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INTRODUCTION TO MAY 1987 ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the fifteenth 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 1986.

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 Unpublished papers appear under the subheading "Released for Publication".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 and a list of sponsors of the work.

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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.

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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 31.

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 28.

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SEMICONDUCTOR TECHNOLOGY

Silicon Materials

Released for Publication

Mayo, S., and Lowney, J.R., **Photoionization Cross-Section Studies of the Platinum-Donor Center in Silicon.**

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 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 ≃ 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]

Analysis Techniques

Released for Publication

Bouldin, C.E., Forman, R.A., and Bell, M.I., **Conversion Yield EXAFS Measurements of Ion-Damaged GaAs.**

Extended x-ray absorption fine structure (EXAFS) measurements of ion-implanted GaAs have been made using conversion electron detection. This total electron yield detection technique (termed CEEXAFS) allows near-surface sensitivity with a sampling depth of 700 to 1000 Å. Measurements of the Ga absorption edge show that implantation of 10^{16} cm^{-2} of Zn ions at 180 keV into GaAs produces heavy lattice damage (amorphization) to a depth of about 700 to 900 Å. After rapid thermal annealing, the amorphous layer is found to be recrystallized and structurally indistinguishable from unimplanted material. The sampling depth of CEEXAFS has been measured for the first time, using standards with known depth dependent structure. The CEEXAFS technique greatly reduces Bragg peak contamination of the EXAFS signal from single crystal materials, and allows measurement of a variety of samples which cannot be fabricated as thin layers for conventional transmission or fluorescence EXAFS measurements. The method permits examination of the local environment of host atoms (in this case Ga) in the near surface region without interference from the underlying bulk and without the distortions found in fluorescence EXAFS measurements of concentrated samples.
[Contact: Charles E. Bouldin, (301) 975-2046]

Recently Published

Baghdadi, A., Gladden, W.K., and Flach, D.R., **Nonlinear Effects of Digitizer Errors in FT-IR Spectroscopy**, Appl. Spectroscopy, Vol. 40, No. 5, pp. 617-628 (1986).

This paper is an investigation of the effects of errors in the analog-to-digital converter (ADC) of a Fourier transform infrared (FT-IR) spectrometer on the photometric accuracy of that spectrometer. The effect of ADC errors on the spectrum after Fourier transfor-

Analysis Techniques, cont'd.

mation are calculated analytically for monochromatic, two-line and wide square band emission spectra. Numerical modeling is used to extend the analysis to absorption spectra, and to include the effects of noise on the amplitude of absorbance bands. These analyses show that ADC errors can generate artifacts throughout the spectrum, although the largest effects occur at sharp spectral features. Errors as large as 8% in the amplitude of absorbance bands can be produced by ADC errors of one least significant bit (LSB), in a 15-bit ADC. These results were confirmed qualitatively by measuring the net height of the oxygen vibrational band in silicon at 1107 cm^{-1} using four different ADC circuit boards in the same FT-IR spectrometer. At the highest signal levels, the boards disagreed by as much as 4%, even though the static transfer characteristics of the ADC boards (which were measured in a separate experiment) exhibited errors of less than ±2 LSBs.
[Contact: Aslan Baghdadi, (301) 975-2062]

Dimensional Metrology

Recently Published

Chandler-Horowitz, D., **Semiconductor Measurement Technology: Analytic Analysis of Ellipsometric Errors**, NBS Special Publication 400-78 (May 1986).

A computer program is given that contains an explicit ellipsometric error analysis. The program can identify the ellipsometric inaccuracies for any ellipsometer, can be used to determine which parameters contribute the most to the overall measurement inaccuracy, and can lead one to an optimum measurement procedure. A FORTRAN program that performs the evaluation of the partial derivative expressions needed to analyze ellipsometric measurement uncertainties is listed. The program determines the uncertainty in the calculation of the refractive index of a bare isotropic substrate or the uncertainty in the determination of the thickness and refractive index of a nonabsorbing film on a substrate of known refractive index. These are the two most commonly used surface models used in ellipsometry performed at a single angle of incidence and a single wavelength. The program input parameters include the wavelength of the light, the angle of incidence and its uncertainty, and the uncertainties in the ellipsometric parameters Δ and ψ. They also include in the ambient-substrate model an estimated value for the substrate's refractive index, and in the film-substrate model the refractive index of the substrate and its uncertainty and estimated values for the film's refractive index and thickness. The case of the conventional null ellipsometer utilizing a quarter-wave plate is treated to find the uncertainties in Δ and ψ from the uncertainties in the polarizer and analyzer null values and the waveplate constants.
[Contact: Deane Chandler-Horowitz, (301) 975-2084]

Nyyssonen, D., **Linewidth Calibration for Bright-Chromium Photomasks**, NBSIR 86-3357 (May 1986).

Linewidth measurement errors are introduced when an anti-reflective (AR) chromium photomask standard such as the NBS SRM 474/475 is used to calibrate an optical linewidth measurement system for subsequent measurements on another material such as bright chromium whose optical properties (index of refraction, thickness, reflectance, and edge geometry) do not match those of the calibration standard. In addition to differences in the optical properties of the materials, the magnitude of these errors varies from system to system and depends upon resolution, choice of edge-detection criterion, flare light in the optical system, and detector response. These errors are greatest when measurements are made in reflected light due to the greater sensitivity to the mismatch in optical parameters of the materials between the calibration standard (AR-

Dimensional Metrology, cont'd.

chromium) and the material to be measured (bright chromium). This report, therefore, recommends use of transmitted light for linewidth measurements on photomasks and as close a match as possible between the material parameters of the calibration standard and those of the part being measured in order to ensure a realistic assessment of the accuracy and precision of subsequent measurements.
[Contact: Robert D. Larrabee, (301) 975-2298]

Integrated Circuit Test Structures

Released for Publication

Cresswell, M.W., Pessall, N., Linholm, L.W., and Radack, D.J., **The Use of Artificial Intelligence and Microelectronic Test Structures for Evaluation and Yield Enhancement of Microelectronic Interconnect Systems**, to be published in the Proceedings of the Conference on VLSI Multilevel Interconnection, Santa Clara, California, June 9-11, 1986.

A major factor limiting the production and performance of high-density VLSI integrated circuits is the fabrication of reliable interconnect systems. Properly designed microelectronic test structures and appropriate test methods can be used to characterize the processes used to fabricate these systems. However, the computer-controlled testing of comprehensive process evaluation and diagnosis structures often results in large quantities of data which cannot be readily or effectively interpreted by the user. As a result, important features of the data are often overlooked or not considered in the evaluation of the fabrication processes. This paper describes an expert system for assisting the user to interpret test results associated with fabricating selected aspects of VLSI interconnect systems.
[Contact: Loren W. Linholm, (301) 975-2052]

Galloway, K.F., Diehl, S.E., and Linholm, L.W., **Metrological Challenges in Semiconductor Technology: Electrical Measurements of Dimensions and Materials Properties Using Integrated Circuit Test Structures**, to be published in the Proceedings of the International Conference on Semiconductor & Integrated Circuit Technology, Beijing, China, October 19-26, 1986.

The effective characterization and control of the materials, processes, devices, and circuits for very-large-scale integration (VLSI) is a major concern for semiconductor technology development. This paper reviews the types of metrological requirements associated with VLSI semiconductor technology and examines dimensional measurements and materials characterization at the wafer or chip level. Integrated circuit test structures for electrical measurements of dimensions and material properties are described.
[Contact: Loren W. Linholm, (301) 975-2052]

Process and Device Modeling

Recently Published

Hefner, A.R., and Blackburn, D.L., **Performance Trade-Off for the Insulated Gate Bipolar Transistor: Buffer Layer Versus Base Lifetime Reduction**, 1986 Power Electronics Specialists Conference, Vancouver, British Columbia, Canada, June 23, 1986, pp. 27-38 (1986).

A one-dimensional analytic model for the Insulated Gate Bipolar Transistor (IGBT) which includes a high-doped buffer layer in the low-doped bipolar transistor base is developed. The model is used to perform a theoretical trade-off study between IGBTs with and without the buffer layer. The study is performed for devices of equal breakdown voltages, and the critical parameters chosen to "trade-off" are turn-off switching energy loss (related to turn-off time) and on-state voltage, both at a given cur-

Process and Device Modeling, cont'd.

rent. In this study, as in reality, the two critical parameters are varied by: 1) adjusting the doping concentration and thickness of a buffer layer included as part of the bipolar transistor base, 2) adjusting the lifetime in the low doped bipolar transistor base with no buffer layer included, or by 3) a combination of 1) and 2). The results of the model predict that for equal breakdown voltages, an optimized device with a buffer layer has less switching energy loss for a given on-state voltage than an optimized device with no buffer layer.
[Contact: Allen R. Hefner, (301) 975-2071]

Wachnik, R.A., and Lowney, J.R., **A Model for the Charge-Pumping Current Based on Small Rectangular Voltage Pulses**, Solid-State Electronics, Vol. 29, No. 4, pp. 447-460 (1986).

