGerrell, R.G., **Three PC-Computer Programs for Antenna Calculations Primarily for Use Below 1000 MHz.**

This article describes three computer programs used frequently by the author when working on various antenna measurement projects in the frequency range below 1000 MHz. These programs were originally written in FORTRAN 4 and run on various main-frame computers at the NBS Boulder Laboratories. During the last year, they were converted, essentially intact, to FORTRAN 77 and compiled using IBM Professional FORTRAN installed on an IBM PC/XT. As a result of this choice of compilers, a math co-processor is required (8087 for the XT) to run the *.EXE files.
[Contact: Mark T. Ma, (303) 497-3800]

Francis, M.H., and Stubenrauch, C.F., **Comparison of Measured and Calculated Antenna Side Lobe Coupling Loss in the Near Field Using Approximate Far-Field Data.**

Computer programs are presently in existence to calculate the coupling loss between two antennas provided that the amplitude and phase of the far field are available. However, for many antennas the complex far field is not known accurately. In such cases it is nevertheless possible to specify approximate far fields from a knowledge of the side lobe level of each antenna along the axis of separation, and the electrical size of each antenna. Measurements of near-field coupling loss between two moderate sized microwave antennas were done to determine the effectiveness of using approximate side lobe level data instead of the detailed far fields. Comparison of the measured results to those from the computer program ENVLP indicates that the use of approximate far fields gives an estimate of the coupling loss with an uncertainty of about ±5 dB.
[Contact: Michael H. Francis, (303) 497-5873]

Recently Published

FitzGerrell, R.G., **Standard Linear Antennas, 30 MHz to 1000 MHz**, Proceedings of the Fifth International Conference on Electromagnetic Compatibility, University of York, England, September 29-October 2, 1986 (Sponsored by the Institution of Electronic & Radio Engineers, London, England), pp. 147-153.

Simple linear antennas are described that are designed to operate in the 30-MHz to 1000-MHz frequency range. Commercial coaxial hybrid junctions are used as balanced-to-unbalanced transmission line transformers (baluns) for the dipole antennas. The monopoles are fed unbalanced against a large ground screen. Calculated site attenuation (insertion loss) between pairs of these antennas over an assumed perfectly conducting plane ground is compared to insertion loss data measured using the 30 m by 60 m NBS ground screen. It is assumed that one-half of the mean value of the difference between the calculated and measured insertion loss data,

Antenna Metrology (cont'd.)

expressed in decibels, is a good esti-
mate of individual antenna performance.
For the antennas described here, this
measure of performance is typically
≤0.05 dB and on the outside, ≤0.42 dB.
[Contact: Richard G. FitzGerrell, (303)
497-3737]

Muth, L.A., **Displacement Errors in
Antenna Near-Field Measurements and
Their Effect on the Far Field**, NBS
Technical Note 1306 (October 1986)
[also accepted for publication in IEEE
Transactions on Antennas and Propaga-
tion].

The effects of probe-displacement errors
in the near-field measurement procedure
on the far-field spectrum are studied.
Expressions are derived for the dis-
placement error functions that maximize
the fractional error in the spectrum
both for the on-axis and off-axis direc-
tions. Planar x-y and z-displacement
errors are studied first, and the
results generalized to position errors
in cylindrical and spherical scanning.
Near-field models are used to obtain
order-of-magnitude estimates for the
fractional error as a function of rele-
vant scale lengths of the near field,
defined as the lengths over which signi-
ficant variations occur.
[Contact: Lorant A. Muth, (303)
497-3603]

Laser Metrology

Recently Published

Bennett, H.E., Guenther, A.H., Milam,
D., and Newnam, B.E., **Laser Induced
Damage in Optical Materials: 1984**,
NBS Special Publication 727 (October
1986).

The Sixteenth Annual Symposium on Opti-
cal Materials for High Power Lasers
(Boulder Damage Symposium) was held at
the National Bureau of Standards in
Boulder, Colorado, October 15-17, 1984.
The Symposium was held under the aus-
pices of ASTM Committee F-1, Subcommit-
tee on Laser Standards, with the joint
sponsorship of NBS, the Defense Advanced
Research Projects Agency, the Department
of Energy, the Office of Naval Research,
and the Air Force Office of Scientific
Research. Approximately 200 scientists
attended the Symposium, including repre-
sentatives of the United Kingdom,
France, West Germany, and the Nether-
lands. The Symposium was divided into
sessions concerning Materials and Mea-
surements, Mirrors and Surfaces, Thin
Films, and Fundamental Mechanisms. As
in previous years, the emphasis of the
papers presented at the Symposium was
directed toward new frontiers and new
developments. Particular emphasis was
given to materials for high power appa-
ratus. The wavelength range of prime
interest was from 10.6 μm to the uv
region. Highlights included surface
characterization, thin-film-substrate
boundaries, and advances in fundamental
laser-matter threshold interactions and
damage mechanisms. Harold E. Bennett of
the Naval Weapons Center, Arthur H.
Guenther of the Air Force Weapons Labo-
ratory, David Milam of the Lawrence
Livermore National Laboratory, and Brian
E. Newnam of the Los Alamos National
Laboratory were co-chairmen of the Sym-
posium. The Seventeenth Annual Symposi-
um was scheduled for October 28-30, 1985
at the National Bureau of Standards,
Boulder.
[Contact: Aaron A. Sanders, (303)
497-5341]

Microwave and Millimeter-Wave Metrology

Released for Publication

Adair, R.T., and Russell, D.H., **A
Calibration Service for 30 MHz Attenua-
tion and Phase Shift**, to be published
as NBS Technical Note 1310.

A calibration service currently being
offered by NBS for attenuation and phase
shift at 30 MHz is described. The
service offers measurements on coaxial
attenuators that are either fixed (stan-
dard attenuation) or variable for incre-

Microwave & Millimeter-Wave (cont'd.)

mental (step) attenuation. Waveguide-below-cutoff variable attenuators with coaxial connectors are also calibrated for incremental attenuation. Ranges of capabilities and estimated limits of systematic and random uncertainty are presented.

Calibration of phase shifters which provide fixed (insertion) phase shift and those with variable phase shift (phase shift difference) are described. Ranges of phase shift and estimated limits of uncertainty are given in degrees. However, a smaller portion of this document is devoted to this calibration service since it is requested only infrequently.

Definitions, capabilities of the system and techniques of calibration are given. The standards, measurement accuracies, results from intercomparisons, quality assurance, and statistical control of the system are discussed and analyzed. Representative reports of calibration are also included.
[Contact: David H. Russell, (303) 497-3148]

Larsen, N.T., **Microwave Power Standards at the National Bureau of Standards**, to be published in the Proceedings of the 1987 National Conference of Standards Laboratories Workshop and Symposium, Denver, Colorado, July 12-16, 1987.

A general review of the history and present status of the microwave power standards in use at the National Bureau of Standards is presented. The standards are calorimeters, and the quantity measured is "effective efficiency." The calibration services are based on these standards. The design and evaluation of these standards is discussed.
[Contact: Neil T. Larsen, (303) 497-3711]

Saulsbery, L.F., and Adair, R.T., **ANA Measurement Results on the ARFTG Traveling Experiment**, to be published

in the 28th ARFTG Conference Digest.

The Automatic RF Techniques Group (ARFTG) Executive Committee has assembled two traveling measurement assessment kits. Each of these kits consists of 1-dB, 20-dB, 40-dB, and 60-dB attenuators; a 50-Ω termination; a 10-cm air line; 1.2-VSWR and 2.0-VSWR mismatched terminations; and a short-circuit termination. These devices are equipped with precision 7-mm coaxial connectors. The traveling kits are being circulated among measurement laboratories who wish to assess their ability to measure reflection coefficient, attenuation, and phase shift from 300 MHz to 17 GHz. The results obtained on ten different automated measurement systems are presented.
[Contact: Gerome R. Reeve, (303) 497-3557]

Recently Published

Adair, R., Reeve, G., and Gatterer, L.E., **The Expanding Need for Microwave and Millimeter Wave Calibration Services**, National Conference of Standards Laboratories Newsletter, Vol. 27, No. 1, pp. 21-31 (January 1987).

Several technology surveys concerning microwave- and millimeter-wave measurement needs and capabilities have recently been conducted by the National Bureau of Standards Boulder Laboratories, and other organizations. The results of some of these studies which covered the frequency range from 1 GHz to above 200 GHz are summarized. Current microwave- and millimeter-wave standards and calibration capabilities at the National Bureau of Standards are reviewed and compared with national needs. The lack of national standards in certain frequency bands may lead to problems with the specification, acceptance testing, calibration, and critical use of some components and systems. Plans to fulfill unmet needs in the frequency range are also presented.
[Contact: Gerome R. Reeve, (303) 497-3557]

Microwave & Millimeter-Wave (cont'd.)

Daywitt, W.C., **A Simple Technique for Determining Joint Losses on a Coaxial Line from Swept-Frequency Reflectometer Data,** CPEM 86 Digest, 1986 Conference on Precision Electromagnetic Measurements, R.F. Dziuba, Editor, National Bureau of Standards, Gaithersburg, Maryland, June 23-27, 1986, p. 40.

A need to separate connector loss from swept-frequency automatic network analyzer measurements to check an attenuation calculation for a low-loss, coaxial line has led to a simple graphical technique for determining the connector loss. It is also possible to determine joint losses around center conductor bead supports on the line itself. Preliminary results indicate that losses in the milli-decibel range can be determined to a precision of a few tenths of a milli-decibel or better, even though the data are obscured by considerable connector loss and calibration error. Results were checked by independent measurements and show excellent agreement.
[Contact: William C. Daywitt, (303) 497-3720]

Engen, G.F., **In Search of a More Realistic Accuracy Statement for Microwave Metrology,** 27th ARFTG (Automatic RF Techniques Group) Conference Digest, Baltimore, Maryland, June 5-6, 1986, pp. 181-183 (August 1986).

