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Application of Ink Jet Technology to a Word Processing Output Printer *by W. L. Buehner, J. D. Hill, T. H. Williams, and J. W. Woods, p. 2.* This paper describes a word processing system output printer that uses the electrostatic synchronous ink jet printing process. An overview of the ink jet matrix printing process is included, as well as brief descriptions of the elements of the printer. Printer performance objectives are outlined, and some of the design problems encountered during development are discussed.

Scale Model of an Ink Jet *by S. A. Curry and H. Portig, p. 10.* A scale model, approximately fifty times the size of its prototype, was used to study drop formation of an ink jet. Viscosity, surface tension, and inertial forces were modeled; gravity and air drag forces were not. The model accurately predicted operating conditions leading to the formation of undesirable satellite drops, thus permitting evaluation of measures designed to avoid them.

Satellite Droplet Formation in a Liquid Jet *by W. T. Pimbley and H. C. Lee, p. 21.* The formation and behavior of satellite droplets in a liquid jet is investigated experimentally and theoretically. The satellite droplet break-off distance is measured stroboscopically as a function of the frequency and amplitude of nozzle vibration. A second-order analysis of spatial instability is developed, which demonstrates the essential features of satellite formation as it is observed. Satellite formation is least likely to occur when the main-drop spacing is five to seven times the jet diameter.

Effect of Parameter Variations on Drop Placement in an Electrostatic Ink Jet Printer *by T. G. Twardeck, p. 31.* This paper discusses the sensitivity of drop-to-drop spacing in the print plane of an ink jet printer to other printer variables. Two designed experiments, a fractional factorial and a central composite, combined with standard analysis identified the critical variables and provided a mathematical expression useful for setting tolerances.

Drop Charging and Deflection in an Electrostatic Ink Jet Printer *by G. L. Fillmore, W. L. Buehner, and D. L. West, p. 37.* This paper describes the drop charging and drop deflection processes in an electrostatic ink jet printer. Included in the discussion of drop charging are induction interaction effects and charge synchronization requirements, as well as design considerations for the charge electrode. In describing the parameters governing drop deflection, some drop placement errors are related to undesired interactions resulting from aerodynamic forces and electrostatic repulsion effects on the drops. A scheme for obtaining accurate drop placement in the presence of these interaction effects is described.

Boundary Layer Around a Liquid Jet *by H. C. Lee, p. 48.* The phenomenon of air wake caused by a train of liquid drops is studied in this paper by approximating the train to a cylindrical jet emerging from a nozzle. The boundary layer equations are derived by applying continuity of jet mass and matching the loss of jet momentum with the air drag on the jet. These equations are solved numerically and compared with experiments in which the velocity change of the jet along the stream is carefully measured through measurements of drop distances. Good agreement is obtained between experimental results and the analysis.

Controlling Print Height in an Ink Jet Printer *by J. M. Carmichael, p. 52.* This paper describes a control system for maintaining constant print height in an ink jet printer. Following power on and during a periodic off-line correction operation a specially designed sensor detects the position of a test group of electrostatically charged ink drops to obtain print height correction data. Information provided by the same sensor is used to synchronize the application of a unique charge to each drop to be printed.

Study of Fluid Flow through Scaled-up Ink Jet Nozzles *by M. Levanoni, p. 56.* A 100-fold scaled-up model of ink jet nozzle flow is described. A theoretical justification for scaling the relevant parameters, starting from the equations of motion, is presented. The scaling procedure and the effects of unscaled parameters are discussed as well as the scaled-up "ink." Following a description of the experimental apparatus, the results of a series of experiments are then presented. These consist of directionality, directional stability and flow efficiency measurements in four nozzle configurations: conical, cylindrical, square, and "hybrid" nozzles.

Development and Characterization of Ink for an Electrostatic Ink Jet Printer *by C. T. Ashley, K. E. Edds, and D. L. Elbert, p. 69.* This paper reviews the development of the ink for an electrostatic ink jet printer. It discusses the formulation logic, test procedures, failure analyses, and problem resolutions. The variables that influence the jet printing process and print quality are defined, and their relationship to specific formulations is discussed. Also considered are the relationships between formulation variables and failure modes inherent in the ink.

Materials Selection for an Ink Jet Printer *by B. L. Beach, C. W. Hildenbrandt, and W. H. Reed, p. 75.* An ink jet printer includes a system of parts that supplies, filters, pumps, circulates, and pulses a jet of ink. These parts, made of various materials (metals, plastics, rubbers, adhesives), must satisfy the mechanical and electrical requirements of the system while being compatible with the chemical composition of the ink. This paper describes the selection and evaluation of these materials for a particular ink and printer design.

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Preface *by P. J. Flory, p. 98.*

Preparation and Properties of $(SN)_x$ *by G. B. Street and R. L. Greene, p. 99.* The chain compound $(SN)_x$ is the first example of a superconducting polymer. In this paper we review the chemistry, structure, and physical properties of $(SN)_x$ and describe how the electrical properties of this novel material depend upon the crystal growth technique. The thermal properties of S_2N_2 and $(SN)_x$ are discussed with particular reference to the crystal growth process. The fibrous nature of the polymer is described and evidence is presented showing that interchain coupling plays a significant role in determining the physical properties of this material. Finally we summarize our attempts to prepare analogous polymeric metals.

NMR Study of the Chain Microstructure of P(MMA-co-MAA) *by J. R. Lyerla, Jr., p. 111.* The usefulness of proton and carbon-13 NMR spectroscopy in characterizing the chain microstructure (i.e., sequence distribution and tacticity) of methyl methacrylate-methacrylic acid (MMA-MAA) copolymers has been investigated. Because the comonomers have such similar structures, assessment of chain tacticity and sequence distribution required computer simulation of spectra to circumvent the problems of resonance overlap. The computer analysis used ^1H and ^{13}C chemical shift data on homopolymers and "sterically-defined" copolymers, Bernoullian and Markovian statistics for the respective tactic and sequence distributions, and a Lorentzian lineshape program to generate a theoretical spectrum. The generating parameters that produced simulation of both the ^1H and ^{13}C spectra provided the basis for describing the triad microstructure of the copolymers. This method of characterizing the microstructure was applied to copolymers of similar composition but different preparative histories. The results indicated that free-radical polymerization in toluene yielded a heterogeneous copolymer system while free-radical polymerization in tetrahydrofuran (THF) and emulsion polymerization yielded relatively homogeneous systems.

Radiation Chemistry of Poly(methacrylates) *by H. Hiraoka, p. 121.* An experimental study comparing radiation-induced degradation of poly(methacrylates) from ultraviolet, gamma-ray (^{60}Co), and electron-beam irradiation is presented. Analytical techniques used include mass spectroscopy, low-temperature electron paramagnetic resonance, and infrared spectrometry. The poly(methacrylate) polymers investigated are poly(methyl methacrylate) (PMMA), poly(*t*-butyl methacrylate) (PBMA), poly(methacrylic acid) (PMA), and poly(methacrylic anhydride) (PMA AN). All are shown to exhibit scission of the main chains and removal of the side groups when irradiated.

Model for the Kinematics of Polymer Dissolution *by Y.-O. Tu and A. C. Ouano, p. 131.* The dissolution of glassy polymers is described by a phenomenological model of the motion of two boundaries: the liquid-gel boundary and the gel-glass boundary. The motion of these boundaries, as well as the concentration profile in the layers of a dissolving polymer, was obtained by numerical solution of the Stefan boundary value problem. Confirmation of the experimental program written to simulate the problem is established by its good agreement with direct observation of the dissolution dynamics of polystyrene in methyl ethyl ketone. A potential application of this model to the study of the dissolution dynamics of other polymer-solvent systems is done by simulating the dissolution of three types of polymer-solvent pairs: 1) swelling of rubber, 2) high glass transition concentration, and 3) low glass transition concentration. Contrasting dissolution characteristics are shown for the effect of different types of polymer-solvent pairs as well as for the effect of different molecular weights for the same type of polymer-solvent pair.

Parameters Affecting the Electron Beam Sensitivity of Poly(methyl methacrylate) *by E. Gipstein, A. C. Ouano, D. E. Johnson, and O. U. Need III, p. 143.* Poly(methyl methacrylate), PMMA, is used as a model polymer to determine quantitatively the effect of molecular weight, molecular weight distribution, and tacticity on electron beam sensitivity. The heterotactic, syndiotactic, and isotactic stereoforms of PMMA were synthesized with molecular weights ranging from 10^4 to 10^7 and dispersivities from 1.2 to about 10. The *G*-values as determined by gamma radiation are about 1.3 and are independent of the three parameters. However, the solubility rate of PMMA is very dependent on the tacticity, and the relative solubility rates are in the order syndiotactic < heterotactic isotactic. The weight-average molecular weight ratio was found to give a better correlation with solubility rate ratio than the number-average molecular weight ratio. The molecular size of the developer solvent was shown to have a much greater effect on the solubility rate than the molecular weight of the resist. An optimal developer solvent for PMMA can be systematically selected from a homologous series of *n*-alkyl acetates which enhance the resist sensitivity.

Strength and Related Properties of Elastomeric Block Copolymers *by T. L. Smith, p. 154.* Stress-strain curves of single-phase noncrystallizable elastomers over extended ranges of temperature and extension rate are considered qualitatively along with phenomenological and mechanistic aspects of fracture. Data are presented to show that single-phase noncrystallizable elastomers lack toughness except when segmental mobility is sufficiently low so that viscoelastic processes near the tip of a slowly growing crack effectively retard its growth. Highly effective strengthening mechanisms are imparted by plastic domains which result from phase separation in elastomeric block copolymers and from strain-induced crystallization in certain elastomers. The stiffness, tensile strength, and extensibility of a poly(urea-urethane) and three polyurethane elastomers over a broad temperature range are discussed in terms of the type, size, and concentration of the domain-forming segments. These elastomers, and particularly their true stress-at-break,

are compared with other block copolymers and with polyurethane elastomers devoid of plastic domains.

Properties of Polymeric Thin Films by Integrated Optical Techniques *by J. D. Swalen, R. Santo, M. Tacke, and J. Fischer, p. 168.* We report an innovative procedure for taking measurements using integrated optical techniques on a number of polymers fabricated into thin film form and used as optical waveguides. Refractive index (including anisotropy), absorption and scattering, and film thickness have been determined by light guiding properties. Techniques for film preparation, including doctor blading, dipping, horizontal flowing, and spinning, are also discussed. The polymers studied are poly(methyl methacrylate), poly(vinyl-formal), poly-acrylonitrile, poly(vinyl alcohol), poly(vinyl pyrrolidone), poly(vinyl benzoate), and polystyrene.

Solubility and Diffusion of Sulfur in Polymeric Materials *by B. S. Berry and J. R. Susko, p. 176.* Radiotracer techniques were used to study the sorption of sulfur vapor by silicone and epoxy polymers and to obtain information on the diffusion of sulfur in these materials. Sulfur was found to enter silicone polymers solely by a physical solution process which obeys Henry's law. The heat of solution is large (-0.43 eV) and at room temperature the solubility coefficient is at least five orders of magnitude greater than for many fully gaseous solutes, a result which fits an empirical rule relating the solubility coefficient of a given solute to its boiling point. Sorption of sulfur by a flexibilized anhydride-cured diglycidyletherbisphenol-A (DGEBA) epoxy is somewhat more complicated and appears to involve a double process of physical solution and chemical reaction. The rapid diffusion of sulfur in silicone rubber necessitated measurements of the diffusion coefficient D by a vacuum desorption technique. The activation energy Q and pre-exponential constant D_0 are found to be 0.74 eV and 4×10^5 cm^2/s, respectively. Corresponding values for the epoxy, as determined by a steady state permeation method, are 1.06 eV and 3×10^5 cm^2/s. These relatively large activation energies and pre-exponential factors are thought to reflect the large size of the S_8 molecule. Near room temperature, the difference in the activation energies causes sulfur diffusion to occur at least four orders of magnitude more slowly in the epoxy, which makes this material much more attractive for encapsulation applications requiring an effective diffusion barrier to elemental sulfur present as a pollutant of the atmosphere.

Rheology and Modeling of the Spin Coating Process *by B. D. Washo, p. 190.* This study examines the spin coating process both experimentally and from a fundamental point of view. The analysis has produced a model and a quantitative relationship between spin coating thickness and pertinent material and process variables. The model predicts that the simplest and most reproducible results occur in a region which is independent of thickness and time and is characterized by low steady state radial flow on the substrate. The model also includes a time-dependent term, shown to be important for the region of high radial flow—fluids of relatively low viscosity and process conditions of relatively high speed and/or long times. Experimentally, Newtonian-like polyamide in iso-amyl alcohol solutions was examined on large rotating substrates, and measurements showed excellent correlation with the model. The sensitivity of the spin coating process to substrate size and shape is also reported and a comparison with other data in the literature, particularly on photoresist solutions, is presented. The potential applicability of the model to non-ideal fluids is also developed.

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Thermal Effects on the Photoresist AZ1350J *by F. H. Dill and J. M. Shaw, p. 210.* An experimental study is reported on the various effects produced by the baking steps normally used in processing positive photoresists for application in microelectronics. The particular material investigated is AZ1350J, made by the Shipley Company, Inc. The thermal effects are studied in terms of a newly modified model that characterizes the exposure and development processes in photoresist. The changes in performance of the photoresist as a result of prebake, post-exposure bake, and post-development bake are discussed and are related to the parameters in the model that govern exposure and development. The model is derived from physical rather than chemical measurements.

Thermal Analysis of Positive Photoresist Films by Mass Spectrometry *by J. M. Shaw, M. A. Frisch, and F. H. Dill, p. 219.* Mass spectrometry is used to monitor the effect of temperature on positive photoresist and its two major components, a base resin and a photoactive compound. This technique is also used to identify the photolytic products of photoresist by exposing it in situ to ultraviolet radiation and to identify the resulting volatile products when it is heated after exposure. Quantitative data are obtained for the two major thermal products of photoresist, and the activation energy is calculated for the thermal degradation of the photoactive compound.

Conduction Studies in Silicon Nitride: Dark Currents and Photocurrents *by D. J. DiMaria and P. C. Arnett, p. 227.* Dark conduction and photoconduction phenomena in amorphous, stoichiometric Si_3N_4 films incorporated into metal-silicon nitride-silicon (MNS) structures are studied in detail. Results demonstrating the importance of hole conduction in Si_3N_4 thin films are presented. The importance of trapped space charge injected from the contacts is shown in an analysis of the effects of Si_3N_4 thickness and the choice of gate metal on conduction. Contact effects that are apparent in the current characteristics of thin Si_3N_4 layers become dominated by bulk conduction mechanisms as the silicon nitride film increases in thickness. Optical interference effects in photoconduction are used to determine the origin of photocarriers.

Automatic Signature Verification Based on Accelerometry *by N. M. Herbst and C.-N. Liu, p. 245.* The fine structure of the muscle forces that are exerted during the writing of a signature is constant and well defined for most people. In general, the fine structure is not subject to conscious control. Based on these observations, an experimental system has been designed that utilizes a person's signature dynamics to verify identities. The design and operational features of this system are described. Experiments on 70 subjects during a four-week period show a 2.9 percent rejection of valid signatures and a 2.1 percent acceptance of forgeries. An average of 1.2 trials was necessary for verification. The forgers were knowledgeable about the verification technique and did their best to deceive the system. The acceptance rate of random forgeries, i.e., accidental matching of two separate signatures, was 0.16 percent.

Discrete Link Capacity and Priority Assignments in Communication Networks *by K. Maruyama and D. T. Tang, p. 254.* This paper deals with the problem of discrete link capacity assignment in store-and-forward packet switching communication networks. Our problem formulation calls for minimizing the network cost while satisfying all the average packet delay constraints specified for different classes of packets. Heuristic algorithms which give near-optimal solutions of the problem are developed.

We first describe a discrete link capacity assignment algorithm for networks with arbitrarily defined classes of packets having individual delay constraints. The problem of priority assignment on different classes of packets is then investigated, and an algorithm is developed which assigns suboptimal priorities on classes of packets based on parameters such as delay requirement, path length, packet length, and packet rate. These two algorithms for capacity assignment and priority assignment are combined and tested over a number of examples. It is found that a substantial reduction on network cost can be achieved by the use of a simple priority queuing discipline.

Buffer Performance Analysis of Communication Processors During Slowdown at Network Control *by W.-M. Chow and L. Woo, p. 264.* An approximate model based on renewal theory has been developed for the performance analysis of communication processors during Network Control Program (NCP) slowdown. Performance values, which include cycle length, buffer utilization, and message loss, were computed as functions of traffic loads and user-assigned threshold values of free buffers were used for slowdown control. Comparison of results obtained by the approximate method with simulated results shows a high degree of accuracy for the approximation.

Improving the Computation of Lower Bounds for Optimal Schedules *by T. Lang and E. B. Fernández, p. 273.* Ways of decreasing the number of operations needed to compute the lower bounds of optimal schedules, by reducing the number of time intervals that must be considered, are presented. The bounds apply to a system of identical processors executing a partially ordered set of tasks, with known execution times, using a non-preemptive scheduling strategy. In one approach we find that the required number of intervals depends on the graph. In our other approach, which subsumes the first, the number of intervals is decreased to at most $\min[D^2/2, n^2]$, where D is the deadline to complete the tasks and n is the number of tasks. The actual number of intervals for a particular graph can be considerably smaller than this worst case.

Dynamic Memories with Faster Random and Sequential Access *by C.-K. Wong and D. T. Tang, p. 281.* This paper extends the dynamic memory proposed by Aho and Ullman in two directions. Instead of a shuffle permutation, block shuffles are introduced. By choosing suitable block sizes, faster random and sequential access may result. Another direction of extension comes from the addition of a reverse cyclic permutation, which results in even faster random and sequential access. Analyses for both the worst and the average cases are given. Generalizations to arbitrary radices are also discussed.

Capacitance Probe Study of Rotating-Head/Tape Interface *by N. A. Feliss and F. E. Talke, p. 289.* A modified version of the capacitance probe technique is used to investigate the head-tape interface in a rotating head configuration. The relationship between air-bearing spacing and contour design is studied as a function of tape tension, head protrusion, and velocity; in addition, the effect of wave dynamics on flying height is examined.

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Two-Dimensional Analysis of High-Voltage Power Transistors *by S. P. Gaur, p. 306.* The internal behavior of a typical n-p-n^--n^+ high-voltage power transistor is presented for several specific steady-state operating conditions obtained from a two-dimensional mathematical model. Internal self-heating and avalanche multiplication effects are taken into account. Poisson's equation, electron and hole continuity equations, and the heat flow equation are solved numerically in a two-dimensional region with the input parameters of device dimensions, doping profile, boundary conditions for external contacts, and various material constants for silicon. The collector n^--n^+ interface is the region of high electrical and thermal stress that causes second breakdown failure at high-voltage and high-current operating conditions. The combined effects of various high-injection levels are illustrated.

Splatter During Ink Jet Printing *by J. L. Zable, p. 315.* When an ink drop traveling at relatively high velocity impinges on a flat surface such as paper, part of the drop breaks up into many very small droplets that are deposited at other points. If these droplets are relatively large, then visible

splatter results. Various parameters (ink properties, drop velocity, drop volume, space between drops, etc.) are investigated to determine their effect upon splatter and hence print quality. Print samples were made while varying these parameters, and the resulting print quality was assessed. A simple relationship among the kinetic energy of the drops, the overlap between drops, and print quality based upon splatter is developed. This relationship can be used to establish design boundaries in an ink jet printer.

AUTOPASS: An Automatic Programming System for Computer Controlled Mechanical Assembly *by L. I. Lieberman and M. A. Wesley, p. 321.* This paper describes an experimental very high level programming system for computer controlled mechanical assembly, AUTOPASS (AUTOmated Parts ASsembly System). The AUTOPASS language is oriented towards objects and assembly operations, rather than motions of mechanical assembly machines. It is intended to enable the user to concentrate on the overall assembly sequence and to program with English-like statements using names and terminology that are familiar to him. To relate assembly operations to manipulator motions, the AUTOPASS compiler uses an internal representation of the assembly world. This representation consists of a geometric data base generated prior to compilation and updated during compilation; it thus represents the state of the world at each assembly step. The level of the language has been chosen to provide a high degree of assistance to the user without the system's having to perform artificial intelligence type problem solving operations.

Linear Filtering Technique for Computing Mersenne and Fermat Number Transforms *by H. J. Nussbaumer, p. 334.* In this paper, the implementation of pseudo-Mersenne and Fermat Number Transforms is discussed. It is shown that some pseudo-Mersenne Transforms can be computed efficiently by a linear filtering approach. This approach is extended to cover the case of Fermat and pseudo-Fermat Number Transforms by using a special coding scheme for implementing arithmetic operations in a Fermat number system.

Worst-Case Pattern Evaluation of Baseband Channels *by R. Kiwimagi, L. Griffiths, and R. Furtney, p. 340.* This paper presents a new method for evaluating the performance of communication systems that use binary-valued signaling formats. This technique permits selection of the best overall code for a particular channel or, alternatively, provides a method for comparing different channels that use the same transmission code. Encoded waveforms at the channel input are presumed to be generated by a constrained-coding procedure, which ensures, for example, that the resulting binary waveform has a certain minimum number of transitions per unit time, limited digital sum variations (DSV), among other characteristics. With this method, one first determines that particular sequence (within the given code constraints) that produces the maximum amount of intersymbol-interference when transmitted through the given channel. A dynamic-programming procedure is used to compute this sequence. Overall channel performance is evaluated by calculating the probability of error and the minimum eye-pattern opening. Numerical examples illustrating the procedure for a synthetic channel are presented and analyzed.

Algorithmic Information Theory *by G. J. Chaitin, p. 350.* This paper reviews algorithmic information theory, which is an attempt to apply information-theoretic and probabilistic ideas to recursive function theory. Typical concerns in this approach are, for example, the number of bits of information required to specify an algorithm, or the probability that a program whose bits are chosen by coin flipping produces a given output. During the past few years the definitions of algorithmic information theory have been reformulated. The basic features of the new formalism are presented here and certain results of R. M. Solovay are reported.

Heuristic Design Algorithm for Computer Communication Networks with Different Classes of Packets *by K. Maruyama, L. Fratta, and D. T. Tang, p. 360.* A typical operating environment of a packet switching (store-and-forward) computer communication network is that it is shared by many users with different classes of packets. Packets may be classified in a very general fashion by types of users, messages, applications, transactions, response time requirements, packet parameters such as packet rate and length, and by network parameters such as source-destination and path length. A well-designed network must provide access and performance assurance to all packet classes. This paper presents a heuristic algorithm for designing such a communication network. The algorithm presented contains heuristic algorithms for discrete link capacity assignment, priority assignment, and flow assignment problems with an additional feature which allows one to alter network topology interactively. Sample results from applications of the overall network design are also given.

Queuing Networks with Population Size Constraints *by S. S. Lam, p. 370.* The class of queuing networks with multiple routing subchains is extended to include mechanisms of state-dependent lost arrivals and triggered arrivals. A sufficient condition is found, involving the loss and trigger functions, for the equilibrium network state probability distribution to have the product form; the known class of queuing networks with a product form solution is thus enlarged. Such queuing networks are useful models for systems with various population size constraints. Potential applications to modeling computer communication systems with storage and flow control constraints are indicated.

Experiments on the Dynamic Response of a Flexible Strip to Moving Loads *by D. M. Albrecht, E. G. Laenen, and C. Lin, p. 379.* Experimental findings are reported on the dynamic response of a flexible strip to moving loads traveling

at an oblique angle to its edges. The strip is wrapped under tension around a pair of supporting pressurized cylinder halves. The moving loads are applied to the flexible strip at the gap between the two cylinder halves. A capacitance displacement transducer measures the dynamic response of the strip, which is shown in isometric perspective for various boundary conditions. It is shown that waves on the strip created by the moving loads can be eliminated by providing a hydrodynamic air film support to the flexible strip in the vicinity of the moving loads. Experiments demonstrate that response to the loads along the edges of the strip differs from that near its center, which is to be expected because of the reflection of flexural waves from the boundaries of the strip.

An Extension of Moore's Result for Closed Queuing Networks *by S. S. Lam, p. 384.* In this communication, Moore's result for the normalization constant of a closed queuing network of exponential servers is extended to the case of nondistinct traffic intensities. We then show that this result can be applied to various more general closed and semiclosed queuing networks with a product-form solution.

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Analysis of the Merged Charge Memory (MCM) Cell *by H.-S. Lee, p. 402.* This paper describes a new MOS dynamic RAM (Random-Access Memory) cell which utilizes a merged surface charge transistor structure. The merged charge memory (MCM) cell uses a polysilicon electrode as both a bit sense line and common plate for a column of storage capacitors. The MCM structure is self-aligned, contactless and free of closely spaced *p-n* junctions. Its spatial density approaches the conceptual limit of the intersection formed by two orthogonal lines or $4W^2$ where W is the minimum geometry feature. The cell area utilization efficiency is improved because of this simplicity. Preliminary experimental results and ASTAP simulations based on the charge control equivalent circuit for a dynamic potential well are described. Implications for chip design constraints are discussed, and the advantages and limitations of MCM are highlighted where appropriate.