The charge-pumping current results from recombination associated with the SiO_2-Si interface traps under the gate of a metal-oxide-semiconductor field-effect transistor (MOSFET) when a voltage pulse is applied to the gate. A model is proposed which predicts this current as a function of the frequency, amplitude, and average voltage of pulses with peak-to-peak amplitudes less than the difference between the flatband and inversion voltages and with pulse transitions fast enough so that negligible capture or emission occurs during the transition. The model is based on Shockley-Read-Hall traps segregated by energy and capture cross section into traps which capture only and traps which tend to emit before capture. It predicts the dominant behavior of the measured current and with the inclusion of surface potential fluctuations and a distribution of cross sections it agrees very well with experiment. Thus, the charge pumping current due to these small rectangular pulses can be used to determine the density, the electron capture cross section, and the hole capture cross section of interface traps near midgap.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Gallium Arsenide Materials

Released for Publication

Bouldin, C.E., Forman, R.A., and Bell, M.I., **Conversion Yield EXAFS Measurements of Ion-Damaged GaAs.**

Extended x-ray absorption fine structure (EXAFS) measurements of ion-implanted GaAs have been made using conversion electron detection. This total electron yield detection technique (termed CEEXAFS) allows near-surface sensitivity with a sampling depth of 700 to 1000 Å. Measurements of the Ga absorption edge show that implantation of 10^{16} cm^{-2} of Zn ions at 180 KeV into GaAs produces heavy lattice damage (amorphization) to a depth of about 700 to 900 Å. After rapid thermal annealing, the amorphous layer is found to be recrystallized and structurally indistinguishable from unimplanted material. The sampling depth of CEEXAFS has been measured for the first time, using standards with known depth dependent structure. The CEEXAFS technique greatly reduces Bragg peak contamination of the EXAFS signal from single crystal materials, and allows measurement of a variety of samples which cannot be fabricated as thin layers for conventional transmission or fluorescence EXAFS measurements. The method permits examination of the local environment of host atoms (in this case Ga) in the near surface region without interference from the underlying bulk and without the distortions found in fluorescence EXAFS measurements of concentrated samples.
[Contact: Charles E. Bouldin, (301) 975-2046]

Lowney, J.R., **Impurity Bands and Band Tailing in n-Type GaAs.**

The density of states of the valence and conduction bands of n-type GaAs have

Gallium Arsenide Materials, cont'd.

been calculated for a donor density of 10^{17} cm^{-3} at 300 K and 20 K. Both the donor-carrier and carrier-carrier interactions have been included. Band tails appear on both bands and the energy gap is narrowed. Calculations were also performed for a donor density of 10^{15} cm^{-3}. The results show the formation of an impurity band at 20 K, whereas a band tail exists at 300 K.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Recently Published

Gans, W.L., **Calibration and Error Analysis of a Picosecond Pulse Waveform Measurement System at NBS**, Proceedings of the IEEE, Vol. 74, No. 1, pp. 86-90 (January 1986).

The primary system used at NBS, Boulder, CO, to measure fast (picosecond-nanosecond range), repetitive, electric pulse parameters consists essentially of a wide-band (dc -18 GHz) sampling oscilloscope interfaced to a minicomputer. This paper describes the major calibration and analysis techniques used to reduce the effects of errors inherent in this system, both deterministic and random in nature.
[Contact: William L. Gans, (303) 497-3538]

Lawton, R.A., **An Efficient Antialiasing Filter**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-34, No. 4., pp. 570-573 (December 1985).

The application of a solid-state reference filter as an efficient antialiasing filter is described. The analytical basis for the efficiency of this filter is described and a specific example of measuring a 1024-point waveform with a resistance-capacitance (RC) filter network and the solid-state filter is given.
[Contact: Robert A. Lawton, (303) 497-3339]

Souders, T.M., Flach, D.R., and Schoenwetter, H.K., **Transient Respons Characterization of Waveform Recorders**, Proceedings of the 5th IEE Pulsed Power Conference, Arlington, Virginia, June 10-12, 1985, pp. 352-355 (May 1986).

Test methods for characterizing the transient response of waveform recorders are presented, together with typical test results. The methods, based on the use of a precision, programmable step generator developed at NBS, are suitable for recorders having up to 10 bits of resolution and 100 MHz bandwidth.
[Contact: T. Michael Souders, (301) 975-2406]

Turgel, R.S., **NBS 50 kHz Phase Angle Calibration Standard**, NBS Technical Note 1220 (April 1986).

A detailed description is given of the features of an electrical phase angle calibration standard designed for operation over a frequency span of 2 Hz to 50 kHz. The phase resolution of this calibrator extends from just below 2 millidegrees at the low end of the frequency range to about 5 millidegrees at the high end. The uncertainty in the phase angle is a function of frequency, amplitude, and amplitude ratio of the two outputs. It varies from 5 to 50 millidegrees.
[Contact: Raymond S. Turgel, (301) 975-2420]

Cryoelectronic Metrology

Released for Publication

Barbanera, S., Lambert, N., and Zimmerman, J.E., **A Versatile Experimental Low-Power 4 K Cryocooler.**

The construction of a low-power cryo-

Cryoelectronic Metrology, cont'd.

cooler consisting of a five-stage plastic Stirling cooler with an additional Joule-Thomson stage is described. Among its novel features are a contamination-free pneumatic helium compressor and displacer drive. Valve timing is under computer control. Titanium foil embedded in the cylinder wall reduces helium diffusion through the plastic. The Joule-Thomson stage uses the same low-pressure helium as the Stirling stages. The Stirling system cools down below 9 K. The Joule-Thomson stage delivers 5-mW cooling at 4.2 K.
[Contact: James E. Zimmerman, (303) 497-3901]

Hamilton, C.A., Kautz, R.L., and Lloyd, F.L., **The NBS Josephson Array Voltage Standard.**

It has been realized for many years that the accuracy of Josephson voltage standards can be substantially improved by using many junctions in series to generate a large voltage. A simple series extension of the single junction standard requires individual control of the bias current for each junction of 100 mV using 20 junctions. In 1977 Levinsen et al. suggested a method to avoid the multiple bias problem by using constant-voltage steps which cross the zero-current axis of the junction I-V curve. This allows a large array of junctions to share a common current bias at or near zero. With an array of 1000 or more junctions, a quantized voltage of 1 V is possible. After nearly ten years of effort, the problems of fabrication, stability, and rf distribution are largely solved and Josephson standards at the 1-V level are a reality. This paper reviews the design and operation of series array voltage standards and describes the efforts at NBS to engineer a versatile, reliable, and easily used voltage standard system.
[Contact: Clark A. Hamilton, (303) 497-3740]

McDonald, D.G., **High Accuracy in Physics** (submitted as a letter to Science).

Philip Abelson, in an editorial in Science [232, 693 (1986)], reviews the National Research Council report "Physics Through the 1990s" and writes "Of all the quantities in physics, time is by far the most accurately measured." I argue that the Josephson effect has comparable accuracy.
[Contact: Donald G. McDonald, (303) 497-5113]

McDonald, D.G., **Modeling a Voltage-Locked Josephson Junction Array Amplifier: Gain, Input Impedance, and Bandwidth.**

Previously published experimental results are used to deduce an equivalent circuit for this amplifier, based on the shunted junction model. It is found that the very small inductances of the junction shunt resistors play an important role in determining the shape of the current-voltage curves in the voltage-locked region. Once the circuit is determined using the shunted junction model, a combination of an approximation method (the method of slowing varying amplitudes) and the shunted junction model is used to approximately maximize the power gain of the circuit. The maximum gain achieved in these simulations of the two-junction amplifier is 11.3. This gain occurred with a negative resistance input impedance of -0.41R and a signal source impedance of 0.167R, where R is the junction shunt resistance. It is estimated that the bandwidth of this amplifier is about 1 GHz.
[Contact: Donald G. McDonald, (303) 497-5113]

Muhlfelder, B.F., Beall, J.A., Cromar, M.W., and Ono, R.H., **Very Low Noise, Tightly Coupled, dc SQUID Amplifiers.**

We have fabricated and tested an all-thin-film niobium edge junction double transformer dc SQUID (Superconductive QUantum Interference Device) amplifier

Cryoelectronic Metrology, cont'd.

that was robust and had very good noise performance. The input inductance was approximately 1.7 μH and the minimum detectable energy per unit bandwidth at 100 kHz was 5×10^{-33} J/Hz. The minimum detectable energy per unit bandwidth at 1 kHz in the flux-locked mode was 6×10^{-32} J/Hz. The noise was low for a wide range of bias current and magnetic flux.
[Contact: James A. Beall, (303) 497-5989]

Recently Published

Clark, A.F., **Conference Report on the Tenth International Cryogenic Engineering Conference,** Cryogenics, Vol. 25, pp. 222-223 (April 1985)

The tenth International Cryogenic Engineering Conference was held in Otaniemi, Finland, 31 July to 3 August 1984, hosted by the Helsinki University of Technology. More than 300 attendees representing 22 countries contributed 220 papers on such diverse subjects as sensing human brainwaves from their magnetic fields to superconducting magnets the size of railroad cars and to ultralow temperature refrigerators which can achieve nuclear temperatures of the order of nanokelvin. The special topic for this conference was cryogenics in medicine, and thus many of the plenary talks covered cryosurgery, magnetic resonance imaging, SQUID magnetometers for heart and brain waves, and biological preservation.
[Contact: Alan F. Clark, (303) 497-3253]

Hamilton, C.A., Kautz, R.L., and Lloyd, F.L., **A Josephson Series Array Voltage Standard at One Volt,** NCSL 1985 Workshop & Symposium, Boulder, Colorado, July 15-18, 1985, pp. 71-77.

Josephson voltage standards have long been limited by their low 1- to 10-mV output level. A new method for operating 1000 or more Josephson junctions in series has produced a practical standard at the 1-V level. The junction array is in the form of a microstrip which is finline coupled to a waveguide at one end and is terminated at the other end. The whole circuit is fabricated on a 6 by 12 mm silicon substrate. With applied radiation at 72 GHz, the junction array produces up to 8000 quantized levels at the voltages nhf/2e. (In the U.S. 2e/h has an assigned value of 483593.420 GHz/V_{NBS}.) By selecting the level, n, and fine tuning the frequency, f, any voltage from 0.1 to 1.2 V can be obtained. The high output voltage eliminates the need for a voltage divider and greatly reduces errors due to thermal voltages. When fully evaluated, the new standard is expected to have a precision of a few parts per billion.
[Contact: Clark A. Hamilton, (303) 497-3740]

Hamilton, C.A., Kautz, R.L., Lloyd, F.L., and Steiner, R.L., **A Practical Josephson Voltage Standard at 1 V,** IEEE Electron Device Letters, Vol. EDL-6, No. 12, pp. 623-625 (December 1985).

A series array of 1484 pairs of Josephson junctions biased by microwaves at 72 GHz is demonstrated to provide stable quantized voltages at the 1-V level. The niobium/lead-alloy junctions used in the array are not affected by thermal cycling.
[Contact: Clark A. Hamilton, (303) 497-3740]

Antenna Metrology

Released for Publication

FitzGerrell, R.G., **Linear Gain-Standard Antennas Below 1000 MHz,** to be published as NBS Technical Note 1098.