The concept of "measurement accuracy" is fundamental to all of metrology. Given two different techniques for measuring the same parameter, an evaluation of their respective accuracies typically plays a major role in an assessment of their relative merit.

Historically, the accuracy achieved by the microwave metrologist has been limited by detector performance, hardware imperfections, and connector problems. Today, the effect of hardware imperfections has been largely eliminated by more complete modeling. More-over, the performance of the detection systems has been improved to the point where in many cases the non-ideal connector behavior is the major error source. Although important refinements in the connectors have also been realized, it is quite possible that these have not kept pace with the other developments.

In any case, it is useful to pose the following question: Assume a measurement system which, apart from being fitted with connectors typical of those in general use, is otherwise perfect. How much measurement accuracy can one realistically claim for it?
[Contact: William E. Little, (303) 497-5479]

McDonald, D.G., **Novel Superconducting Thermometer for Bolometric Applications,** Applied Physics Letters, Vol. 50, No. 12, pp. 775-777 (March 23, 1987).

The temperature dependence of the magnetic penetration depth in a superconductor is proposed as a basis for a sensitive thermometer. This depth is monitored through the inductance of a microstrip transmission line, which is incorporated into an impedance measuring bridge. The bridge is envisioned as an integrated circuit with all critical components at low temperature. It is estimated that the contribution to the noise equivalent power by the sum of the Josephson noise and the preamplifier noise can be reduced to about 7×10^{-20} watt per root hertz, which is approximately four orders of magnitude below currently realized values. Performance of this device as a bolometer is limited by noise from the thermal conductance of the bolometer mount with the present state of the art.
[Contact: Donald G. McDonald, (303) 497-5113]

Optical Fiber Metrology

Released for Publication

Danielson, B.L., and Whittenberg, C.D.,

Optical Fiber Metrology (cont'd.)

A New Method for High Resolution Reflectometry.

We describe a new type of optical reflectometry which is useful in testing single-mode micro-optic lightguide systems. This technique uses a scanning Michelson interferometer in conjunction with a broadband illuminating source and cross-correlation detection. High resolution is achieved through the limited coherence of the backscattered radiation. It is possible to distinguish scattering centers separated by only a few micrometers. In some cases loss may be estimated for components in the transmission path of a test lightguide. The basic principles of this diagnostic technique, along with some performance characteristics, are illustrated for an all-fiber reflectometer. We also discuss several laboratory applications which serve to demonstrate the resolution capabilities of this measurement concept.
[Contact: Bruce L. Danielson, (303) 497-5620]

Veeser, L., Chandler, G.I., and Day, G.W., **Fiber Optic Sensing of Pulsed Currents**, to be published in SPIE Advanced Institute Series on Broadband Photonic Sensors [SPIE - The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227].

This manuscript reviews work at Los Alamos National Laboratory on the use of optical fiber sensors for the measurement of pulsed electric currents. It is based on a presentation at the SPIE Advanced Study Institute Series on Broadband Photonic Sensors held in Howey-in-the-Hills, Florida, in April 1986.
[Contact: Gordon W. Day, (303) 497-5294]

Recently Published

Day, G. W., **Compact Fiber Sensors for the Measurement of Low Level Electric Currents**, Proceedings of the 4th

International Conference on Optical Fiber Sensors, Tokyo, Japan, October 7-9, 1986, pp. 81-84.

Recent progress in the development of fiber current sensors includes the fabrication of low-loss, low-birefringence, 3-cm diameter coils by annealing, and the demonstration of a noise equivalent current of 180 microamperes per root Hertz.
[Contact: Gordon W. Day, (303) 497-5204]

Engelsrath, A., Danielson, B.L., and Franzen, D.L., **Attenuation Measurements on Deformed Optical Fibers**, NBSIR 86-3052 (July 1986).

Attenuation measurements were made on several different optical fibers subjected to bending, tension, twisting, and overlapping. The measurements were performed with an optical time-domain reflectometer which gives a partial separation between the various contributions to the measured deformation loss. The graded- and step-index multimode fibers had a variety of different dimensions and coatings. The results of bending attenuation are compared with models and other reported experimental loss data. Based on the results of the present experiments, an empirical model has been derived which permits a prediction of the smallest bend radius consistent with a given allowed attenuation.
[Contact: Bruce L. Danielson, (303) 497-5620]

Franzen, D.L., **Standard Measurement Procedures for Characterizing Single-Mode Fiber**, Conference Digest, Test & Measurement World Expo, San Jose, California, April 8-10, 1986, pp. 70-77 (October 1986).

Parameters used to describe single-mode fiber include attenuation, cut-off wavelength, mode-field diameter, and dispersion. Some measurement results depend on test-fiber condition and testing methods.
[Contact: Douglas L. Franzen, (303) 497-3346 or -5342]

Optical Fiber Metrology (cont'd.)

Gallawa, R.L., and Li, X., **Calibration of Optical Fiber Power Meters: The Effect of Connectors**, Applied Optics, Vol. 26, No. 7, pp. 1170-1174 (April 1987).

This paper addresses the question of accurate measurement of optical power at the wavelengths and power levels of interest to the telecommunications community. In particular, we examine the calibration of power meters that are destined for use in a field environment. Connectors and adapters are shown to skew the measurements, leading to errors attributable to reflections from the connector or to angular dependence of detector response. Calibration data are taken using two popular connector types: a biconic and an SMA type. The data are sufficient to illustrate the problem but definitive conclusions cannot be drawn regarding variability of performance with connector or connector type, because of the limited data.
[Contact: Robert L. Gallawa, (303) 497-3761]

Maisonneuve, J., and Gallawa, R.L., **The Use of Power Transfer Matrices in Predicting System Loss: Theory and Experiment**, Fiber and Integrated Optics, Vol. 6, No. 1, pp. 11-26 (1985).

The phase space diagram for parabolic and step-index fibers leads to a graphic representation of the bound, leaky, and refracted rays of ray theory. This concept is used to predict the attenuation of typical components of local area networks. The technique uses power transfer matrices to track the evolution of power distribution in ray packets. In particular, we predict and then measure the power transfer of two ray packets for a step-index fiber. The comparison is encouraging.
[Contact: Robert L. Gallawa, (303) 497-3761]

Electro-Optic Metrology

Released for Publication

Veeser, L., and Day, G.W., **Fiber Optic Faraday Rotation Current Sensor**, to be published in the Proceedings of the Fourth International Conference on Megagauss Field Generation and Related Topics, Santa Fe, New Mexico, July 14-17, 1986.

The manuscript reviews work at Los Alamos National Laboratory on the use of optical fiber sensors for the measurement of pulsed electric currents.
[Contact: Gordon W. Day, (303) 497-5204]

Recently Published

Day, G.W., Hale, P.D., Deeter, M., Milner, T.E., Conrad, D., and Etzel, S.M., **Limits to the Precision of Electro-Optic and Magneto-Optic Sensors**, NBS Technical Note 1307 (March 1987). [Original title: High-Precision Electro-Optic and Magneto-Optic Sensors for Power System Applications: Technical Feasibility].

The principles of electro-optic and magneto-optic sensors suitable for use in power system applications are reviewed with particular attention to the properties of materials and components that limit the precision of such sensors. Section topics include precision and accuracy in electro-optic and magneto-optic sensors; electro-optic and magneto-optic sensor configurations suitable for current and voltage measurements; critical evaluation of electro-optic sensor technology; critical evaluation of magneto-optic sensor technology; and suggested approaches to the development of high-precision optical current and voltage sensors. Data on a number of materials are collected and presented. For high-precision electro-optic sensors, it is recommended that crystals of the polar class having point symmetry 43 m be used. For high-precision magneto-optic sensors, a lead glass with a low stress-optic coefficient is recommended. Choices for

Electro-Optic Metrology (cont'd.)

other components are also suggested.
For both types of sensors, a precision
of roughly ±1% over a 100°C temperature
range should be attainable. To achieve
a precision better than that, it will be
necessary to use temperature compensa-
tion techniques, several of which are
proposed and discussed.
[Contact: Gordon W. Day, (303)
497-5204]

Franzen, D.L., Yamabayashi, Y., and
Kanada, T., **Optical Sampling with
Gain-Switched, Pulse-Compressed Dis-
tributed-Feedback Laser Diodes**, Elec-
tronics Letters, Vol. 23, No. 6, pp.
289-290 (March 1987).

Chirped pulses from gain-switched, dis-
tributed feedback laser diodes at a
wavelength of 1.3 μm are compressed to
8.7 ps full width at half maximum by the
linear dispersion properties of single-
mode fiber. These pulses are used to
optically sample fast waveforms from
other 1.3-μm laser diodes. The high
time resolution sampling system uses a
fibre coupler to combine beams; this
eliminates critical alignment and
results in a practical design.
[Contact: Douglas L. Franzen, (303)
497-3346 or -5342]

Young, M., and Weppner, M., **Hybrid
Computer-Optical Processing With
Inexpensive Liquid Crystal
Television**, Proceedings of the 1986
International Optical Computing
Conference, Jerusalem, Israel, July
6-11, 1986, pp. 146-153 [SPIE - The
International Society for Optical
Engineering, P.O. Box 20, Bellingham,
WA 98227].