Digital Technique for Generating Synthetic Aperture Radar Images *by W. J. van de Lindt, p. 415.* This paper describes a digital processing method applicable to a synthetic aperture radar, to be carried by the space shuttle or by satellites. The method uses an earth-fixed coordinate system in which corrective procedures are invoked to compensate for errors introduced by the satellite motion, earth curvature, and wavefront curvature. Among the compensations discussed are those of the coordinate system, skewness, roll, pitch, yaw, earth rotation, and others. The application of a Fast Fourier Transform in the numerical processing of the two-dimensional convolution is discussed in detail.

Safe Operating Area for Bipolar Transistors *by S. P. Gaur, p. 433.* A mathematical model is utilized to predict the safe operating area (SOA) for proper circuit applications of bipolar transistors in the forward as well as reverse operating regions. Nonuniformity of the temperature within the transistor structure due to internal self-heating and the avalanche multiplication effect in the reverse operating region, which cause second breakdown failure, are taken into account. Steady-state electrical and time-dependent thermal problems are solved to establish stability of a specified operating condition. Safe operating area curves for three transistor designs of similar power handling capability are presented. Current density and temperature distributions within the transistor structure for various operating conditions in the stable as well as unstable regions are presented. Suitability of V_{BE} to estimate peak temperature within the device is discussed.

Multidimensional Bin Packing Algorithms *by L. T. Kou and G. Markowsky, p. 443.* A comparative study is made of algorithms for a general multidimensional problem involving the packing of *k*-part objects in *k* compartments in a large supply of bins. The goal is to pack the objects using a minimum number of bins. The properties and limitations of the algorithms are discussed, including *k*-dimensional analogs of some popular one-dimensional algorithms. An application of the algorithms is the design of computer networks.

Zero Order and Nonzero Order Decision Rules in Medical Diagnosis *by R. J. Peters, p. 449.* In searching for the optimal solution to the medical diagnostic problem, it seems useful to distinguish between different possible decision rules (strategies). Two different classes of decision rules are considered: nonzero order decision rules and constant or zero order decision rules. For each class, solution methods as well as heuristic approaches to finding the optimal member of the class are discussed. As an exercise, the diagnosis of a hematologic disease belonging to the group macrocytic anemia is considered.

Variable Geometry Cochlear Model at Low Input Frequencies: A Basis for Compensating Morphological Disorders *by A. Inselberg, p. 461.* The implementation of an algorithm suitable for interactive experimentation with a mathematical model of the cochlea is described. In the model, the cochlea's exterior shell is represented by a surface of revolution. Internally, the cochlea is partitioned symmetrically into two chambers (the scalae) by a midplane representing the basilar membrane with its bony supports together with the "collapsed" cochlear duct (third chamber). The two chambers are filled with a viscous and incompressible fluid and communicate through a small opening (the helicotrema), at the cochlea's apex. The system is driven by the piston-like movement with frequency ω of the stapes at the cochlea's basal end. An isotropic sectorial plate widening toward the apex represents the basilar membrane. Some of the effects of the cochlear duct are considered through a provision for nonzero net pressure at the basilar membrane's apical end. The behavior of this system in the

neighborhood of the low-frequency threshold, where the effects of cochlear geometry are most pronounced, is described from the solutions of the equations of motion for $\omega \rightarrow 0$.

Laser-Optical System of the IBM 3800 Printer *by J. M. Fleischer, M. R. Latta, and M. E. Rabedeau, p. 479.* A helium-neon laser, acousto-optical modulator and rotating polygonal mirror are used for the optical design of a computer printout system. This combination of technologies in the printer produces high-quality nonimpact printing at speeds of 23,000 to 52,000 characters per second. A new technique utilizing a cylindrical/toroidal lens pair is described which reduces, by two orders of magnitude, scan line displacement errors produced by the polygonal mirror. The optical design principles and alignment techniques used in the assembly are shown.

Comment on "Decomposition of a Data Base and the Theory of Boolean Switching Functions" *by C. Delobel, R. G. Casey, and P. A. Bernstein, p. 484.*

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Automatic Registration in an Electron-Beam Lithographic System *by D. E. Davis, R. D. Moore, M. C. Williams, and O. C. Woodard, p. 498.* In the fabrication of integrated circuits, electron-beam systems are increasingly used to directly expose circuit patterns on resist-covered semiconductor wafers. These systems are made attractive by their inherent capability for writing patterns at high resolution, which eliminates the need for the masks used in optical exposure systems. To compete economically in production, electron-beam systems must attain a high level of wafer throughput. To achieve this, the system must be fully automated and spend the minimum of time in performing overhead functions such as various calibrations, pattern registration, and mechanical positioning of the wafers. This paper describes pattern registration, a process by which the circuit patterns required at a particular level of device fabrication are mapped to those of the preceding level. It discusses the considerations taken as basic in designing an accurate, high-speed registration process for a production-type electron-beam exposure system. This automatic registration system operates in 150 milliseconds per integrated circuit chip, allowing the system to achieve a throughput of 2000 5-mm chips per hour with overlay error of less than 0.75 μm (3σ). The operation of this system, its performance characteristics, and measurements of its pattern-matching accuracy are presented.

Correction of Nonlinear Deflection Distortion in a Direct Exposure Electron-Beam System *by H. Engelke, J. F. Loughran, M. S. Michail, and P. M. Ryan, p. 506.* This paper describes a distortion correction technique, used in a high-throughput electron-beam exposure system, which achieves an absolute deflection accuracy of about 30 parts per million (ppm) throughout a 5-mm field. To accomplish this, a cyclic, numerically controlled magnetic deflection with an accuracy of about 1000 ppm and high repeatability is first established. Horizontal and vertical errors in this deflection are measured by sensing the apparent locations of features in a calibration grid that is placed in the exposure field of the beam. The measured error is smoothed by means of a two-dimensional spline-fitting method, and the parameters for the correction surfaces are calculated. Corrections to position and speed, defined by a set of digital tables, are superimposed on the basic deflection, and the process is iterated until acceptable precision is achieved. Parameters relating registration scans to field-writing scans are then calculated for use in the registration of all written fields.

Electron Optics of an Electron-Beam Lithographic System *by J. L. Mauer, H. C. Pfeiffer, and W. Stickel, p. 514.* This paper describes the electron optics of a practical scanning electron-beam lithographic system (EL1) that provides high-volume direct wafer exposure. The throughput limitation inherent in serial exposure is greatly reduced by exposing entire pattern segments with a shaped beam. The shaped-beam concept represents a combination of scanning and projection methods. Twenty-five image points are exposed simultaneously to increase the spot current accordingly over that of a Gaussian round-beam system that exposes one image point at a time. The higher total current could lead to intensified Coulomb interaction between beam electrons, causing excessive Boersch effect and additional aberrations. However, the imaging and deflection methods described here are shown, by theoretical and experimental means, to reduce both the effects of Coulomb interaction and the total aberration of the system. This results in improvement of the beam current and field coverage compared with those found in conventional systems.

Control of Magnetic Properties During the Processing of Single Crystal Garnet Films *by J. E. Davies, p. 522.* Thin single-crystal rare earth iron garnet films are currently the most attractive materials for magnetic bubble domain applications. To utilize their potential, tight control of the magnetic properties is needed at each of the film processing steps. Such steps include the growth of large-area films from a supersaturated $PbO\text{-}B_2O_3$ fluxed melt, the phosphoric acid trimming of as-grown films to adjust the bubble collapse field, ion implantation of the film surface to suppress the formation of hard bubbles and the subsequent annealing the implanted layer receives during the thermal cycling of the device fabrication steps. Control of film properties at each of these stages will be discussed and data presented to show how each of these stages may be optimized.

Permutation Clustering: An Approach to On-Line Storage Reorganization *by B. T. Bennett and P. A. Franaszek, p. 528.* A class of dynamic reorganization algorithms is described which embodies a number of desirable systems properties. Experiments on a trace taken from a large data base application indicate that a member of this class may be

used to obtain time-varying or quasistatic organizations that exhibit improved paging performance.

Functional Dependencies in a Relational Database and Propositional Logic *by R. Fagin, p. 534.* An equivalence is shown between functional dependency statements of a relational database, where "→" has the meaning of "determines," and implicational statements of propositional logic, where "⇒" has the meaning of "implies." Specifically, it is shown that a dependency statement is a consequence of a set of dependency statements iff the corresponding implicational statement is a consequence of the corresponding set of implicational statements. The database designer can take advantage of this equivalence to reduce problems of interest to him to simpler problems in propositional logic. A detailed algorithm is presented for such an application. Two proofs of the equivalence are presented: a "syntactic" proof and a "semantic" proof. The syntactic proof proceeds in several steps. It is shown that 1) Armstrong's Dependency Axioms are complete for dependency statements in the usual logical sense that they are strong enough to prove every consequence, and that 2) Armstrong's Axioms are also complete for implicational statements in propositional logic. The equivalence then follows from 1) and 2). The other proof proceeds by considering appropriate semantic interpretations for the propositional variables. The Delobel-Casey Relational Database Decomposition Theorems, which heretofore have seemed somewhat fortuitous, are immediate and natural corollaries of the equivalence. Furthermore, a counterexample is demonstrated, which shows that what seems to be a mild extension of the equivalence fails.

Sequential Stopping Rules for the Regenerative Method of Simulation *by S. S. Lavenberg and C. H. Sauer, p. 545.* We consider the estimation via simulation of confidence intervals for steady-state response variables for stochastic systems which have a regenerative stochastic structure. Sequential stopping rules are investigated which allow the ratio of the width to the mid-point of an estimated confidence interval to be specified ahead of time. We prove that the resulting confidence intervals are valid asymptotically as the relative width decreases to zero. For various relative widths we empirically investigate the validity of the confidence intervals obtained when the stopping rules are applied to the simulation of queuing systems having a regenerative stochastic structure. For the queuing systems and response variables considered, a relative width of 0.05 is found to be sufficiently small to yield valid confidence intervals in almost all cases. In addition, we empirically compare the sequential stopping rules with a fixed stopping rule.

Data Flow Analysis in the Presence of Procedure Calls *by D. B. Lomet, p. 559.* The aliasing that results in a variable being known by more than one name has greatly complicated efforts to derive data flow information. The approach we take involves the use of a series of claims that, after we compute the data flow for some of the aliasing possibilities, allows us to produce good approximations for the remaining cases. The method can thus limit the potential combinatorial explosion of aliasing computations while providing results that are frequently exact and almost always very good. The method is illustrated in the context of data flow analysis involving multiple procedures and their calling interactions. It is applicable also in the treatment of recursive procedures.

Potential Significance to Neurophysiology of Design Algorithms for Digital Computers *by R. D. Traub and J. P. Roth, p. 572.* A set of algorithms has been developed within the computer industry that aids in the design and comparison of large switching circuits. To apply these algorithms to the nervous system in a realistic way, it is necessary to find neurons where (a) the electrophysiological data exist to allow construction of a plausible model; and where (b) the behavior of the neuron is not dependent on its distant past, so that the cell may be approximated by a switching circuit. It is also necessary to find areas of the nervous system whose structure resembles that of so-called regular designs; a regular design is a logic circuit in which feedback loops are constrained to take certain simple forms. In cases where local feedback loops are an intricate part of the design (as is true in virtually all areas of the mammalian central nervous system), this constrains one to analyze the behavior of the area in question only over time intervals sufficiently short so that such feedback loops can be ignored. Certain areas, such as the retina, are excluded because the individual neurons behave nondiscretely and are intimately coupled together (i.e., the retina does not resemble a regular design).

Effect of Substrate Bias on Properties of RF-Sputtered Cr-SiO Films *by H. Matino and T. Ushiroda, p. 576.* Properties of rf-sputtered Cr-SiO cermet films have been studied as a function of rf substrate bias. Films with five orders-of-magnitude change in electrical resistivity have been deposited from one Cr-SiO(50:50 wt %) target by changing the substrate bias. Resistivities of about 200 $\Omega \cdot$ cm at 5% bias and about $2 \times 10^{-3}\ \Omega \cdot$ cm at 20% bias have been obtained.

Origin and Effects of Negative Ions in the Sputtering of Intermetallic Compounds *by J. J. Cuomo, R. J. Gambino, J. M. E. Harper, and J. D. Kuptsis, p. 580.* An unexpected etching phenomenon during the sputtering of rare earth-gold alloys has been found to be caused by a large flux of negative gold ions from the sputtering target. We find this effect to occur in a range of intermetallic compounds. A model is presented which predicts when negative ion formation will be important. Effects of negative ions on sputter deposition of thin films include reduced deposition rate or substrate etching, and changes in film composition and other properties. Negative ion formation must also be taken into account for accurate quantitative analysis by Secondary Ion Mass Spectrometry (SIMS).

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Control of the IBM 3800 Printing Subsystem *by G. I. Findley, D. P. Leabo, and A. C. Slutman, p. 2.* The IBM 3800 Printing Subsystem is controlled by a high speed multilevel, interrupt-driven microprocessor. The design of this system has included several innovative concepts to take advantage of the flexibility of electrophotographic laser printing. New functions that are introduced include intermixed pitches, fonts, and line spacings; user-alterable character sets; on-line forms generation; and superior retry, fail-soft and diagnostic capabilities. Compatibility with the operational characteristics of IBM 1403 and 3211 printers is maintained. This paper discusses many of the objectives, development tradeoffs, and resultant control implementations for an on-line computer output printing subsystem.

Paper Path of an On-Line Computer-Output Printer *by R. G. Svendsen, p. 13.* This paper describes the development of a paper handling system designed to move paper at a speed of 81 cm/s in the IBM 3800 Printing Subsystem. During the development of the printer a number of unique problems arose from the interaction among paperline components. The various approaches and solutions to these problems, including paper path alignment, character stretch, registration within the fuser, and path error detection, are discussed and illustrated.

Paper Servo Design for a High Speed Printer Using Simulation *by T. J. Cameron and M. H. Dost, p. 19.* The design of feedback systems for control of paper motion through the IBM Printing 3800 Subsystem is described. The main tool for analysis and optimization is DSL, a digital simulation language for systems of continuous nature. The several stages in the evolution of the design are discussed.

Design of the Fusing System for an Electrophotographic Laser Printer *by K. D. Brooms, p. 26.* This paper discusses the development and design of the fusing system used in the IBM 3800 Printing Subsystem. The design solutions provide satisfactory fusing of powdered toner print images to paper at a processing rate of 81 cm/s under a variety of operating conditions.

Electrophotographic Process in a High Speed Printer *by U. Vahtra and R. F. Wolter, p. 34.* The IBM 3800 printing subsystem was developed for on-line computer system output printing in hard copy form at high speeds. The subsystem combines laser and electrophotographic technology with a multiformat paper handling system and on-line character set variability to provide increased data handling flexibility, throughput and print quality at reduced cost. This paper presents design considerations for the electrophotographic process. It provides an overview of the process and discusses methods and technical approaches used in the design of the printer.

Light Scattering Study of Structures in a Smectic Liquid Crystal *by W. H. Chu and J. T. Jacobs, p. 40.* The effect of surface treatment, sample thickness, and cooling rate on the structural order in the smectic phase of *p*-*n*-octyl-*p*'-cyano-biphenyl has been investigated by light scattering, and the results have been interpreted in terms of theories developed for crystalline polymers. Fan-shaped superstructures are found when the long dimension of the liquid crystal molecules is aligned parallel to the wall of a cell. But banded two-dimensional spherulites exist when the long dimension of the molecules is aligned perpendicular at one wall and parallel at the opposite wall. Uniaxially oriented rodlike structures are observed when the wall surface is lapped. Because surfaces have a strong effect, the superstructures are less highly ordered in thick than in thin cells. With an increase in cell thickness, the size of the superstructures increases along with the degree of disorder. If a sample is cooled rapidly to the solid state and then heated to the smectic state, the order in the smectic liquid crystal is reduced, as shown by a marked increase in the effect of density fluctuations on light scattering patterns. In a sample cooled slowly from the nematic to the smectic state, light scattering results primarily from orientation fluctuations.

Phase Equilibria in Liquid Crystal Mixtures *by R. J. Cox and J. F. Johnson, p. 51.* The thermodynamic relationships for mixtures of nonmesomorphic compounds are applied to liquid crystalline materials. Equations developed for ascending solid solutions have been applied to mixtures of liquid crystalline materials. Computer programs, written to calculate the theoretical curves for such mixtures, are found to agree with the experimental data obtained for 4-alkyl and 4-alkoxy 4'-cyanobiphenyls and a series of *p*,*p*'-dialkoxyazoxybenzenes. The heats and temperatures of the transitions of the pure components, necessary for the theoretical calculations, were determined by polarized light microscopy and by differential thermal analysis. Polarized light microscopy was also used to determine the transition temperatures of the mixtures.

Automated Validation of a Communications Protocol: the CCITT X.21 Recommendation *by C. H. West and P. Zafiropulo, p. 60.* The call establishment procedure of the X.21 interface recommended by the International Telegraph and Telephone Consultative Committee (CCITT) has been validated as a test of a recently developed theory and of an implemented system for automated communications protocol validation. The test demonstrated the applicability of the validation technique and identified a number of points where the interface state diagram does not completely define the interface behavior.

Relation Between an Atomic Electronegativity Scale and the Work Function *by H. B. Michaelson, p. 72.* Recently compiled data for the first electron affinity and the first ionization potential are used to obtain values for an atomic electronegativity scale, based on the Mulliken relation. From this scale and a new compilation of work function data, a

linear equation is obtained which includes a parameter for any given element, depending on its subgroup in the periodic table. Data are plotted for 51 elements, including simple metals, transition metals, and semiconductors. These data fit the straight-line equation better than 10 percent. Data for the transition metals deviate within the same limits as those for elements having simpler electronic configurations. The electronegativity scale differs significantly from the Pauling scale and is shown to be a useful guide to preferred values of the work function for elements.

Data Acquisition and Reduction Program for Thermogravimetry *by A. Doelman, A. R. Gregges, and E. M. Barrall II, p. 81.* An on-line data acquisition system for thermogravimetry using the IBM S/7 computer followed by data reduction on a 360/195 is described by means of flow charts. The system is designed so that no knowledge of programming is required to acquire, display and manipulate data on an interactive graphics terminal. The program not only extracts weight loss data, but also computes the energies of activation, *E*, for any selected weight loss interval by two methods, i.e., tabular integral and derivative. The system is demonstrated by a study of the activation energies for loss of water, loss of carbon monoxide, and loss of carbon dioxide during the thermal decomposition of calcium oxalate monohydrate. The results are in good agreement with the best literature values. The derivative method was found to give more consistent results than the tabular integral approach because of problems encountered in the precise measurement of temperature in the thermobalance.

Influence of Jet Printing Inks on Wear *by R. G. Bayer and J. L. Sirico, p. 90.* This communication reports the results of wear tests performed to determine the influence of jet printing inks on the wear of several polymer-metal pairs, which were known to be compatible with the inks. It is shown that these inks generally tend to increase wear beyond that occurring in a dry state. The principal reason for this increase was concluded to be the adverse influence that the inks have on the establishment of a beneficial transfer film on the metal surface.

***IBM Journal of Research and Development*: Information for Authors** *by R. J. Joenk, p. 94.* This paper combines background information about the *IBM Journal of Research and Development* with guidelines for the preparation of *Journal* manuscripts. The purpose is to acquaint authors with the *Journal* as a primary, professional publication and to present suggestions to ease the work of author and editor in preparing clear, concise, and useful manuscripts.

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Novel Materials and Devices for Sunlight Concentrating Systems *by H. J. Hovel, p. 112.* Photovoltaic conversion under concentrated sunlight is a highly promising technique that could make solar-electric power generation economically competitive with fossil fuel power generation by the mid-1980s. An economic analysis has been performed which demonstrates that solar cell efficiency, concentrator efficiency, and concentrator cost are the most important parameters in a concentrating photovoltaic system; solar cell cost is only of secondary importance (at least for Si solar cells). Six novel structures are described, including modified conventional Si cells, $Ga_{1-x}Al_xAs/GaAs$ devices, interdigitated cells, vertical and horizontal multijunction cells and "multicolor" devices.

Solar Radiative Heating in the Presence of Aerosols *by P. Halpern and K. L. Coulson, p. 122.* A theoretical study is carried out to evaluate the effects of aerosols on the shortwave flux divergence in the lower troposphere (0–2 km) by using four computational methods: *Gauss-Seidel iteration,* a reference method by which all orders of scattering are accounted for, and three approximations, *primary scattering, no-scattering* and *median wavelength.* By using these procedures, the radiative transfer equation is solved for a cloudless plane parallel atmosphere of infinite extent in the horizontal, but of finite extent in the vertical. The Gauss-Seidel procedure is taken as a standard and comparisons of the flux divergence are made by using various combinations of solar zenith angle, aerosol size frequency distribution and aerosol refractive index. In many of the simulations the median wavelength approximation gives accuracies comparable to those of the no-scattering approximation, in which case the choice of method is based on the required computational time. However, inaccuracies appear with all the approximations and the degree of superiority of one method over another depends on the aerosol and gaseous constituents of the model atmosphere.

Computation of Convolutions and Discrete Fourier Transforms by Polynomial Transforms *by H. J. Nussbaumer and P. Quandalle, p. 134.* Discrete transforms are introduced and are defined in a ring of polynomials. These polynomial transforms are shown to have the convolution property and can be computed in ordinary arithmetic, without multiplications. Polynomial transforms are particularly well suited for computing discrete two-dimensional convolutions with a minimum number of operations. Efficient algorithms for computing one-dimensional convolutions and Discrete Fourier Transforms are then derived from polynomial transforms.

Language Facilities for Programming User-Computer Dialogues *by J. M. Lafuente and D. Gries, p. 145.* Extensions to PASCAL that provide for programming man-computer dialogues are proposed. An interactive application program is viewed as a sequence of *frames,* representing stages of dialogue activity, and separate computational steps. First, extensions are presented to allow the description of the items of information contained in each frame. Second, PASCAL is extended to allow the inclusion of *behavior rules* for a frame to specify the interactive dialogue. The behavior rules are specified nonprocedurally. Previously, programming such

dialogues has required the specification of all possible interactions and their effects in a procedural fashion.

Variational Principles for Semiconductor Device Modeling with Finite Elements *by J. H. Hohl, p. 159.* Variational principles related to three areas of semiconductor device modeling by the finite element method are presented. Some subtle points which are crucial to the successful application of the method are explored. It is suggested that the validity of the selected variational formulations must be carefully ensured, and that the physics disciplines provide the best guidance for the right selections.

Convex Cubic Splines *by B. Dimsdale, p. 168.* Control curves used in industry are usually planar cubic splines, continuous and single-valued for a specific independent variable. If large slopes are specified at certain points, the spline coefficients, which are computed in order to preserve second derivative continuity of the spline, invariably lead to wildly oscillatory curves. Normally the large slopes occur at the ends of the curve, and this paper deals with such cases, developing methods which have been used successfully to combat the problems encountered. The end point where the difficulty occurs is ignored for the moment and a curve (spline or not) is designed for the remaining points. Then, with the point and slope adjacent to the difficult point known, the design is completed with one or more spline segments so that the resulting curve, which connects the difficult point to the next point, is convex (or concave), and has at least first derivative continuity. For the large finite slope case, two methods are described. The first method constructs the desired curve as a sequence of spline segments with finite slope everywhere, whereas the second expands the interval so that a single spline segment with infinite end slope passes through the difficult point with the required slope. The case of infinite end slope is also treated. In this and the preceding cases, second derivative continuity can be preserved at the juncture under certain conditions.

Steady Axisymmetric Solutions for Pressurized Rotating Flexible Disk Packs *by D. B. Bogy and F. E. Talke, p. 179.* Steady solutions are obtained for undisturbed pressurized flexible disk packs of various configurations. Simplified fluid equations of motion are coupled with the equations governing the deflection of flexible membranes in order to arrive at the differential equations for the spacing between the disks of the pack. A simple asymptotic-solution formula is derived for computing the dependence of the spacing between two neighboring disks on air density and viscosity, the volume rate of flow of air between the two disks, the angular speed of rotation, and the radial position on the disks.

Effect of Replacement Algorithms on a Paged Buffer Database System *by E. B. Fernández, T. Lang, and C. Wood, p. 185.* In a database system a buffer may be used to hold recently referenced pages. If this buffer is in virtual memory, the database paging system and the memory paging system affect its performance. The study of the effect of main memory replacement algorithms on the number of main memory page faults is the basic objective of this paper. We assume that the buffer replacement algorithm is least recently used (LRU), and page fault rates for LRU, random (R), and generalized least recently used (GLRU) main memory replacement algorithms are calculated and compared. A set of experiments validates these fault rate expressions and establishes some conditions for the practical application of the results.

Model for Database Reference Strings Based on Behavior of Reference Clusters *by M. C. Easton, p. 197.* The observation that references to a particular page are clustered (in time) in typical database reference strings is used as the intuitive motivation for a model of page reference activity in an interactive database system. The model leads to a two-parameter form for the (Denning) working-set functions associated with a page. Methods for estimating parameter values from measurements or from logical descriptions of applications are discussed. Results from the model are shown to agree well with measurements from two database systems.