Gain and antenna parameters related to input impedance are calculated using a computer program named HVD6. This program uses well-documented equations to

Antenna Metrology, cont'd.

compute these parameters for gain-standard antennas used in relative-gain or gain-transfer measurements at frequencies below 1000 MHz. In this frequency range, the physical size of the antennas is often quite large, and the measurements are often made outdoors. The utility of this program is that it calculates gain patterns and input impedances for linear dipoles above perfect or imperfect ground and in free space and for monopoles on plane, perfect ground. Uncertainties in the calculated parameters are estimated to be less than those of the measured parameters.
[Contact: Richard G. FitzGerrell, (303) 497-3737]

Hill, D.A., and Francis, M.H., **Out-of-Band Response of Antenna Arrays,** to be published as NBSIR 86-3047.

The response of antenna arrays to out-of-band frequencies has been analyzed using the effective aperture approach. An average value of effective aperture can be obtained by averaging out the incidence angle and the polarization of the incidence field. Far-field patterns have also been calculated by treating the array element excitations as random variables. The randomness in the element excitations causes a decrease in directivity and an increase in sidelobe level. Out-of-band measurements of reflection coefficient and near-field response have been made on two large slotted-waveguide arrays for frequencies from 2 to 18 GHz. Both arrays are narrow band, attributable to the large impedance mismatch at out-of-band frequencies.
[Contact: David A. Hill, (303) 497-3472]

Newell, A.C., and Stubenrauch, C.F., **The Effect of Random Errors in Planar Near-Field Measurements.**

Equations have previously been derived to predict the effect of systematic errors in planar near-field measurements. Similar expressions for random errors have not been generally available, although computer simulation has been used to study some specific cases. In this report, simple general expressions are derived to predict the effect of random errors, and these expressions require only minimal information about the antenna and the error distributions.
[Contact: Allen C. Newell, (303) 497-3743]

Recently Published

Jesch, R.L., **Measured Vehicular Antenna Performance,** National Institute of Justice Report-201-85 (May 1986). [A similar paper by the same title appeared in IEEE Transactions on Vehicular Technology, Vol. VT-34, No. 2, pp. 97-107 (May 1985).]

Power gain radiation patterns of mobile antennas mounted in six different locations on a test vehicle were measured with and without typical lights and sirens mounted on the roof. The measurements were performed at frequencies representing the frequency bands of 25 to 50, 150 to 174, 400 to 512, and 806 to 866 MHz. In addition, the radiation patterns were measured of three disguised antennas operating at discrete frequencies of 40.27, 162.475, and 416.975 MHz and one slot antenna operating at 413 MHz. Plots of power gain radiation patterns are given for the mobile antennas mounted in six different locations on the test vehicle, for the other four antennas, and to show the effects of improper grounding of the trunk lid and of the lights and siren. Recommended antenna mounting locations are identified for specific frequency bands and an appendix of power gain measurement data is included.
[Contact: Ramon L. Jesch, (303) 497-3496]

Kanda, M., Chang, D.C., and Greenlee, D.H., **The Characteristics of Iris-Fed**

Antenna Metrology, cont'd.

Millimeter-Wave Rectangular Microstrip Patch Antennas, IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-27, No. 4, pp. 212-220 (November 1985).

The fabrication of various iris-fed millimeter-wave rectangular microstrip patch antennas is described. A mathematical model is proposed to describe the iris-fed antenna. An iris having 15% of the area of the patch is used to couple energy into the antenna. Resonance of the antenna is observed to be insensitive to the size of the iris for irises up to 115% of the size of the patch. A study is also made of the coupling to the antenna as a function of position of the iris with respect to the transverse plane of the waveguide, the iris always being centered with respect to the patch. In general, the antenna has a VSWR in the waveguide feed of roughly 5:1 at resonance, except for the fully open waveguide which gives rise to a VSWR of 2.9:1 at resonance. Far-field antenna power patterns are observed to be quite broad with H-plane beamwidths about 130°. Maximum antenna gain observed was 4.5 dB relative to an isotropic source (dBi), with 2 dBi typical. An initial study is made of the microstrip patch antenna fed from a longitudinal waveguide wall. Results indicate that this feed structure is likely to prove valuable for microstrip patch antennas, with coupling at least as good as for the transverse-fed patch, added to the possibility of feeding multiple patches from a single waveguide.
[Contact: Motohisa Kanda, (303) 497-5320]

Noise Metrology

Released for Publication

Daywitt, W.C., **10-60 GHz G/T Measurements Using the Sun as a Source--A Preliminary Study,** to be published as NBSIR 86-3046.

Preliminary studies show that it may be possible 1) to determine the solar flux density incident on the earth's atmosphere using a simple algorithm with an uncertainty less than 8%; 2) to overcome a deteriorating accuracy in atmospheric loss calculations by using a "tipping curve" measurement, and 3) to reduce starshape correction factor uncertainty by using an equivalent solar diameter.
[Contact: William C. Daywitt, (303) 497-3720]

Microwave and Millimeter-Wave Metrology

Released for Publication

Daywitt, W.C., **Complex Admittance of a Lossy Coaxial Open Circuit with a Hollow Center Conductor.**

The reflection coefficient and complex discontinuity admittance of a coaxial open circuit with a hollow center conductor are derived from fields correct to first order in the skin depth. Results show an admittance terminating the line at the plane of the discontinuity and consisting of a resistance in parallel with a capacitive reactance. The first-order fields are also used to derive equations for the characteristic admittance, series impedance, and shunt admittance of the line. These equations include terms neglected in the well-known expressions used to calculate the line parameters, enabling error limits to be assigned to the latter.
[Contact: William C. Daywitt, (303) 497-3720]

Engen, G.F., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Background and Theory.**

One of the major challenges confronting the microwave metrologist today is that of providing an accuracy assessment for the automatic network analyzer (ANA). This paper provides the background and theory for the recently developed on-line solution now in use with the

Microwave & Millimeter-Wave, cont'd.

six-port systems at the National Bureau of Standards.
[Contact: Cletus A. Hoer, (303) 497-3511]

Hoer, C.A., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Treatment of Systematic Errors.** [Abbreviated version published in CPEM (Conference in Precision Electrical Measurements) Digest, pp. 238-239 (June 23-27, 1986, NBS Gaithersburg, R. F. Dziuba, Ed.); complete paper to be published in a special issue of IEEE Transactions on Instrumentation and Measurement.]

Expressions are derived for calculating systematic errors in dual six-port or four-port measurements of reflection coefficient and scattering parameters due to imperfections in the transmission line standard used to calibrate the system. A new mathematical model for a four-port reflectometer makes it easier to visualize and analyze these errors. In this new model, two of the three parameters needed to characterize a four-port can be determined without standards. All imperfections in the standard perturb only the third parameter, which acts like an impedance transformer.
[Contact: Cletus A. Hoer, (303) 497-3703]

Hoer, C.A., and Engen, G.F., **Calibrating a Dual Six-Port or Four-Port for Measuring Two-Ports With Any Connectors**, to be published in IEEE-MTT (Microwave Theory and Techniques Society) Symposium Digest.

A technique is described for calibrating a dual six-port or four-port automatic network analyzer (ANA) so that the scattering parameters or two-port devices having any combination of connectors can be measured. The technique is a generalization of the "thru-reflect-line" calibration technique in which the "thru" is replaced with a second length of precision transmission line.
[Contact: Cletus A. Hoer, (303) 497-3705]

Hoer, C.A., and Engen, G.F., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Extension to Non-Mating Connectors.** [Abbreviated version published in CPEM (Conference in Precision Electrical Measurements) Digest, pp. 241-242 (June 23-27, 1986, NBS Gaithersburg, R. F. Dziuba, Ed.); complete paper to be published in a special issue of IEEE Transactions on Instrumentation and Measurement.]

In a series of companion papers, the background, theory, and experimental results have been presented for a real-time on-line accuracy assessment for the dual six-port automatic network analyzer. As formulated, however, the procedures are based on the "thru-reflect-line" calibration procedure which, in turn, assumes that the connector interface is of the "sexless" variety. This paper extends the methodology to mating (e.g., Type N) connector types and also to "noninsertable" adapters, etc.
[Contact: Cletus A. Hoer, (303) 497-3705]

Juroshek, J.R., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Experimental Results.** [Abbreviated version published in CPEM (Conference in Precision Electrical Measurements) Digest, p. 240 (June 23-27, 1986, NBS Gaithersburg, R. F. Dziuba, Ed.); complete paper to be published in a special issue of IEEE Transactions on Instrumentation and Measurement.]

When a calibration laboratory such as the National Bureau of Standards performs a measurement for a customer, the accuracy which the laboratory attaches to its measurements is a significant part of the customer's report. In some instances, the accuracy statement may be more important to the customer than the measurement itself. Modern automated measurement systems can often perform hundreds of measurements in a fraction

Microwave & Millimeter-Wave, cont'd.

of a second. However, few, if any, of these systems attempt to assess the accuracy of those measurements in a real-time or on-line basis.

The accuracy of a modern automatic network analyzer is a function or a number of variables. Connector quality, operator technique, system hardware, and system calibration are just a few of the many parameters that affect the day-to-day accuracy of an automated system. This paper describes the results of the current efforts at NBS to implement on-line accuracy estimates for its dual six-port network analyzers. Results are presented showing uncertainty estimates obtained in quasi-real time during the measurement of customers' devices.
[Contact: John R. Juroshek, (303) 497-5362]

Judish, R.M., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Statistical Methods for Random Errors.** [Abbreviated version published in CPEM (Conference in Precision Electrical Measurements) Digest, p. 237 (June 23-27, 1986, NBS Gaithersburg, R. F. Dziuba, Ed.); complete paper to be published in a special issue of IEEE Transactions on Instrumentation and Measurement.]