We describe a computer-optical
processing system that uses an
inexpensive liquid crystal television
monitor and a selective holographic
filter for coherent pattern recognition.
Specifically, we use a digital computer
to generate an edge-enhanced image of an
object, expose a Fourier transform

hologram of this image, and use the
hologram as a sort of matched filter for
recognizing the original object in real
time.
[Contact: Matt Young, (303) 497-3223 or
-5342]

Complex Testing

                Recently Published

Leedy, T.F., **A View of Metrology Sup-
port for ATE Systems**, The Reflector,
Vol. 35, No. 9, p. 20 (May 1, 1987).

Several approaches are used to assure
that automatic test equipment (ATE)
performs properly. The traditional
approach is the calibration and adjust-
ment of critical instruments contained
in the automatic test system by a cali-
bration laboratory where the performance
of the instrumentation is evaluated and
any necessary adjustments are made.
However, the normal operating environ-
ment experienced by the equipment in the
ATE system may be quite different than
that encountered in the calibration
laboratory where such effects as ele-
vated temperature and the presence of
high-frequency interfering signals (pos-
sibly produced by other instrumentation
and computers in the ATE system) may
degrade the performance of precision
measurement equipment. Thus, the user
of an ATE system, which has had instru-
ments removed and calibrated in a labo-
ratory, may have greater confidence in
the equipment performance than is war-
ranted.

Another calibration approach employed
with ATE systems is the use of various
types of built-in test or self-testing
schemes. If properly implemented, such
schemes may be valuable towards assuring
that measurements made by an ATE system
are consistent. However, such tech-
niques alone cannot perform a calibra-
tion function to determine the differ-
ence between values of physical quanti-
ties, such as voltage and frequency,
measured by the ATE system and those
measured quantities that have traceabil-
ity to national standards. For success-

Complex Testing (cont'd.)

ful calibration of a test system, a combination of traditional laboratory calibration techniques and built-in test techniques is usually desirable.
[Contact: Thomas F. Leedy, (301) 975-2410]

Other Fast Signal Topics

Released for Publication

Bell, B.A., **A Report on the NBS/CEEE Survey of Electronic Measurement Needs Below 10 MHz**, to be published in the Proceedings of the 1987 National Conference of Standards Laboratories Workshop and Symposium, Denver, Colorado, July 12-16, 1987.

This paper describes the results of a recent survey conducted by the Electrosystems Division of the Center for Electronics and Electrical Engineering at the National Bureau of Standards. A summary is provided of the data obtained on questions concerning critical electrical quantities and associated instrumentation and devices, automatic test equipment/complex measurement systems, and conducted electromagnetic interference.
[Contact: Barry A. Bell, (301) 975-2402]

Lehman, J., **Warming Up to Cold: A Curriculum Boost Using Cryogenics.**

Sometimes, a well-rounded curriculum for the physical sciences is burdened with bringing into the classroom topics that do not necessarily correspond to our daily observations and intuition. Heat, energy, resistance, kinetics, and countless other topics challenge not only the student's imagination, but also an instructor's ability to present such topics in realistic and interesting ways. Cryogenics, known informally as the science of cold, offers many avenues for learning beyond the obvious effects of cold temperature. This paper includes some justification, pedagogy,

and motivation for use of cryogenics in science curricula.
[Contact: John Lehman, (303) 497-3654]

Mattis, R.L., **A Day in the Life of a VAX System Manager**, to be published in The DEC Professional.

A day in the life of a VAX system manager is presented in the form of a diary showing what an eight-hour day really looks like.
[Contact: Richard L. Mattis, (301) 975-2235]

Oates, C.W., and Young, M., **Microscope Objectives, Cover Slips, and Spherical Aberration.**

Microscope objectives with powers of 20X and higher will display significant spherical aberration when used to examine an optical fiber without a cover slip.
[Contact: Matt Young, (303) 497-3223 or -5342]

Recently Published

Sorrells, J.R., **A Survey of Electronic Measurement Needs Below 10 MHz**, NBSIR 87-3549 (June 1987).

The results of a survey to assess the electronic measurement needs from dc to 10 MHz are presented. The questionnaire used in the survey covered three broad areas of measurement need: 1) basic electrical quantities and related precision instruments, 2) automatic test equipment and other complex measurement systems, and 3) conducted electromagnetic interference. The data provided by 527 respondents are summarized, and the results of various analyses are described. Several conclusions, suggested by the analyses, are also discussed.
[Contact: Barry A. Bell, (301) 975-2402]

Weppner, M., and Young, M., **Image Processing for Optical Engineering Applications**, NBSIR 87-3065 (April

Other Fast Signal Topics (cont'd.)

1987).

This report describes the development
and testing of image processing software
designed for optical engineering appli-
cations.   Image processing functions in
this software include two-dimensional
Fourier transforms, convolution, noise
reduction, multiple image resolutions,
and low-level image processing func-
tions. The software also contains image
information display tools including
Gaussian beam and g-profile characteri-
zation for optical fiber measurements.
The necessary image file input/output
routines are presented in the software
and are used to read and store images in
conjunction with other image processing
software, digitizing cameras, and output
display devices.
[Contact: Matthew Weppner, (303)
497-3223]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Fenimore, C., and Hebner, R.E., **The
Thermally Induced Growth of Bubbles:
An Arc in a Liquid.**

The effects of an electrical arc on a
liquid in which it burns are modeled as
an expanding bubble. The arc is treated
as a heat source with a specified sur-
face temperature, radius, and duration.
The mass and pressure in the bubble grow
as the flow of heat to the bubble sur-
face vaporizes the liquid.   The bubble
does work as it expands against the
external pressure field in the liquid.
The model is a system of ordinary dif-
ferential equations which are solved for
the bubble radius as a function of time
and for the maximum bubble size as a
function of the ambient pressure in the
liquid. These computations are compared
with the corresponding measured quanti-
ties in an experiment in which an arc is
ignited in water at ambient pressures

ranging between 0.1 and 15 MPa.
[Contact: Charles Fenimore, (301)
975-2428]

Hebner, R.E., Kelley, E.F., FitzPatrick,
G.J., and Forster, E.O., **The Effect
of Pressure on Streamer Inception and
Propagation in Liquid Hydrocarbons.**

This paper shows that for pressures
between 0.1 and 5.0 MPa, the structure
of a streamer originating from a cathode
is significantly modified while that
initiating from an anode is relatively
unchanged, in toluene and hexane. For
cathode streamers, the inception voltage
increased from 40 ± 6 kV at 0.1 MPa to
99 ± 22 kV at 5.0 MPa.   For anode
streamers, the inception voltage
increased from 53 ± 6 kV at 0.1 MPa to
123 ± 55 kV at 5.0 MPa.
[Contact: Robert E. Hebner, (301)
975-2403]

Lagnese, J., and McKnight, R.H., **Esti-
mates of Confidence Intervals for
Divider Distorted Waveforms**, to be
published in the Proceedings of the 5th
International High Voltage Symposium,
Braunschweig, West Germany, August
20-21, 1987.

This paper describes a method for com-
puting confidence intervals for a high
voltage impulse distorted by a divider
system. The technique is based on a
recent algorithm designed to calculate
confidence intervals for solutions to
ill-posed problems subject to inequality
constraints. Applications of the method
to measurements made with a resistive
divider illustrate its value for obtain-
ing useful stochastic error bounds for
high-voltage impulse restoration.
[Contact: Ronald H. McKnight, (301)
975-2431]

Misakian, M., **Appendix A.   Exposure
Systems and Measurements**, National
Council on Radiation Protection and
Measurements (NCRP) Report on ELF Field
Effects.

This appendix describes apparatus that

Power Systems Metrology (cont'd.)

can be used to generate electric and magnetic fields in the laboratory for bioeffects studies. A number of electrical parameters which are useful for characterizing the fields are identified and methods for their measurement are described. Emphasis is given to describing exposure systems which simulate the electric and magnetic fields in the vicinity of ac power lines and which are suitable for small animal studies. The measurement techniques may be used to determine higher frequency ac fields provided that the criterion for quasi-static fields that $f \ll c/\sqrt{2}\pi L$ is satisfied. Here f is the frequency, c is the velocity of light, and L is a significant dimension of the structure being considered. The generation and measurement of power-frequency electric fields in conductive media, for in vitro studies, and the radiofrequency electromagnetic fields which are sinusoidally amplitude-modulated at extremely low frequencies are discussed briefly. Methods for generating and measuring pulsed magnetic fields are also considered briefly. References which give more complete accounts of these subjects are provided.
[Contact: Martin Misakian, (301) 975-2426]

Sieck, L.W., and Van Brunt, R.J., **Rate Constants for F⁻ Transfer from SF_6 to Fluorinated Gases and SO_2. Temperature Dependence and Implications for Electric Discharge in SF_6.**

The reactivity of SF_6^- towards SO_2, SOF_2, SO_2F_5, SOF_4, SF_4, and SiF_4 has been investigated using the technique of pulsed-electron-beam, high-pressure mass spectrometry. With the exception of the $SF_6^- + SiF_4$ reaction, all of the pairs exhibited a negative temperature coefficient in that the rate constants for F⁻ transfer decreased substantially with increasing temperature. The reaction $SF_6^- + SiF_4 \rightarrow SiF_5^- + SF_5$ was found to proceed with a rate constant of 5.6 ± 0.8 × 10^{-10} cm³/mol-s throughout the

temperature range studied (298 to 510 K), which corresponds to a collision efficiency of unity. The other reactions were found to approach unit collision efficiency only at reduced temperatures (<300 K).
[Contact: Richard J. Van Brunt, (301) 975-2425]

Van Brunt, R.J., Aschwanden, T., and Bieber, M.E., **Analysis of Dielectric Strength Data for Binary Electronegative Gas Mixtures**, to be published in the Proceedings of the 18th International Conference on Phenomena in Ionized Gases, University of Wales, United Kingdom, July 12-16, 1987.