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Preface *by E. Kay, p. 212.*

Model Study in Chemisorption: Molecular Orbital Cluster Theory for Atomic Hydrogen on Be(0001) *by C. W. Bauschlicher, Jr., P. S. Bagus, and H. F. Schaefer III, p. 213.* The interaction between atomic hydrogen and the (0001) surface of Be has been studied by using clusters of Be atoms to simulate the substrate. The largest cluster used contains 22 Be atoms, 14 in the first layer and 8 in a second layer. An H atom is added to the Be clusters at four high symmetry adsorption sites. *Ab initio* molecular orbital Hartree-Fock wave functions have been obtained and the interaction energy of H with the Be cluster is studied as a function of vertical distance from the surface. Thorough studies of various aspects of the computations and of the appropriate interpretation of the cluster results are reported. Our results show that three of the sites considered have similar binding energies, $D_e \approx 50$ kcal/mol ($\approx 2.1 \times 10^5$ J/mol), and (vertical) equilibrium distances from the surface, $r_e \approx 0.1$ nm. For the fourth site, H directly over a Be atom, D_e is ≈ 30 kcal/mol (1.3×10^5 J/mol), and r_e is ≈ 0.14 nm. We expect that the dissociative adsorption of H_2 on Be(0001) will be exothermic. A model calculation for diffusion of H into the bulk indicates that this process is energetically unfavorable for an ideal (0001) surface. The vibrational energies for the motion of H normal to the surface are found to be substantially different for sites with different surface coordinations. The nature of the covalent bond formed between H and Be(0001) is analyzed.

Core-Level Photoemission and LEED Studies of Adsorption at Fe Surfaces: Comparison Between CO and

O_2 *by C. R. Brundle, p. 235.* Carbon monoxide and oxygen interactions with α Fe(100) and polycrystalline surfaces have been studied by x-ray photoemission (XPS or ESCA) and low energy electron diffraction (LEED) at temperatures between 123 K and 473 K. For CO, the XPS results demonstrate the existence of four electronically distinct CO adsorption states; one is dissociative and three are molecular. The binding energy analyses are consistent with one of the latter molecular adsorption states, formed on the polycrystalline surface, having a stretched CO bond compared with the equivalent state on the Fe(100) surface. For oxygen, only dissociative chemisorption is observed, even at 123 K. Assuming monolayer coverage at saturation allows calibration of the coverage for all other situations of CO and O_2 adsorption. It is demonstrated that at coverages of just greater than a monolayer (293 K adsorption), Fe oxide species are already present and that Fe^{III} dominates. Studies at grazing angles, designed to enhance the surface sensitivity of the core-level measurements, fail to reveal recognizable Fe^{II} or Fe^{III} species much below monolayer coverage even though LEED studies indicate that an FeO-like geometric structure has developed at coverages much lower than this.

Reaction of Atomic Hydrogen with Si(111) Surfaces: Formation of Monohydride and Trihydride Phases *by K. C. Pandey, p. 250.* By using a realistic tight-binding or LCAO (linear combination of atomic orbitals) model, detailed calculations of surface states, local densities of states, and theoretically simulated photoemission spectra have been carried out for two qualitatively distinct structural models for chemisorption of atomic hydrogen on Si(111)1×1 surfaces. In the low-coverage model, called the monohydride phase or Si(111):H, it is assumed that a single hydrogen atom sits on top of each surface Si atom, thus saturating all dangling bonds. In the high-coverage model, designated as the trihydride phase or Si(111):SiH_3, SiH_3 radicals are bonded to the surface Si atoms. Due to the radically different atomic structures, the theoretical spectra of the two phases show striking differences. A comparison of the theoretical spectra with the ultraviolet photoemission spectra taken during hydrogen chemisorption on the quenched Si(111)1×1 surface clearly shows that at low coverages the monohydride is formed, while at high coverages the trihydride phase is formed. Formation of the monohydride phase is expected on simple chemical and structural considerations, and it has been observed on other Si surfaces. However, formation of the trihydride phase is unique to Si(111)1×1 and as such, it has important implications regarding the structure and stability of clean Si(111)1×1.

Chemisorption of Ethane on W(111) *by H. F. Winters, p. 260.* Ethane is chemisorbed on W(111) with a sticking probability of ≈0.003. The carbon Auger spectrum at saturation coverage exhibits a two-peak structure similar to that for graphite, while the LEED (low energy electron diffraction) pattern is almost identical to that obtained for an atomically clean surface. Heating the surface to ≈773 K causes desorption of hydrogen and changes the carbon Auger spectrum to a three-peak structure similar to that for tungsten carbide. After annealing, the LEED pattern is affected in different ways depending on the precise conditions, but it may in certain circumstances almost disappear. Exposure to ethylene produces a similar sequence of events. A large kinetic isotope effect is observed with the ratio of the sticking probabilities [$S(C_2H_6)/S(C_2D_6)$, W(111), $T = 300$ K] being ≈3. A similar ratio is measured for tungsten at $T = 2500$ K. These data suggest that chemisorption is dissociative in nature, probably involving the reaction $C_2H_6 \rightarrow C_2H_5^* + H \rightarrow$ subsequent steps. Heating of the surface completely dissociates the adsorbed gas, leaving adsorbed carbon and gas phase hydrogen. In analogy with previous work on methane, we believe the large isotope effect suggests that the initial dissociation reaction is dominated by the tunneling of a hydrogen atom through a potential barrier. The implications of this conclusion for other saturated molecules will be discussed.

Molecular Geometries of Acetylene and Ethylene Chemisorbed On Cu, Ni, Pd, and Pt Surfaces *by J. E. Demuth, p. 265.* Ultraviolet photoemission measurements of the valence orbital electronic structure of acetylene and ethylene chemisorbed on Cu(100) or Cu(111), Ni(111), Pd(111), and Pt(111) are presented. We compare the measured energy levels of these chemisorbed species to those of the free molecule and use a similar comparison of the relative changes in ground state energy levels of distorted free molecules calculated with a SCF-LCAO (Self Consistent Field—Linear Combination of Atomic Orbitals) method to determine the molecular geometries of these chemisorbed species. The limitations and accuracies of such an approach are discussed. From the determined geometries we identify two trends in the structure of these chemisorbed molecules on these surfaces: first, increasingly greater molecular distortions occur with increasing atomic number of the substrate atom, and secondly, greater molecular distortions occur for ethylene than for acetylene on the same metal. These trends are consistent with a π-d bonding interaction and can be accounted for by the electronic structure of the substrate and of the molecule, respectively. With the exception of ethylene on Pd or Pt, we determine molecular geometries characteristic of small rehybridization. The molecular geometry of ethylene on Pd or Pt is generally characteristic of rehybridization to an sp^3 configuration.

Sputter Profiling Through Ni/Fe Interfaces by Auger Electron Spectroscopy *by T. J. Chuang and K. Wandelt, p. 277.* Sputter characteristics of nickel-iron systems in the form of layer interfaces and bulk alloy films have been studied by Auger electron spectroscopy. The sputter rates for pure nickel and iron and their alloys have been determined and are independent (within 10%) of the grain size and film composition. The various factors that contribute to the broadening of depth profiles have been examined. The initial broadening of 4.5 nm at zero overlayer thickness is mainly attributed to the effects of electron escape depth and

compositional mixing due to ion bombardment. For thin films, the depth-dependent broadening induced by sputter damage has an approximately exponential dependence on the overlayer thickness. For thick films, this broadening is estimated to be about 10% of the sputter distance. The effect of ion-induced surface compositional mixing as a function of incident Ar^+ ion energy has been studied by taking advantage of the different sampling depths of low and high energy Auger electrons.

Characterization of Electron Traps in Aluminum-Implanted SiO_2 *by D. R. Young, D. J. DiMaria, W. R. Hunter, and C. M. Serrano, p. 285.* Johnson, Johnson, and Lampert have studied the effect of Al implantation on the trapping behavior of SiO_2. The large fluence that they used (1×10^{14} Al/cm^2) and the low annealing temperatures (up to 600°C) resulted in a trapping efficiency of 1 and made it impossible to characterize the traps. In the present study a lower fluence and higher annealing temperatures to reduce the trapping efficiency are used to permit characterization of the traps. The predominant trap cross sections are 1.26×10^{-16} and 1.40×10^{-17} cm^2. In a companion paper by DiMaria, Young, Hunter, and Serrano the location of the trapped charge is discussed.

Location of Trapped Charge in Aluminum-Implanted SiO_2 *by D. J. DiMaria, D. R. Young, W. R. Hunter, and C. M. Serrano, p. 289.* The position of the centroid of electrons trapped on sites resulting from aluminum implantation into SiO_2 is measured by using the photo *I-V* technique for energies from 15–40 keV, oxide thicknesses from 49–140 nm, and post-implant annealing temperatures from 600–1050°C in N_2 for 30 min. The centroid of the trapped electrons is found to be identical to that of the implanted aluminum from SIMS measurements, regardless of annealing temperature from 600 to 1050°C, and located closer (by less than 9 nm) to the Al-SiO_2 interface than predicted from the Lindhard-Scharff-Schøtt (LSS) calculations of Gibbons, Johnson, and Mylroie. Comparison of centroids determined from photo *I-V* and SIMS measurements as a function of SiO_2 thickness also implies that the distributions of the ions and negative trapped charge are the same. The trapping behavior of these sites is discussed in the accompanying paper by Young et al.

X-Ray Photoelectron Spectroscopy of SiO_2-Si Interfacial Regions: Ultrathin Oxide Films *by S. I. Raider and R. Flitsch, p. 294.* The composition and width of the interfacial region formed between thin thermally-grown oxide films and single-crystal Si substrates were nondestructively characterized by means of x-ray photoelectron spectroscopy. Data obtained from variations in core-level binding energies, from variations in photoelectron line intensities, and from variations in photoelectron linewidths indicate the presence of a nonstoichiometric oxide-Si transition region. The composition and width of this region are dependent upon substrate orientation, but are invariant with change in other oxidation processing parameters. Transition regions formed on <100> oriented substrates are narrower and more completely oxidized than those formed on <111> oriented substrates. Although both Si-Si bonds and SiO-Si groups are present in this nonstoichiometric region, they do not appear to be a mixture of Si and SiO_2. Instead, a continuous distribution of Si tetrahedra, Si-$(O)_x(Si)_{4-x}$, are formed, in which x changes from 0 to 4 as one proceeds from the substrate to the stoichiometric SiO_2 film.

Electronic Properties of (100) Surfaces of GaSb and InAs and Their Alloys with GaAs *by R. Ludeke, p. 304.* Smooth, monocrystalline (100) surfaces of the alloys $In_{1-x}Ga_xAs$ and $GaSb_{1-y}As_y$ were prepared by molecular beam epitaxy. Both As-stabilized c(2 × 8) and metal-stabilized c(8 × 2) surface reconstructions were observed for $In_{1-x}Ga_xAs$ over the entire alloy range. $GaSb_{1-y}As_y$ exhibited a c(2 × 6) or (2 × 3) structure for $y \, ltequiv$ 0.2, and, after a transition region, the anion-stabilized c(2 × 8) or the Ga-stabilized c(8 × 2) structures for $y \, gtequiv$ 0.5. Electron energy loss spectroscopy revealed the simultaneous presence of two empty, dangling-bond derived surface states in both alloy systems. For $In_{1-x}Ga_xAs$ the In-derived empty surface state lies ≈0.4 – 0.5 eV below that of Ga and moves from above the conduction band edge into the band gap for $x \, gtequiv$ 0.6. The overlap between the Ga-and In-derived empty surface states causes the quenching of the Ga(3d) surface exciton. For $GaSb_{1-y}As_y$ the Sb dangling bonds generate an empty, localized surface state which lies 0.2 – 0.3 eV above the empty, Ga-derived surface state. Both levels lie above the conduction band edge throughout the alloy range.

Oriented Epitaxial Films of (NMP) (TCNQ) *by E. E. Simonyi, J. F. Graczyk, and J. B. Torrance, p. 315.* An important step in the characterization of organic conductors is the ability to correlate the solid state electrical properties of these materials with their composition and crystal structure. In many cases it has not been possible to grow single crystals of suitable size or purity for such investigations. The use of epitaxial films represents an alternative approach. In addition, such films may be potentially useful as larger area conductive surfaces. This paper describes the preparation of relatively large-area, oriented epitaxial films of the organic conductor N-methylphenazinium- 7,7,8,8-tetracyanoquinodimethanide (NMP) (TCNQ) by means of vacuum evaporation. Factors that appear to affect the degree of orientation, the film areas, and the chemical composition include the source temperature, the kind of evaporation (rapid or slow), the degree of lattice matching between the substrate and the organic material, and the substrate surface charge potential.

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Low Cost Silicon for Solar Energy Conversion Applications *by G. H. Schwuttke, T. F. Ciszek, K. H. Yang, and A. Kran, p. 335.* Economically viable means of producing silicon solar cells for the conversion of solar energy into

electric power are discussed. Emphasis is given to the discussion of crystal growth techniques capable of growing single-crystal silicon ribbons directly and inexpensively from molten silicon. The capillary action shaping technique (CAST) recently developed by IBM has a good potential for producing low cost silicon sheets suitable for solar cells. This technique has produced ribbon 100 mm wide and 0.3 mm thick. Problems that CAST must overcome in order to supply material for low cost solar cells are discussed. Economic and technological computer-modeled comparisons indicate that continuously grown CAST ribbons of these dimensions can meet a cost objective below $\$50/m^2$ of sheet material. The results require that it be possible to fabricate a twelve-percent-efficient solar cell from CAST ribbon 100 mm wide and 0.3 mm thick at a polycrystalline silicon cost of \$10/kg.

Growth of Polycrystalline GaAs for Solar Cell Applications *by A. E. Blakeslee and S. M. Vernon, p. 346.* Films of polycrystalline GaAs have been grown on foreign substrates by the metal-organic process. The main objective was to produce films with as large a grain size as possible, so that high-efficiency photovoltaic devices may eventually be fabricated from such thin film/substrate structures. At 973 K the average grain size was less than 1 μm, and was unaffected by the choice of substrate. Increasing the deposition temperature to 1123 K, while maintaining all other conditions the same, resulted in grains as large as 10 to 20 μm in diameter. Grain sizes as large as 10 μm could be obtained by precoating the substrates with thin films of evaporated gold or tin. However, both of these methods gave films that were discontinuous. A two-step procedure in which the films were nucleated at 873 K prior to growth at 1123 K yielded continuous films with an average grain size of 5 μm. Schottky barrier solar cells fabricated from these films exhibited short-circuit current densities as high as 15.7 mA/cm^2, even though the highest conversion efficiency (AM0, uncoated) was only 1.3 percent because of the low fill factor (0.28).

Organic Photovoltaic Materials: Squarylium and Cyanine-TCNQ Dyes *by V. Y. Merritt, p. 353.* The photovoltaic properties of Schottky barrier sandwich cells consisting of sublimed and solution-cast thin films of selected squarylium (bis-anilino derivatives of cyclobuta-1,3-diene-2,4-dione) and cyanine-tetracyanoquinodimethanide (TCNQ) dyes have been measured. For hydroxy squarylium (OHSq), maximum power conversion efficiencies (η) were 0.2% for 850-nm light (1 mW/cm^2); 0.05% for 633-nm light (94 mW/cm^2); 0.06% for "white" light (21 mW/cm^2); 0.15% for low intensity (0.14 mW/cm^2) simulated AM0 light (sunlight under outer space conditions), and 0.02% for high intensity (140 mW/cm^2) AM0 light. Efficiencies of selected OHSq cells were observed to increase fivefold when the cells were doped with bromine or 1-phenyl-3-p-N, N-diethylaminostyryl-5-p-N,N-diethylaminophenyl-Δ^2-pyrazoline (DEASP), e.g., 0.05 to 0.23% (Br); 0.004 to 0.021% (DEASP). The efficiency of a solution-cast cell of amorphous 2,2'-dicarbocyanine-TCNQ was 0.02% when 933-nm light (approximately (1 mW/cm^2) was used. Amorphous solid solutions of 1,1'-diethyl-2,2'-dicarbocyanine-and oxa-2,2'-dicarbocyanine-TCNQ salts were also tested. The effects of various material and device properties on the performance of organic photovoltaic cells are discussed, and it is proposed that organic solar cells having efficiencies of one percent or more can be made by using existing technologies.

Solar Absorbing Surfaces of Anodized Dendritic Tungsten *by G. D. Pettit, J. J. Cuomo, T. H. DiStefano, and J. M. Woodall, p. 372.* Anodization of textured tungsten is shown to have merit either in creating a solar absorber of extremely high absorptance when applied to a large dendritic surface, or in enhancing the solar absorptance-to-emittance ratio when applied to smaller hillock topographies. The angular dependence of the absorption is reduced by the anodization coating, which consists of a thin conformal coating of WO_3. The surface is stable up to temperatures of 520 K in air.

Optimization Applied to the Design of an Energy-Efficient Building *by S. A. Jurovics, p. 378.* There are several public domain, and numerous proprietary, computer programs that provide detailed simulations of the heating and cooling requirements for a building. Such programs are often used to evaluate changes in the design of a building that are made to decrease its energy requirements. A user is considered to be working in a trial-and-error mode if each execution of the program provides no formal guidance for the next change. This work reports on an investigation of the imbedding of such an energy analysis program into an optimization structure. Such an arrangement would enable a user to specify a set of architectural and construction parameters and the limits within which they might vary, and from this to determine the parameters that yield a local minimum in thermal load and the sensitivity of this load to changes in these parameters.

Color Composite Pictures from Principal Axis Components of Multispectral Scanner Data *by T. Kaneko, p. 386.* When principal axis transformations are applied to multispectral scanner (MSS) data, the majority of data variability is shown to be contained in the first two or three components. This paper describes a method for generating a color composite picture from these components whereby most of the information collected by an MSS can be conveyed in a single color picture. The first component is found to be a weighted sum of image data from all channels, and therefore it is natural to associate the first component with brightness. To be consistent with this interpretation, only the first component of the transformed data is used to control the brightness of the color composite picture.

General Technique for Communications Protocol Validation *by C. H. West, p. 393.* A technique for the validation of protocols in communications systems is described. It can be used for systems composed of processes that can be modeled as finite directed graphs. The validation exhaustively exercises the interaction domain of a system and identifies all occurrences of a number of well-defined error conditions. The method can detect when individual processes have no predefined response to incoming messages, as well as system deadlocks and potential loss of messages due to overflow conditions.

Adaptive Variation of the Transfer Unit in a Storage Hierarchy *by P. A. Franaszek and B. T. Bennett, p. 405.* Consider a paged storage hierarchy with at least two levels L_1 and L_2, where L_1 denotes main storage and L_2 secondary storage. Suppose that the unit of replacement for L_1 is a single page, and that the L_2-to-L_1 transfer unit, given a page fault, is an integer number of pages. Then, given a suitable replacement policy for L_1, increasing the unit of transfer often results in a lower miss ratio at the expense of increased paging traffic. This paper explores the possibility of adaptively varying the L_2-to-L_1 transfer unit as a function of the reference history of the data to be fetched. Experiments on traces drawn from two large data base systems suggest that such adaptation can result in improved tradeoffs between miss ratios and paging traffic.

A Machine-Independent APL Interpreter *by M. Alfonseca and M. L. Tavera, p. 413.* The problem of writing machine-independent APL interpreters is solved by means of a systems programming approach making use of an intermediate level language specially designed for that purpose. This paper describes the language, as well as the procedure used to build universal interpreters. Three compliers that translate this language for three different machines have been written so far, and an APL interpreter has been finished.

Regression Model for LPE Film Property Control *by S. J. Lewis, p. 422.* Empirical regression equations permit the calculation of liquid phase epitaxial (LPE) film properties from film growth parameters. Numerical differentiation of these equations facilitates examination of the sensitivities of film properties to fluctuations in growth conditions and the development of depletion-compensating growth strategies. Regression equations for nominal 3-μm bubble size CaGe and Ga films have been generated and used for quantitative comparisons of the growth behavior of the two systems. A real time feedback control scheme has been applied to the Ga system resulting in 70 percent of the as-grown films falling within ±1 percent of the target collapse field.

Representation for Complex Numbers *by W. N. Holmes, p. 429.* This communication suggests the feasibility of a single-component scheme for representing complex numbers with real bases. Several advantages are pointed out, including the very simple extraction of the real and imaginary parts of a complex number.

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Preface *by L. M. Branscomb.*

Principal Components of a Multispectral Image: Application to a Geological Problem *by A. Santisteban and L. Muñoz, p. 444.* The principal components of a multispectral image are studied with special emphasis placed on photointerpretation applications. The method used to obtain these components involves a linear radiometric enhancement which avoids artifact creation and does not require extra computational work. The results have been particularized to Landsat multispectral scanner images and applied to the geological study of a sedimentary basin in central Spain.

Machine Processing of Remotely Sensed Data: Three Applications in Mexico *by M. Hernández V. and A. Flores M., p. 455.* In general, ground-data acquisition procedures in developing countries are not very efficient, and the resulting lack of reliable data produces significant delays in important management-planning decisions. This paper describes three studies involving different applications of machine processing of remotely sensed data, a recent technology that appears to have potential use for timely ground-information acquisition. The general methodology describes the use of a special software processing system. Finally, some conclusions are presented relating to the specific problems discussed and to the advantages of remote sensing in general.

Using a Desk-Top Computer for an On-Line Flood Warning System *by E. Todini, p. 464.* The paper deals with the development of an adaptive model that is applicable to real-time forecasting of hydrologic processes. The rainfall-runoff process is considered here. In this model the discharge was modeled as autoregressive with past discharges and a moving average representation on the precipitation. The model makes use of the Constrained Linear Systems (CLS) technique to split the precipitation into two rainfall inputs by using a threshold based on an antecedent precipitation index. This technique can be thought of as a piecewise linearization of a nonlinear process. The real-time forecasting model is a time invariant linear state model where the state variables, discharge and rainfall, are estimated by the Kalman filtering algorithm and the unknown model parameters by using the instrumental variables approach. This technique was applied in a case study using data from the Ombrone River Basin, Italy, and was implemented on a small desk-top computer.

Hydrodynamic Numeric Modeling of the Lagoon of Venice *by P. Sguazzero, C. Chignoli, R. Rabagliati, and G. Volpi, p. 472.* This paper describes two hydrodynamic numeric models and their application to the Lagoon of Venice, Italy. The models are based on the same mesh, bottom topography, boundary conditions, and spatial distribution of the bottom

friction coefficient (Chézy coefficient). Although quite different in structure, both models ultimately provide sea level fluctuation and current speed at each meshpoint as functions of time. The first model numerically integrates the time-dependent, nonlinear, hyperbolic shallow water equations, written in conservation form, with a space-staggered leapfrog-type (time dense) scheme. The model is suited to episode simulation and is a particularly useful tool for system management and control. The second model is suited to long-term simulations and models only the astronomic tide; it solves a hybrid (differential-algebraic) system resulting from semilinearization of the shallow water equations under harmonic assumptions for the tide. Because of the superior computational efficiency of this second model, it has been used in conjunction with Powell's algorithm to identify the *a priori* unknown spatial distribution of the Chézy parameter. If the same Chézy distribution is fed into the two models, there can be obtained a complete, self-calibrating, consistent modeling tool for tidal basins with arbitrary geometric configurations and boundary conditions in the presence of hydraulic works.

Extrapolation of Seismic Waveforms by Fourier Methods *by J. Gazdag, p. 481.* The problem of constructing a cross section of reflectivity from the wave field recorded at the surface of the medium is discussed with particular reference to migration of seismic records. The numerical procedures are formulated in the frequency and wavenumber domain. The operations are defined in a fixed coordinate system, whereas finite difference methods require a downward-moving reference frame. The numerical algorithms in the frequency wavenumber domain are simpler and give more accurate results than finite difference methods. This is particularly true when the lateral velocity variation in the medium can be neglected. In this case the downward wave extrapolation is accomplished by implementing a phase change in the Fourier coefficients. Numerically, this is equivalent to the multiplication by a complex number of unit modulus. There is no stability condition associated with this operation. This means that the source and recorder positions can be lowered by any amount within one computational step.

A Directed Weather Data Filter *by D. W. Low, p. 487.* It is important to reduce the computational burden of energy-analysis computer programs (such as those that compute expected heating and cooling loads and the energy required to meet these loads) since the input may include, for example, hourly measurements of several weather variables over periods of time of up to ten years. It is possible to generate a small set of weather data to represent a larger, more comprehensive set by using computer programs called weather data filters. However, existing filters that are generally able to preserve statistical properties of the original data offer no *a priori* method for controlling or even estimating the errors they introduce in the output of the energy analysis programs. This problem exists because these filters deal only with weather data and do not utilize any information regarding the building to be analyzed, its occupancy schedule, its mechanical systems, or the energy analysis function itself. This paper describes a weather filter that preserves the "energy content" of the data; i.e., given a particular building design and usage schedule, this filter generates a small set of weather data which, when properly weighted, produces the same total heating and cooling loads as the original data. Because the error caused by using the filtered weather data falls well within acceptable bounds even when changes are made in the building design, the filter described allows the designer to test a large number of design or retrofit alternatives for energy efficiency at very low computational cost.