A basic property of a measurement process is that repeated observations of the same quantity will not give identical results due to the presence of random errors. In order to assess the effects of random errors in our measurement process, we need to build in redundancy. This paper presents the statistical methods which converts the redundancy built into the Dual six-port automatic network analyzer (ANA) into meaningful estimates of the random errors.
[Contact: Robert M. Judish, (303) 497-3380]

Reeve, G.R., **National Bureau of Standards Metrology Capabilities and Limitations at Millimeter Wave Frequencies.**

The National Bureau of Standards (NBS) establishes national reference standards and measurement services, thus providing a metrology base for U.S. industry and technology. In order to provide proper interfacing between subcontractors and system integrators and to ensure that performance goals are met, traceability to NBS standards is frequently required in government procurement contracts. In the millimeter-wave frequency spectrum, NBS has not established all of the required metrology to meet the needs of industry or government for this technology. It is the intent of this paper to describe the organizational, fiscal, and technical demands of responding to the challenges of millimeter-wave technology, and the need for timely input on future metrology requirements which present research and development activities may generate. A description of NBS capabilities is given for those parameters and frequencies where measurement services exist. Plans to develop new standards and measurement services to serve the millimeter-wave community are also included.
[Contact: Gerome R. Reeve, (303) 497-3557]

Recently Published

Holt, D.R., and Hoer, C.A., **Estimation of True Power Ratios in Six-Port Network Analyzers Using Diode Detectors,** IEEE Transactions on Instrumentation and Measurement, Vol. IM-34, No. 4, pp. 558-563 (December 1985). [A shortened version of this paper appeared in the Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Tampa, Florida, March 20-22, 1985, pp. 140-141.]

A model for detector nonlinearity is included in the determination of six-port parameters without using additional standards. A computer simulation was performed assuming that the true power

Microwave & Millimeter-Wave, cont'd.

performed assuming that the true power into each six-port detector is related to the power observed by the detector. Simultaneous estimation of the six-port and detector parameters is accomplished through a nonlinear least-squares algorithm. Results of the simulation compare the reflection coefficient Γ computed from corrected power readings and Γ calculated from observed power readings.
[Contact: Donald R. Holt, (303) 497-3574]

Laser Metrology

Recently Published

Rasmussen, A.L., and Sanders, A.A., **Transfer Standards for Energy and Peak Power of Low-Level 1.064 Micrometer Laser Pulses and Continuous Wave Laser Power**, Optical Engineering, Vol. 25, No. 2, pp. 277-285 (February 1986).

For the first time, traceable transfer standards have been developed for measuring 1.064-μm laser pulses having durations of about 10 to 100 ns, peak power densities of about 10^{-8} to 10^{-4} W/cm^2, and energy density of about 10^{-16} to 10^{-11} J/cm^2. These power and energy transfer standards use silicon avalanche photodiode (APD) and PIN photodiode detectors, respectively (PIN refers to the detailed semiconductor structure: a "sandwich" of p-conductivity type material, intrinsic layer, and n-conductivity type material). These standards are stable and have total uncertainties of about 10%. The system for calibrating them and other devices consists of a continuous wave (cw) Nd:YAG laser beam acousto-optically modulated to provide low-level laser pulses of known peak power and energy. Using a pulse-height analyzer readout, the PIN transfer standard system records each pulse, from which the mean pulse energy and laser stability may be evaluated. Using an integrating voltmeter readout, this system can measure energy or average power. These pulsed and cw measurement techniques can be extended to the visible and other near-infrared wavelengths.
[Contact: Alvin L. Rasmussen, (303) 497-5367 or -3616]

Optical Fiber Metrology

Released for Publication

Day, G. W., **Compact Fiber Sensors for the Measurement of Low Level Electric Currents,** to be published in the Proceedings of the 4th International Conference on Optical Fiber Sensors, Tokyo, Japan, October 1986.

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 μA per root Hertz.
[Contact: Gordon W. Day, (303) 497-5204]

Day, G.W., Vesser, L.R., Chandler, G.I., and Cernosek, R.W., **Progress in the Design of Optical Fiber Sensors for the Measurement of Pulsed Electric Currents.**

The state of the art in the design of fiber sensors for pulsed electric currents is reviewed. Some of the more useful configurations are described and compared. Transfer functions are computed and used to illustrate the effect of linear birefringence and twisting on the characteristics of the sensors. The technique of annealing bend-induced birefringence is described and its present capabilities indicated. An analysis of the ultimate limits to noise equivalent current is given, indicating that several orders of magnitude improvement should be obtainable.
[Contact: Gordon W. Day, (303) 497-5204]

Engelsrath, A., Danielson, B.L., and

Optical Fiber Metrology, cont'd.

Franzen, D.L., **Attenuation Measurements on Deformed Optical Fibers,** to be published as NBSIR 86-3052.

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]

Recently Published

Rasmussen, A.L., and Franzen, D.L., **Low-Level Germanium Detector Transfer Standard at 1.064 μm,** NBSIR 85-3041 (January 1986).

Two PIN germanium photodiodes have been calibrated in the 1- to 250-fJ/cm^2 range with 15 percent uncertainty for 10- to 100-ns duration, 1.064-μm laser pulses [PIN refers to a "sandwich" structure of a layer of p-conductivity type material, an intrinsic layer, and an n-conductivity type layer]. To do these calibrations, we used (1) a continuous wave Nd:YAG laser beam acousto-optically modulated and a PIN silicon photodiode transfer standard to provide low-level laser pulses of known energy and (2) a pulsed 1.06-μm LED beam. A 1-cm^2 collecting lens and a ground glass diffuser were placed in front of each detector to improve sensitivity and spatial uniformity, respectively. In the future, these detectors may also be useful as transfer standards at wavelengths out to 1.7 μm. [Contact: Alvin L. Rasmussen, (303) 497-5367 or -3616]

Electro-Optic Metrology

Released for Publication

Peterson, R.L., **Numerical Study of Currents and Fields in a Semiconducting Optical Detector.**

A numerical study of the current, field, and carrier density distributions within an optical detector is presented. The detector - an interdigitated Schottky barrier diode - is made of semiconductor overlaid with metallic fingers of alternating voltage bias. The Poisson and continuity equations for electrons and holes are treated in two dimensions. A modified successive line over-relaxation method, faster than a capacitance matrix method, is developed as the Poisson solver. A simple alternative to the Scharfetter-Gummel treatment of current density is also introduced. Steady-state cases with and without optical illumination, and transient responses to picosecond optical pulses, are studied. The steady-state current shows near saturation with increasing voltage, as observed experimentally. The calculated typical response of this detector to a picosecond optical pulse is a current pulse lasting on the order of 10 ps. [Contact: Robert L. Peterson, (303) 497-3750 or -3227]

Young, M., and Weppner, M., **Hybrid Computer-Optical Processing With Inexpensive Liquid Crystal Television.**

We describe a computer-optical processing system that uses an inexpensive liquid crystal (LCD) 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

Electro-Optic Metrology, cont'd.

time.
[Contact: Matt Young, (303) 497-3223 or -5342]

Recently Published

Hebner, R.E., **Electro-Optical Measurement Techniques,** Fast Electrical and Optical Measurements, Vol. 1, pp. 5-25 (Martinus Nijhoff, Boston, MA, 1986) [Proceedings of the NATO Advanced Study Institute on Fast Electrical and Optical Diagnostic Principles and Techniques].

This paper reviews the use of the Faraday effect, the Pockels effect, and the Kerr effect to measure electric fields, magnetic fields, voltages, currents, and space charge density. Each of the three effects is introduced conceptually, the use of Jones or Mueller matrices to describe the optical system is presented, and some applications of these effects are described.
[Contact: Robert E. Hebner, (301) 975-2403]

Other Fast Signal Topics

Released for Publication

Jesch, R.L., **Fixed and Base Station FM Transmitters.**

This document establishes minimum performance requirements and methods of test for fixed and base station frequency-modulated (FM) transmitters. The standard applies primarily to the law enforcement community, and as such covers the four frequency bands 25 to 50 MHz, 150 to 174 MHz, 400 to 512 MHz, and 806 to 866 MHz. This standard supersedes NILECJ-STD-0201.00 Fixed and Base Station FM Transmitters.
[Contact: Ramon L. Jesch, (303) 497-3496]

Lawton, R.A., and Meyer, K., **Waveform Standards for Electro-Optics: A Pulse Duration Comparison.**

A transfer standard has been developed for use in comparing the measurement capability of the Automatic Pulse Measurement System (APMS) at the National Bureau of Standards to that of recently developed electro-optic samplers. This transfer standard is a comb generator driven by a 90-MHz sine wave. Measurements were made of the pulse waveform of the comb generator output with both the APMS and an electro-optic sampler. A comparison was then made of the pulse duration (full width at half maximum) obtained in the two waveform measurements. The result was a duration of 102 ps as measured by the APMS and 112 ps as measured by the electro-optic sampler. This agreement is well within the measurement uncertainty of the two systems. The signal-to-noise ratio at the comb generator input was improved over that of previous measurements, and a correction for pulse broadening was made to achieve this result. The pulse broadening was caused by the impedance mismatch between the sampler and the transmission system (50 ohms).
[Contact: Robert A. Lawton, (303) 497-3339]

McDonald, D.G., **High Accuracy in Physics** (submitted as a letter to Science).

Philip Abelson, in an editorial in Science [232, 693 (1986)], reviews the National Research Council report "Physics Through the 1990s" and writes "Of all the quantities in physics, time is by far the most accurately measured." I argue that the Josephson effect has comparable accuracy.
[Contact: Donald G. McDonald, (303) 497-5113]

Recently Published

Laug, O.B., Stenbakken, G.N., and Leedy, T.F., **Electrical Performance Tests for Audio Distortion Analyzers,** NBS Technical Note 1219 (January 1986) [previously published as NBSIR 85-3269 (November 1985)].

Other Fast Signal Topics, cont'd.

Electrical performance test procedures for audio distortion analyzers were developed by the National Bureau of Standards for the U.S. Army Communications-Electronics Command. The report provides detailed, step-by-step test procedures that are based on specifications supplied by the Army for purposes of evaluating audio distortion analyzer bid samples. Examples of data sheets and tables are also provided for recording interim and final results.

The report discusses the philosophy of each measurement procedure with a view toward providing an understanding of the basic metrology required to perform the measurements. In addition, the sources of measurement error are discussed. The primary applications and basic principles of modern audio distortion analyzers are also presented.
[Contact: Owen B. Laug, (301) 975-2412]

Miller, C.K.S., Taggart, H.E., and Bensema, W.D., **Mobile FM Transceivers,** National Institute of Justice Standard-0210.00 (May 1986).