The consistency among dielectric strength, electron swarm, and collision cross-section data for ionization, attachment, and momentum transfer has been determined for the binary gas mixtures SF_6/He, SF_6/Ne, SF_6/Ar, and SF_6/CO_2 using a theoretical approach recently developed by Van Brunt. Dielectric strength data for SF_6/Ar and SF_6/CO_2 measured by Aschwanden can be accurately described by the model calculation and exhibit a high degree of consistency with swarm and cross-section data. The model also appears to successfully describe preliminary electrical breakdown data for SF_6/Ne mixtures. The theoretical model fails for SF_6/He because it does not allow for the important effect of Penning ionization which is possible in this case.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Van Brunt, R.J., Herron, J.T., and Fenimore, C., **Corona-Induced Decomposition of Dielectric Gases**, to be published in the Proceedings of the Fifth International Symposium on Gaseous Dielectrics, Knoxville, Tennessee, May 3-7, 1987.

A three-zone model for chemical decomposition of electronegative gases in negative point-plane corona discharges is proposed which considers the discharge glow, ion-drift, and main gas volumes,

Power Systems Metrology (cont'd.)

respectively, as separate regions of diminishing chemical activity and increasing relative size. The proposed model is shown to be useful in predicting discharge by-product yields and the dependences of these yields on discharge current and gas mixture composition. As an example, the model is applied here to the decomposition of pressurized SF_6 containing trace levels of water vapor and is shown to yield results for oxyfluoride production that are in satisfactory agreement with observations.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Van Brunt, R.J., and Siddagangappa, M.C., **Identification of Corona Discharge-Induced SF_6 Oxidation Mechanisms Using $SF_6-{}^{18}O_2-H_2{}^{16}O$ and $SF_6-{}^{16}O_2-H_2{}^{18}O$ Gas Mixtures.**

The absolute yields of gaseous oxyfluorides SOF_2, SO_2F_2, SOF_4 from negative, point-plane corona discharges in pressurized gas mixtures of SF_6 with O_2 and H_2O enriched with ${}^{18}O_2$ and $H_2{}^{18}O$ have been measured using a gas chromatograph-mass spectrometer. The predominant SF_6 oxidation mechanisms have been revealed from a determination of the relative ${}^{18}O$ and ${}^{16}O$ isotope content of the observed oxyfluoride by-products. The results are consistent with previously proposed production mechanisms and indicate that SOF_2 and SO_2F_2 derive oxygen predominantly from H_2O and O_2, respectively, in slow, gas-phase reactions involving SF_4, SF_3, and SF_2 that occur outside of the discharge region. The species SOF_4 derives oxygen from both H_2O and O_2 through fast reactions in the active discharge region involving free radicals or ions such as OH and O, with SF_5 and SF_4.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Van Brunt, R.J., and Sieck, L.W.,

Transfer of F^- in Collisions of SF_6^- with Fluorinated Gases and SO_2 at Thermal Energies, to be published in the Proceedings of the Fifteenth International Conference on the Physics of Electronic and Atomic Collisions, Brighton, United Kingdom, July 22-28, 1987.

Measured temperature dependences of F^- transfer rates for collisions of SF_6^- with SOF_2, SO_2F_2, SOF_4, SO_2, SF_4, and SiF_4 are reported. The results are used to interpret the complex anionic chemistry that occurs during electrical discharges in SF_6.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Van Brunt, R.J., Sieck, L. W., Sauers, I., and Siddagangappa, M.C., **Transfer of F^- in SF_6^- + SOF_4 Collisions and Its Influence on SOF_4 Yield from Corona Discharges in Gases Containing SF_6.**

The temperature (T) and electric field-to-gas pressure (E/P) dependences of the rate constant k for the reaction $SF_6^- + SOF_4 \rightarrow SOF_5^- + SF_5$ have been measured. For T < 270 K, k approaches a constant of 2.1×10^{-9} cm^3/s, and for 433 K > T > 270 K, k decreases with T according to k(cm^3/s) = 0.124 exp (-3.3 ℓn T(k)). For E/P < 60 V/cm·torr, k has a constant value of about 2.5×10^{-10} cm^3/s, and for 130 V/cm·torr, the rate is approximately given by k(cm^3/s) ~ 7.0×10^{-10} exp(-0.022 E/P). This reaction is shown to be important in controlling the yield of SOF_4 from corona discharges in gas mixtures containing SF_4 and at least trace amounts of O_2 and H_2O. The observed behavior of SOF_4 production rates for negative, point-plane corona discharges is analyzed using k in a chemical kinetics model of the ion-drift region in the discharge gap, and it is shown that competing reactions not involving SOF_4 are effective in deactivating SF_6^-.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Power Systems Metrology (cont'd.)

Recently Published

Laug, O.B., **A Precision Power Ampli-fier for Power/Energy Calibration Applications,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, IMTC/87, Boston, Massachusetts, April 27-29, 1987, pp. 129-134.

A precision power amplifier for use in power/energy calibration applications is described. The amplifier was primarily designed to boost the output amplitude of a dual-channel digital generator to provide the nominal 120 or 240 rms volt-age component of a "phantom" calibration power source. The amplifier has a fixed gain of 40 and can provide a maximum output voltage swing of 970 Volts peak-to-peak or 340 V rms at 100 mA rms. The bandwidth is from dc to 150 kHz, and at 60 Hz the observed no-load, short-term amplitude and phase instabilities are ±5 ppm and ±5 microradians, respectively. The amplifier design uses high-voltage N-channel MOSFETs in the output driver stage together with a unique circuit topology of opto-isolators between the low-level input stage and the high-level output stage.
[Contact: Owen B. Laug, (301) 975-2412]

Misakian, M., McKnight, R.H., and Feni-more, C., **Calibration of Aspirator-Type Ion Counters and Measurement of Unipolar Charge Densities,** Journal of Applied Physics, Vol. 61, No. 4, pp. 1276-1287 (February 15, 1987). [A more extended treatment of this topic is given in NBS Technical Note 1223 (May 1986).]

The characterization of a parallel plate apparatus which can produce a unipolar charge density that is suitable for calibrating aspirator-type ion counters operating in the ground plane is de-scribed. Influences of a dc electric field, air motion, Coulomb repulsion, and diffusion on the transport of ions into the ion counter are examined to determine their effects on instrument calibration and measurements in the vicinity of high-voltage dc transmission lines. A charge density which is known with an uncertainty of less than ±9% is used to check the performance of an ion counter with and without a duct at its entrance.
[Contact: Martin Misakian, (301) 975-2426]

Van Brunt, R.J., **Common Parameteriza-tions of Electron Transport, Collision Cross Section, and Dielectric Strength Data for Binary Gas Mixtures,** Journal of Applied Physics, Vol. 61, No. 5, pp. 1773-1787 (March 1, 1987).

Previously used parameterizations of dielectric strengths (electrical break-down data) for gas mixtures in terms of electron collision and transport parame-ters are reviewed. A new method of fitting experimental data on dielectric strengths for binary electronegative gas mixtures is proposed based upon the principal assumption that the electron kinetic energy distributions in the gas are Maxwellian. The method provides physical insight into such behavior as pressure-dependent or pressure-indepen-dent synergisms, and is useful in check-ing the consistency between dielectric strength data and available information on electron transport and ionization, attachment, and momentum transfer col-lision cross sections. The method is applied here to the mixtures SF_6/N_2, $CC\ell_2F_2/N_2$, and $SF_6/CC\ell_2F_2$.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Pulse Power Metrology

Released for Publication

Lagnese, J., and McKnight, R.H., **Cal-culation of Confidence Intervals for High Voltage Impulse Reconstruction.**

A recently described algorithm designed to calculate confidence intervals for solutions to ill-posed problems subject

Pulse Power Metrology (cont'd.)

to inequality constraints is applied to the calculation of confidence intervals for a high-voltage impulse distorted by a divider system. Applications of the method to measurements made with resistive and capacitive dividers illustrate its value for obtaining useful stochastic error bounds for high-voltage impulse restoration.
[Contact: Ronald H. McKnight, (301) 975-2431]

McKnight, R.H., **Measuring Fast-Rise Impulses by Use of E-Dot Sensors**, to be published in the Proceedings of the 5th International High Voltage Symposium, Braunschweig, West Germany, August 20-21, 1987.

Field coupled sensors such as capacitive dividers, derivative (E-dot or B-dot) sensors and Rogowski coils, are commonly used in pulse power applications. Measurement devices using E-dot sensors in combination with passive or active integrators provide broadband capability, but with limited sensitivity. The use of this category of sensor in measurements of fast rise pulses, such as electromagnetic pulse, in power system equipment offers some advantages, such as ease of construction and versatility in installation.
[Contact: Ronald H. McKnight, (301) 975-2431]

Superconductors

Released for Publication

Ekin, J.W., **Effect of Transverse Compressive Stress on the Critical Current and Upper Critical Field of Nb_3Sn.**

A large reversible degradation of the critical current of multifilamentary Nb_3Sn superconductors has been observed under the application of uniaxial compressive stress at 4 K applied transverse to the conductor axis. In bronze-process multifilamentary Nb_3Sn, the onset of significant degradation occurs

at about 50 MPa. In an applied field of 10 T, the magnitude of the effect is about seven times larger for transverse stress than for stress applied along the conductor axis. The transverse stress effect increases with magnetic field and is shown to have its origin in a reversible degradation of the upper critical field. The intrinsic effect of transverse stress on the upper critical field is about ten times greater than for axial stress. It is shown that the transverse stress from the Lorentz force on the conductor is proportional to conductor thickness, and thus the effect will need to be considered in the internal stress design of large magnets. The effect may be particularly significant in cabled conductors where large transverse stress concentrations can occur at strand crossover points.
[Contact: John W. Ekin, (303) 497-5448]

Ekin, J. W., **Transport Critical Currents in Bulk Sintered $Y_1Ba_2Cu_3O_x$ and Possibilities for Its Enhancement.**

Several general processing methods for increasing the critical current density, J_c, in a bulk sintered $Y_1Ba_2Cu_3O_x$ superconductor are outlined. Data are presented which indicate that the transport J_c in bulk polycrystalline specimens is dominated by a weak-link region between high-J_c grains and that potentially much higher J_c is possible. Two possible causes of the weak-link phenomenon are considered: non-high-T_c phases or impurities localized in the grain boundary region and anisotropy of the superconducting properties. Several methods for minimizing the weak-link effects to increase the J_c are discussed.
[Contact: John W. Ekin, (303) 497-5448]

Ekin, J.W., **Transverse Stress Effect on Multifilamentary Nb_3Sn Superconductor**, to be published in Advances in Cryogenic Engineering, Volume 34, 1988.