An Analytic Model of the VM/370 System *by Y. Bard, p. 498.* This paper describes an analytic model of an interactive multiprogrammed computer system. The model accepts a multiple-user-class, transaction-oriented workload description and a system configuration description, and it produces predictions of resource utilizations, transaction rates, and average transaction response times. The solution method involves nearly complete decomposition, with a closed queuing network representing the multiprogrammed set. Asymptotic formulas are used to generate good initial guesses for an overall iterative scheme. Extensive validation results are presented.

Algorithm and Hardware for a Merge Sort Using Multiple Processors *by S. J. P. Todd, p. 509.* An algorithm is described that allows log (n) processors to sort n records in just over $2n$ write cycles, together with suitable hardware to support the algorithm. The algorithm is a parallel version of the straight merge sort. The passes of the merge sort are run overlapped, with each pass supported by a separate processor. The intermediate files of a serial merge sort are replaced by first-in first-out queues. The processors and queues may be implemented in conventional solid logic technology or in bubble technology. A hybrid technology is also appropriate.

Computer-Aided Diagnosis with an Application to Endocrinology *by W. Schild, B. Lunenfeld, and B. Gavish, p. 518.* An interactive system for computer-assisted medical diagnosis is described. Medical experts are provided with a framework in which to translate the knowledge on which their decisions are based. The technique is based on simulating the physician's own diagnostic process. The approach taken allows consistency and completeness checks to be made, thereby achieving a high degree of reliability. Information related to a given specialty is described in terms of disorder patterns, clinical facts, and logical relationships among the clinical data. Laboratory results are processed by a subsystem which uses physician-supplied rules to establish validity and to interpret the test data with respect to their diagnostic significance. The system incorporates a dynamically generated questionnaire which provides efficient gathering of anamnestic, observational, and other clinical parameters. The physician is prompted for relevant patient data by an algorithm which assures that an almost minimal amount of

information is requested. Simulation facilities allow the user to examine clustering phenomena among disorders, and an option is included that traces the logic of any decision taken to exclude candidates for a final diagnosis.

Noun-Phrase Model and Natural Query Language *by M. Sibuya, T. Fujisaki, and Y. Takao, p. 533.* Basic considerations in designing a natural data base query language system are discussed. The notion of the noun-phrase data model is elaborated, and its role in making a query system suitable for general use is stressed. An experimental query system, Yachimata, embodying the concept, is described.

AQL: A Problem-solving Query Language for Relational Data Bases *by F. Antonacci, P. Dell'Orco, V. N. Spadavecchia, and A. Turtur, p. 541.* AQL is a query language based on a data base management system which uses Codd's relational model of data. It has been designed mainly to be used by the nonspecialist in data processing for interactive problem solving, application building, and simulation. Ease of use is achieved by providing an interface which allows the use of default options, synonyms, and definitions of attributes, inference, and the possibility of interactive completion of the query (i.e., menu). AQL combines the capabilities of the relational model of data with the powerful computational facilities and control structure of the host programming language (i.e., APL). A prototype version of AQL, which has been implemented, is reviewed.

Interpretation of Natural Language in an Information System *by H. Lehmann, p. 560.* This paper discusses some of the linguistic problems encountered during the development of the User Specialty Languages (USL) system, an information system that accepts a subset of German or English as input for query, analysis, and updating of data. The system is regarded as a model for portions of natural language that are relevant to interactions with a data base. The model provides insight into the functioning of language and the linguistic behavior of users who must communicate with a machine in order to obtain information. The aim of application independence made it necessary to approach many problems from a different angle than in most comparable systems. Rather than a full treatment of the linguistic capacity of the system, details of phenomena such as time handling, coordination, quantification, and possessive pronouns are presented. The solutions that have been implemented are described, and open questions are pointed out.

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AC Gas Discharge Panels: Some General Considerations *by A. Reisman and K. C. Park, p. 589.* This introductory paper attempts to provide some perspective on the key technology issues associated with ac gas panel displays to set the stage for a series of nine technology and physics-oriented papers that follow. It uses the cathode ray tube as a reference for comparison and defines some of the unique technological features of matrix-addressed displays generally and ac gas discharge panels specifically.

Single-Cycle Gas Panel Assembly *by A. Reisman, M. Berkenblit, and S. A. Chan, p. 596.* A single-cycle process has been developed in which the two halves of a gas panel are assembled, sealed, and filled in a continuous, automatically sequenced, controlled-ambient furnace. The entire fabrication operation, including seal, degas, backfill, and tip-off, may be accomplished in a single thermal cycle. During heat-up, the panel parts and furnace chamber are degassed in a programmed cyclic fill (to 20 mm of Hg) and pump-down to (100 μm of Hg). The panels are sealed in a clean-air ambient at a temperature of 495 ± 5°C. Prior to backfilling with a purified Penning gas mixture and tip-off of the panel, the same gas is used in a cyclic fill and evacuate process to remove air and other contaminants. The entire panel fabrication program takes about 8 hours. Details of equipment construction and operation are presented, as well as advantages of the process compared to conventional gas panel fabrication processes.

Obtaining Gas Panel Metallization Patterns by Vacuum Deposition Through Rib-supported Mask Structures *by R. Hammer, p. 601.* Gas discharge display panel metallization patterns have been obtained directly in a single vacuum deposition step through rib-supported mask structures. This approach provides a simple alternative to screening or photoetching. The rib-supported structures were developed to solve problems of fabricating masks containing long and narrow closely spaced apertures, poorly supported cantilever sections, and free-standing islands. The design of these structures minimizes shadowing from support ribs by using non-line-of-sight deposition techniques. Made out of graphite to avoid chemical attack during cleaning operations and fabricated by air abrasion machining, the self-supported masks are held in intimate mask-to-substrate contact during vacuum deposition by an electrostatic hold-down technique.

E-Beam Evaporated Glass and MgO Layers for Gas Panel Fabrication *by K. C. Park and E. J. Weitzman, p. 607.* An electron-beam evaporation process has been developed that is capable of depositing stable, thick, borosilicate glass films ($0.5 - 50$ μm) on various substrates at a rate exceeding 0.5 μm/min. A very low stress of $4 - 10 \times 10^7$ N/m^2 in compression was obtained in freshly deposited glass films, and a further reduction below measurable levels of stress was observed after a thermal annealing at 500°C. The effects of evaporation parameter variation and thermal annealing on the film properties of the borosilicate glass layers, as well as the MgO secondary emission layers employed in the fabrication of gas discharge display panels, are presented.

Electrical and Optical Characteristics of Evaporable-Glass-Dielectric AC Gas Display Panels *by J. F. O'Hanlon, K. C. Park, A. Reisman, R. Havreluk, and J. G. Cahill, p. 613.* This paper presents the characteristics of a prototype gas display panel fabricated with electron-beam

deposited dielectric films. It is shown that panels with a 6-μm-thick dielectric layer and a 0.2-μm-thick MgO layer exhibit short stabilization times (15 min), long life (20,000 h), small drift effects (<0.5 V), and adequate brightness (21 cd/m^2). The devices have a large dynamic write margin (>10 V) over a wide pressure range. Dielectric glass layers as thin as 3.2 μm were found to be stable. A panel with a small H_2O impurity concentration was used to show that the hydrated MgO surface caused charge leakage and loss of memory margin, while a panel with an air leak confirmed that the surface saturated before the effects of gas contamination were observed.

Effect of Reactive Gas Dopants on the MgO Surface in AC Plasma Display Panels *by W. E. Ahearn and O. Sahni, p. 622.* Experimental results are presented for the influence of controlled levels of important reactive impurities (N_2, O_2, H_2O, CO_2) on the aging characteristics of the operating voltages of ac plasma display panels. Details are also given of a novel method of modifying the electronic properties of MgO surfaces by discharge processing in an oxygen-doped Ne-0.1% Ar Penning mixture.

A Phenomenological Study of AC Gas Panels Fabricated with Vacuum-Deposited Dielectric Layers *by J. F. O'Hanlon, p. 626.* This paper presents the results of an experimental investigation of ac gas display panel parameters. The ignition and extinction voltages were measured for panels filled with Ne-0.1% Ar gas to pressures ranging from 0.75×10^4 Pa to 8×10^4 Pa (50 torr to 600 torr). The panels were constructed with chamber spacings, d, of 0.56×10^{-2} cm to 2×10^{-2} cm, and electrode widths, x, of 1.5×10^{-3} cm to 0.1 cm. Scaling of the Paschen minimum was not found to hold for the narrowest chamber spacing. The dependence of ignition voltage on linewidth was found to be proportional to $\exp(-1.6\, x/d)$ for $(x/d) < 1$. An electron diffusion process was invoked to explain this behavior.

Characterization of Voltage and Charge Transfer in AC Gas Discharge Displays *by E. S. Schlig and G. R. Stilwell, Jr., p. 634.* New techniques have been applied to the characterization of voltage and charge transfer in ac gas discharge display cells. This paper presents a new method of measuring the voltage transfer curve and several aspects of the operation of the cells which are revealed by these measurements. In the steady sustain region the voltage transfer is nearly equal to the initial gas voltage. Over most of the voltage transfer curve, the voltage transferred is independent of the history and operating environment of the test cell. On the other hand, the charge transfer does depend upon these factors. The voltage and charge transferred vary differently with the initial gas voltage, so the effective wall capacitance depends upon the initial wall voltage as well as on history and environment. This is attributed to the dependence of the lateral spread of the discharge upon its strength.

Numerical Calculation of the Characteristics of an Isolated AC Gas Discharge Display Panel Cell *by C. Lanza and O. Sahni, p. 641.* Device characteristics calculated from a one-dimensional dynamic simulation, incorporating space charge effects, of the gaseous discharge occurring at an isolated cell of an ac gas discharge panel are presented. The theoretical model shows all the qualitative features associated with plasma panels, and the quantitative agreement with experimental data inspires confidence in the general validity of the method.

Al-Cu Alloy for Gas Panels *by V. Brusic, F. M. d'Heurle, R. D. MacInnes, E. I. Alessandrini, J. Angilello, J. J. Dempsey, and M. Sampogna, p. 647.* The composition, phase formation, stress, resistivity, and, in particular, the oxidation and corrosion behavior of Cu-Al films with a variety of Cu:Al ratios have been determined. Their relevance to the gas panel is discussed.

Contact Stress and Wear Study for Type Characters *by F. I. Chow, P. A. Engel, D. C. Heath, and S. Lawphongpanich, p. 658.* To ensure the structural integrity of solid print characters subjected to millions of stress cycles, the contact stresses encountered in service must be known. In the present paper various type geometries are explored for their influence on stress distribution. A linear programming method of stress analysis is adopted. Experimental analysis and wear characteristics are considered.

Mechanism of Wear by Ribbon and Paper *by R. G. Bayer, p. 668.* While wear by materials such as ribbon and paper represents a significant and identifiable problem in the business machine industry, it has received little attention in the wear literature. In this paper the results of a study into the nature of the wear processes involved and the various factors which influence them are presented. A significant result of that study is the conclusion that the basic wear processes for both materials are similar, i.e., abrasion by small hard particles as compared to an adhesive mechanism for paper as proposed by some in the literature.

Work-hardening of Ferrite Head Surfaces by Wear with Flexible Recording Media *by R. W. Polleys, p. 675.* The ferrite surfaces of rotating magnetic heads were found to have been work-hardened to different degrees depending upon the abrasiveness of the flexible recording media used. For the more abrasive tape, the work-hardening was less than for the less abrasive tape. Associated with the increase in microhardness was decreased signal read-back and increased incidence of surface "pull-outs." These phenomena may be understood in the context of fracture mechanics where residual stress, resulting from plastic deformation of the ferrite, is predominant in the wear mechanism.

Electroplated Diamond-Composite Coatings for Abrasive Wear Resistance *by D. D. Roshon, p. 681.* This paper

describes electroplated diamond-composite coatings which are capable of attaining wear resistance a number of orders of magnitude greater than conventional materials when subjected to abrasion by paper. The coatings consist of a single layer of diamond particles held in a matrix of electroplated metal. During the course of these studies, many parameters were found to play important roles in the wear resistance. These parameters include the diamond particle size, its size distribution, the particle density, particle shape, plating uniformity, and the properties of the matrix metal. The influence of these variables is discussed, and the results of the wear testing are presented. The plating process is also briefly described.

Calculations of the Effect of Emitter Compensation on β and f_T of Bipolar Devices *by A. Phillips, Jr., p. 687.*
Significant increases in bipolar device β and f_T are predicted when emitter compensation is reduced. The prediction was made after accurately calculating all room temperature device parameters with a bipolar device program. The use of empirical concentration-dependent energy gap values allowed the accurate device calculation.

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Preface *by S. S. Husson, p. 2.*

Electrical Properties of RF Sputtering systems *by J. H. Keller and W. B. Pennebaker, p. 3.* A theory is developed that gives a relatively complete electrical characterization of rf sputtering systems. Three types of systems are analyzed: tuned substrate, driven substrate, and controlled area ratio of electrode (CARE) systems. The theory is applicable to any of these systems that do not use magnetic fields to confine the plasma. Given the input rf power and voltage at the target, and any other parameters that can be specified as independent variables (e.g., pressure, substrate drive voltage, tuning impedance, and system geometry), the theory provides explicit values for all dc and rf electrical parameters of the system. The dc bias developed at the substrate is explained and related to the resputtering energy. In addition, an approximate calculation is presented for the ion density in the plasma; this calculation allows a semiquantitative estimate of the rf voltage developed at the target for a given value of rf input power. It also shows the influence of pressure and frequency on rf sputtering system operation. Comparisons are made with real rf sputtering systems; these show that the theory is quite successful in predicting the operation of these systems. In addition, a much better understanding is achieved of some of the complex electrical phenomena encountered in these systems. The theory should prove useful both for new system design and for diagnostic work on existing equipment.

Influence of Scattering and Ionization on RF Impedance in Glow Discharge Sheaths *by W. B. Pennebaker, p. 16.* The effects of scattering and ionization on the rf impedance of a glow discharge sheath are calculated using an equivalent dc sheath model. The effects of scattering are treated in terms of a drag force; equilibrium between the ion drift velocity and field is not required. The ratio of first ionization coefficient to pressure, α/p, is assumed to be constant, and the ion energy and ion current injected from the glow are assumed as initial parameters. In the limit of low pressures, the calculation agrees with the Child-Langmuir law. At intermediate pressures, the results agree with the mobility limited solution. At high pressures, the product of pressure and sheath dimension, pd, becomes constant because of ionization effects. The results of this calculation, obtained by numeric integration, can be accurately approximated by an interpolation formula. This formula provides a simple means for calculating the rf impedance of a sheath.

Sputtering Process Model of Deposition Rate *by J. H. Keller and R. G. Simmons, p. 24.* A model of the sputtering process has been developed that predicts the deposition rate of a sputtering system with parallel-plate geometry. By using data for sputtering yield vs voltage obtained from an ion-beam sputtering system, the model applies a new theory for computing the backscatter of the sputtered material, and, from the results, predicts deposition rates. The model also considers the effects of charge exchange in the sheaths, and of re-emission of sputtered material at the substrate. The model is valid for magnetic, tuned substrate, driven substrate, and controlled area ratio diode systems. Comparison with observed deposition rates shows good agreement for clean systems. An experimental APL program that uses the model has been written.

Some Chemical Aspects of the Fluorocarbon Plasma Etching of Silicon and Its Compounds *by J. W. Coburn and E. Kay, p. 33.* Mass spectrometric sampling of fluorocarbon glow discharges and *in situ* measurements of the etch rate of Si and SiO_2 with quartz crystal microbalances have been used to provide additional insight concerning the chemistry involved when additive gases such as O_2, H_2, N_2, H_2O, and C_2F_4 are injected into a CF_4 glow discharge. The results obtained in our low-pressure, long-residence-time system indicate that the etching behavior of the discharge is not significantly influenced by the molecular structure of the injected gas molecules but is determined primarily by the elemental composition of the glow discharge. This phenomenologically observed result can be used to predict qualitatively the relative etching behavior of a large class of gaseous etchant mixtures as well as the role of various electrode or wall materials in the plasma etching process. Although this oversimplified interpretation should not be extended to short-residence-time plasma systems, it is believed to be valid for some of the configurations used in plasma etching and reactive ion etching.

Photochemical Decomposition Mechanisms for AZ-Type Photoresists *by J. Pacansky and J. R. Lyerla, p. 42.* The photochemical decomposition mechanism of orthonaphthoquinonediazides has been investigated principally by infrared and carbon-13 nuclear magnetic resonance spectroscopies. The results demonstrate that the decomposition proceeds via a ketene intermediate to a photoproduct, the nature of which depends on the reaction conditions. Model resist systems were prepared by mixing orthonaphthoquinonediazides and 2,3,6-trimethylphenol or the diazide plus Novolak resin. Under ambient thermal and humidity conditions, ultraviolet (UV) exposure of the diazide yields 3-indenecarboxylic acid as the final photoproduct. However, UV exposure in vacuo results in ester formation via a ketene-phenolic OH reaction. The decomposition pathway and ensuing reactions have been shown to be the same for both 1- and 3-orthonaphthoquinonediazides attached to mono- and trihydroxybenzophenones. The technological implications for resist processing derived from these studies are also discussed.

Annealing of Poly(ethylene terephthalate)-Film-Based Magnetic Recording Media for Improved Dimensional Stability *by B. F. Blumentritt, p. 56.* PET-film-based magnetic recording media are subject to a number of dimensional instabilities, a major one being in-plane shrinkage due to stress relaxation in the biaxially oriented substrate. Annealing the

media allows stress relaxation without significantly degrading other properties and makes possible the use of higher track densities. Effects of annealing on mechanical properties, coefficients of thermal and hygroscopic expansion, and long-term dimensional stability of the media are described.

Laminated Films with Isotropic In-Plane Properties *by B. F. Blumentritt, p. 66.* Commercially available polymer films used in structural applications, such as biaxially oriented poly(ethylene terephthalate), exhibit pronounced anisotropy in mechanical properties, thermal expansion, and long-term dimensional stability. Films with more nearly isotropic in-plane properties have been produced by laminating plies of PET film at various angles to one another. In addition, composite films have been made with nearly isotropic properties and with significantly reduced coefficients of expansion compared to those of commercially available polymer films. A laminate with PET faces bonded to a low expansion alloy foil core had the best dimensional stability and the least anisotropy of the films studied.

On Future-Dependent Block Coding for Input-Restricted Channels *by P. A. Franaszek, p. 75.* Consider a restricted channel whose constraints may be characterized by a finite state machine model. Conventional coding techniques for such channels result in codes where the choice of a word to be transmitted is only a function of the current state and the information to be represented by this word. This paper develops techniques for constructing codes where the code word choice may also depend on future information to be transmitted. It is shown that such future-dependent codes exist for channels and coding rates where no conventional code may be constructed.

Algorithm to Check Network States for Deadlock *by V. Ahuja, p. 82.* The problem of checking the states of a system for deadlock is treated for a single class of systems, or networks, and for a single class of resources, or buffers. An algorithm is described that, for a given state, requires $O[m + n^2]$ operations, where m and n are, respectively, the number of tasks and nodes in the state. (In general, m is greater than n.)

Break-Up of a Liquid Jet: Second Perturbation Solution for One-Dimensional Cosserat Theory *by D. B. Bogy, p. 87.* The second perturbation solution is derived within the nonlinear one-dimensional Cosserat theory for a liquid jet emanating from a nozzle with harmonic excitation. Numerical results are presented for parameters relevant to ink-jet printing technology. Satellite drops are predicted but always in the backward merging condition. The results are compared with the corresponding solution obtained by Pimbley and Lee, who used a different one-dimensional set of equations with a different formulation of the problem and obtained forward merging satellite drops under some conditions.

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HeNe Parallel Plate Laser Development *by D. A. Chance, J.-C. A. Chastang, V. S. Crawford, R. E. Horstmann, and R. O. Lussow, p. 108.* A parallel plate format is used for fabricating "hard" sealed HeNe lasers. The new packaging geometry and construction process are suitable for large scale manufacturing. Cut plate, molded plate, and folded beam lasers have been built and tested. Several changes from conventional lasers, such as evaporated film cathode and anode, square cross section bore, glass sealed Brewster windows, and "soft" glass bore materials, are discussed. The power output capability, measurements of gain and loss parameters, and the reliability of these lasers are also considered.

Cathodes for HeNe Lasers *by D. A. Chance, V. Brusic, V. S. Crawford, and R. D. MacInnes, p. 119.* Vapor deposited aluminum cathodes for parallel plate HeNe lasers have been used with considerable success. It is shown that the aluminum cold cathode is improved by the addition of copper and that other alloying elements of bulk Al 2024 do not contribute to cathode performance. The plasma oxidation process of Hochuli improves cathode performance by cleaning the surface and optimizing the oxide film for maximum efficiency. There appears to be a trade-off between life and electron tunneling efficiency for optimum oxide thickness. Auger electron spectroscopy, ellipsometry, and scanning electron microscopy are the techniques used for surface characterization.

Nondestructive Analysis for HeNe Lasers *by W. E. Ahearn and R. E. Horstmann, p. 128.* The methods used to measure the gas properties in sealed helium-neon lasers are described. Such parameters as total gas pressure, minor constituent concentration (i.e., He/Ne ratio), and gas purity can be measured using spectral emission methods. How these parameters and measurement techniques relate to the electrical operating characteristics of the laser is described.

Polarization Problems of Parallel Plate Lasers *by J.-C. A. Chastang, p. 132.* Parallel plate laser technology requires that the plasma envelope and particularly the Brewster windows be "hard sealed." The first part of this study reports the effects of misalignments of the Brewster windows on laser performance. This turned out not to be a serious problem. In the second part the increase in the birefringence of the Brewster windows resulting from the hard seal technique is examined. We found that this problem, which is serious, can be eliminated by careful control of the temperature during sealing and the annealing process.

Reduction of Storage Fragmentation On Direct Access Devices *by P. A. Franaszek and J. P. Considine, p. 140.* A technique is described for partially reorganizing the contents of disk storage so as to reduce the level of fragmentation. The method entails choosing that fraction of the contents

which is estimated to have the greatest impact on the free space distribution, followed by the relocation of these data to more favorable locations, subject to the system integrity requirements.

Arithmetic Coding *by J. Rissanen and G. G. Langdon, Jr., p. 149.* The earlier introduced arithmetic coding idea has been generalized to a very broad and flexible coding technique which includes virtually all known variable rate noiseless coding techniques as special cases. An outstanding feature of this technique is that alphabet extensions are not required. A complete decodability analysis is given. The relationship of arithmetic coding to other known nonblock codes is illuminated.

High-Speed Programmable Logic Array Adders *by A. Weinberger, p. 163.* Programmable Logic Array (PLA) adders are described which perform an addition in one cycle with a single pass through a PLA and require a reasonable number of product terms for an 8-, 16-, or even a 32-bit adder. The PLA features two- bit input decoders feeding an AND array followed by an OR array whose outputs are pairwise EXCLUSIVE-ORed. Carry-look-ahead adder equations, adapted to the PLA to require relatively few product terms, are adjusted for maximum sharing of product terms. The number of unique product terms is a relative measure of one of the physical dimensions of the PLA. Equations for contiguous sum bits are grouped into strings, each using a common input carry. A procedure optimally assigns sum bits to strings to further minimize the total number of unique product terms. The methods are extended to PLAs with decoders of increased inputs and substantially reduced product terms. They can serve as dedicated macro functions on a chip, using special decoders relevant to adders. As a result, the other PLA dimension comprising the number of outputs from all input decoders increases only moderately, and can even decrease, with larger decoders. Finally, the PLA adder can be further substantially compressed by splitting the OR array into two parts such that a row of the AND array is shared between two product terms, and an OR array column is shared between two sums of product terms.

Thermal Stress in Bonded Joints *by W. T. Chen and C. W. Nelson, p. 179.* This paper considers the stress distributions in bonded materials induced by differential expansion or contraction of these materials. The analytical approach is similar to the lap joint theories attributed to Volkersen and expanded by Goland and Reissner. Several simple and typical analytical models are presented to bring out the relative importance of different geometrical and material parameters and to give some insight into different modes in which the bonds might fail.

Implications of a Selective Acknowledgment Scheme on Satellite Performance *by M. A. Reed and T. D. Smetanka, p. 189.* Data link response time is becoming more of a concern today with the onset of satellite transmissions of computer data. The long propagation delay inherent to satellite communications may lead to a degradation in data link response time as compared to the same transmission over purely terrestrial links. Furthermore, data link errors need be considered in any such study of response time of satellite data links. A model has been developed to study data link response time under a selective acknowledgment retransmission protocol. The model not only calculates mean link response time, but also the second moment of the response time. This model is then applied to various interactive data transmission schemes over a half-duplex (HDX) satellite link with terrestrial tails, although modifications can easily be made to analyze pure terrestrial or satellite links. The model parameters include bit error rate (*BER*), terrestrial as well as satellite propagation delay, modem transit delay, *MAXOUT* (maximum number of unacknowledged data frames), frame size (bits), and message size (bits).

Study of Head-Tape Interaction in High Speed Rotating Head Recording *by H. J. Greenberg, p. 197.* The steady state tape dynamics resulting from the interaction of a high speed rotating head and a flexible recording tape are formulated within the framework of linear shell theory. Tape displacements in the area above the head are coupled with the solution to the Reynolds equation in order to calculate the film thickness (flying height) between head and tape. Simulated results for spherical heads are compared to observed behavior on experimental systems.