The purpose of this document is to establish performance requirements and methods of test for non-trunked, frequency modulated (FM) mobile transceivers. This standard applies to transceivers which either do not have special subsystems such as selective signaling or voice privacy, or in which such subsystems are bypassed or disabled during testing for compliance with this standard. This standard supersedes NILECJ-STD-0202.00, Mobile FM Transmitters and NILECJ-STD-0207.00, Mobile FM Receivers.
[Contact: Charles K. S. Miller, (303) 497-3131]

Miller, C.K.S., Taggart, H.E., Jesch, R.L., and Wainright, A.E., **Personal/Mobile FM Transceivers,** National Institute of Justice Standard-0224.00 (May 1986).

The purpose of this document is to establish performance requirements and methods of test for non-trunked, frequency modulated (FM) personal/mobile transceivers. This standard applies to personal transceivers with rechargeable batteries and personal/mobile transceivers which use a charger/mobile unit, with or without an rf power amplifier, and which either do not have special subsystems such as selective signaling or voice privacy, or in which such subsystems are bypassed or disabled during testing for compliance with this standard. The individual personal FM transceivers are expected to meet the minimum performance requirements as established in NIJ Standard-0209.01 for Personal FM Transceivers prior to being tested for the requirements of this standard. Due to the lack of use of personal/mobile transceivers in the 25 to 50 MHz and 806 to 866 MHz frequency bands, requirements for these transceivers are not included in this standard.
[Contact: Charles K. S. Miller, (303) 497-3131]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Kelley, E.F., Hebner, R.E., Anderson, W.E., Lechner, J.A., and Blue, J.L., **The Effect of an Oil-Paper Interface Parallel to an Electric Field on the Breakdown Voltage at Elevated Temperatures.**

This paper reports the measurements made in a study of the electrical breakdown location in the vicinity of an oil-paper interface over the temperature range from room temperature to 150°C. The data indicate that the electrical breakdown occurred at the interface from 15% to 43% of the time, depending on the details of the particular set of measurements. A theoretical analysis shows that this experimental result is consistent with the electric field enhancement, the area over which the enhancement occurs, and the spread in the

Power Systems Metrology, cont'd.

breakdown voltages for nominally identical tests.
[Contact: Edward F. Kelley, (301) 921-3121]

Kelley, E.F., Hebner, R.E., FitzPatrick, G.J., Forster, E.O., **The Effect of Pressure on Streamer Initiation in n-Hexane,** to be published in the Proceedings of the 1986 IEEE International Symposium on Electrical Insulation, Washington, DC, June 9-12, 1986.

High-speed photographs of the breakdown process at pressures in the range 0.1 to 10 MPa indicate that the structure of the streamer changes with the pressure. The typical structures associated with primary streamers are no longer visible at elevated pressures. Over this range, the average cathode streamer velocity increases from about 0.25 km/s to 2.5 km/s. The anode streamer, however, does not generally exhibit a bushy primary streamer structure, and its velocity appears to be less affected by pressure.
[Contact: Edward F. Kelley, (301) 975-2424]

Misakian, M., **Power Frequency Electric and Magnetic Field Measurements: Recent History and Measurement Standards,** to be published in the Proceedings of the 1986 Workshop and Symposium of the National Conference of Standards Laboratories, Gaithersburg, Maryland, October 6-9, 1986.

During the early 1970s, reports appeared in the literature which raised questions regarding possible biological effects from exposure to power frequency electric and magnetic fields in the vicinity of high-voltage transmission lines and in substations. In response to the concerns generated by these reports, numerous bioeffects studies were initiated in the United States in the mid-1970s by government and private agencies; a number of studies are still underway. Sponsored by the Department of Energy, the NBS Fields Project took an early interest in the instrumentation, calibration procedures, and measurement techniques for characterizing the electrical parameters in the vicinity of power lines and in laboratory apparatus designed to simulate the electrical environment for bioeffects studies. In the mid-1970s, there was no standard which provided guidance for measurement of the ac fields near power lines or for calibration of instrumentation used for such measurements. Similarly, no guidance was available for measuring the fields in biological exposure systems. Today, a U.S. (IEEE) standard exists for measurement of ac power line fields and an NBS technical note is available which describes the measurement of electrical parameters in biological exposure systems. This paper focuses on selected results of NBS studies which have been incorporated into the U.S. standard for measurement of power frequency electric and magnetic fields and the NBS technical note for measuring electrical parameters in bioeffects exposure systems.
[Contact: Martin Misakian, (301) 975-2426]

Misakian, M., McKnight, R.H., and Fenimore, C., **Calibration of Aspirator-Type Ion Counters and Measurement of Unipolar Charge Densities.**

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 described. The influence 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]

Power Systems Metrology, cont'd.

Van Brunt, R.J., and Sauers, I., **Gas Phase Hydrolysis of SOF_2 and SOF_4,** to be published in the Journal of Chemical Physics (Publication of the American Institute of Physics).

The rates for gas-phase hydrolysis of SOF_2 (thionylfluoride) and SOF_4 (thionyltetrafluoride) have been measured at a temperature of 298 K. The second order rate constant for SOF_2 hydrolysis in SF_6 buffer gas was found to have the value $(1.2 \pm 0.3) \times 10^{-23}$ cm^3/s which agrees with previous estimates of Sauers et al., but is three orders of magnitude lower than the value obtained by Ruegsegger et al. at 340 K. The rate constant for SOF_4 hydrolysis has not previously been measured, and its value in both SF_6 and N_2 buffer gases was found here to be $(1.0 \pm 0.3) \times 10^{-21}$ cm^3/s.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Recently Published

Anderson, W.E., Ramboz, J.D., and Ondrejka, A.R., **Final Report: Technical Contributions to the Development of Incipient Fault Detection/Location Instrumentation,** NBSIR 86-3392 (April 1986).

The transmission of electrical energy by use of underground cables is increasing. Fault location techniques have certain limitations; incipient fault detection and location would help reduce the maintenance cost of these lines as well as improve the reliability of service. This report discusses some test results related to radio-frequency (rf) probing techniques applied to high-voltage transmission lines. The high-frequency losses and attenuation in high-voltage cables places certain ultimate limitations on rf-probing techniques for incipient fault detection. Time domain reflectrometry methods were employed to assess the rf-transmission properties of high-voltage cables at frequencies up to 6 GHz. Fast Fourier transform deconvolution was used to obtain loss measurements as a function of frequency. The loss mechanisms were identified. The measurement hardware and methods are discussed as well as analysis approach leading to the conclusions.
[Contact: William E. Anderson, (301) 975-2423]

Hebner, R.E., **Electro-Optical Measurement Techniques,** Fast Electrical and Optical Measurements, Vol. 1, pp. 5-25 (Martinus Nijhoff, Boston, MA, 1986) [Proceedings of the NATO Advanced Study Institute on Fast Electrical and Optical Diagnostic Principles and Techniques].

This paper reviews the use of the Faraday effect, the Pockels effect, and the Kerr effect to measure electric fields, magnetic fields, voltages, currents, and space charge density. Each of the three effects is introduced conceptually, the use of Jones or Mueller matrices to describe the optical system is presented, and some applications of these effects are described.
[Contact: Robert E. Hebner, (301) 975-2403]

Kelley, E.F., Hebner, R.E., Fitzpatrick, G.J., and Forster, E.O, **The Effect of Pressure on Streamer Initiation in n-Hexane,** Proceedings of the 1986 IEEE International Symposium on Electrical Insulation, Washington, DC, June 9-12, 1986, pp. 66-68.

High-speed photographs of the breakdown process at pressures in the range 0.1 to 10 MPa indicate that the structure of the streamer changes with the pressure. The typical structures associated with primary streamers are no longer visible at elevated pressures. Over this range, the average cathode streamer velocity increases from about 0.25 km/s to 2.5 km/s. The anode streamer, however, does not generally exhibit a bushy primary streamer structure, and its velocity appears to be less affected by pressure.
[Contact: Edward F. Kelley, (301) 975-2424 or -5826]

Power Systems Metrology, cont'd.

Misakian, M., McKnight, R.H., and Fenimore, C., **Calibration of Aspirator-Type Ion Counters and Measurement of Unipolar Charge Densities**, NBS Technical Note 1223 (May 1986).

The characterization of a parallel-plate apparatus which can produce a unipolar ion density that is suitable for calibrating aspirator-type ion counters operating in the ground plane is described. The influence 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. An ion 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. The results of laboratory measurements of ion density under a monopolar high voltage line, which complement the studies with the parallel-plate apparatus, are also described.
[Contact: Martin Misakian, (301) 975-2426]

Siddagangappa, M.C., Van Brunt, R.J., and Phelps, A.V., **Influence of Oxygen on the Decomposition Rate of SF_6 in Corona**, Proceedings of the 1986 IEEE International Symposium on Electrical Insulation, Washington, DC, June 9-12, 1986, pp. 225-229.

The absolute charge rates-of-production of discharge generated gaseous by-products SOF_4, SOF_2, SO_2F_2, SO_2, and CO_2 have been measured in compressed SF_6/O_2 mixtures at a constant pressure. The normalized total rate of oxyfluorides plus SO_2 production per SF_6 mole does not increase significantly with the addition of O_2 up to 50% in SF_6 and increases slowly for $[O_2]>50\%$. The formation of SO_2 in all SF_6/O_2 mixtures was insignificant. Instead, the deposition of sulfur (S- ions) on the anode increased with O_2 concentration. The yield of CO_2 from oxidation of carbon on the electrode was also observed to increase with O_2 content. Probable mechanisms for the formation of SOF_2, SO_2F_2, SOF_4, S- ions, and CO_2 are discussed. The measured by-product yield as a function of percent O_2 is compared with the calculated maximum rate of SF_6 decomposition induced by electron collision in the discharge. The theoretical model used to calculate the rate of SF_6 decomposition in SF_6/O_2 mixtures is briefly discussed. As observed for SF_6/N_2 and SF_6/Ne mixtures, the primary effect of O_2 on SF_6 decomposition appears to be retardation of the recombination of SF_6 dissociation products due to dilution.
[Contact: Richard J. Van Brunt (301) 975-2425]

Van Brunt, R.J. **Water Vapor-Enhanced Electron-Avalanche Growth in SF_6 for Nonuniform Fields**, J. Appl. Phys., Vol. 59, No. 7, pp. 2314-2323 (April 1, 1986).