Superconductors (cont'd.)

A large reversible degradation of the critical current of multifilamentary Nb_3Sn superconductors has been observed under the application of uniaxial compressive stress at 4 K applied transverse to the conductor axis. In bronze-process multifilamentary Nb_3Sn, the onset of significant degradation occurs at about 50 MPa. The intrinsic effect of transverse stress on the upper critical field is about ten times greater than for axial stress. Although transverse stress on the Nb_3Sn filaments is less than axial stress, it will need to be considered in the internal stress design of large magnets. The effect scales with conductor thickness and consequently will place limits on conductor dimensions and the spacing between distributed reinforcement in large magnets.
[Contact: John W. Ekin, (303) 497-5448]

Ekin, J.W., Panson, A.J., Braginski, A.I., Janocko, M.A., Hong, M., Kwo, J., Liou, S.H., Capone, D.W., and Flandermeyer, B., **Transport Critical-Current Characteristics of $Y_1Ba_2Cu_3O_x$**, to be published in the Proceedings of the Materials Research Society Symposium on High Temperature Superconductors, Anaheim, California, April 23-24, 1987.

Voltage vs. current (V-I) characteristics were measured at magnetic fields up to 24 T at temperature of 77 K in several $Y_1Ba_2Cu_3O_x$ samples fabricated at different laboratories. Critical temperatures, T_c, measured by resistivity were about 93 K. All samples showed linear V-I characteristics at current levels much greater than the critical current, I_c. However, the slope was significantly less than the normal resistance at T_c. The slope increased with magnetic field and reached the normal resistance value only at fields greater than 24 T. Values of the transport critical-current density J_c near zero magnetic field were generally low and variable (about 1 to 200 A/cm^2).

The transport J_c fell sharply when magnetic field was applied, decreasing by about an order of magnitude between 10^{-3} T and 1 T. This leads to an effective upper critical field for transport critical currents in $Y_1Ba_2Cu_3O_x$ that is significantly less than the upper critical field defined by the field at which the resistance increases to the normal-state value. The transport J_c appears to be significantly less than J_c calculated from magnetization data on similar samples. These results are consistent with the transport critical-current in the $Y_1Ba_2Cu_3O_x$ system being dominated by a "weak-link" region between high-J_c grains.
[Contact: John W. Ekin, (303) 497-5448]

Goldfarb, R.B., Clark, A.F., Panson, A.J., and Braginski, A.I., **AC Susceptibility Measurements Near the Critical Temperature of a Y-Ba-Cu-O Superconductor**, to be published in the Proceedings of the Materials Research Society Meeting, Anaheim, California, April 23-24, 1987.

The loss component of complex susceptibility of a Y-Ba-Cu-O superconductor near its critical temperature is strongly dependent on ac field amplitude but virtually independent of frequency. This implies that magnetic hysteresis is the major loss mechanism in these materials. The temperature at which the loss first becomes positive upon warming corresponds to an equivalence between the amplitude of the ac field and the lower critical field of the superconductor.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Goldfarb, R.B., Clark, A.F., Panson, A.J., and Braginski, A.I., **Evidence for Two Superconducting Components in Oxygen-Annealed Single-Phase Y-Ba-Cu-O**.

The complex susceptibility of a sintered Y-Ba-Cu-O superconductor is strongly dependent on ac field amplitude, h.

Superconductors (cont'd.)

Very small values of h must be used in order that the real component of susceptibility, X', reach a value corresponding to bulk diamagnetism just below the critical temperature, T_c. The imaginary component of susceptibility, X'', represents hysteresis loss in the sample. Thus, X'' versus temperature becomes positive when h exceeds the lower critical field, H_{c1}, of the superconductor.

Annealing the material in oxygen gives rise to two distinct components, a 'good' superconductor and a 'bad' superconductor, with different critical temperatures and lower critical fields. Curves of susceptibility versus temperature reflect the dual nature of the annealed sample: X' has an inflection at the T_c of the bad component and approaches zero at the T_c of the good component, while X'' has a peak at each T_c. Both critical temperatures decrease linearly with increasing h, though at very different rates. H_{c1} of the good component is vastly greater than H_{c1} of the bad component. The lower critical fields decrease linearly with increasing temperature.

Two possible models explain the susceptibility data. In one, the good component consists of superconducting grains and the bad component is intergranular Josephson material. In the second model, the good component is at the interior of the sample and the bad component is a surface region. This condition could arise if there was oxygen depletion at the surface subsequent to overall enrichment during annealing.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Goodrich, L.F., Bray, S.L., and Clark, A.F., **Current Ripple Effect on Superconductive DC Critical Current Measurements**, to be published in Advances in Cryogenic Engineering - Materials, Volume 34, 1988.

The effect of sample current power supply ripple on the measurement of dc critical current is reported. Measurements were made on multifilamentary NbTi superconductors. Ripple in a current supply becomes more significant above 500 A because effective filtering becomes more difficult. The presence of current ripple reduces the measured dc critical current. Ripple can also directly affect the voltmeter used for the measurements, because it has to operate with a noisy input. The quantitative effect of current ripple was studied using a battery current supply instrumented to allow the creation of ripple current with variable frequency and amplitude. Problems common to all large conductor critical current measurements are discussed.
[Contact: Loren F. Goodrich, (303) 497-3143]

Moreland, J., Ekin, J.W., Goodrich, L.F., Capobianco, T.E., and Clark, A.F., **Electron Tunneling Measurements in LaSrCuO and YBaCuO**, to be published in the Proceedings of the Materials Research Society Meeting, Anaheim, California, April 23-24, 1987.

The break junction technique whereby vacuum tunneling occurs within the fracture of a bulk sample is used to study the LaSrCuO and YBaCuO perovskite superconductors. Structure in the current-versus-voltage characteristics is reminiscent of previous quasiparticle curves obtained for BCS superconducting materials. Some curves have anomalous qualities, including large dips in the junction conductance with increasing voltage just above a well-defined tunneling gap edge, linearly increasing junction conductance with applied bias, along with features occurring near voltage intervals following a 1, 3, 5 pattern.
[Contact: John Moreland, (303) 497-3641]

Moreland, J., Goodrich, L.F., Ekin, J.W., Capobianco, T.E., and Clark, A.F., **Electron Tunneling Measurements**

Superconductors (cont'd.).

of High T_c Compounds Using Break Junctions, to be published in the Proceedings of the 18th International Conference on Low Temperature Physics, Kyoto, Japan, August 10-16, 1987.

We report on the break junction technique and its application to the high T_c superconductors LaSrCuO and YBaCuO. In this technique, bulk samples are fractured and the freshly fractured surfaces adjusted to form a tunneling junction with vacuum or liquid helium as the insulating barrier. Precise mechanical adjustment permits the study of electron tunneling phenomena between pieces of a bulk superconductor. The current-voltage characteristics of these break junctions are variable, indicating sample inhomogeneity. However, some junction settings result in the more familiar quasi-particle signatures in the current-voltage characteristics. Low-leakage junctions indicate the presence of a sharp superconductive energy gap as well as large variations in junction conductance above the gap edge in both materials.
[Contact: John Moreland, (303) 497-3641]

Moreland, J., Goodrich, L.F., Ekin, J.W., Capobianco, T.E., and Clark, A.F., Josephson Effect Above 77 K in a YBaCuO Break Junction.

We have observed the Josephson effect in a YBaCuO break junction. Critical currents as high as 10 mA were measured at 4 K for break junctions with a point contact within the fracture of a sample. The junction was susceptible to microwave radiation showing Shapiro steps with the ratio of V/f of 2.04 ± 0.05 $\mu V/Ghz$ compared to the pair tunneling value of $h/2e = 2.068$ $\mu V/GHz$. These steps were clearly visible in the current-voltage characteristics at temperatures up to 85 K.
[Contact: John Moreland, (303) 497-3641]

Recently Published

Goodrich, L.F., Bray, S.L., Dube, W.P., Pittman, E.S., and Clark, A.F., Development of Standards for Superconductors, Interim Report, January - December 1985, NBSIR 87-3066 (April 1987).

A cooperative program with the Department of Energy, the National Bureau of Standards, and private industry is in progress to develop standard measurement practices for use in large-scale applications of superconductivity. The goal is the adoption of voluntary standards for the critical parameters and other characterizations of practical superconductors. Progress for the period January through December 1985 is reported. The major effort was the measurement of large conductor critical current. Other work reported here includes stability and a discussion of possible future Standard Reference Materials.
[Contact: Loren F. Goodrich, (303) 497-3143]

Magnetic Materials and Measurements

Recently Published

Goldfarb, R.B., and Bussey, H.E., Method for Measuring Complex Permeability at Radio Frequencies, Review of Scientific Instruments, Vol. 58, No. 4, pp. 624-627 (April 1987).