Rapid and Precise Method for Analysis of Energy Dispersive X-Ray Spectra *by T. C. Huang, p. 206.* A new, precise, and rapid method for the analysis of energy dispersive x-ray spectra generated by electron beam or x-ray excitation is presented. It includes the use of Gaussian profiles and a polynomial of $1/E$ (where E is the x-ray energy) to represent the observed x-ray characteristic lines and background, automatic sectioning of the entire spectrum, and a figure of merit to estimate goodness of fit. Details of the method and its programming techniques are given. Results of analyzing complicated energy dispersive x-ray (EDX) spectra of multi-element alloys are presented.

Contrast Attenuation Factors for Remote Sensing *by J. V. Dave, p. 214.* Attenuation factors for the contrast of objects lying on the earth's surface and observed through five different atmospheric models are calculated as a function of the wavelength (0.31-0.9935 μm), solar zenith angle, ground reflectivity, and the nadir and azimuth angles of view. The first model is free of aerosols and absorbing gases. Absorption by average amounts of oxygen, ozone, and water vapor is included in the remaining four models. The second model is also free of aerosols, but the last three models contain aerosols in the form of a spherical polydispersion made from a substance with a spectrally independent refractive index of 1.5-0.01 *i*. Models 3 and 4 are expected to represent, respectively, the average and strong turbid

conditions encountered over large continental areas. Models 3 and 5 contain aerosols with different size distribution characteristics, but have the same amount of aerosol mass loading per unit horizontal area. The contrast attenuation factor is found to increase with an increase in wavelength and reflectivity of the surrounding surface, and a decrease in the atmospheric turbidity and gaseous attenuation. It also depicts strong azimuthal dependence especially for models illuminated by low-altitude solar radiation of longer wavelengths.

On the Application of Coding Theory to Hashing *by N. Pippenger, p. 225.* Quick proofs are given for the characterization (due to Schay, Raver, Hanan, and Palermo) of the collision distance of a linear hashing function and for a dual notion (called the restriction distance), which relates to the accessibility of addresses by sets of keys and the uniform distribution of sets of keys over addresses.

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Simulation of a Moving Bed Gasifier for a Western Coal *by R. Stillman, p. 240.* This paper describes an adiabatic steady state plug flow model for a moving bed coal gasifier with gas-solid heat transfer. The model considers 17 solid stream components, 10 gas stream components and 17 reactions. The kinetic and thermodynamic parameters were derived for a Wyoming subbituminous coal. Examples of calculated results are given.

The Analysis and Comparison of Actual to Predicted Collector Array Performances *by W. H. McCumber and M. W. Weston, p. 253.* The Hottel-Whillier-Bliss (HWB) equation has been the standard tool for the evaluation of collector thermal performance for four decades. This paper presents a technique that applies the criteria of ASHRAE Standard 93-77 to the determination of the HWB equation coefficients from field-derived data. Results of the analysis of a sample collector array illustrate the technique. Actual dynamic performances of various collector arrays in the field are compared to those predicted by the steady-state efficiency models for the individual panels. In certain cases, the HWB model produces deviations of over 100% from measured hourly performances and 35% from measured monthly performances when compared with the single-panel laboratory-derived model. However, when the field-derived HWB model is used as the basis of comparison the performance deviations were typically less than 5%.

Solar-Grade Silicon by Directional Solidification in Carbon Crucibles *by T. F. Ciszek, G. H. Schwuttke, and K. H. Yang, p. 270.* Directional solidification of silicon in carbon crucibles was achieved by using two variations of the Bridgman-Stockbarger method. One was a static technique wherein liquid silicon in a carbon crucible was positioned in a temperature gradient of about 35°C/cm, with the highest temperature at the top of the crucible. Solidification was achieved by lowering the system temperature at a rate of 4–5°C/min. The second technique entailed lowering a silicon-loaded carbon crucible through a fixed-rf coil at a rate of 0.55 cm/min. Crack-free silicon was produced by both methods. The equilibrium grain structure was initiated by nucleation at the crucible walls, with surviving grains tending to grow in alignment with the temperature gradient to produce an axially columnar grain structure of mainly <110> orientation. The average grain diameter was 0.11 cm; a typical length was 0.7 cm. Solar cells made with this material gave an AM1 conversion efficiency of 11.5%.

Encapsulation of Radioactive Noble Gas Waste in Amorphous Alloy *by J. A. Van Vechten, R. J. Gambino, and J. J. Cuomo, p. 278.* Public demand for the containment and safe storage of radioactive waste materials has caused the U.S. Government to require that, beginning in January 1983, most of the ^{85}Kr, which until now has been vented to the atmosphere during the reprocessing of nuclear fission fuel rods, will have to be captured and retained for several decades. The cost of accomplishing this with present compressed-gas technology is enough to increase the cost of nuclear generated electricity by an estimated 0.3%. However, materials developed for amorphous magnetic bubble memory devices have been found to be capable of storing large quantities of Kr (30 atomic percent) with great stability up to temperatures above 1070 K. The cost of ^{85}Kr storage in the magnetic bubble memory material appears to be less than 1% of that for present compressed-gas technology.

An Access Specification Language for a Relational Data Base System *by R. A. Lorie and J. F. Nilsson, p. 286.* We address the problem of executing high level language queries submitted to a relational data base system. As a step in the process of constructing an "efficient" compiler for a high level language we suggest the elaboration of an intermediate level language acting as a target language for the optimizer part of the compiler. This language may be conceived as one of several levels in a chain of abstract machines mapping a nonprocedural relational language onto primitive data base access operations. It is our conjecture that the introduction of an access specification language provides a conceptual platform facilitating the handling of the "optimization" problem.

Transform Techniques for Error Control Codes *by R. E. Blahut, p. 299.* By using the theory of finite field Fourier transforms, the subject of error control codes is described in a language familiar to the field of signal processing. The many important uses of spectral techniques in error control are summarized. Many classes of linear codes are given a spectral interpretation and some new codes are described. Several alternative encoder/decoder schemes are described by frequency domain reasoning. In particular, an errors-and-erasures decoder for a BCH code is exhibited which has virtually no additional computations over an errors-only decoder. Techniques for decoding BCH, RS, and

alternant codes (Goppa codes) a short distance beyond the designed distance are discussed. Also, a modification to the definition of a BCH code is described which reduces the decoder complexity without changing the code's rate or minimum distance.

Electrodes with Covalently Attached Monolayers *by A. F. Diaz and K. K. Kanazawa, p. 316.* We have used cyclic and second-harmonic ac voltammetry to study solution and solid state electrochemical reactions on metal oxide surfaces chemically modified with silyl derivatives of the type $SnO_2/Si(CH_2)_3NH(CH_2)_xNR_1R_2$. The R groups studied include pyrazoline derivatives, tetrathiafulvalene, and ferrocene. Electrode effects on solution redox reactions involving phenothiazine and benzoquinone have also been compared using both platinum electrodes and the chemically modified electrodes. The results from the various approaches used consistently indicate that the redox reactions are slower on modified as opposed to unmodified electrode surfaces.

On the Zigzag Form of Charged Domain Walls *by M. J. Freiser, p. 330.* Unusual domain walls have been found in ferrofluid patterns on thin film materials with low magnetization that is in or near the plane of the film. These walls carry a net magnetic charge and are characteristically kinked in a regular manner to form a zigzag. A simple account is given of the energetics of such walls whose form follows from a compromise between magnetostatic terms and the energy of anisotropy. It is argued that an array of closure domains at straight edges in these materials should have a boundary of similar character, and these too have been observed.

Probabilistic PERT *by A. Nádas, p. 339.* A solution is offered to the problem of determining a probability distribution for the length of the longest path from source (start) to sink (finish) in an arbitrary PERT network (directed acyclic graph), as well as determining associated probabilities that the various paths are critical ("bottleneck probabilities"). It is assumed that the durations of delays encountered at a node are random variables having known but arbitrary probability distributions with finite expected values. The solution offered is, in a certain sense, a worst-case bound over all possible joint distributions of delays for given marginal distributions for delays. This research was motivated by the engineering problem of the timing analysis of computer hardware logic block graphs where randomness in circuit delay is associated with manufacturing variations. The probability distribution of the critical pathlength turns out to be a solution of an unconstrained minimization problem, which can be recast as a convex programming problem with linear constraints. The probability that a given path is critical turns out to be the Lagrange multiplier associated with the constraint determined by the path. The discrete version of the problem can be solved numerically by means of various parametric linear programming formulations, in particular by one which is efficiently solved by Fulkerson's network flow algorithm for project cost curves.

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Guest Editorial *by P. A. Engel, p. 360.*

Air Film System for Handling Semiconductor Wafers *by J. A. Paivanas and J. K. Hassan, p. 361.* In an automated fabrication facility, the thin, fragile silicon wafers in which semiconductor circuits are formed must be transported to and from processing stations with a minimum of contact with other solid objects so as to minimize damage, contamination, and consequent lowering of product yield. This task has been undertaken for some time now, in IBM and elsewhere, by systems based on a lubricating film of air as a means for levitating and moving wafers. However, due to inherent motion instabilities and specific control needs, some solid contact is typically involved in effecting prescribed wafer motion. The need for solid contact control is greatly reduced by the air film system described in this paper. It is based on a surface configuration that combines two fluid mechanics phenomena to generate a supporting air film that provides and guides wafer motion. Wafer transportation and positioning are achieved with the air film operating in conjunction with special control device techniques.

Micromechanical Membrane Switches on Silicon *by K. E. Petersen, p. 376.* A new class of electronic devices, micromechanical membrane switches, has been developed. These switches have operating characteristics that fill the gap between conventional silicon transistors and mechanical electromagnetic relays. Although they are batch fabricated on silicon using conventional photolithographic and integrated circuit processing techniques, their unique properties allow them to perform functions not ordinarily associated with silicon. The devices are basically extremely small, electrostatically controlled mechanical relays, typically less than 100 μm long. Their high off- to on-state impedance ratio and all-metal conduction paths make them ideally suited for ac signal switching arrays. This paper describes the design, fabrication, operating behavior, and potential applications of these voltage-controlled, micromechanical switches.

An Application of Beam Dynamics to a Damper Design *by H. C. Lee and J. W. Raider, p. 386.* Flexural wave propagation may be used as a means of absorbing impact energy to prevent excessive rebound or to shorten the cycle time of high-speed printing devices. For optimal damping action, however, the dynamic analysis of beams used in the mechanism is necessary; this paper presents such an analysis. It also presents an application of a damper ring design that is used to prevent so-called "shadow printing" by suppressing the rebound of the type elements in a disk printer.

Interposer for Disk Printer *by J. H. Meier and J. W. Raider, p. 392.* In an impact printer which selects characters by

having a hammer hit type elements as they travel at constant velocity past the print location, a significant design problem results from the requirement that the hammer hit only the selected character. In the usual configuration this requirement limits printing speed because the hammer penetrates the plane of the moving type elements and spends a sufficient time in this plane to risk collision with an adjacent type element. This paper describes, for printers with widely separated hammers, a technique to effectively eliminate the "in-plane" time. A cammed interposer is used to transfer most of the kinetic energy of the hammer to the type element, with the remaining energy being absorbed in strain energy of the interposer. For one printer, this technique resulted in an increase in the printing speed from 15 to 30 characters per second.

A Cylindrical Print Element System for a Serial Impact Printer *by J. Zable, p. 396.* For an impact serial printer, like a typewriter terminal, it is desirable to print fast and to print with a minimum of maintenance. For printing to take place, the carrier containing the print element must be in the correct position along the print line and the character selection must be made by the proper positioning of the print element. This paper discusses a cylindrical thin-walled print element containing an entire character array on its outside surface. The print element is rotated and translated independently by two prime movers (motors). The cylindrical print element geometry and the prime movers are optimized to minimize the time required for character selection. Surface area, stress, inertia, torque, and motor requirements are considered. Selection times and printing rates are computed for simulated printing conditions.

Dynamic Response of a Print Belt System *by P. A. Engel, H. C. Lee, and J. L. Zable, p. 403.* The dynamic response of a print belt system, when the print belt is subjected to impulsive print forces, is analyzed in this paper. The system consists of a flat steel print belt tightly wrapped around pulleys with one of the pulleys driven by a motor. Analytical modeling allows the prediction and analysis of belt motion and thus the prediction of print misregistration. Discrete parameters used in the analysis permit simulation of the belt motion as affected by variations in belt tension, stiffness, pulley inertias, and motor-operating parameters. Conditions of belt slippage are examined, as well as the effect of dynamic loading upon the drive motor.

Harmonic-Drive Ribbon Stuffer for Impact Printers *by E. F. Helinski, p. 411.* This paper describes a harmonic-motion ribbon-stuffing device for impact printers, which maintains a consistent placement pattern for large-capacity (120 yards) endless-loop fabric ribbons. The ribbon is uniformly placed into a cavity by eccentric drive rolls that ensure alternate ribbon switching due to the geometric relationship of drive rolls and strippers. The ribbon is positively placed in a manner much like a fixed-displacement drive, thus differing significantly from the principle used by existing ribbon packers, which achieve ribbon placement by balancing the difference in net driving force against the buckling resistance of the ribbon.

Document Scanner Mechanism *by W. D. Clark, p. 415.* A document scanner mechanism, developed for use in a conventional copier having mirrors which scan a document and reflect the image onto a rotating photoconductor drum, is described in this paper. The engineering design and operation of the mechanism are presented, and the development of an analytical model for simulating its operational characteristics is described, together with the results and conclusions of the simulation. A novel means of generating the scan motion and the important design considerations leading to the development of the scanner mechanism are also presented.

Planning and Execution of Straight Line Manipulator Trajectories *by R. H. Taylor, p. 424.* Recently developed manipulator control languages typically specify motions as sequences of points through which a tool affixed to the end of the manipulator is to pass. The effectiveness of such motion specification formalisms is greatly increased if the tool moves in a straight line between the user-specified points. This paper describes two methods for achieving such straight line motions. The first method is a refinement of one developed in 1974 by R. Paul. Intermediate points are interpolated along the Cartesian straight line path at regular intervals during the motion, and the manipulator's kinematic equations are solved to produce the corresponding intermediate joint parameter values. The path interpolation functions developed here offer several advantages, including less computational cost and improved motion characteristics. The second method uses a motion planning phase to precompute enough intermediate points so that the manipulator may be driven by interpolation of joint parameter values while keeping the tool on an approximately straight line path. This technique allows a substantial reduction in real time computation and permits problems arising from degenerate joint alignments to be handled more easily. The planning is done by an efficient recursive algorithm which generates only enough intermediate points to guarantee that the tool's deviation from a straight line path stays within prespecified error bounds.

A Numerical and Experimental Study of the Bistable-Unstable Transition in Pressurized Flexible Disk Files *by D. B. Bogy, J. E. Fromm, and F. E. Talke, p. 437.* The bistable operating region of flexible disk files is limited at decreasing air flow rates by a transition at which undesirable gaps appear in the otherwise uniformly spaced disks of the pack. These spontaneous gaps, as opposed to the externally controlled gaps of the bistable range, are a consequence of local air flow fields at the outer edge of the disks. Experiments with external shrouds of various clearance showed axial periodicity in the occurrence of the gaps and provided physical insight which led to quantitative numerical solution of the nonlinear fluid equations. Two scales of the flow, i.e., the flow between individual disks and a peripheral

unstable Couette flow, are found to couple in such a manner as to delineate the transition.

Experimental Determination of Creep Functions for Thin Orthotropic Polymer Films *by D. B. Bogy, N. Bugdayci, and F. E. Talke, p. 450.* Stringent requirements on the dimensional stability of polymer films used as substrates for magnetic recording make it necessary to experimentally determine their anisotropic viscoelastic behavior. This paper deals with the measurement of the time-dependent, longitudinal elongation and lateral contraction of 50×900-mm biaxially oriented orthotropic polyethylene terephthalate (PET) strips. Two different methods are described for measuring longitudinal elongation, and a laser-scanning technique is used for measuring lateral contraction. Preliminary investigations are carried out to determine the static Poisson's ratio, to check the linearity of longitudinal creep with respect to load, and to investigate the validity of the time-temperature superposition hypothesis. In addition, tests are described in which longitudinal and lateral creep of the specimens are simultaneously measured under constant loads in temperature- and humidity-controlled environments. It is found that the Poisson's ratio has only a weak dependence on time, and, therefore, a good approximation may be obtained by treating the Poisson's ratio as independent of time.

Tunnels in Semiconductor Epitaxy *by J. C. Marinace, p. 459.* On (100) surfaces of III-V or II-VI compounds, tunnels or grooves can be grown over oxide or Mo stripes, the axes of which are in one of the two orthogonal <110> directions on the surface. One <110> direction produces grooves and the other, tunnels. By switching from *n*- to *p*-type layers at frequent intervals during growth, the mechanism can be elucidated.

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Contributions of IBM to Laser Science—1960 to the Present *by P. P. Sorokin, p. 476.* IBM's role in the discovery of new lasers and in the development of their scientific potential is described. A brief survey is presented of laser-related projects conducted within IBM's Research Division laboratories at Yorktown Heights, NY, San Jose, CA, and Zurich, Switzerland.

Systematic Behavior in Alkaline Earth Spectra: A Multichannel Quantum Defect Analysis *by J. J. Wynne and J. A. Armstrong, p. 490.* "Two-electron" atoms are more complex than "one-electron" atoms because of electron-electron interactions. This leads to spectra that are not well understood. Using multiple photon excitation and ionization detection, we have extensively studied Rydberg series of states in Ca, Sr, and Ba. The spectroscopic data were interpreted by using multichannel quantum defect theory (MQDT). In this context, systematic trends in the atom series Ca, Sr, and Ba are discussed.

Two-Photon Coherent Transients *by M. M. T. Loy, p. 504.* Two-photon nutation, free-induction decay, and population inversion by adiabatic rapid passage have been studied in NH_3. These effects are easily visualized with a vector model. Relaxation time T_1 and T_2 have been measured.

Cooperative Emission of an Excited Monolayer into Surface Plasmons *by H. Morawitz, p. 517.* The cooperative emission of an excited molecular monolayer into surface plasmons of a metallic substrate is described. The effect arises from the very strong coupling of an electronically excited molecule to surface plasmons at distances that are short compared to the wavelength of the electronic transition. Strong resonant enhancement of this excited molecule-surface plasmon interaction occurs for near-degeneracy of the electronic transition frequency and the asymptotic surface plasmon frequency $\omega_p/2^{1/2}$. It is shown theoretically how the two-dimensional analogue of superradiance can arise, leading to a highly directional and very intense surface plasmon pulse. This pulse or series of pulses has soliton-like characteristics and may be expected to propagate for considerably longer distances along the metal-vacuum interface than do individual surface plasmons.

Subnanosecond Optical Free-Induction Decay *by R. G. DeVoe and R. G. Brewer, p. 527.* A novel form of laser frequency switching is devised that extends coherent optical transient studies to a 100-picosecond time scale, the measurements being performed in real time. Free-induction decay (FID) on a subnanosecond time scale reveals new features, such as a first-order FID that dephases with the inhomogeneous dephasing time T_2^* and interferes with the well-known nonlinear FID. A complete analytical expression for optical FID is derived and supports our FID observations for the sodium D_1 transition.

One- and Two-Photon Laser Photochemistry in Organic Solids *by D. M. Burland and D. Haarer, p. 534.* The criteria for site-selective low-temperature laser photochemistry in organic solids are discussed within a general framework that includes both one- and two-photon photochemical reaction schemes. We identify requirements for the use of this photochemistry in photochemical hole burning applications such as high-resolution spectroscopy and the study of low-temperature reaction mechanisms. The one- and two-photon reaction schemes are quite different from one another with respect to excited state geometries and short-lived photoreactive intermediates. The reversible tautomerism of quinizarin in hydrogen-bonded host materials is studied as a one-photon example. The photochemistry involves both intra- and intermolecular hydrogen bonds. The photodissociations of s-tetrazine (ST) and dimethyl-s-tetrazine (DMST) are studied as examples of the two-photon reaction and a kinetic scheme is proposed for the tetrazine case. The intensity dependence of the photochemistry in solids is modeled mathematically.

Photochemical Hole Burning in Free-Base Porphyrin and Chlorin in n-Alkane Matrices *by S. Völker and R. M. Macfarlane, p. 547.* In inhomogeneously broadened lines, selective photochemistry with narrow band lasers leads to photochemical hole burning. We describe this phenomenon with particular reference to free-base porphyrin (H_2P) and chlorin molecules in n-alkane matrices at low temperatures. It is shown that hole burning, which is permanent at low temperatures, can be used to study homogeneous optical dephasing processes as a function of temperature, to measure fast vibronic relaxation, and to assign complex vibronic spectra. Some of the parameters that are important to the potential use of photochemical hole burning for information storage in inhomogeneously broadened lines are measured and discussed.

Time-Resolved Infrared Spectral Photography: A New Technique *by D. S. Bethune, J. R. Lankard, M. M. T. Loy, and P. P. Sorokin, p. 556.* A new technique for photographic or multichannel photoelectric recording of broad band infrared absorption spectra with approximately 5-ns time resolution is described. The technique is based on resonant four-wave mixing in alkali metal vapors.

(GaAl)As Laser Requirements for Local Attached Data Link Applications *by J. D. Crow, p. 576.* The characteristics of (GaAl)As double heterostructure stripe contact injection lasers as they relate to applications in fiber optic data transmission systems are reviewed. The laser characteristics are treated as optical, electrical, thermal, and mechanical interfaces to the system in order to emphasize the necessity of designing devices as a functional part of a system or subsystem. It is concluded that the laser is generally well suited as an optical source in a card-mountable hybrid module transmitter for data links up to a few km and ≈100 Mbit/s data rates. Areas requiring further development include lowering of the laser threshold current, improving the modal stability, packaging the laser with electronics and fiber optic transmission lines, and improving the laser lifetime under varying ambient temperature conditions.

GaAs/(GaAl)As Laser Technology *by R. T. Lynch, Jr., M. B. Small, and R. Y. Hung, p. 585.* This paper is a review of some recent work at IBM on semiconductor injection lasers. An automated system has been built and used for the epitaxial growth of laser material and we describe testing procedures used to characterize this material. Results on the degradation of these lasers at high continuous wave optical power are also presented.

Molecular Beam Laser-Induced Fluorescence Studies of Chemical Reactions *by A. C. Luntz, p. 596.* Crossed molecular beam experiments that use laser-induced fluorescence spectroscopy as the detector allow measurements of the internal state distribution in the products of chemical reactions studied under well-controlled single-collision conditions. This technique provides direct information on the chemical dynamics and the intermolecular potential surfaces. Application to the reactions $H + NO_2 \rightarrow OH + NO$ and $O(^3P) + C_6H_{12} \rightarrow OH + C_6H_{11}$ is discussed where the OH state distribution has been measured.

Forced Rayleigh Scattering *by D. W. Pohl, p. 604.* Forced Rayleigh scattering (FRS) is a light scattering technique used to investigate light-induced grating structures that decay in a relaxational or almost relaxational manner. Such gratings can be created by interference and absorption of two pump beams and probed by a third beam, usually of different frequency. They may consist of spatially varying excited state populations with picosecond lifetimes or of long-lived variations in temperature, composition, and/or density. Forced Rayleigh scattering provides high sensitivity with respect to the amplitude and dynamics of such gratings and allows investigations not accessible by classical scattering techniques. The principles, techniques, and applications of FRS are reviewed.

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Survey of Computer-Aided Electrical Analysis of Integrated Circuit Interconnections *by A. E. Ruehli, p. 626.* In the last decade an important shift has taken place in the design of hardware with the advent of smaller and denser integrated circuits and packages. Analysis techniques are required to ensure the proper electrical functioning of this hardware. In this paper we give a coherent survey of the modeling and computer-aided design techniques applicable to solving these problems. Methods are considered for the computation of resistances, capacitances, and inductances. Also, an extensive list of references is given.

Potential Distribution and Multi-Terminal DC Resistance Computations for LSI Technology *by C. M. Sakkas, p. 640.* Computer time and storage requirements are the two main considerations in the design of a packaging analysis software tool for the problem of calculating the electric potential distribution in arbitrary geometrical shapes. The FEM (Finite Element Method) is the accepted approach for solving such problems. A new formulation for the linear triangular element is presented which is used to derive a very simple and computationally inexpensive linear rectangular element equation interrelating only the geometrical centers of the elements. The result is a much sparser assembly matrix with a maximum of five non-zero entries per equation compared with the usual nine of the FEM formulation. In addition, a method to obtain the minimum bandwidth of the matrix is given for the efficient and static use of external storage, permitting the solution of any size problem. The methods are applicable to multi-plane, multi-terminal configurations for the production of equivalent-resistance networks and for the calculation of the potential distribution throughout the configurations.

Resistive and Inductive Skin Effect in Rectangular Conductors *by W. T. Weeks, L. L.-H. Wu, M. F. McAllister, and A. Singh, p. 652.* A model based on network theory is presented for calculating the frequency-dependent resistance and inductance per unit length matrices for transmission line systems consisting of conductors with rectangular cross sections. The calculated results are compared with actual measurements. Excellent agreement is obtained over a wide range of frequencies, including the mid-range where neither dc values nor high-frequency limit values apply.