When water vapor content is increased from 10 to 100 ppm in SF_6 at pressures from 200 to 300 kPa, a dramatic enhancement occurs in the mean size of electron avalanches formed near a positive-point electrode. Although this effect can be attributed to a change in gas composition, it is not due to a change in the ionization rate for the gas. It is proposed that the avalanche enhancement is due primarily to an increase in the probability for initiating electron release from minor negative ions associated with water vapor that collisionally detach more readily at a given field strength than the predominant negative ions associated with SF_6. The profiles of the electron avalanche size distributions exhibit a monotonic decrease of probability with increasing number of electrons for avalanches with fewer than 10^7. These peaks are not consistent with the behavior expected from a stochastic model of electron-avalanche growth in nonuniform electric fields which neglects the influence of space charge.

Power Systems Metrology, cont'd.

[Contact: Richard J. Van Brunt, (301) 975-2425]

Pulse Power Metrology

Recently Published

Hebner, R.E., **High-Speed Data Systems for Pulsed Power Applications**, Proceedings of the 5th IEEE Pulsed Power Conference, Arlington, Virginia, June 10-12, 1985, pp. 168-171 (May 1986).

Data-acquisition systems for pulsed power applications generally must provide nanosecond resolution, operate in an environment of high levels of electromagnetic interference, and acquire significant amounts of data simultaneously. To meet these demands, electrical systems have been used and optical systems are being introduced. Voluntary standards have been and are being developed which categorize the errors in the electrical measurement systems. Optical systems are in too early a state of development for similar standardization.
[Contact: Robert E. Hebner, (301) 975-2403]

Superconductors

Released for Publication

Dragomirecky, M., Minervini, J.V., Ekin, J. W., Goldfarb, R.B., and Clark, A.F., **Losses in a Nb-Ti Superconductor as Functions of AC Field Amplitude and DC Transport Current,** to be published in the Proceedings of the 11th International Cryogenic Engineering Conference - ICEC 11, Berlin, West Germany, April 22-25, 1986, Butterworth & Co. (Publishers) Ltd.

Hysteretic shielding losses and transport losses were measured in a multifilamentary Nb-Ti superconducting coil as functions of transverse ac field amplitude and dc transport current. The conductor was biased with a dc field. There was significant agreement with the predictions of Minervini's two-dimensional theoretical model.
[Contact: John W. Ekin, (303) 497-5448]

Ekin, J.W., Goodrich, L.F., Moreland, J., Pittman, E.S., and Clark, A.F., **Electro-Mechanical Properties of Superconductors for High Energy Physics Applications**, to be published as NBSIR 86-3059.

This report covers the first nine months of a 33-month project to establish a systematic base of experimental data on electro-mechanical effects in superconducting wire and cables for high-energy-physics magnet applications.
[Contact: John W. Ekin, (303) 497-5448]

Goldfarb, R.B, and Ekin, J.W., **Hysteresis Losses in Fine-Filament Internal-Tin Superconductors.**

Hysteresis losses were measured on a series of fine-filament Nb_3Sn superconductors made by the internal-tin process. Hysteresis was measured as a function of filament diameter and interfilament separation using a vibrating-sample magnetometer in transverse field. Losses were greater than expected compared to predictions of the critical-state model that expresses loss as a function of filament diameter. Micrographs of the reacted wire cross sections show some interfilament bridging for all wires. This bridging gives rise to effective filament diameters that are greater than actual diameters. The critical interfilament separation, above which the losses would be expected to follow the critical-state model, was determined.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Moreland, J., **Squeezable Junctions for Electron Tunneling and Surface Electric Field Experiments.**

Superconductors, cont'd.

Mechanically adjusted junctions can be used for electron tunneling or surface electric field measurements. This tutorial paper discusses what squeezable electron tunneling (SET) junctions are and how measurements with SET junctions can contribute to the characterization of superconductors and semiconductors and to our understanding of the surface physics of conducting materials. An outline of how to construct a simple SET junction is provided.
[Contact: John Moreland, (303) 497-3641]

Recently Published

Ekin, J.W., Moreland, J., and Brauch, J.C., **Electromechanical Properties of Superconductors for DOE Fusion Applications,** NBSIR 86-3044 (March 1986).

This is an interim report presenting data on superconductor performance under mechanical load, data needed for the selection of superconductors and the mechanical design of superconducting magnets for DOE fusion energy systems. A further aim of the reported research is to measure and understand the electromechanical properties of promising new superconductor materials with strong application potential at high magnetic fields. Results include the following. The first studies of strain vs. critical-current were made on a Chevrel-phase superconductor, $PbMo_6S_8$. Chevrel-phase superconductors were found to have a large strain effect, comparable in magnitude to that in A-15 superconductors like Nb_3Sn. Electromechanical-property measurements of an experimental liquid-tin-infiltrated Nb_3Sn conductor showed it to have an irreversible strain limit twice as large as that of bronze-process superconductors and a significantly higher overall critical-current density; the liquid-infiltration process thus has the potential for development of a practical Nb_3Sn conductor with both superior critical-current density and extremely good mechanical properties. Electromechanical parameters were obtained on several Nb_3Sn conductors that are candidate materials for superconducting fusion magnets, including conductors fabricated by the bronze, internal-tin, and jelly-roll processes. Thermal contraction data are reported on several new structural materials for superconductor sheathing and reinforcement, and a new diagnostic tool for probing the energy gap of practical superconductors has been developed using electron tunneling.
[Contact: John W. Ekin, (303) 497-5448]

Goldfarb, R.B., **Transient Losses in Superconductors,** NBSIR 86-3053 (June 1986).

Under steady-state conditions, there are no losses in superconducting wires. However, when subjected to alternating or transient magnetic fields or transport currents, losses in type-II superconductors can become significant. This report deals with hysteresis losses at 4 K measured by magnetization and complex magnetic susceptibility. The theoretical and experimental relationships between ac susceptibility and magnetization as functions of dc field were examined in terms of the critical-state model as developed by Carr and Clem. Minor-loop hysteresis loss is shown to be obtainable by direct measurement of loop area, from the imaginary component of ac susceptibility, and from the reversible susceptibility plus the critical current density or full-penetration field. Hysteresis and transport losses measured simultaneously in a Nb-Ti superconducting coil were found to agree substantially with the predictions of Minervini's two-dimensional model. Hysteresis loss measurements in a series of fine-filament Nb_3Sn superconductors showed that the effective filament diameter is a function of interfilament separation and local area ratio of matrix material to Nb. A review of internal fields in superconductors showed the importance of demagnetization factors and internal fields for the

Superconductors, cont'd.

correct analysis of magnetic data. A theoretical method of calibrating ac susceptometers for cylindrical specimens, which is based on a mutual-inductance calculation, was developed.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Magnetic Materials and Measurements

Released for Publication

Goldfarb, R.B., **Internal Fields in Magnetic Materials and Superconductors.**

This paper reviews some of the concepts needed for the correct analysis of magnetization data, both for magnetic materials and superconductors. Demagnetization factors, initial suceptibilities, and hysteresis losses are discussed.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Recently Published

Goldfarb, R.B., Rao, K.V., and Chen, H.S., **New Magnetic Phase Diagram of the Amorphous Pd-Fe-Si Ferroglass Alloy System**, Journal of Magnetism and Magnetic Materials, Vol. 54-57, pp. 111-112 (1986).

The magnetic phase diagram of amorphous $Pd_{80-x}Fe_xSi_{20}$ was examined. The peak in the imaginary component of ac susceptibility was used to determine the ferromagnetic-like/spin-glass transition temperatures T_{fg}. It was found that the T_{fg} line is highly field dependent and rises with increasing iron concentration.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Other Electrical Systems Topics

Recently Published

Hebner, R.E., Stenbakken, G.N., and Hillhouse, D.L., **Report of Tests on Joseph Newman's Device**, NBSIR 86-3405 (June 1986).

This report describes electrical measurements performed by the National Bureau of Standards on Joseph Newman's device. The tests were conducted between March and June 1986 at the request of the U.S. Patent and Trademark Office in accordance with several court orders. As a Federal science and engineering research laboratory that specializes in measurements and is responsible for maintaining U.S. standards for electricity, NBS has extensive experience and facilities for measuring the performance of electrical equipment.

The purpose of the measurements was to test the inventor's claim that the output power from the device was greater than the power which was supplied to the device from a battery pack. NBS was not requested to examine the theory behind the operation of the device.

The tests consisted of electrical measurements of the power drawn from the battery pack by the device (input power) and separate as well as simultaneous measurements of the output power. These measurements were done with several different sets of conventional, well-documented test instruments. Due to the specialized nature of the equipment, however, the instrumentation would not generally be found in most research laboratories. The electrical characteristics of the device, especially the sharp spikes in input and output waveforms, necessitated a variety of extensive and careful measurements and experimental checks to ensure that valid data resulted. Equipment selection was critical.

The device's efficiency -- defined as the ratio of output power to input power -- varied depending on the voltage, load on the device, and the degree of degradation of the tape on the commutator of the device. If the device simply transferred the power from the batteries to the load, its efficiency would be 100%; in no case did the device's efficiency approach 100%.

Other Electrical Systems Topics, cont'd.

At all conditions tested, the input power exceeded the output power. That is, the device did not deliver more energy than it used.
[Contact: Robert E. Hebner, (301) 975-2403]

ELECTROMAGNETIC INTERFERENCE

Radiated Electromagnetic Interference

Released for Publication

Crawford, M.L., and Koepke, G.H., **EMR Test Facilities - Evaluation of Reverberation Chambers Located at NSWC, Dahlgren, VA,** to be published as NBSIR 86-3051.