An established method for measuring complex rf magnetic permeability is based on the change in inductance and resistance of a coaxial transmission line upon insertion of a sample toroid. It is not necessary to wind coils on the toroid or to correct for geometric demagnetization factors. The use of modern commercial impedance analyzers, as described in this paper, makes measurements from 1 kHz to 1 GHz particularly easy, fast, and accurate.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Magnetic Materials, etc. (cont'd.)

Moulder, J.C., and Capobianco, T.E., **Detection and Sizing of Surface Flaws With a SQUID-Based Eddy Current Probe,** Journal of Research of the National Bureau of Standards, Vol. 92, No. 1, pp. 27-33 (January-February 1987).

In a new approach to eddy current detection and sizing of surface-breaking flaws, we have coupled a conventional reflection probe to a superconducting quantum interference device (SQUID) to produce an eddy current probe with increased sensitivity and signal-to-noise ratio. The reflection probe consists of an air-core excitation coil surrounding two counterwound ferrite-core pickup coils connected in series. A room-temperature probe is inductively coupled to a SQUID, which operates in a liquid helium bath. The new probe was used to obtain flaw signals from a number of electrical-discharge machined (EDM) slots in aluminum alloy 6061. Results indicated that by scanning the probe along the length of the flaw, the length could be determined from the extent of the flaw signal. The peak amplitude of the flaw signal was found to be proportional to the cross-sectional area of the flaw. Empirical calibration curves relating these quantities were used to invert successfully the experimental data obtained for the EDM slots.
[Contact: Thomas E. Capobianco, (303) 497-3141]

ELECTROMAGNETIC INTERFERENCE

Radiated Electromagnetic Interference

Released for Publication

Adams, J.W., and Friday, D.S., **Measurement Procedures for Electromagnetic Compatibility Assessment of Electroexplosive Devices.**

Electroexplosive devices (EEDs) are electrically-fired explosive initiators used in a wide variety of applications.

The nature of most of these applications requires that the devices function with near certainty when required and otherwise remain inactive. Recent concern with pulsed electromagnetic interference and the nuclear electromagnetic pulse made apparent the lack of methodology for assessing EED vulnerability. A new and rigorous approach for characterizing EED firing levels is developed in the context of statistical linear models and is demonstrated in this paper. We combine statistical theory and methodology with thermodynamic modeling to determine the probability that an EED of a particular type fires when excited by a pulse of a given width and amplitude. The results can be applied to any type of EED for which the hot-wire explosive binder does not melt below the firing temperature of the primary explosive. Included are methods for assessing model validity and for obtaining probability plots, called "Firing Likelihood Plots." These statistical methods are both more general and more efficient than previous methods for EED assessment. The results provide information which is crucial for evaluating the effects of currents induced by impulsive electromagnetic fields of short duration relative to the thermal time constant of an EED. Methods of measuring the thermal time constant of an EED and the energy needed to fire an EED with a single current impulse are given. These parameters are necessary not only to determine suitable ranges in the design of the statistical experiment, but also in assessing the effect of pulses on EEDs in electromagnetic compatibility analyses.
[Contact: John W. Adams, (303) 497-3328]

Crawford, M.L., **A TEM Driven Reverberating Chamber: A Single Facility for Radiated EMS/V Testing, 10 kHz - 18 GHz?**

This paper discusses the design, operation, and evaluation of a transverse electromagnetic (TEM) transmission line-driven reverberating chamber for use in establishing radiated electromagnetic

Radiated EMI (cont'd.)

fields for susceptibility/vulnerability testing of electronic equipment. The potential range of application is from 10 kHz to 18 GHz. Included are brief descriptions of the facility, the operation procedures, how the test field amplitude is determined inside the chamber, and the evaluation of the chamber's electrical parameters such as VSWR, and electrical-field (E-field) strength as a function of input power. Also presented are the E-field spatial uniformity and a summary of measurement uncertainties and conclusions derived from the test results.
[Contact: Myron L. Crawford, (303) 497-5497]

FitzGerrell, R.G., **Monopole Impedance and Gain Measurements on Finite Ground Planes.**

The purpose of the work described here is to determine if it is possible to make "acceptably accurate" input impedance and gain measurements of monopoles on a reduced ground plane. Ideally, monopoles are 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. Measured and calculated data show that the diameter of a highly conducting ground plane should be at least 4 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 in diameter. Model impedance measurements and calculations presented here imply that a space only 10 m by 11 m is required by using 16 resistively loaded wire radials to extend a 3.66-m by 4.88-m rectangular aluminum ground plane. Measured insertion loss data acquired using a 1:5 scale model ground plane with resistively-loaded radials indicate that it is sufficiently large for gain measurements as well. Measured and calculated mono-

pole SWR and insertion loss of a full-scale ground plane verify the results of the model measurements.
[Contact: Mark T. Ma, (303) 497-3800]

Hill, D.A., **A Circular Array for Plane-Wave Synthesis.**

We analyze a circular array of electric line sources for generating a uniform plane wave in the interior region of the array. Identical results for the synthesized element weightings are obtained using matrix inversion or a Fourier series technique. A physical optics approximation for the element weightings is also presented, but it yields a much poorer result for the synthesized field. The angle of arrival of the plane wave can be scanned by recalculating the element weightings, and the quality of the field is maintained. Frequency scanning is also possible, but the number of array elements limits the maximum frequency.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., **Effect of a Thin Conducting Sheet on the Fields of a Buried Magnetic Dipole.**

The effect of a thin conducting sheet on the fields of a subsurface vertical magnetic dipole has been analyzed. The integral representation of the fields has been evaluated numerically, and numerical results for the vertical magnetic field above the source at the surface are presented in parametric form. It is found that the predicted fields give better agreement with previous transmission measurements than do the fields of a homogeneous half-space model.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., **Electromagnetic Scattering by Buried Objects of Low Contrast.**

The Born approximation is used to derive the plane-wave scattering matrix for objects of low dielectric contrast. For

Radiated EMI (cont'd.)

general shapes, a numerical integration over the volume of the scatterer is required, but analytical expressions are derived for a sphere, a circular cylinder, and a rectangular box (parallelepiped). Plane-wave, scattering-matrix theory is used to account for the air-earth interface. Numerical results are presented for the scattered near field and far field for plane-wave excitation. The scattered fields are weak for low-contrast objects, but the near-field results have application to electromagnetic detection of buried objects.
[Contact: David A. Hill, (303) 497-3472]

Misakian, M., **Appendix A. Exposure Systems and Measurements,** National Council on Radiation Protection and Measurements (NCRP) Report on ELF Field Effects.

This appendix describes apparatus that can be used to generate electric and magnetic fields in the laboratory for bioeffects studies. A number of electrical parameters which are useful for characterizing the fields are identified and methods for their measurement are described. Emphasis is given to describing exposure systems which simulate the electric and magnetic fields in the vicinity of ac power lines and which are suitable for small animal studies. The measurement techniques may be used to determine higher frequency ac fields provided that the criterion for quasi-static fields that $f \ll c/\sqrt{2}\pi L$, is satisfied. Here f is the frequency, c is the velocity of light and L is a significant dimension of the structure being considered. The generation and measurement of power-frequency electric fields in conductive media, for in vitro studies, and the radiofrequency electromagnetic fields which are sinusoidally amplitude-modulated at extremely low frequencies are discussed briefly. Methods for generating and measuring pulsed magnetic fields are also considered briefly. References which give more complete accounts of these subjects are provided.
[Contact: Martin Misakian, (301) 975-2426]

Vanzura, E., and Adams, J.W., **Generating Constant Electromagnetic Fields Inside a Partially-Loaded Shielded Room.**

This paper describes a computer-controlled feedback system that can maintain field strength levels within moderate bounds inside a partially-loaded shielded room. These levels are relatively uniform over a large enough volume to allow radiated immunity testing of moderate-sized objects. The frequency range depends on the characteristics of the transmit antenna; we used 50 to 200 MHz, which is otherwise a difficult range to cover because of limitations of other electromagnetic compatibility susceptibility test facilities. The measurement system consists of a computer, signal generator, amplifier, biconical antenna, and an isotropic probe system.
[Contact: John W. Adams, (303) 497-3461]

Wilson, P.F., **Relationships for Comparing Coaxial-Dipole Near-Field and Loaded-Aperture Material Shielding-Effectiveness Measurements.**

Shielding-effectiveness relationships are developed which allow covered aperture measurements (such as made in a dual TEM cell) to be compared to near-field, coaxial-dipole results. Low frequency approximations and the assumption that the shielding material is highly conductive lead to simple expressions in both cases.
[Contact: Perry F. Wilson, (303) 497-3842]

Recently Published

Crawford, M.L., and Koepke, G.H., **Preliminary Evaluation of Reverberation Chamber Method for Pulsed RF Immunity Testing,** Proceedings of the IEEE

Radiated EMI (cont'd.)

International Symposium on Electromagnetic Compatibility, San Diego, California, September 16-18, 1986, pp. 270-278.

This paper describes the evaluation of the performance characteristics of a reverberation chamber excited by pulsed rf (1.0 μs to 10 μs, 0.001 duty cycle) in the frequency range, 0.9 GHz to 10 GHz. The purpose of this work was to investigate the potential use of a reverberation chamber for pulsed rf immunity testing of electronic equipment. Information given includes a description of the reverberation chamber evaluated, the instrumentation used for performing the measurements, and results obtained showing the pulse dispersion characteristics of the chamber.
[Contact: Myron L. Crawford, (303) 497-5497]

Hill, D.A., **An Error Bound for Near-Field Array Synthesis**, IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-28, No. 4, pp. 273-276 (November 1986).