Three-Dimensional Inductance Computations with Partial Element Equivalent Circuits *by P. A. Brennan, N. Raver, and A. E. Ruehli, p. 661.* Inductance computations represent an important part in the design of hardware packages, especially for high performance computers. Partial element equivalent circuits (PEEC) are used in this paper to investigate two problems, viz., the inductance of ground plane connections and the reduction in inductance due to eddy currents set up in perpendicular crossing wires. The results from the PEEC models are compared, for the first problem, to experimental hardware measurements and, in the second case, to simplified analytical solutions.

Exploiting Symmetry in Electrical Packaging Analysis *by W. T. Weeks, p. 669.* Many properties of physical systems can be expressed by symmetric matrices of order n, where n is the number of components in the system. The computer storage requirement for inverting the most general symmetric matrix is $n(n+1)/2$ storage locations. For large values of n, the number of multiplications required is proportional to n^3. If the physical system possesses certain geometrical symmetries, both the amount of storage and the number of multiplications can be reduced substantially. It will be shown that if the physical system possesses p orthogonal planes of symmetry, where $p = 1$, 2, or 3, and if n is sufficiently larger, then the storage requirement can be reduced approximately by $1/2^p$ and the number of multiplications by $1/4^p$.

Transient Analysis of Uniform Resistive Transmission Lines in a Homogeneous Medium *by A. J. Gruodis, p. 675.* Transient analysis of resistive transmission lines has always been difficult. The need for this type of analysis, however, did not become critical until high-density circuit packaging became commonplace. This paper discusses a method for the transient analysis of resistive lines. It does not require a large number of equivalent circuit elements, and yet it can be used to represent a resistive line to any desired accuracy.

Geometry Effects of Small MOSFET Devices *by F. H. Gaensslen, p. 682.* The effects of diminishing MOS inversion channel length or width on device characteristics are discussed. As opposed to the geometric device size, an "electric device size" is established by normalizing all dimensions on an appropriately chosen depletion layer width. It is shown how this "electric size" governs the intensity of geometry effects. DC device modeling methods are reviewed with respect to their ease of application to electrically small devices. Finally, means for reduction of geometry effects are considered.

Stability of Lateral pnp Transistors During Accelerated Aging *by S. J. Gillespie, p. 689.* Lateral *pnp* devices stressed under accelerated temperature and voltage conditions show a degradation in the transistor breakdown voltage. These results and additional experiments that were conducted to better understand the mechanisms involved in the observed behavior are described. It was concluded that the degradation can be related to a negative surface charge in the base region of the transistor. This preliminary finding has design and process implications for potential improvement of bipolar device reliability in applications that call for high voltages and low epitaxial doping concentration.

An Elementary Proof of Nonexistence of Isometries between U_p^k and U_q^k *by D. Coppersmith, D. T. Lee, and C.-K. Wong, p. 696.* For $k = 2$, the two-dimensional coordinate spaces U_1^2 and U_∞^2 are isometric. Consequently, results on computational complexity for one space can be transplanted to the other in a natural way. In this note, an elementary proof is given for the nonisometry between U_p^k and U_q^k for general k, p, and q.

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Design of Large ALUs Using Multiple PLA Macros *by M. S. Schmookler, p. 2.* This paper describes methods of designing large Arithmetic and Logical Units (ALUs) using multiple Programmable Logic Array (PLA) macros in which the outputs are obtained in one cycle corresponding to one pass through any PLA. The design is based on the well-known technique of providing conditional sums and group carries in parallel and selecting the proper sum using gating circuits. The PLA for each group of bits uses an adder design published by Weinberger in which each bit of the sum is formed from the EXCLUSIVE-OR of two outputs of the OR array. By placing the gating circuits in front of the EXCLUSIVE-OR circuits, the sums can be obtained using two OR array outputs for each bit and one additional OR array output for each internal string of bits. Also discussed are how ALUs containing more than two groups can obtain the group carries using a separate carry-look-ahead PLA macro and how this macro can be compressed by using special decoders and special physical design layout techniques. Additionally, the paper demonstrates how the PLAs can be used to provide detection of overflow and of zero results, and to also provide Boolean operations.

A Heuristic Test-Pattern Generator for Programmable Logic Arrays *by E. B. Eichelberger and E. Lindbloom, p. 15.* This paper describes a heuristic method for generating test patterns for Programmable Logic Arrays (PLAs). Exploiting the regular structure of PLAs, both random and deterministic test-pattern generation techniques are combined to achieve coverage of crosspoint defects. Patterns to select or deselect product terms are generated through direct inspection of an array; test paths to an observable output are established by successive, rapidly converging assignments of primary input values. Results obtained with a PL/I program implementation of the method are described; these results demonstrate that the method developed is both effective and computationally inexpensive.

Design Automation and the Programmable Logic Array Macro *by R. L. Golden, P. A. Latus, and P. Lowy, p. 23.* The Programmable Logic Array (PLA) macro is a physical structure which simplifies LSI chip design while yielding high density and good performance. In addition, the inherent order and regularity of this structure provide opportunities to speed design through automated logic documentation, design verification by computer simulation, and computer-automated physical design. In this paper a chip design methodology is described which is based on the use of PLA structures (or macros) within a chip. Logic functions in array form are specified in a compact notation that is automatically converted either to array personalization patterns or to conventional logic blocks for input to existing checking and testing software. Simulation of any logic array is performed by a single program subroutine operating on these patterns. In addition, the simple, regular nature of the logic array lends itself to automatic generation of the layout geometries necessary to actually build the array on a silicon chip. Programs developed for these purposes and the PLA macro design procedures are described in the context of an engineering design system.

Error Recovery Scheme for the IBM 3850 Mass Storage System *by A. M. Patel, p. 32.* The IBM 3850 Mass Storage System (MSS) stores digital data on flexible magnetic tape media; however, it is different in many respects from the conventional multitrack tape machines. In particular, the use of a single-element rotary read-write head imposes new demands in the areas of data encoding and error recovery. This paper presents a comprehensive scheme for error recovery for the 3850 MSS which features a new error-correction code in a serial, single-stripe data format. The recovery procedure is designed around resynchronizable sections of data which are rendered independent of each other in error modes through the use of zero-modulation encoding and self-contained error-detection pointers. These error-detection pointers and the resynchronization signals are utilized in conjunction with interleaved codewords of the error-correction code. The code is designed with a generating polynomial in which the roots are chosen from the set of elements of a 16-element subfield of the Galois field $GF(2^8)$. This choice provides the necessary code structure for desired code capabilities and facilitates fast decoding of errors with an economical implementation of the decoder. The scheme provides correction capabilities for various combinations of mixed-mode short and long errors common to magnetic tape recording of digital data.

Synchronous Bounded Delay Coding for Input Restricted Channels *by P. A. Franaszek, p. 43.* Consider the class of input restricted channels whose constraints can be modelled by finite state machines. This paper treats the problem of constructing fixed rate (synchronous) codes for such channels subject to a constraint that the coding delay be bounded by a parameter M. M is the maximum number of information symbols required by the coder in choosing a word during transmission.

Determining Deadlock Exposure for a Class of Store and Forward Communication Networks *by V. Ahuja, p. 49.* Given a network design, is the network exposed to deadlock for message buffers? This problem is addressed for a class of networks called "routed networks." A routed network is a store and forward communication network in which all transmissions follow predefined routes through the network. It is shown that a routed network is exposed to deadlock if and only if there exists a complete weighted matching of an appropriately defined bipartite graph for some subgraph of the network graph. An approach for determining whether a deadlock can occur is presented.

On a Class of One-Step Majority-Logic Decodable Cyclic Codes *by S. Lin and G. Markowsky, p. 56.* Majority-logic decoding is attractive for three reasons: (1) It can be simply

implemented; (2) the decoding delay is short; and (3) its performance, while suboptimal, is always superior to bounded distance decoding. For these reasons, majority-logic decodable cyclic codes are very suitable for error control in high speed digital data transmission systems. Among the majority-logic decodable codes, the one-step decodable codes can be most easily implemented; they employ a single majority-logic gate. In this paper we study a class of one-step majority-logic decodable cyclic codes. First, we describe these codes in a simple manner. Second, a way of finding the orthogonal polynomials for decoding these codes is presented. Third, we show that for a given error correction capability, the ratio of the number of parity digits to the code length goes to zero as the code length increases. For error correction capabilities of the form $2^k - 1$ or 2^k, we determine the dimensions of the codes exactly.

A Geometric Modeling System for Automated Mechanical Assembly *by M. A. Wesley, T. Lozano-Pérez, L. I. Lieberman, M. A. Lavin, and D. D. Grossman, p. 64.* Very high level languages for describing mechanical assembly require a representation of the geometric and physical properties of 3-D objects including parts, tools, and the assembler itself. This paper describes a geometric modeling system that generates a data base in which objects and assemblies are represented by nodes in a graph structure. The edges of the graph represent relationships among objects such as *part-of, attachment, constraint*, and *assembly*. The nodes also store positional relationships between objects and physical properties such as material type. The user designs objects by combining positive and negative parameterized primitive volumes, for example, cubes and cones, which are represented internally as polyhedra. The data base is built by invoking a procedural representation of the primitive volumes, which generates vertex, edge, and surface lists of instances of the volumes. Several applications in the automatic assembly domain have been implemented using the geometric modeling system as a basis.

On the Complexity of Permuting Records in Magnetic Bubble Memory Systems *by K. Chung, F. Luccio, and C.-K. Wong, p. 75.* In this paper we study the problem of permuting records in various simple models of magnetic bubble memories. Previous studies usually assumed the memory system either had one switch or n independently controlled switches, where n is the number of records to be permuted. In the former case, the time complexity to permute a set of n records is $O(n^2)$, while in the latter case, the time complexity is $O(n)$. In this paper, we propose several simple models of bubble memory systems with their numbers of switches ranging between 1 and n and analyze the respective time complexities and respective numbers of control states for some permutation algorithms designed especially for them. Specifically, four models are studied: They have essentially $\log_2 n$, $2\sqrt{n}$, $(\log_2 n - \log_2 \log_2 n)^2$, and k switches; their respective time complexities are essentially $(3/2)n \log_2 n$, $(5/2)n$, $(7/2)n$, and $2^{-1/k}kn^{1+(1/k)}$; and their respective numbers of control states are essentially $4 \log_2 n$, $2^{\sqrt{n}+1}$, $2n/\log_2 n$, and $4k$.

Interferometric Wavelength Measurements through Post-Detection Signal Processing *by R. V. Pole, A. J. Spiekerman, and T. W. Hänsch, p. 85.* Modern electronic signal processing techniques make it possible to use a conventional scanning Fabry-Perot interferometer for highly accurate measurement of (tunable) laser wavelengths. An experimental device is described in which the time intervals between resonances of an unknown wavelength are compared with those of a stabilized He-Ne reference laser by the use of highly accurate electronic timing devices. The accuracy is further enhanced through signal averaging over many scan periods. Accuracies approaching one part in 10^7 are expected to be readily achievable.

Pattern Optimization for UPC Supermarket Scanner *by B. U. Braunecker, p. 89.* Different scanning patterns χ are analyzed in order to determine the degree of redundancy. To this purpose, we evaluate the number of resolution points N_χ which are generated by a sweeping laser beam, while the merchandise is moved across the scanning window. The goal is to find the pattern which minimizes N_χ for an acceptable detection rate.

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Josephson Computer Technology: An IBM Research Project *by W. Anacker, p. 107.* This special issue of the IBM Journal of Research and Development describes the status of IBM's research project on Josephson computer technology. This first paper traces the origins and history of Josephson technology as it led to the project and outlines the project's scope. The potential of the technology for ultrahigh-performance computer mainframes is discussed and the major technological characteristics of LSI Josephson devices are examined. The paper then provides an overview outline of the remaining papers presented in this issue.

Overview of Josephson Technology Logic and Memory *by J. Matisoo, p. 113.* This paper serves as an introduction to the other logic and memory papers in this issue. Basic concepts of superconductivity and electron tunneling underlying the operation of Josephson devices are outlined and an overview of the literature on the subject is presented, with emphasis on work performed at the IBM research laboratories since the beginnings of the Josephson computer technology program in 1965.

Design of 2.5-Micrometer Josephson Current Injection Logic (CIL) *by T. R. Gheewala, p. 130.* This paper describes Josephson Current Injection Logic (CIL) circuits. The design of the basic logic circuits, the two-and four-input OR and AND gates, and a timed inverter circuit, is presented in full detail and the logic delay and its sensitivity to design and fabrication parameters are investigated using detailed models

of devices based on a 2.5-μm technology. The nominal logic delay of the circuits is estimated at 36 ps per gate for an average fan-in of 4.5 and fan-out of 3. The corresponding average power dissipation is 3.4 microwatts per gate. Finally, experimental delay measurements are presented for two-input and four-input OR and AND gates. The delay experiments are in excellent agreement with computer simulations.

Basic Design of a Josephson Technology Cache Memory *by S. M. Faris, W. H. Henkels, E. A. Valsamakis, and H. H. Zappe, p. 143.* Design work on components for Josephson computer technology nondestructive read out cache memories has been published previously. In this paper, presenting a design for a 2.5-μm technology, 4 × 1K-bit cache chip with a nominal access time of about 500 ps as a basis, we show for the first time how these components are structured and interfaced. The cell, drivers, decoder, and a sense bus are based on designs which were experimentally verified in a 5-μm technology for which excellent agreement was found between computer simulations and measurements.

Investigations for a Josephson Computer Main Memory with Single-Flux-Quantum Cells *by P. Guéret, A. Moser, and P. Wolf, p. 155.* The paper first summarizes requirements for a main memory with Josephson junctions and reviews the work carried out on an experimental main memory model containing an array of single-flux-quantum cells, line drivers, and address decoders with a total of nearly 4500 Josephson junctions. In the second part, theoretical and experimental investigations on the y drive system, including sense circuit, are presented. The investigations deal with both the read and write phases. Finally, the on-chip logic circuits and the address decoders are discussed, and the experimental results presented. Drivers and decoders based on the principle of current steering in superconducting loops are intended to be used on a fully populated main-memory chip.

An Overview of Josephson Packaging *by A. V. Brown, p. 167.* An overall packaging philosophy for high-speed Josephson computers is outlined in this paper. The unique characteristics of such a package, operating a liquid helium temperature, are described, and a description is given of the technologies needed to build the package.

The Characteristics of Chip-to-Chip Signal Propagation in a Package Suitable for Superconducting Circuits *by H. C. Jones and D. J. Herrell, p. 172.* We have measured the electrical characteristics of chip-to-chip-carrier connectors ideally suited to high-performance Josephson LSI circuits. Self- and mutual inductances between connectors were measured by incorporating the connectors in a dc SQUID (Superconducting Quantum Interference Device) and confirmed by detailed signal delay and crosstalk measurements made with Josephson logic circuits.

Modeling of Characteristics for Josephson Junctions Having Nonuniform Width or Josephson Current Density *by R. F. Broom, W. Kotyczka, and A. Moser, p. 178.* Several models, both static and dynamic, for calculating the maximum dc Josephson current versus external magnetic field "characteristic" of tunnel junctions of various geometries are described. The static models have the advantage of short computation times; the dynamic models, although slower, yield additional information on circuit-switching times. The dependence of the characteristics on the junction shape is described. The accuracy of a one-dimensional approximation used in the models has been tested experimentally, and theoretically against a two-dimensional approximation. In both cases, the one-dimensional treatment yields quantitatively good agreement provided the inductance of the junction is included in the model. Junctions defined by an oxide "window" of sinusoidal shape (maximum and minimum width at the center and ends, respectively) have a characteristic in which the side lobes are almost completely suppressed. The characteristics of a wide variety of junction shapes, including interferometers having two or more junctions, have been accurately calculated, permitting the design of devices for specific purposes.

An Overview of Materials and Process Aspects of Josephson Integrated Circuit Fabrication *by I. Ames, p. 188.* Presented here is an overview of materials and process aspects of a method that has been developed for fabricating experimental integrated circuits containing Josephson junctions as active elements. Superconducting Pb-alloy thin films are used for forming the junction electrodes, and a combination of thermal and rf oxidation is used for forming the tunnel barrier oxides. In addition to the junctions, the circuits, which are formed above an insulted, superconducting Nb ground plane, also contain: superconducting Pb-alloy lines, contacts, and transformers; $AuIn_2$ damping and terminating resistors; insulated crossings; etc. Insulation between the ground plane and overlying conducting layers is achieved through use of a combination of Nb_2O_5 and SiO. The latter is also used to achieve insulation between overlying conducting layers and as a final protective coating. Photoresist processes are used for layer patterning.

Fabrication Process for Josephson Integrated Circuits *by J. H. Greiner, C. J. Kircher, S. P. Klepner, S. K. Lahiri, A. J. Warnecke, S. Basavaiah, E. T. Yen, J. M. Baker, P. R. Brosious, H.-C. W. Huang, M. Murakami, and I. Ames, p. 195.* A process for fabricating experimental Josephson integrated circuits is described that is based primarily on the use of vacuum-deposited Pb-alloy and SiO films patterned by photoresist stencil lift-off. The process has evolved from one previously reported, with changes having occurred in junction electrodes, tunnel barrier formation, layer patterning, device geometry, and minimum linewidths. Films of Pb-In(12 wt%)-Au(4 wt%) alloy (200-800 nm thick) are used for forming junction base electrodes, interferometer controls, and interconnection lines. Tunnel barriers are formed on the base electrode films by thermal oxidation and subsequent sputter-etching in an rf-oxygen plasma. Junction counter

electrodes are formed from 400-nm-thick Pb-Bi(29 wt%) alloy films. Ground planes are formed from 300-nm-thick Nb films patterned by subtractive etching and insulated in part by a Nb_2O_5 layer formed by liquid anodization. Films of the intermetallic compound $AuIn_2$ (30-43 nm thick) are used for forming terminating, load, and damping resistors. The SiO films are used for interlayer insulation, for defining junction areas in interferometers, and as protective coatings. Layer patterning is achieved mainly by means of photoresist lift-off stencils. By utilizing this process, experimental logic and memory circuits containing ≈100 interferometers with lines as small as 2.5 μm in width have been successfully fabricated.

Effect of Process Variables on Electrical Properties of Pb-Alloy Josephson Junctions *by R. F. Broom, R. Jaggi, T. O. Mohr, and A. Oosenbrug, p. 206.* Our studies on the effect of process variables on the electrical properties of Josephson tunnel junctions were directed toward optimization of the process for cryogenic memory applications, for which special importance is placed on the dc Josephson current density j_1, its stability and reproducibility, and the junction quality. Variables studied included rf voltage, oxygen plasma pressure, the presence of oxygen during deposition of the counter electrode, the composition and surface state of the base electrode, junction geometry, radial position on the wafer, and storage and annealing conditions. Various process adjustments were made in order to obtain acceptable device characteristics. For example, good tunnel characteristics could be obtained using Pb-Au-In alloys if In concentrations >8 wt% (for a fixed 3% Au concentration) were used in the base electrode. High pressure and low rf voltage during oxidation were preferable, since these conditions led to low annealing factors. We were also able to adjust j_1 locally by irradiation with high-energy (>5 keV) electrons.

Fabrication and Properties of Niobium Josephson Tunnel Junctions *by R. F. Broom, R. B. Laibowitz, T. O. Mohr, and W. Walter, p. 212.* The fabrication of thin-film Nb tunnel junctions is described. The main emphasis is on improvement of the tunneling characteristics through studies of the conditions influencing the formation of the tunnel barrier. *In situ* ellipsometric measurements have been made during growth of the tunnel oxide on the base electrode of the junctions in an rf plasma. The results are compared with electrical measurements on completed junctions. Two additional processes are found to have an important influence on the junction characteristics: precleaning of the base electrode in an Ar plasma before oxidation and a further treatment of the grown oxide in a low-voltage, high-pressure plasma. At the present time, the most effective gas for this process is N_2. Data on annealing, storage effects, and thermal cycling are discussed. Finally, the results obtained on arrays of 80 two-junction interferometers are found to be rather encouraging for the design and construction of high-density memory arrays.

Structure of Tunnel Barrier Oxide for Pb-Alloy Josephson Junctions *by J. M. Baker, C. J. Kircher, and J. W. Matthews, p. 223.* The oxide formed on Pb-In and Pb-In-Au alloy films by processes similar to those used to fabricate oxide tunnel barriers for experimental Josephson junction devices has been investigated with transmission electron microscopy and diffraction (TEM/TED), Auger electron and x-ray photoelectron spectroscopies (AES and XPS), and ellipsometry. Thermal oxidation of Pb-In(13 at%) alloys at room temperature results in a noncrystalline oxide, whereas oxides formed at ≥ 60°C in low pressures of O_2 result in a continuous stable epitaxial layer of cubic In_2O_3 ≈2.5 nm thick. The oxide formed by sputtering such a thermal oxide in an rf-excited O_2 glow discharge (rf oxidation) results in a layered structure ≈6.5 nm thick, the bulk of which consists of an upper layer of epitaxial In_2O_3 and a lower layer of crystalline orthorhombic and tetragonal PbO. The thickness of the PbO layer depends on the availability of In at the metal-oxide interface, and thus, on the alloy composition and the temperature and rate of oxidation. For In concentrations above ≈18 at%, the bulk of the oxide was found to be entirely epitaxial In_2O_3. An additional ≈0.3-nm-thick surface layer of PbO is observed, which arises from material sputtered from the Pb-coated rf electrode and subsequently backscattered onto the surface of the oxide. Altering this backscattered material from lead oxide to indium oxide increases the current densities of completed junctions by more than a factor of 40. In contrast, variations in the composition of the lower portions of the oxide have little effect on the junction characteristics. Factors affecting the composition and reproducibility of the oxide are discussed.

Properties of $AuIn_2$ Resistors for Josephson Integrated Circuits *by C. J. Kircher and S. K. Lahiri, p. 235.* The influences of film thickness and composition on the resistivity and microstructure of $AuIn_2$ films, which are used as resistors in Josephson integrated circuits, have been investigated. The films were prepared by evaporating Au and In layers onto SiO-coated Si wafers held at 348 K. The resistivity at 4.2 K was found to be ≈5 μΩ-cm for 40-nm-thick films and to vary as $\approx d^{-0.76}$ over the thickness range 30-250 nm. Corresponding sheet resistances ranged from 0.05 to 2 Ω/□. Resistivity changes were also observed as the composition was altered. A decrease of ≈10% in the In/Au thickness ratio from that of $AuIn_2$ produced an increase of ≈50% in resistivity. A similar increase in In/Au ratio produced ≤ 10% decrease in resistivity. Electron microscopy analysis revealed that the grain size of $AuIn_2$ films increases with film thickness, and is approximately two times smaller for the low In/Au ratio films than for those of nominal or larger In/Au ratios. The factors governing the resistivity of $AuIn_2$ films were analyzed using the Fuchs surface scattering and Mayadas-Shatzkes (M-S) grain boundary scattering theories. It was found that the M-S theory can be used to explain the resistivity data for a range of choices of r and p, the grain-boundary-reflection and surface-reflection coefficients, respectively. Reasonable agreement was obtained for parameter values between

$r = 0.31$, $p = 0$, $\rho l = 3 \times 10^{-11}$ Ω-cm² and $r = 0.74$, $p = 1$, $\rho l = 0.8 \times 10^{-11}$ Ω-cm². The available evidence is interpreted as favoring grain boundary scattering as the dominant scattering mechanism.

JSP—A Research Signal Processor in Josephson Technology *by F. F. Tsui, p. 243.* This paper describes briefly the main architectural and design features of the Josephson Signal Processor (JSP), including its data flow, basic circuit arrangement, and packaging concept. Preliminary partitioning has indicated that, using a 5-μm "single turn logic" technology, the JSP—consisting of about 5000 cells (each with four Josephson junctions) of logic, about 150K bits of nondestructive read out (NDRO) memory, 256K bits of destructive read out (DRO) memory, and 6K bits of read only memory (ROM)—can be packaged in about 20 modules, occupying about 60 cc and consuming about 500 mW of power. The target cycle time for the JSP is 5 ns, with the NDRO and DRO memories having an access/cycle time of about 2.5/4 and 15/30 ns, respectively. Using a 2.5-μm "current injection logic" technology, the JSP—consisting of about 9000 three-junction and 5000 two-junction interferometers—can be packaged in seven modules occupying about 12 cc and will consume about 250 mW of power. The target cycle time for this technology is about 2 ns, with the NDRO and DRO memories having access/cycle times of 0.9/1.4 and 15/30 ns, respectively.

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Preface *by S. S. Husson, p. 267.*

A Silicon and Aluminum Dynamic Memory Technology *by R. A. Larsen, p. 268.* The Silicon and Aluminum Metal Oxide Semiconductor (SAMOS) technology is presented as a high-yield, low-cost process to make one-device-cell random access memories. The characteristics of the process are a multilayer dielectric gate insulator (oxide-nitride), a *p*-type polysilicon field shield, and a doped oxide diffusion source. Added yield-enhancing features are backside ion implant gettering, dual dielectric insulators between metal layers, and circuit redundancy. A family of chips is produced using SAMOS, ranging from 18K bits to 64K bits. System features such as on-chip data registers are designed on some chips. The chip technology is merged with "flip-chip" packaging to provide one-inch-square modules from 72K bits through 512K bits, with typical access times from 90 ns to 300 ns.