This report describes measurement procedures and results obtained from evaluating the reverberation chamber facilities located at the Naval Surface Weapons Center, Dahlgren, Virginia. Two chambers were tested referred to as 1) the half chamber, and 2) the full chamber. The facilities were developed by the NSWC for use in measuring and analyzing the electromagnetic susceptibility/vulnerability of weapon systems and the shielding effectiveness of enclosures and shielding materials. A brief description of each facility is given, including the instrumentation used for performing the evaluation and calibration of the facilities by the National Bureau of Standards. Measurements described include: 1) evaluation of the chamber's transmitting and receiving antennas voltage standing wave ratios; 2) measurement of the chamber's insertion loss or coupling efficiency versus frequency; 3) measurement of the effectiveness of the chamber tuners; 4) determination of the electric-field uniformity in the chamber's test zones versus frequency; 5) determination of the absolute amplitude calibration of the test electric fields in the chambers, based upon received power measurements of the reference antenna and calibrated dipole probe antenna measurements; and 6) comparison of the response of reference equipment under test to test fields established inside the NSWC reverberation chambers and the NBS reverberation chamber. These results can then be compared to anechoic chamber results. Conclusions given indicate that the NSWC chambers can be used at frequencies down to approximately 150 MHz. Estimates are given of the measurement uncertainties derived empirically from the test results.
[Contact: Myron L. Crawford, (303) 497-5497]

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

This paper describes the evaluation of the performance characteristics of a reverberation chamber excited by pulsed radiofrequency (rf) energy (pulse duration 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 is 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]

Crawford, M.L., and Koepke, G.H., **Performing EM Susceptibility/Vulnerability Measurements Using a Reverberation Chamber.**

This paper discusses the design, evaluation, and use of a reverberation chamber for performing electromagnetic susceptibility (EMS) measurements of electronic equipment. Included are brief descriptions of the test procedures, application advantages and limitation, some EMS test results, intrepretation of test results relative to free-space test methods, and an estimate of measurement uncertainties.

Radiated EMI, cont'd.

[Contact: Myron L. Crawford, (303) 497-5497]

Cruz, J.E., and Larsen, E.B., **Assessment of Errors for MIL-STD-461/462 Measurements,** to be published as NBS Technical Note 1300.

This report deals with the instrumentation and equations for several systems used by the U.S. Army for electromagnetic compatibility (EMC) testing and calibrations. Most testing for MIL-STD-461/462 is performed in a shielded enclosure (screenroom) rather than an open field site, which leads to uncertainty in the measurement of emissions from electronic equipment, or the susceptiblity of equipment to radiation. Assessment of error bounds by the National Bureau of Standards is covered in this report, and suggestions are given for improving the measurements.

Four areas of concern were studied as follows: (a) EM fields generated in a parallel plate transmission line (stripline), (b) EM fields beneath a single-wire transmission line in a screenroom (longwire line), (c) determination of antenna factors for EMI antennas located in a screenroom, and (d) calibration of EMI receivers to measure broadband impulsive signals. Most EMC antennas at NBS are calibrated at an open field site or in an anechoic chamber. This report presents antenna factors determined in a typical screenroom using the two-antenna method, and comparison with those determined at an open field site. The video pulse technique prescribed in MIL-STD-462 for calibrating EMI receivers was also evaluated. Four different methods were tested for comparison with the MIL-STD approach. They are defined and discussed in this report.
[Contact: Jose E. Cruz, (303) 497-3763]

Hill, D.A., **Radio-Wave Propagation From a Forest to a Clearing.**

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 previous integral equation and analytical continuation methods. The agreement with the integral equation method is good, but the analytical continuation method predicts higher field strengths. For a very thin forest, all three methods agree.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., and Cavcey, K.H., **Coupling Between Two Antennas Separated by a Planar Interface.**

The plane-wave spectrum technique is used to analyze the coupling between a pair of antennas separated by a planar interface. Multiple reflections between the antennas or between either antenna and the interface are included in the formulation. The formulation is used to model detection of buried objects, and a low-frequency metal detector example is analyzed in detail. For a transmitting loop and a buried oblate spheroid, the plane-wave spectrum technique is shown to agree with well-known quasi-static approximations. Some experimental results from a 3-kHz metal detector are also shown.
[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.**

A new broadband electric-field probe, capable of accurately characterizing and quantifying electromagnetic 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 GHz, with a

Radiated EMI, cont'd.

flatness of ±2 dB. A 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, D.R., **Near-Field Gain of a Horn and an Open-Ended Waveguide: Comparison Between Theory and Experiment.**

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 ±2 dB.
[Contact: Motohisa Kanda, (303) 497-5320]

Ma, M.T., and Kanda, M., **Electromagnetic Compatibility and Interference Metrology,** to be published as NBS Technical Note 1099.

The material included in this report is intended for a short course on electromagnetic compatibility/interference (EMC/EMI) metrology to be offered jointly by the staff of the Fields Characterization Group and the Interference Characterization Group of the Electromagnetic Fields Division. The purpose of this short course is to present a review of some of the radiated EMC/EMI measurement methods, to which the National Bureau of Standards (NBS) at Boulder, Colorado has made significant contributions during the past two decades. The technical foundation for these methods, and interpretations of the measured results are emphasized, as well as strengths and limitations. The entire course is presented in nine chapters with the introductory part given as Chapter 1. The particular measurement topics to be covered are: i) open sites (Chapters 2 and 6), ii) transverse electromagnetic cells (Chapter 3), iii) techniques for measuring the electromagnetic shielding of materials (Chapter 4), iv) anechoic chambers (Chapter 5), and v) reverberating chambers (Chapter 8). In addition, since a small probe antenna plays an important role in some of the EMC/EMI measurements covered herein, a separate chapter on various probe systems developed at NBS is given in Chapter 7. Selected contemporary EMI topics such as the characterization and measurement of a complex EM environment, interferences in the form of out-of-band receptions to an antenna, and some conducted EMI problems are also briefly discussed (Chapter 9).
[Contact: Mark T. Ma, (303) 497-3800]

Randa, J.P., and Kanda, M., **A Lattice Approach to Complex Electromagnetic Environments.**

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]

Wilson, P.F., and Ma, M.T., **Methods for Measuring the Near-Field and Far-Field Shielding Effectiveness of Materials.**

Radiated EMI, cont'd.

Techniques for measuring the shielding effectiveness of materials are investigated. Specific approaches considered are coaxial transmission line holders and the use of a time-domain signal for simulating plane wave shielding performance, and the dual transverse electromagnetic (TEM) cell and an apertured TEM cell in a reverberation chamber for the simulation of near-field shielding capability. The advantages and limitations or each technique are summarized.
[Contact: Perry F. Wilson, (303) 497-3842]

Wilson, P.F., and Ma, M.T., **Shielding Effectiveness Measurements Using an Apertured TEM Cell in a Reverberation Chamber.**

Near-field shielding effectiveness measurements 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]

Wilson, P.F., and Ma, M.T., **A Study of Techniques for Measuring the Electromagnetic Shielding Effectiveness of Materials,** to be published as NBS Technical Note 1095.

Shielding effectiveness relates to a material's ability to reduce the transmission of propagating fields in order electromagnetically to isolate one region from another. Because a complex material's shielding capability is difficult to predict, it often must be measured. A number of measurement approaches are studied including the use of a shielded room, coaxial transmission line holders, time-domain signals, the dual transverse electromagnetic (TEM) cell, and an apertured TEM cell in a reverberation chamber. In each case, we consider the system's frequency range, test sample requirements, test field types, dynamic range, time required, analytical background, and present data taken on a common set of materials.
[Contact: Perry F. Wilson, (303) 497-3842]

Recently Published

FitzGerrell, R.G., **Linear Gain-Standard Antennas Below 1000 MHz,** NBS Technical Note 1098 (May 1986).

Gain and antenna parameters related to input impedance are calculated using a computer program named HVD6. This program uses well-documented equations to compute these parameters for gain-standard antennas used in relative-gain or gain-transfer measurements at frequencies below 1000 MHz. The utility of this program is that it calculates gain patterns and input impedances for linear dipoles above perfect or imperfectly conducting plane ground and in free space, and for monopoles on perfectly conducting plane ground. Examples are included to illustrate the use of the program. Uncertainties in the calculated parameters are estimated to be less than those of the measured parameters.
[Contact: Richard G. FitzGerrell, (303) 497-3737]

FitzGerrell, R.G., **Site Attenuation,** IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-28, No. 1, pp. 38-40 (February 1986). [Note: NBS Technical Note 1089 (November 1985) presents similar material and includes a derivation of the expression for site attenuation, an appendix describing the dipole antennas and an analysis of their mismatch loss and input impedance, and an appendix incorporating listings of the two FORTRAN 4 codes used.]

Site attenuation is a measure of performance of an open test site at fre-

Radiated EMI, cont'd.

quencies below about 1 GHz. These sites typically consist of a large obstruction-free ground plane and the hemispheric volume above it. Calculations of site attenuation are presented which provide a reference for measurements made on a 30- by 60-m wire-mesh ground screen. Measured data are compared to the calculated results.
[Contact: Richard G. FitzGerrell, (303) 497-3737]

Friday, D.S., and Adams, J.W., **A Statistical Characterization of Electroexplosive Devices Relevant to Electromagnetic Compatibility Assessment,** NBS Technical Note 1094 (May 1986).

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 remain inactive otherwise. Recent concern with pulsed electromagnetic interference and nuclear electromagnetic pulse made apparent the lack of methodology for assessing EED vulnerability. A new and vigorous 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. Included are methods for assessing model validity and for obtaining probability plots, called "Firing Likelihood Plots". A method of measuring the thermal time constant of an EED is given. This parameter is necessary to evaluate the effect of a train of pulses. 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 the EEDs.
[Contact: Dennis S. Friday, (303) 497-5395]

Hill, D.A., **A Numerical Method for Near-Field Array Synthesis,** IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-27, No. 4, pp. 201-211 (November 1985).

A numerical method for near-field array synthesis is developed for arbitrary array geometries. The intended application is for generating a planar field in a test volume for electromagnetic susceptibility testing, but the method is valid for arbitrary field distributions. A uniqueness theorem is utilized to allow the field conditions to be enforced on the surface of the test volume rather than throughout the volume. The synthesis method is a least-squares solution with a constraint on the source norm; the constraint keeps the field small outside the test volume. Numerical results are shown for the case of synthesizing a plane wave in the near field of an array of line sources.
[Contact: David A. Hill, (303) 497-3472]

Jesch, R.L., **Susceptibility of Emergency Vehicle Sirens to External Radiated Electromagnetic Fields,** National Institute of Justice Report-200-85 (May 1986).

This report provides the results of an exploratory study to determine the susceptibility of electronic sirens to interference from typical communications equipment such as the transmitters and antennas likely to be operated in and around a law-enforcement vehicle.