An expression for the upper bound of any component of the electric or magnetic field at any point in a region is derived in terms of a product of two surface field integrals. The result is most useful for bounding errors in near-field array synthesis, but might have other applications where upper bounds on field magnitudes are desired.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., **Radio-Wave Propagation From a Forest to a Clearing**, Electromagnetics, No. 6, pp. 217-228 (1986).

Kirchhoff integration over a vertical aperture is used to obtain a simple expression for radio-wave propagation from a forest to a clearing. Numerical results are presented for a frequency of 10 MHz, and the classical recovery effect is observed. Numerical comparisons

are made with a previous integral equation solution, and the agreement is good.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., and Koepke, G.H., **A Near-Field Array of Yagi-Uda Antennas for Electromagnetic Susceptibility Testing**, IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-28, No. 4, pp. 170-178 (November 1986) [condensed version of NBS Technical Note 1082, July 1985].

In electromagnetic-susceptibility testing of electronic equipment, the ideal incident field is a plane wave. To approximate this condition, a seven-element array of Yagi-Uda antennas has been constructed and tested at a frequency of 500 MHz. The element weightings are determined by a near-field synthesis technique, which optimizes the uniformity of the field throughout a rectangular test volume in the near field of the array. The amplitude and phase of the electric field have been measured throughout the test volume with a short-dipole probe, and the agreement with theory is excellent.
[Contact: David A. Hill, (303) 497-3472]

Kanda, M., and Driver, L., **An Isotropic Electric-Field Probe With Tapered Resistive Dipoles for Broadband Use, 100 kHz-18 GHz**, IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-35, No. 2, pp. 124-130 (February 1987) [also appeared in the Proceedings of the IEEE International Symposium on Electromagnetic Compatibility, San Diego, California, September 16-18, 1986, pp. 256-261].

A new broadband electric-field probe, capable of accurately characterizing and quantifying electromagnetic (EM) fields, has been developed at the National Bureau of Standards. The probe's 8-mm resistively tapered dipole elements allow measurement of electric fields between 1 and 1600 V/m from 1 MHz to 15

Radiated EMI (cont'd.)

GHz, with a flatness of ±2 dB. The mutually orthogonal dipole configuration provides an overall standard deviation in isotropic response, with respect to angle, that is within ±0.3 dB. Both the theoretical and developmental aspects of this prototype electric-field probe are discussed in this paper.
[Contact: Motohisa Kanda, (303) 497-5320]

Kanda, M., and Orr, R.D., **Near-Field Gain of a Horn and an Open-Ended Waveguide: Comparison Between Theory and Experiment,** Proceedings of the Fifth International Conference on Electromagnetic Compatibility, University of York, September 29-October 2, 1986 (sponsored by the Institution of Electronic and Radio Engineers, London, England), pp. 137-145.

This paper gives the theory and supporting experimental measurements for the near-field gain of a rectangular pyramidal horn and an open-ended waveguide (OEG) at 450 MHz. The empirical near-field gain for the OEG is derived from experimental results obtained by a two-antenna method at about 2 GHz. The theoretical near-field gain for the rectangular pyramidal horn is derived from Schelkunoff's formula. Two independent near-field gain measurements of these antennas are made using a three-antenna method and a transfer-standard-probe method. The discrepancy between theoretical and experimental results is typically less than ±1 dB.
[Contact: Motohisa Kanda, (303) 497-5320]

Randa, J.P., and Kanda, M., **A Lattice Approach to Complex Electromagnetic Environments,** Proceedings of the IEEE International Symposium on Electromagnetic Compatibility, San Diego, California, September 16-18, 1986, pp. 329-331.

We outline an approach to the characterization of complicated electromagnetic environments based on a lattice (finite-difference) approximation to Maxwell's equations. Approximate solutions to the equations are found numerically, subject to constraints imposed by boundary conditions and by measurements of the field at some number of points. The technique is illustrated by simple two- and three-dimensional examples.
[Contact: James P. Randa, (303) 497-3150]

Reeve, G.R., **Alternate EMI Measurement Techniques for Microelectronic Circuits,** Symposium Record, EMC EXPO 86 International Conference on Electromagnetic Compatibility, Washington, D.C., June 16-19, 1986, pp. T26.1-T26.4.

The purpose of this paper, which was orginally presented as an unpublished talk at a seminar held in March 1985 at the National Bureau of Standards in Gaithersburg, Maryland, is to suggest some new possibilities in metrology for evaluating the effects of electromagnetic interference on microelectronics and integrated circuits in particular.

With increasingly complex integrated circuits being designed for the Very-Large-Scale Integrated Circuit (VLSI) programs, and the Very High Speed Integrated Circuit (VHSIC) programs, utilizing larger chip areas and smaller device geometries, there is some concern that these units, either by themselves or in application circuits will prove more susceptible to the effects of electromagnetic interference (EMI). Existing techniques using pin voltage upset measurements may not be sufficient to properly characterize the behavior of these integrated circuits in the presence of EMI. Some possible adaptations of EMI measurement techniques presently in use or being developed at the National Bureau of Standards and other laboratories are presented for consideration.
[Contact: George R. Reeve, (303) 497-3557]

Wilson, P.F., and Ma, M.T., **Shielding Effectiveness Measurements Using an**

Radiated EMI (cont'd.)

Apertured TEM Cell in a Reverberation Chamber, Proceedings of the IEEE International Symposium on Electromagnetic Compatibility, San Diego, California, September 16-18, 1986, pp. 265-269.

Measurements of near-field shielding effectiveness are performed in a reverberation chamber using an apertured transverse electromagnetic cell as the receiver. This configuration allows one to investigate the electric- and magnetic-field shielding properties of a material simultaneously. Coupling to the cell is modeled using small-aperture theory, and predicted results agree well with measured data.
[Contact: Perry F. Wilson, (303) 497-3842]

Conducted Electromagnetic Interference

Recently Published

Martzloff, F.D., and Gruzs, T.M., **Power Quality Site Survey: Fact, Fiction and Fallacies**, Conference Record, Industrial & Commercial Power Systems Technical Conference, Nashville, Tennessee, May 4-7, 1987, pp. 21-33 [also to appear in IEEE Transactions on Industry Applications].

The quality of the power supplied to sensitive electronic equipment is an important issue. Monitoring disturbances of the power supply has been the objective of various site surveys, but results often appear to be instrument- or site-dependent, making comparisons difficult. After a review of the origins and types of disturbances, the types of monitoring instruments are described; a summary of nine published surveys reported in the last 20 years is presented. A close examination of underlying assumptions allows meaningful comparisons which can reconcile some of the differences. Finally, the paper makes an appeal for improved definitions and applications in the use of monitoring instruments.
[Contact: Francois D. Martzloff, (301) 975-2409]

Reeve, G.R., **Alternate EMI Measurement Techniques for Microelectronic Circuits**, Symposium Record, EMC EXPO 86 International Conference on Electromagnetic Compatibility, Washington, D.C., June 16-19, 1986, pp. T26.1-T26.4.

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[Contact: George R. Reeve, (303) 497-3557]

ADDITIONAL INFORMATION

Lists of Publications

Gibson, K.A., Page, J.M., and Miller, C.K.S., **A Bibliography of the NBS Electromagnetic Fields Division Publications**, NBSIR 85-3040 (February 1986).

Lists of Publications (cont'd.)

This bibliography lists publications of the National Bureau of Standards' Electromagnetic Fields Division for the period from January 1984 through September 1985, with selected earlier publications from the Division's predecessor organizations.
[Contact: Kathryn A. Gibson, (303) 497-3132]

Kline, K.E., and DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications,** NBSIR 86-3048 (June 1986).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NBS in the period from January 1970 through December 1985. A few earlier references that are directly related to the present work of the Division are included.
[Contact: Kathryn E. Kline, (303) 497-3678]

Palla, J.C., and Meiselman, B., **Electrical and Electronic Metrology: A Bibliography of NBS Electrosystems Division Publications, NBS List of Publications 94** (January 1987).

This bibliography covers publications of the Electrosystems Division, Center for Electronics and Electrical Engineering, NBS, and of its predecessor sections for the period January 1963 to January 1987. 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: A Bibliography of NBS Publications for the Years 1962-1986,** NBSIR 87-3522 (February 1987).

This bibliography contains reports of work performed at the National Bureau of Standards in the field of Semiconductor Measurement Technology in the period from 1962 through December 1986. An

index by topic area and a list of authors are provided.
[Contact: E. Jane Walters, (301) 975-2050]

1987 CEEE CALENDAR

September 22-25 (Boulder, CO), **Noise Measurement Seminar.**

CANCELED

October 26-28 (Boulder, CO)

Symposium on Optical Materials for High Power Lasers (Nineteenth Boulder Damage Symposium). This Symposium is cosponsored by the National Bureau of Standards, the American Society for Testing and Materials, the Air Force Office of Scientific Research, the Office of Naval Research, and the Defense Advanced Research Projects Agency and constitutes a principal forum for the exchange of information on the physics and technology of materials for high-power lasers.