Cross-Coupled Charge-Transfer Sense Amplifier and Latch Sense Scheme for High-Density FET Memories *by K. S. Gray, p. 283.* This paper describes a sense scheme for use on high-density one-device cell field effect transistor random access memories (FET RAMs). The high-sensitivity threshold-independent cross-coupled charge-transfer sense amplifier and latch is used. The IBM 64K-bit one-device dynamic memory cell FET RAM chip design is used as the vehicle for the discussion. Adaptations made on the sense amplifier and latch for use with the sense scheme are discussed. Also described are 1) dummy cell design, 2) subthreshold leakage considerations, 3) single-ended input/output (I/O) circuitry sensing and ramifications, 4) multiple cycle signal degradations, and 5) a maximum supply voltage (V_H) buffer circuit sense scheme improvement.

Circuit Implementation of Fusible Redundant Addresses on RAMs for Productivity Enhancement *by B. F. Fitzgerald and E. P. Thoma, p. 291.* This paper describes the circuit schemes used to substitute redundant storage locations for defective ones found during testing. Word or bit lines are added along with appropriate bit steering circuitry to allow the replacement of a defective word or bit line. On-chip storage elements are "set" by the tester and used to store the binary addresses of the failing word or bit lines, which are then compared to the incoming addresses by the redundancy circuitry. This circuitry then activates the replacement word or bit lines and, by various means described, steers out the defective ones. A variation is described briefly which includes a word redundant circuit scheme that provides no penalty in memory access time by using separate sense amplifiers for the redundant lines.

VLSI Device Phenomena in Dynamic Memory and Their Application to Technology Development and Device Design *by R. R. Troutman, p. 299.* Ever-increasing density poses significant challenges to the device designer, who must relate an integrated technology to the numerous electrical characteristics required for successful memory design. Success of a VLSI technology depends as much on the extensive design of small devices as on the sophisticated lithography with which to fabricate them. Several dimensional limitations arise from the electrical characteristics both of intentionally switching devices and of possible parasitic devices. Account must be taken of threshold dependence on both channel length and width. Furthermore, any isolation scheme must not introduce leakage from the storage node, such as parasitic subthreshold and low-level punch-through currents. Hot electron emission depends on both horizontal and vertical dimensions and must be minimized to guarantee the requisite long-term device behavior. This paper will briefly discuss the physical origins of the above fundamental device phenomena, their influence on SAMOS device design, and implications for future memory technologies.

Reduction of Leakage by Implantation Gettering in VLSI Circuits *by H. J. Geipel and W. K. Tice, p. 310.* Damage introduced by ion implantation on the back side of the wafer is used to reduce the MOS transient (relaxation) and junction leakage; the technique is applied to dynamic memory cells. Conditions necessary to ensure efficient gettering by various species (B, Ar, Kr, and Xe) are established based on achieving a sufficient density of $\mathbf{b} = \frac{1}{2}\langle 110 \rangle$ dislocations. When the implantation occurs through a screen oxide, dose levels of less than 3×10^{14} ions/cm² for Ar were found to be suitable.

Equivalent leakage reduction was obtained for all species. Specifically, B at 5×10^{15} ions/cm^2 was as effective in reducing relaxation leakage as was 1×10^{15} ions/cm^2 of Ar for the particular thermal history of the investigated process.

A 64K FET Dynamic Random Access Memory: Design Considerations and Description *by T. C. Lo, R. E. Scheuerlein, and R. Tamlyn, p. 318.* The major design considerations and design features of an experimental 64K-bit random access memory (RAM), implemented in a double polysilicon gate technology, are described in this paper. Design tradeoffs addressing power supply selection and chip configuration alternatives are presented. This is followed by a description of the 8K-word by 8-bit FET dynamic RAM which uses single-transistor cells with first-level-metal bit lines and second-level-metal stitched polysilicon word lines. Test results obtained on early engineering hardware chips fabricated with linear dimensions 1.2 times those of the base design are also presented.

A 256K-Bit Charge-Coupled Device Memory *by A. Tzou, Y. Gopalakrishna, E. Blaser, O. Bar-Gadda, and R. Carballo, p. 328.* This paper describes the design of an experimental 256K-bit serial-access memory using VLSI fabrication technology and low-power dynamic circuits. The memory array chip is implemented with a double polysilicon process and uses charge-coupled devices (CCDs) grouped in 64 blocks of 4K bits each. Operation is typically at a 300-ns-per-bit cycle for both read and write modes, with operating voltages of +8.5, +5.0, and −2.2 volts, and with 310 mW of power dissipation. All inputs and outputs, with the exception of a chip enable and two system clock lines, are TTL-level compatible. The unique design features and the organization of the 256K CCD chip are discussed; the array organization, the chip layout, the peripheral circuitry, and the buried-channel CCD device design are described; and test results obtained on experimental hardware are presented.

A One-Device Memory Cell Using a Single Layer of Polysilicon and a Self-Registering Metal-to-Polysilicon Contact *by V. L. Rideout, J. J. Walker, and A. Cramer, p. 339.* The fabrication and operation of a novel one-device dynamic memory cell are described. Like the conventional double overlapping polysilicon cell, the new memory cell has a diffused bit line and a metal word line, uses five basic masking operations, and provides essentially equivalent cell area for the same lithographic feature size. Unlike the double polysilicon cell, however, the new cell uses a single layer of polysilicon to provide a more planar surface topography, and a self-registering metal-to-polysilicon contact to provide a small cell area. An essential aspect of the fabrication method of the self-registered contact cell is the use of two lithographic masking operations that define two patterns in a single polysilicon layer, the MOSFET gate electrode and the MOS capacitor electrode. The self-registering contact also facilitates a powerful polysilicon wiring technique that is applicable to the access circuits located peripherally to the array of memory cells.

Near-Ideal Si-SiO_2 Interfaces *by L. A. Kasprzak and A. K. Gaind, p. 348.* The Si-SiO_2 interface plays a key role in insulated-gate field-effect transistors (IGFETs). Of principal concern are the interface charge density Q_{ic} and the fast-state density N_{fs}. These properties can be optimized by eliminating the transition region and creating an abrupt interface. Our work with the chemical vapor deposition (CVD) of SiO_2 using a CO_2-SiH_4-H_2 system in the presence or absence of trace amounts of HCl gas at 1000°C has demonstrated that unannealed CVD SiO_2 on (100) Si using a vertical-cold-wall reactor has properties similar to those of unannealed SiO_2 on (100) Si formed by the usual thermal oxidation procedure. In addition, using only 2.27 vol% HCl, we have produced films of SiO_2 on (111) Si that are better than their thermal counterparts, unannealed or annealed; i.e., $Q_{ic} \approx 5 \times 10^{10}$ cm^{-2} and $N_{fs} \approx 10^{10}$ cm^{-2}-eV^{-1}. We attribute these results, at least in part, to an abrupt interface between the CVD SiO_2 and Si. Deposition rates of 10-20 nm/min were used to reproducibly deposit 30-50 nm of SiO_2. The CVD SiO_2 films also show a significantly lower standard deviation in the breakdown fields ($\pm$ 1.5%) and the mobile charge densities ($\pm$ 5%) than their thermal counterparts. In general, N_{fs} was independent of Q_{ic}.

Reliability of SiO_2 Gate Dielectric with Semi-Recessed Oxide Isolation *by D. W. Ormond and J. R. Gardiner, p. 353.* This paper reports the results of a study to minimize defects in the gate oxide and in the single crystal substrate of semi-recessed oxide (Semi-ROX) structures. It is shown that both an increase in oxidation mask thickness and a decrease in wet field oxidation temperature markedly reduce the incidence of low voltage breakdown in the gate oxide. Microscopic studies of samples which exhibited low voltage breakdown showed that the Si_3N_4 oxidation mask had failed to protect the surface of the region in which the gate oxide was grown. Semi-ROX processing also exhibited edge breakdown, most likely due to the Kooi effect (nitrided Si surface). The use of a thicker "pad" oxide and a decrease in the wet field oxide thickness were beneficial in reducing the magnitude of degradation in gate breakdown due to this edge effect.

Implanted Source/Drain Junctions for Polysilicon Gate Technologies *by H. J. Geipel and R. B. Shasteen, p. 362.* Shallow (<1.0-μm) n^+-p junctions are required for dense dynamic FET memory. Ion implantation is a natural technology to fulfill the geometric requirements of shallow highly doped n^+ regions in a dual polysilicon gate IGFET technology. However, implantation of ^{31}P and ^{75}As at high dose levels severely damages the crystal lattice and subsequently is difficult to anneal. This tends to make implanted junctions more leaky than their diffused counterparts and causes them to have lower apparent reverse breakdown voltages. The detrimental effect of residual end of process damage, resulting from the implantation, is

correlated to the electrical characteristics of the n^+-p junction. A junction process technology is described that can provide leakage levels of less than 0.25 fA/μm² (25 nA/cm²), sharp reverse *I-V* characteristics, and junction depths of 0.25 to 1.0 μm.

A Contactless Method for High-Sensitivity Measurement of p-n Junction Leakage *by R. L. Verkuil, H. W. Curtis, and M. S. Pak, p. 370.* A contactless *p-n* junction leakage measurement method is described that uses low-noise vhf oscillator circuitry to examine the dynamic memory-like behavior of the junctions. This method utilizes the eddy current loading effect, via inductive coupling, in order to determine the leakage-dependent decay time of the photoinduced voltage across the diffused *p-n* junctions. The contactless measurement is made under low forward bias conditions (≤10 mV) such that this measurement is a function of only generation-recombination processes in the junction depletion region. In the low-noise circuitry, sensitivity is enhanced when the oscillatory amplitude is made directly proportional to the figure of merit *Q* of the coupled oscillator resonant *LC* tank. This simple oscillator circuit contains only one JFET and a small number of inductors and capacitors, and is supplied by a constant-current source. Junction decay times between 10^{-4} and 1 s, corresponding to junction leakages between 10^{-6} and 10^{-10} A/cm², respectively, have been measured and are in excellent agreement with the derived theory showing the contactless decay time to be inversely proportional to the conventional contacting reverse leakage.

1/*N* Circuit and Device Technology *by A. Bhattacharyya, D. P. Gaffney, R. A. Kenyon, P. B. Mollier, J. E. Selleck, and F. W. Wiedman, p. 378.* The 1/*N* memory cell is the bipolar analog of the FET one-device cell. A thin dielectric and doped polysilicon are combined with bipolar technology to achieve a vertically integrated, high-density, fast-performance memory chip. The circuit design, device structure, and processing implementation for a 64K-bit dynamic, 1/*N* fractional-device, experimental bipolar memory are presented. Test results for several geometrical and structural variations, including 16K-bit storage arrays, are given.

A System Solution to the Memory Soft Error Problem *by D. C. Bossen and M. Y. Hsiao, p. 390.* High-density and/or high-performance memory chip designs often create new reliability problems; one good example is the alpha-particle problem for high-density RAM and CCD chips, the problem being that soft errors may "line up" with existing hard errors, giving rise to double errors which are not correctable with conventionally implemented single-error-correcting double-error-detecting codes. In this paper it is shown that an overall system approach based on error-correcting codes and system maintenance strategy will reduce the main memory failure rate at the system level as if the alpha-particle problem had not occurred. This system solution is designed to be compatible with most existing memory designs so that there should be minimal additional cost for implementing it. The procedure described herein uses the capability of a single-error-correcting and double-error-detecting code to detect one hard and one soft error; then a microcode and hardware algorithm performs the correction of both errors. Results of both analytical and simulation modeling of the method and its comparison with other techniques are also included.

Yield Model for Productivity Optimization of VLSI Memory Chips with Redundancy and Partially Good Product *by C. H. Stapper, A. N. McLaren, and M. Dreckmann, p. 398.* A model with mixed Poisson statistics has been developed for calculating the yield for memory chips with redundant lines and for partially good product. The mixing process requires two parameters which are readily obtained from product data. The product is described in the model by critical areas which depend on the circuit's sensitivity to defects, and they can be determined in a systematic way. The process is represented in the model by defect densities and gross yield losses. These are measured with defect monitors independently of product type. This paper shows how the yield for any product can be calculated given the critical areas, defect density, and mixing parameter. Future yields are forecast by using expected improvements in defect densities. Examples show good agreement between actual and calculated yields.

A Charge Injection Transistor Memory Cell *by I. T. Ho, J. Riseman, and H. Greenhaus, p. 410.* In this paper, two versions of an experimental bipolar dynamic memory cell are described. The memory cell consists of one *p*-channel MOSFET and a bipolar *npn* transistor with extensive node sharing. The MOSFET device controls the charge injection into the floating base of the *npn* transistor, and the bipolar device provides amplification for the stored charge during read operation. For memories, this cell offers performance associated with bipolar technology and chip density comparable to MOSFET memories.

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Computer Simulation of Electron-Beam Resist Profiles *by D. F. Kyser and R. Pyle, p. 426.* A user-oriented, conversational computer program, LMS (Lithography Modeling System), has been developed for rapid investigation of the total lithographic process used in electron-beam lithography, including electron exposure and resist development. Electron scattering and energy deposition within the resist film are simulated with Monte Carlo techniques, including the significant effects of electrons backscattered from the substrate. The magnitude of and correction for the resulting intra- and inter-line proximity effects in the latent image and their dependence on variables such as beam voltage, film thickness, substrate material, and line-pattern geometries are easily investigated with LMS. The latent image in the resist film is transformed into a solubility-rate image. The time evolution of the

developed-resist profile and its dependence on electron dose, solvent, etc. can also be determined.

Proximity Effects in Electron Lithography: Magnitude and Correction Techniques *by M. Parikh, p. 438.* Proximity effects due to electron scattering in the resist and substrate seem to set a fundamental limit to the areal density that can be achieved in electron lithography. This work briefly reviews the form and the magnitude of the proximity function and its extent as evidenced by deviations in designed linewidths. It also discusses methods to decrease the proximity effect as well as the algorithms used for correction of such effects.

Single-Step Optical Lift-Off Process *by M. Hatzakis, B. J. Canavello, and J. M. Shaw, p. 452.* A process is described that allows the use of the lift-off metallization technique with ultraviolet exposure of a single layer of ®AZ-type photoresist. The process consists of soaking the resist layer for a predetermined time either in chlorobenzene or other aromatic solvents such as toluene and benzene before or after exposure. After development, resist profiles with overhangs suitable for lift-off metallization are obtained. It appears that removal of solvent and low-molecular-weight resin from the AZ resist may be responsible for the observed differential development rates. In addition, the soak time and temperature behavior indicate a diffusion-type process.

Overlay in Lithography *by H. R. Rottmann, p. 461.* Advances in lithography rely largely on the capability of reducing overlay errors, which in turn depends on the capability to make two-dimensional overlay measurements. This paper describes a simple and accurate method of determining singular overlay errors of step-and-repeat exposure systems with a precision of ± 0.01 μm (standard deviation).

Defect-Related Breakdown and Conduction in SiO_2 *by M. Shatzkes, M. Av-Ron, and R. A. Gdula, p. 469.* A statistical model incorporating the effects of defects provides a good representation of breakdown results for Al-SiO_2-Si MOS capacitors. Implications of this model for interpretation of the yield from life tests and histograms obtained from ramp tests are discussed for the case of a Poisson distribution of defects over the capacitors. The breakdown rates of MOS capacitors in life tests are found to be correlated to defects inferred from conduction measurements.

Stand-Alone Wiring Program for Josephson Logic *by W. E. Donath, p. 480.* This paper describes a channel routing wiring program and its interface to the user. Of particular interest are its interface facilities, which permit manual update of the routing, pre-routing, and incremental routing. A hierarchical organization of the logic is feasible, which permits moving of complex entities, such as latches, adders and others, as complete entities. The internal wiring of these entities could either be done manually and be fixed before layout, which would be desirable when the wiring was used as a delay line, or could be left in the wiring program, which would route them more flexibly. The features above are made possible by the special-interface organization used here. In this interface the pins on the devices can be directly addressed, relatively addressed, and indirectly addressed; a simple macrocompiler permits the hierarchical organization of the data.

Existence of Good δ-Decodable Codes for the Two-User Multiple-Access Adder Channel *by S. Lin, T. Kasami, and S. Yamamura, p. 486.* This paper defines a class of δ-decodable codes for the two-user multiple-access adder channel with binary inputs. This class is a generalization of the class of two-user codes investigated by Kasami and Lin (1978). Lower bounds on the achievable rates of codes in this class are derived. We show that, for a wide range of error correcting capability, this class contains good two-user δ-decodable codes with rates lying above the timesharing line.

Optimal Accelerometer Layouts for Data Recovery in Signature Verification *by J. S. Lew, p. 496.* Current experimental use of pen acceleration data for signature verification has prompted the mathematical theory of our recent paper on the subject, expounding motion recovery techniques for a special pen with imbedded accelerometers. This continuation seeks to optimize the instrument layout as a mechanical filter which serves to extract the kinematic observables from the experimental noise. Our early sections, through various algebraic postulates, determine a simplest function of the layout geometry expressing the relative desirability of an accelerometer configuration. Any nontrivial layout demands some off-axial instruments, but natural "feel" requires few such placements. Hence, our middle sections prove mathematical results under various geometric assumptions which yield optimal layouts with one, two, or three off-axial instruments. Our final sections discuss the further constraint that all accelerometers measure just three directions. They assume not more than two off-axial instruments and obtain the best configurations of these tridirectional types.

Procedures for the Study of the Flexible-Disk to Head Interface *by G. G. Adams, p. 512.* The response of a rotating flexible disk interacting with a read-write head is analyzed. The disk deflection due to an arbitrary distributed normal pressure is coupled with the Reynolds lubrication equation for the disk-to-head air bearing. Procedures which considerably reduce the computation time necessary for obtaining a converged solution are described. A parameter study is then discussed and its results presented.

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Pattern Partitioning for Enhanced Proximity-Effect Corrections in Electron-Beam Lithography *by M. Parikh and D. E. Schreiber, p. 530.* This paper presents new

algorithms for judicious partitioning (or subdivision) of arbitrary lithographic patterns in order to achieve increased quality of proximity-effect correction as well as increased efficiency in the computation of such corrections. Experimental results verifying the correctness of such algorithms are also presented.

Proximity Correction Enhancements for 1-μm Dense Circuits *by W. D. Grobman, A. J. Speth, and T. H. P. Chang, p. 537.* The proximity effect in electron-beam lithography, which is due to electron scattering in the resist and wafer, results in nonuniform exposure and development for patterns in which the incident doses of all the shapes are the same. Correction for this effect has been accomplished in the past primarily by varying the incident doses of all the shapes in order to achieve an equal average resultant dose per unit area for all shapes. We show that in the case of dense circuits with linewidths of about 1 μm or smaller, two enhancements to the proximity correction technique can be easily implemented. One of these is a simple approach to shape breakup (partitioning) to enable dose correction to be applied nonuniformly within the original design shapes. The other technique is a new type of algorithm for forming subsets of the design to perform self-consistent dose correction. These two enhancements are applied to LSI chip data for dense circuits and are shown to permit fabrication of circuits which would be more difficult to process using the proximity correction techniques described previously, due to the particular geometries present in these circuit designs. We also show the application of step and repeat pattern recognition algorithms to compact the resulting data, and consequently to reduce the amount of data by an amount which is greater than the increase in the number of shapes caused by partitioning.

Registration Mark Detection for Electron-Beam Lithography—EL1 System *by D. E. Davis, p. 545.* In electron-beam lithography for the direct exposure of wafers for integrated circuit manufacturing, accurate registration is necessary to achieve the required pattern overlay. This paper examines elements that should be considered to optimize the registration mark detection process in an automatic registration system for an e-beam lithography tool such as IBM's EL1. Included is a section on the generation of the backscatter signals and the proper combination of these signals to reduce the detection uncertainty errors in a system with four backscatter detectors. Signals obtained from resist-coated marks with several vertical profiles are presented for illustration and comparison with the predicted results. Beam shot noise, resist effects, and other factors that affect the signal-to-noise ratio are discussed and some pattern overlay results from EL1 are given.

Electron-Beam Resists for Lift-Off Processing with Potential Application to Josephson Integrated Circuits *by J. H. Magerlein and D. J. Webb, p. 554.* Several electron-beam resists suitable for lift-off processing have been investigated with particular attention to the requirements for fabricating Pb-alloy Josephson integrated circuits. The desired resist must perform well with a baking temperature near 70°C, provide a reproducible undercut edge profile with good linewidth control, and adhere to the necessary substrates. Diazo resists as well as the commonly used PMMA and copolymer materials were studied. Initial results suggest that ®AZ-1350J soaked in chlorobenzene to enhance the undercut profile can satisfy many of these requirements. At present, the amount of undercut obtained is larger than desired, limiting the minimum separation between exposed features to about 1.5 μm.

Estimation of State Probabilities Using the Maximum Entropy Principle *by Y. Bard, p. 563.* A simple method is derived for computing state probabilities of a system when the probabilities of certain aggregate states are known. The method is based on maximizing the system entropy. It is shown that the results obtained by the method satisfy certain assumptions on statistical independence between events. The method is applied to a problem arising in computer performance analysis.

Variance Reduction Techniques for the Simulation of Markov Processes, I: Multiple Estimates *by P. Heidelberger, p. 570.* A method for reducing the variance of simulation-generated estimates is proposed and discussed. The method may be applied to the estimation of steady state parameters of discrete and continuous time Markov chains, semi-Markov processes, and regenerative discrete time Markov processes on a general state space (such as the waiting time process in a multiple-server queue). The method is similar to the technique of control variables, but differs in that the means of the controls need not be explicitly known. Numerical results for a variety of simple queueing models are presented.

Fleshing Out Wire Frames *by G. Markowsky and M. A. Wesley, p. 582.* Given a polyhedral object, its wire frame is the set of its edges and vertices. In this paper, we present an algorithm which discovers all objects with a given wire frame. This algorithm, which has a number of applications to mechanical design besides being of mathematical interest, has been implemented and has performed well on complex objects.

Digital System for Convergence of Three-Beam High-Resolution Color Data Displays *by J. S. Beeteson, K. T. Jarzebowski, and B. R. Sowter, p. 598.* This paper describes a new method of generating and adjusting convergence waveforms required by a delta-gun cathode-ray tube for digital color data display applications to ensure that the primary color images produced by three guns are correctly registered with respect to each other. The display is divided into 480 zones, and a number of correction values are associated with each zone. Digital values are converted into convergence currents using special smoothing techniques to ensure that quantizing effects do not cause unacceptable image distortion. A

microprogram is described which enables the total of 2016 digital correction values to be adjusted rapidly from the keyboard by a simple procedure using a crosshair adjustment pattern which is displayed sequentially at 13 positions on the screen. Special attention is paid to rounding errors which can occur during adjustment. Also accounted for in the waveform generation is the effect of phase delay between convergence coil current and its effect on the electron beams. Improvements necessary to the design of the radial and lateral convergence coil assemblies, normally found in the television industry, to reduce spot distortion and to improve sensitivity and temperature stability, are also presented. The design is realized in the IBM 3279 Color Display Station.

Macro Generation Algorithms for LSI Custom Chip Design *by B. Vergnieres, p. 612.* Presented in this paper are macro generation algorithms which have been developed and implemented for the optimization of physical and electrical designs of LSI macro circuits. Any type of logical macro circuit for a custom chip design can be automatically generated and optimized through the use of the concepts and numerical techniques for algorithmic layout generation and electrical network design which are described. The application of this design method to programmable logic array macros, which allow the generation of very attractive designs, is also discussed and illustrates the efficiency and flexibility of the macro generation concept.

Integral Point-Matching Method for Two-Dimensional Laplace Field Problems with Periodic Boundaries *by H. C. Lee and H. D. Chai, p. 622.* An integral point-matching technique is applied to two-dimensional Laplacian fields between periodic boundaries. This formulation leads to an algorithm that reduces the size of the matrix, economizing on computer workspace and inversion time. Several example problems solved on an APL terminal system are included.

Silicon Torsional Scanning Mirror *by K. E. Petersen, p. 631.* Conventional batch photolithography and thin film techniques are employed to fabricate an electrostatically driven torsional scanning mirror from single-crystal silicon. This device is extremely simple to make and operate, has operational characteristics comparable to commercial magnetically driven high-frequency scanners, and has exhibited a promising reliability.

A General Method for Channel Coding *by P. A. Franaszek, p. 638.* A procedure is described for constructing minimum delay codes for discrete noiseless channels. The method is based on a simple recursive algorithm for finding a set of coding paths.

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Preface *by S. S. Husson, p. 658.*

Improved Optimization of FORTRAN Object Programs *by R. G. Scarborough and H. G. Kolsky, p. 660.* For many years the FORTRAN H Extended compiler has produced highly optimized object programs for IBM System/360 and System/370 computers. A study of the object programs revealed, however, that important additional optimizations were possible, and the compiler has been enhanced accordingly. First, the range of cases handled by the optimization techniques already present in the compiler has been extended. For example, more duplicate computations are eliminated, and more invariant computations are moved from inner to outer loops. Second, several new optimizations have been added, with subscript computation and register allocation receiving particular attention. Third, certain optimization restrictions have been removed. This paper describes these improvements and reports their effects.