Tests were performed using five specimen sirens and communications equipment operating at frequencies representing the frequency bands of 25 to 50, 150 to

Radiated EMI, cont'd.

174, 400 to 512, and 806 to 866 MHz. The sirens were mounted on top of a vehicle equipped with transmitters and roof-mounted antennas and subjected to levels of field strength generated by mobile transmitting equipment having output power levels up to 100 W. In addition, the siren controllers were subjected to various levels of field strength inside either a transverse electromagnetic (TEM) cell or an anechoic chamber to determine their susceptibility to known electromagnetic fields.
[Contact: Ramon L. Jesch, (303) 497-3496]

Conducted Electromagnetic Interference

Released for Publication

Martzloff, F.D., **Surge Suppressors and Clamps,** to be published in the Proceedings of EXPO 86, Washington, DC, June 16-19, 1986.

The paper presents a review of technologies developed for surge suppressor devices used in electronic circuits. Three generic types are described: crowbars, varistors, and avalanche diodes. The significant differences in their performance characteristics are pointed out, together with guidance on proper application and measurements.
[Contact: Francois D. Martzloff, (301) 975-2409]

Martzloff, F.D., and Wilson, P.F., **Fast Transient Tests - Trivial or Terminal Pursuit.**

Measurements, augmented by theoretical simulation techniques, have been performed to determine the attenuation of fast-transients propagating in typical power lines. The rise time of the applied pulses ranged from 0.7 to 50 ns. Theory and measurements agree and confirm that pulse attenuation increases significantly for shorter pulses.
[Contact: Francois D. Martzloff, (301) 975-2409]

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).

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**

Lists of Publications, cont'd.

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

May 12-14 (Colorado Springs, CO)

Laser Measurements Short Course. This Short Course will be offered by the NBS Electromagnetic Technology Division in cooperation with the University of Colorado and representatives of industry; its content emphasizes the concepts, techniques, and apparatus used in measuring laser parameters. The faculty are laser experts from NBS, academia, and industry; sessions will be held at the Clarion Hotel in Colorado Springs. An optional visit to the NBS laser measurement laboratories is part of the program. The course is intended for those holding a degree in physics or electrical engineering; the organizers consider some experience in the use of lasers desirable.

Topics to be addressed include: optics for laser measurements, attenuation techniques, laser operation, basic laser power/energy standards, transfer standards, pulse measurements, beam-profile measurements, diode lasers, laser measurements for optical communications, statistics and error analysis, and laser safety. [Contact: Office of Conference Services, University of Colorado, (303) 492-5151/8630]

June 8-11 (Boulder, CO)

1987 EMI Metrology Short Course. The NBS Electromagnetic Fields Division will present this Short Course at the University of Colorado, Boulder, and the NBS Boulder Laboratories to provide attendees with up-to-date information on instruments and techniques for measuring electromagnetic interference (EMI). The Course will combine lectures at the University campus by NBS staff with laboratory demonstrations and hands-on participation at NBS. A special feature will be a presentation by a military representative on various EMI-related military standards.

The planned schedule provides for the following topics: <first day> military standards and practices, measurements in shielded rooms, open-site measurements (as related to FCC requirements); <second day> TEM cells (fundamentals, susceptibility testing, emission testing), EM probe development, generation of standard fields in the anechoic chamber; <third day> shielding effectiveness of materials (introduction, theory, practice), reverberating chamber (theory, practice), conducted EMI problems (CEMI sources and measurements, generating constant fields for electromagnetic compatibility testing); <fourth day> electrostatic discharge, measurement problems associated with complex electromagnetic environments, time-domain measurement techniques. [Contact: Steve Horowitz, Office of Conference Services, University of Colorado, (303) 492-5151]

September 14-16 (Research Triangle Park, NC)

VLSI and GaAs Packaging Workshop. This Workshop is co-sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE and NBS; attendees are expected to be knowledgeable in the field and to participate in discussions. Topic areas include: VLSI and wafer scale package design (characterization and implementation, cost and performance driven solutions); package thermal design (characteristics, results, and issues); package interconnection options (wire bonding, TAB, flip

1987 CEEE Calendar, cont'd.

nection options (wire bonding, TAB, flip chip, or optical); GaAs IC packaging (high speed packaging considerations); package electrical issues (reduction of parasitics and improvements in electrical performances); integrating package design (from die to system, including assembly and test issues); VLSI package materials advancements; die-attach solutions for large chips; new failure mechanisms in VLSI packaging. [Contact: George G. Harman, (301) 975-2097]

September 22-25 (Boulder, CO)

Noise Measurement Seminar. This four-day course is presented and hosted by the Electromagnetic Fields Division in cooperation with representatives from industry and the NBS Time and Frequency Division. It is intended for practicing noise metrologists and technical managers responsible for systems in which accurate measurements of thermal and phase noise are important. Attendees will learn the most important precautions to take in making accurate noise measurements and will receive a set of notes that are suitable for use in solving precision noise measurement problems. Course topics include reference thermal noise sources; thermal noise measuring systems and techniques; phase noise; and the problems of measuring thermal noise in passive components, amplifiers, and communication systems.

The course design combines formal lectures on theory presented by NBS staff and industry experts with demonstrations in NBS laboratories and demonstrations of commercial equipment. A special feature of the Seminar is the opportunity each day for attendees to share their experiences in solving specific problems or their insights on practical noise measurement issues through short presentations to the assembled group. Time is scheduled for group discussions of these presentations and other topics raised by the Seminar. [Contact: Sunchana Perera (303) 497-3546]

September 23-25 (Gaithersburg, MD)

Workshop on the Role of Optics in Power System Electrical Measurements. This Workshop is sponsored by NBS, the Bonneville Power Administration (BPA), the Electric Power Research Institute (EPRI), and the Empire State Electric Energy Research Corporation (ESEERC) and is intended for research and development engineers in utilities and in companies that supply equipment to the utility industry. The objective of this workshop is to identify anticipated opportunities for improved measurement techniques that should arise as power systems individually and collectively evolve to meet the needs of the 1990s. Presentations will stress the design and testing of optical systems for 60-Hz voltage or current measurement; the interfacing of electronic or optical components with existing metering and control systems; opportunities for new measurement hardware resulting from increased automated control of power systems and of the testing of power system components; and optical techniques for the measurement of electric and magnetic fields in power systems or system components. The results of an NBS study evaluating optical techniques for power-system electrical measurements and carried out in agreement with BPA, EPRI, and ESEERC will be presented as an invited keynote. [Contact: Robert E. Hebner, (301) 975-2403]

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 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]

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Center for Electronics and Electrical Engineering

10. SUPPLEMENTARY NOTES

All technical information included in this document has been approved for publication previously.

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

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12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

antennas; electrical engineering; electrical power; electromagnetic interference; electronics; instrumentation; laser; magnetics; microwave; optical fibers; semiconductors; superconductors

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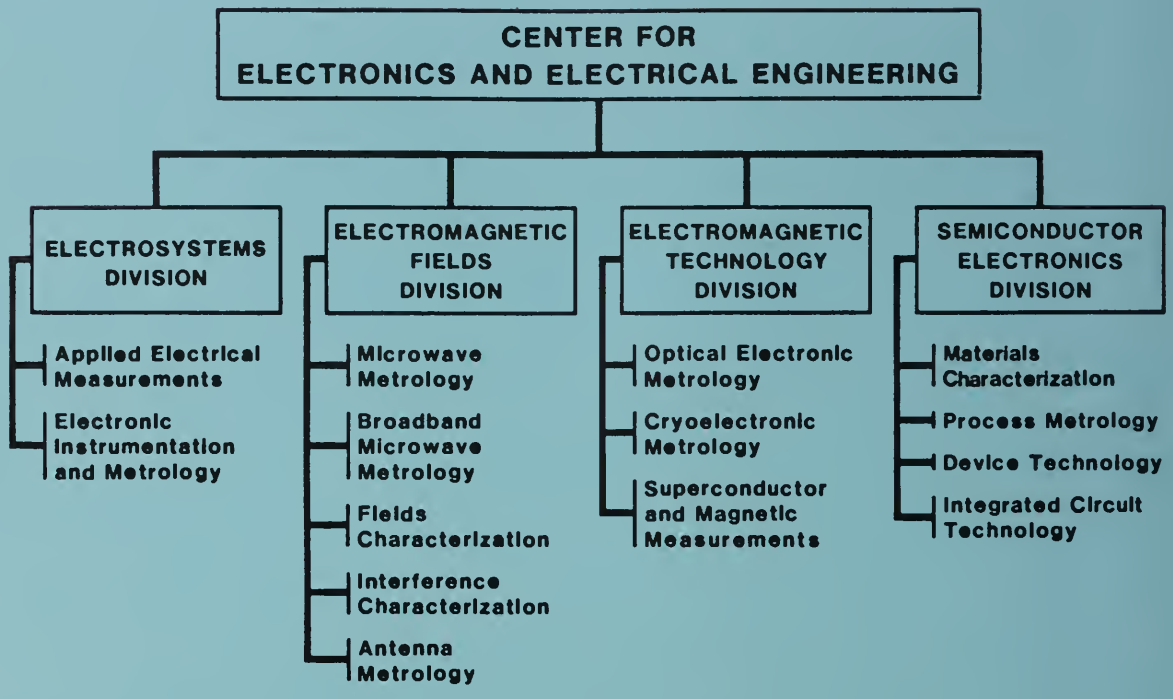

KEY CONTACTS:

Center Headquarters (720)	Director, Mr. Judson C. French (301) 975-2220
	Deputy Director, Mr. Robert I. Scace (301) 975-2220
Electrosystems Division (722)	Chief, Dr. Oskars Petersons (301) 975-2400
Electromagnetic Fields Division (723)	Chief, Mr. Charles K.S. Miller (303) 497-3131
Electromagnetic Technology Division (724)	Chief, Dr. Robert A. Kamper (303) 497-3535
Semiconductor Electronics Division (727)	Chief, Mr. Frank F. Oettinger (301) 975-2054

INFORMATION:

For additional information on the Center for Electronics and Electrical Engineering, write or call:

Center for Electronics and Electrical Engineering
National Bureau of Standards
Metrology Building, Room B-358
Gaithersburg, MD 20899

Telephone (301) 975-2220