Topics to be discussed include new materials, bulk damage phenomena, surface and thin-film damage, design considerations for high-power systems, and fundamental mechanisms of laser-induced damage. Proceedings of the Symposium will be published (Note: The collection of Symposium proceedings contains information on optics for all aspects of high-power/high-energy lasers, including environmental degradation, durability, fabrication, material growth and deposition processes, and testing). [Contact: Susie A. Rivera (303) 497-5342]

December 10-11 (Gaithersburg, MD)

Power Semiconductor Devices Workshop. This Workshop, sponsored jointly by IEEE and NBS, is intended to bring together for interactive participation those actively working in the field of power semiconductor devices. It will be held in conjunction with the 1987 IEEE International Electron Devices Meeting in Washington, DC. Four specific topic

1987 CEEE Calendar (cont'd.)

areas have been selected, based on the response to a questionnaire sent to over 200 power device researchers worldwide. They are: power and high voltage integrated circuits, discrete devices, device modeling, and packaging. Attendees are expected to be prepared to contribute to the development of responses to specific questions that arise in the context of the particular topic areas; a final schedule identifying the topic areas should be available at the end of October. [Contact: David L. Blackburn, (301) 975-2053]

1988 CEEE Calendar

February 10-12 (San Diego, CA)

IEEE Semiconductor Thermal and Temperature Measurement Symposium. This fourth annual **SEMI-THERM** symposium is sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE in cooperation with NBS and constitutes an international forum for the presentation of new developments in, and applications relating to, generation and removal of heat within semiconductor devices and measurement of junction temperatures experienced in various applications and environments. Major SEMI-THERM topic areas include thermal measurements, thermal characterization, applications, and computation and software.

The program includes keynote speakers, technical presentations, tutorial sessions, workshops, and an exhibit. In addition, the Semiconductor Equipment and Materials Institute has scheduled in conjunction with SEMI-THERM a meeting of its Thermal Measurements Task Force, to which attendees are invited. [Contact: Frank F. Oettinger, (301) 975-2054]

May 11-13 (Los Angeles, CA)

Intersociety Conference on Thermal Phenomena in Fabrication and Operation of Electronic Components. This Con-

ference is sponsored by the Components, Hybrids, and Manufacturing Technology Society of the IEEE, in cooperation with ASME Committee K-16 on Heat Transfer and NBS. It is intended to provide an interdisciplinary forum for exploring the progress made in understanding, analyzing, and modeling thermal transport processes and thermally induced failures in the fabrication, assembly, and use of logic, memory, and data-storage systems. Major topic areas covered are 1) processing and fabrication, including state-of-the-art semiconductor crystal growing techniques; thermal stress in wafers, chips, substrates, PC boards, and joints; and encapsulant behavior with respect to solidification, outgassing, mechanical properties, and water vapor diffusion and absorption; 2) packaging technology, including means for cooling components from cryogenic to high temperatures and reliability as affected by failure mechanisms such as dopant migration and intermetallic growth; and 3) peripheral equipment, including data storage in both magnetic and optical media and thermal issues in dot-matrix and thermal printer heads. The conference is being held in conjunction with the Electronics Components Conference (May 9-11) at the same site. [Contact: Frank F. Oettinger, (301) 975-2054]

Planned

Early summer (Vail, CO)

Combined Short Course on Optical Fiber and Laser Measurements. [Contact: Aaron A. Sanders, (303) 497-5341]

Early fall (Boulder, CO)

Fiber Optics Symposium. [Contact: Aaron A. Sanders, (303) 497-5341]
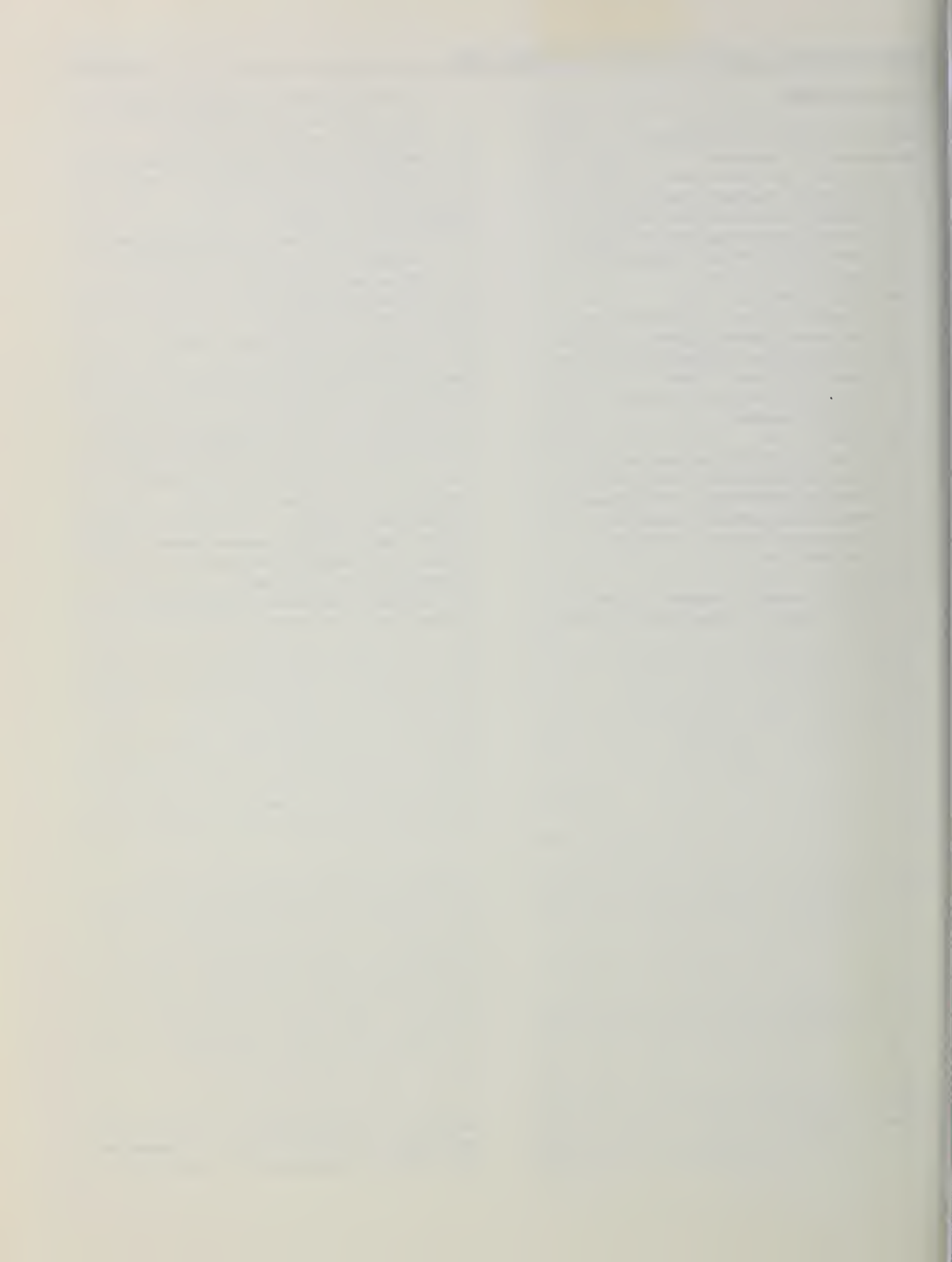
Late fall (Boulder, CO)

Symposium on Optical Materials for High Power Lasers (20th Boulder Damage Symposium). [Contact: Aaron A. Sanders, (303) 497-5341]
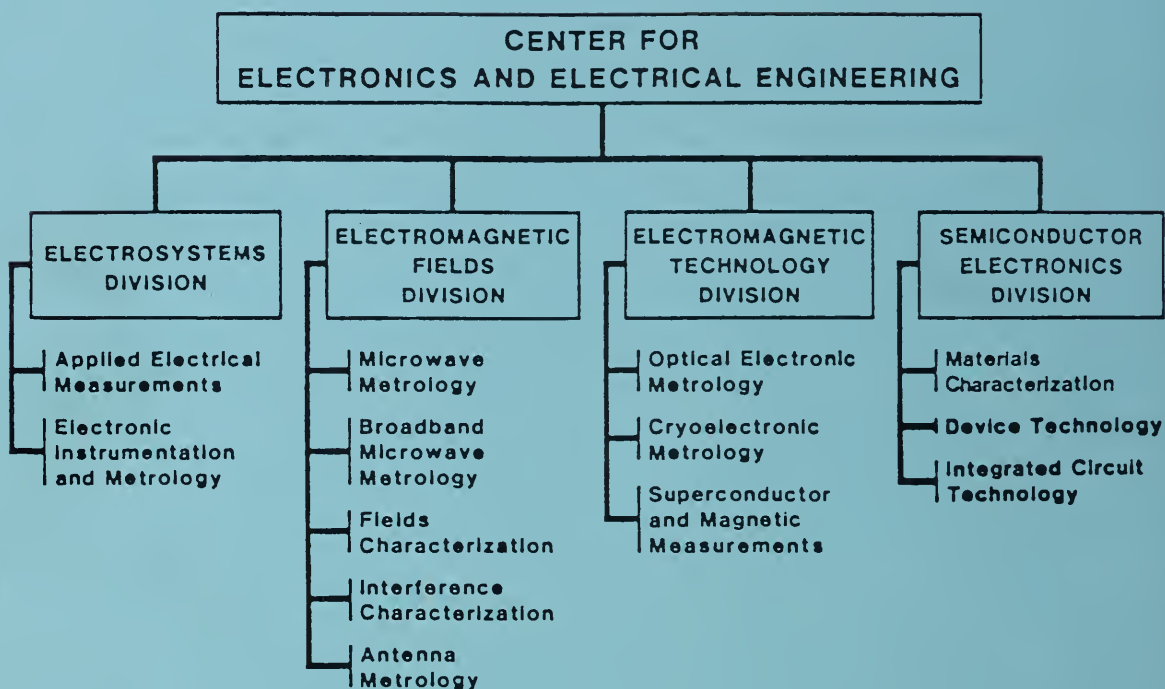
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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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This is the nineteenth issue of a quarterly publication providing information on the technical work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the second quarter of calendar year 1987. Abstracts are provided by technical area for both published papers and papers approved by NBS for publication.

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