Optimization and Code Generation in a Compiler for Several Machines *by D. Boyle, P. Mundy, and T. M. Spence, p. 677.* This paper describes optimization techniques that have been implemented in a compiler which was designed to produce code comparable to that produced by hand. Additional optimization methods were incorporated into successive versions of the compiler. It was found that no single method was effective with all compiled programs but that each of the techniques described was effective for some programs.

Compilation to Compact Code *by B. Marks, p. 684.* A compilation process is described that emphasizes small object code rather than fast object code. The approach entails synthesizing an instruction set and an interpreter for that instruction set during compilation of an individual source program. Numerical results are given for compiling a systems programming subset of PL/I to System/370 code.

Strength Reduction for Division and Modulo with Application to Accessing a Multilevel Store *by J. Cocke and P. W. Markstein, p. 692.* A method for replacing certain division and modulo operations by additions and subtractions is presented. This optimization allows efficient and easy use of partitioned arrays to access a multilevel store.

The Experimental Compiling System *by F. E. Allen, J. L. Carter, J. Fabri, J. Ferrante, W. H. Harrison, P. G. Loewner, and L. H. Trevillyan, p. 695.* The Experimental Compiling System (ECS) described here represents a new compiler construction methodology that uses a compiler base which can be augmented to create a compiler for any one of a wide class of source languages. The resulting compiler permits the user to select code quality ranging from highly optimized to interpretive. The investigation is concentrating on easy expression and efficient implementation of language semantics; syntax analysis is ignored.

Some Techniques for Compile-Time Analysis of User-Computer Interactions *by J. M. Lafuente, p. 716.*

Compile-time techniques for analyzing user-computer interactions and the relationships and dependencies among items of data that exist during the execution of interactive application programs are presented. These techniques are useful in constructing efficient compilers for languages in which such interactions and data item relationships and dependencies are described by nonprocedural statements. The practical value of using nonprocedural descriptions is that they ease the task of the application programmer.

A Business Language *by N. J. Denil, p. 732.* The paper describes a language and supporting interactive system for use by the small businessman. To help the businessman-user understand and apply an application program expressed in the language, he can watch the application run in a single-step mode. If tailoring of the application program is necessary, the system guides the user by diagnosing inconsistencies in the modified program. The user controls production processing from the same user interface. In the first part of the paper, the language is described. Next some example user sessions are outlined. Finally the prototype implementation and some design issues are discussed.

A Language for Extended Queueing Network Models *by C. H. Sauer, E. A. MacNair, and S. Salza, p. 747.* Queuing networks are popular as models of performance of computer systems and communication networks. The Research Queueing Package, Version 2 (RESQ2), is a system for constructing and solving extended queuing network models. We refer to the class of RESQ2 networks as "extended" because of characteristics absent from most queuing models. RESQ2 incorporates a high-level language to concisely describe the structure of the model and to specify constraints on the solution. A main feature of the language is the capability to describe models in a hierarchical fashion, allowing an analyst to define parametric submodels which are analogous to macros or procedures in programming languages. RESQ2 thus encourages use of structured models to effectively evaluate complex systems.

Grammar Characterization of Flowgraphs *by J. L. Becerril, J. Bondia, R. Casajuana, and F. Valer, p. 756.* An extension of the scheme grammar concept given by Urschler is formalized. It is also shown that, in the usual hierarchy of the theory of formal languages, the language generated by the scheme grammar is regular (type 3). The last section gives the description of a system for the automatic structuring of programs, which applies these concepts to the Mills algorithm with some modifications.

A Data Definition Facility Based on A Value-Oriented Storage Model *by D. B. Lomet, p. 764.* A data definition facility is presented that provides a consistent description of both primitive and user data. It is based on a value-oriented storage model which carefully distinguishes between values and objects. It is values that are typed in this model, and operations of the type work explicitly on the values. Objects are accessible only via reference values. Objects are described via descriptors called templates, which ultimately yield reference type values. Operations, both primitive and user-defined, are part of a "machine interface," and all executable language constructs can ultimately be defined as explicit operations of the interface. Importantly, these operations must respect the typing constraints imposed by both the primitive types and the user extensions. The interactions of definition facility, storage model, and execution model are illustrated via a series of examples in which commonly user data constructs are defined.

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Network Problem-Determination Aids in Microprocessor-Based Modems *by S. Huon and R. Smith, p. 3.* Recent significant developments in large-scale integration (LSI) and in digital signal-processing techniques have combined to provide the base for a new generation of modems. LSI microprocessors now have the characteristics and performance to provide superior modem function as well as a design base for the addition of new function. The extendability afforded by a microprocessor-based modem design is being increasingly used to provide advanced communications network management functions. This paper describes the design objectives, implementation decisions, and design rationale for implementing these characteristics in the IBM 3863, 3864, and 3865 family of data modems. This network management function, which has been integrated into IBM Communications Network Management (CNM) offerings for IBM's Systems Network Architecture user networks, extends the problem-determination capability to cover the modems and communications lines. Support for this new function has been integrated into the 3705 ACF/NCP/VS control program and the System/370 NPDA program product.

A 2400-Bit/s Microprocessor-Based Modem *by D. Godard and D. Pilost, p. 17.* This paper describes the main characteristics of a new microprocessor-implemented 2400-bit/s data modem, the IBM 3863. In addition to the execution of signal processing tasks, the microprocessor provides a variety of other significant functions such as diagnostics and aids in network problem determination. The lack of hardware multiplication capability imposes certain constraints in the design of the signal processing algorithms. The analytical approach and computational techniques, based on the processing of signals in polar coordinates, which are used to circumvent these constraints, are described. It is shown in particular that timing phase control, carrier recovery, and adaptive equalization can be achieved at the receiver by processing only the phase of the sampled signal. Additionally, experimental results are presented which demonstrate the superiority of this design over conventional coherent demodulators.

Coupled Lossy Transmission Line Characterization and Simulation *by A. J. Gruodis and C. S. Chang, p. 25.* It has been shown that the frequency domain solution of the coupled lossy transmission line differential equations has a similar appearance to that of the single line. The frequency-dependent n × n characteristic admittance matrix Y_0 and propagation matrix Γ can be obtained from network analyzer insertion loss data treating the coupled transmission lines as a 2*n*-port network. This paper develops a transient simulation technique for coupled lossy transmission lines based on frequency-dependent Y_0 and Γ data. Simulation results agree very well with transient measurements.

[Pt]Polypyrrole: A New Organic Electrode Material *by A. Diaz, J. M. Vasquez Vallejo, and A. Martinez Duran, p. 42.* Films of BF_4-doped polypyrrole grown on platinum, hereafter termed [Pt]polypyrrole, were used as electrodes in a series of reactions. These organic electrodes are found to be quite stable and nonporous; they generally do not perturb the redox reactions of dissolved species and they display rapid surface-substrate electron-transfer kinetics. The polypyrrole films are sensitive to the presence of Lewis bases in solution, which apparently act as nucleophiles, leading to degradation of the electrode properties.

Conducting Polymers: A Review of Recent Work *by G. B. Street and T. C. Clarke, p. 51.* The conductivities of all the currently reported conducting polymers are compared to those of the classical metals. The requirements for a technologically useful conducting polymer are considered and the degree to which existing conducting polymers meet these requirements is evaluated. The mechanism of doping is discussed together with the final state of the dopant and the polymer. The available structural data are described as well as the problems of structurally characterizing these systems. Some of the problems of inhomogeneous distribution of dopant species are also pointed out.

Computer Simulation of High-Resolution Electron Micrographs Using Dynamical Electron Scattering *by W. Krakow, p. 58.* A system of computer programs has been implemented that calculates both high-resolution images and diffraction patterns of generalized objects for the conventional transmission electron microscope. Multi-slice dynamical electron scattering of 256 × 256 = 65,536 beams is incorporated into these programs, which allows Bragg reflections and the diffuse scattering contributions between these reflections to be included in the computations. Images can therefore be obtained from imperfect crystalline structures and for disordered objects such as amorphous materials. Both bright- and dark-field images are obtained with this system in either the axial or tilted-beam imaging modes. Examples of surface effects in Au crystals, the [111] split Crowdion interstitial in tungsten, and an amorphous Fe film model are considered in the context of dynamical electron scattering.

Tomographic Reconstruction of Ultrasonic Attenuation with Correction for Refractive Errors *by K. M. Pan and C. N. Liu, p. 71.* The nonionizing and noninvasive characteristics of ultrasonics promote its increasing use in medical applications. Computerized ultrasonic attenuation tomography is one area where medically significant images may be reconstructed for diagnostic purposes. The objective of this work is to make an initial correction for refraction error and other problems present in computerized ultrasonic tomography. As a refinement of the scanning technique, our method attempts to provide high-quality projection profiles to the reconstruction algorithms. The important aspect of this new scanning mode lies in its correction for refraction in the measured attenuation profiles. In reconstructing phantom

targets scanned by our experimental system, results superior to traditional line-of-sight scanning were obtained.

A Number Representation Convertor for Magnetic Bubble String Comparators *by G. Bongiovanni and C.-K. Wong, p. 83.* Conventionally, there are four common ways to represent negative numbers, namely, 1's-complement, 2's-complement, signed-magnitude, and excess-2^{m-1}. In all these representations except the last one (excess-2^{m-1}), 1 is used as the sign bit to denote negative numbers. However, in a recently reported magnetic bubble device, using 1 as the sign bit for negative numbers may cause problems when two numbers are compared. In this paper we define a new number representation (called *B1's-complement*), and we propose a simple, read-free device for converting numbers represented in any of the above standard representations to either the excess-2^{m-1} or the B1's-complement representation.

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Preface *by S. S. Husson, p. 106.*

Techniques for Improving Engineering Productivity of VLSI Designs *by J. C. Logue, W. J. Kleinfelder, P. Lowy, J. R. Moulic, and W.-W. Wu, p. 107.* The ability of the semiconductor industry to produce chips with higher and higher circuit densities has created a challenge for the product designer: to utilize this capacity and still develop chips rapidly at reasonable cost. A multi-faceted approach to VLSI design is described that significantly reduces product development time and resource from those required with existing methods. This approach is based on the use of PLA structures or macros. It consists of a hardware/software modeling technique, use of laser-personalizable PLAs for rapid modeling of PLA macros, and a method for repairing design errors (that may hide other errors) on the actual VLSI wafers with a laser tool. A two-pass VLSI design is therefore highly probable.

Bipolar Circuit Design for a 5000-Circuit VLSI Gate Array *by A. H. Dansky, p. 116.* Ever-increasing gate-array chip circuit count and size pose challenges to the circuit designer, who must optimize the cell layout and power dissipation of logic circuits. This paper describes the design of a bipolar gate array for a 5000-circuit microprocessor. The physical design data obtained after completion of automatic placement and wiring are presented. The distribution of projected circuit delay for the 4437 nets is then calculated and this information is used to determine the selective increase in circuit power to reduce wide spreads in turn-off and turn-on delays. It is shown that this technique improves power/performance and has implications for future VLSI designs. It was also found that voltage drop violations were manageable even with the long net lengths occurring in this large VLSI gate array. Several commonly used bipolar circuit types are compared on the basis of capacitance drive capability at low power.

A 1024-Byte ECL Random Access Memory Using a Complementary Transistor Switch (CTS) Cell *by J. A. Dorler, J. M. Mosley, G. A. Ritter, R. O. Seeger, and J. R. Struk, p. 126.* This paper presents the design of a 1K-byte random access memory using a cross-coupled complementary transistor switch (CTS) cell. The memory operates with a 4.25-V power supply and achieves a 15-ns access time with a power dissipation of 1.8 W. This paper also demonstrates the advantages of using the CTS cell to achieve high circuit density and good performance of memory arrays. Array attributes, cell selection criteria, and cell operation (both ideal and in situ) as well as design considerations are covered. Hardware performance is also briefly summarized.

Delay Regulation—A Circuit Solution to the Power/Performance Tradeof *by E. Berndlmaier, J. A. Dorler, J. M. Mosley, and S. D. Weitzel, p. 135.* This paper introduces the concept of delay regulation as a means of controlling circuit delay variations from chip to chip, which is especially important in VLSI products. An embodiment of this concept which applies a phase-locked loop to individually control chip performance and power is presented together with computer-simulated results of an example design. It is shown that accurate delay equations and the potential for improved product yield result from application of the concept. The circuit overhead for large circuits is shown to be negligible. Application to a wide range of logic circuit types is also described.

A High-Density Bipolar Logic Masterslice for Small Systems *by J. Z. Chen, W. B. Chin, T.-S. Jen, and J. Hutt, p. 142.* A new high-density bipolar logic masterslice which uses a simple Schottky Transistor Logic (STL) circuit cell as its basic building block is presented in this paper. The STL cell is derived from Integrated Injection Logic (I^2L). The use of low-barrier Schottky diodes for AND logic, as diodes function in Diode Transistor Logic (DTL), makes possible achieving the NAND circuit operation. A brief description of the Schottky diode fabrication process is also given. A new concept of contact hole personalization is introduced and is shown to be an efficient approach to masterslice design as well as a factor in achieving high cell density. Due to the unusual structure of the basic cell and the arrangement of the cells in the masterslice, a new physical design methodology was developed for the design of different part numbers, corresponding to unique logic functions, on this masterslice. The STL circuit operates with a 1.7-V power supply and yields a typical delay of 3 ns at 0.5 mW and 5 ns at 0.15 mW. The I/O circuits are TTL-level compatible. The cells, the circuits, the unique features of the masterslice, and its application in an I/O controller chip are described.

Wire Length Distribution for Placements of Computer Logic *by W. E. Donath, p. 152.* It is shown from simple theoretical considerations that the distribution f_k of wire lengths for a good two-dimensional placement on a square

Manhattan grid should be of the form $f_k = g/k^\gamma$ $(1 \le k \le L)$ and $f_k \approx 0$ $(k > L)$, where γ is related to the Rent partitioning exponent p by the equation $2p + \gamma \approx 3$. Three placements were investigated and the distribution functions for wire length were found to follow the above relationships.

High-Speed Binary Adder *by H. Ling, p. 156.* Based on the bit pair (a_i, b_i) truth table, the carry propagate p_i and carry generate g_i have dominated the carry-look-ahead formation process for more than two decades. This paper presents a new scheme in which the new carry propagation is examined by including the neighboring pairs $(a_i, b_i; a_{i+1}, b_{i+1})$. This scheme not only reduces the component count in design, but also requires fewer logic levels in adder implementation. In addition, this new algorithm offers an astonishingly uniform loading in fan-in and fan-out nesting.

Statistics of Breakdown *by M. Shatzkes and M. Av-Ron, p. 167.* A derivation is given for the statistics of breakdown, including the effect of defects. The particular case where breakdowns are random in time and defects are randomly distributed is considered in detail. Results are obtained that are applicable to any kind of breakdown test. It is shown how relationships between the breakdown distributions for various breakdown tests and for different conditions in a particular test are generated. These relations are given for life tests (constant field) and for ramp tests (field proportional to time). It is found that an ordering of defect types according to their susceptibility to breakdown is not unique, but generally depends on the test conditions. This implies that the fields and temperatures used in screening procedures must be chosen with care.

Attraction Force Characteristics Engendered by Bounded, Radially Diverging Air Flow *by J. A. Paivanas and J. K. Hassan, p. 176.* When axially directed air flow enters a parallel plate passage through a hole in one of the plates, the ensuing diverging radial flow is such that a depressed pressure region occurs to some extent over the inlet region of the passage. If the plate against which the inlet air stream impinges is allowed to move freely, it will, under proper flow and other conditions, assume a position of stable equilibrium reflecting a balance among plate weight, the momentum repelling force of the stream, and a net restraining attraction force due to the radial pressure distribution in the passage. This phenomenon, the "Bernoulli" or "axi-radial" effect, has long been of interest in areas such as gas film lubrication and radial diffusers, and it has been applied extensively in IBM systems for contactless transport and motion control of semiconductor wafers on an air film. A steady, laminar, incompressible flow analysis for a representative axisymmetric circular disk model is presented here. A one-dimensional approach, using the general energy equation in conjunction with a passage flow friction factor variation, is applied to obtain an approximate relationship for radial pressure distribution. The friction factor, embodying the influence of varying viscous and inertial forces, is postulated on the basis of specialized radial flow studies in the literature. By also applying the momentum balance condition, an approximate overall solution is obtained which, for arbitrary model dimensions, describes the relationship among equilibrium passage spacing, resultant reaction fluid force and free disk weight, and a flow Reynolds number. The analytical predictions are compared with results from model experiments, and generally favorable agreement is indicated.

An On-Line Chinese Character Recognition System *by E. F. Yhap and E. C. Greanias, p. 187.* This paper describes an experimental system for the on-line recognition of handwritten Chinese characters. Constituent shapes of the characters are recognized as they are formed on an electronic tablet. The 72 constituent shapes can define a very large set of Chinese characters. The implementation described recognizes more than 2200 Chinese characters. More symbols can be added with relative ease. Experimental results are given for two writer populations.

A Magnetic Sensor Utilizing an Avalanching Semiconductor Device *by A. W. Vinal, p. 196.* A new semiconductor device for sensing uniaxial magnetic fields has been realized. The device is basically a dual-collector open-base lateral bipolar transistor operating in the avalanche region, and is referred to as a Magnetic Avalanche Transistor. It exhibits high magnetic transduction sensitivity compared to traditional Hall-effect and conventional nonlinear magnetoresistive devices. Several hundred experimental devices have been designed, fabricated, and tested over the past two years. Many structural and some process parameters were varied. The magnetic sensitivity of a typical device was found to be proportional to substrate resistivity. A sensitivity of 30 volts per tesla was measured for devices which used 5-ohm-cm p-type substrates. The output signal measured between collectors is differential and responds linearly with field magnitude and polarity. A typical signal-to-noise ratio is 20,000 per tesla. The bandwidth is known to extend well beyond 5 MHz. The sensitive area is calculated to be on the order of 5 μm^2. This communication describes the basic structure, fabrication, and characteristics for the magnetic avalanche transistor.

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Finite-Element Analysis of Semiconductor Devices: The FIELDAY Program *by E. M. Buturla, P. E. Cottrell, B. M. Grossman, and K. A. Salsburg, p. 218.* The FIELDAY program simulates semiconductor devices of arbitrary shape in one, two, or three dimensions operating under transient or steady-state conditions. A wide variety of physical effects, important in bipolar and field-effect transistors, can be modeled. The finite-element method transforms the continuum description of mobile carrier transport in a semiconductor device to a simulation model at a discrete number of points. Coupled and decoupled algorithms offer two methods of linearizing the differential equations. Direct

techniques are used to solve the resulting matrix equations. Pre- and post-processors enable users to rapidly generate new models and analyze results. Specific examples illustrate the flexibility and accuracy of FIELDAY.

Semiconductor Analysis Using Finite Elements—Part I: Computational Aspects *by G. D. Hachtel, M. H. Mack, R. R. O'Brien, and B. Speelpenning, p. 232.* We describe the computer implementation of SAFE, a general-purpose program for finite-element analysis of systems of nonlinear, nonvariational PDE. The form and nonlinearity of the PDE, as well as the domain, parameters, and boundary conditions of the problem, are user-specified. We discuss the problems of numerical integration in space and in time and describe the results of applying sparse-matrix methods to some practical problems. A method is given for unified treatment of nonstandard finite elements such as bicubic-spline and "current-continuous" elements. We give an assessment of the potential impact and reliability of general-purpose nonlinear finite-element programs. We conclude from out data that as the number of elements becomes large, sparse-matrix solutions dominate the overall operation count, even though the methods used are near-optimal for problems of moderate size.

Semiconductor Analysis Using Finite Elements—Part II: IGFET and BJT Case Studies *by G. D. Hachtel, M. H. Mack, and R. R. O'Brien, p. 246.* Semiconductor-like Applications of Finite Elements (SAFE), a novel, nonlinear, general-purpose two-dimensional finite-element code, is applied to problems in device modeling. Case studies of contemporary insulated gate field effect transistor (IGFET) and bipolar junction transistor (BJT) structures are given which demonstrate the reliability, versatility, and efficiency of finite-element methods in general and of the SAFE program in particular. The user-defined SAFE physical model is compared with experiments on a doubly implanted short-channel IGFET. Computer experiments are performed, indicating how to select the type, distribution, and numerical-integration method of finite elements for maximally efficient, assured-convergence, engineering-accuracy analysis, either steady state or transient.

Number of Vias: A Control Parameter for Global Wiring of High-Density Chips *by D. T. Lee, S. J. Hong, and C.-K. Wong, p. 261.* In integrated circuits, components are frequently interconnected by horizontal and vertical wires in respective wiring planes whether on chip, card, or board. The wire changes direction through "vias" that connect the orthogonal wiring planes. Because of technology constraints, the arrangement of vias must conform with certain neighborhood restrictions. We present results on the guaranteed minimum number and maximum possible number of vias in a given wiring cell for various technology constraints. These numbers provide an early means of control on global wiring routes to further the success of the exact embedding process that follows global wiring.

Logic Synthesis Through Local Transformations *by J. A. Darringer, W. H. Joyner, Jr., C. L. Berman, and L. Trevillyan, p. 272.* A logic designer today faces a growing number of design requirements and technology restrictions, brought about by increases in circuit density and processor complexity. At the same time, the cost of engineering changes has made the correctness of chip implementations more important, and minimization of circuit count less so. These factors underscore the need for increased automation of logic design. This paper describes an experimental system for synthesizing synchronous combinational logic. It allows a designer to start with a naive implementation produced automatically from a functional specification, evaluate it with respect to these many factors, and incrementally improve this implementation by applying local transformations until it is acceptable for manufacture. The use of simple local transformations in this system ensures correct implementations, isolates technology-specific data, and will allow the total process to be applied to larger, VLSI designs. The system has been used to synthesize masterslice chip implementations from functional specifications, and to remap implemented masterslice chips from one technology to another while preserving their functional behavior.

GRIN: Interactive Graphics for Modeling Solids *by W. Fitzgerald, F. Gracer, and R. Wolfe, p. 281.* This paper describes an experimental system for the original generation and subsequent modification of volume models of complex physical objects, using interactive computer graphics. The models are built up from primitive volumes, *e.g.*, cuboids, cylinders, swept surfaces, etc., entered by a mechanical engineer interacting with a two dimensional projection of the model on a graphic display screen. The primitives may be entered at any orientation in 3-space and combined to form a single polyhedral model. The central issue is the provision of an efficient, natural means for generating these models.

Propagation of 1-μm Bubbles in Contiguous Disk Devices *by K. Ju, H. L. Hu, R. G. Hirko, E. B. Moore, D. Y. Saiki, and R. O. Schwenker, p. 295.* Propagation margins of contiguous disk devices fabricated on both single- and double-layer garnet films have been measured. These performance measurements for 1-μm diameter magnetic bubble propagation were made on devices with cell sizes of 18 and 30 μm^2. The dependence of bias margin on ion-implantation conditions, material parameters, propagation pattern geometries, and temperature is discussed. Deuterium implantation is introduced, together with a new propagation pattern. Implantation with deuterium induces an anisotropy field change similar to that with hydrogen but with 50% smaller dosage. The new propagation pattern, with sawtooth-shaped tracks, reduces the interaction between charged walls of adjacent propagation tracks, thus resulting in improved performance at low bias fields.

Pi-Donor Intercalate Polymers: Synthesis, Charge-Transfer Interactions, and Applications *by F. B.*

Kaufman, p. 303. When low-ionization-potential organic donor molecules D such as tetrathiafulvalene, ferrocene, or triarylpyrazolines are chemically attached to a polymer backbone, a number of interesting and potentially useful phenomena are observed in films of the resulting polymers. For example, chemical oxidation, irradiation, or electrochemical treatment of these materials leads to a series of polymers, poly$[D_x(D^+A^-)_{1-x}]$, where D is the polymer-coupled organic molecule, x is the extent of oxidation, and A^- is the charge-compensating anion. Depending on the nature of the bound donor group, these polymers exhibit two kinds of electronic interactions between donor sites which are of charge-transfer origin. These phenomena are responsible for several important properties of this new class of materials that make them interesting as polymer-modified electrodes, as semiconducting polymers, and a high-resolution electron-beam (or x-ray) resists.

Computer Simulations of Complex Chemical Systems: Solvation of DNA and Solvent Effects in Conformational Transitions *by E. Clementi, p. 315.* As is known, atomic and small molecular systems can be realistically simulated with quantum-mechanical models. In complex chemical systems, however, the natural parameters for a description are not only the electronic density and energy but also entropy, temperature, and time. We have considered as an example for a complex chemical system the structure of water surrounding DNA with counterions. No direct experimental determination of the solvent structure around a single DNA macromolecule is available from experimental data, despite continuous efforts during the last twenty years to obtain both single crystals of DNA and scattering data from solutions. A very detailed representation is now available concerning the structure and interaction energy of water molecules in the first solvation shell or in the "grooves" of the DNA. The data obtained by our computer simulation are in good agreement with indirect data from DNA fibers at different relative humidities and with other indirect evidence. In addition, our simulated results allow us to present a preliminary model for the solvent effects in transition processes between different DNA conformations. The model presented is also in agreement with available experimental data. Finally, our results report the first determination of the position of counterions in DNA at different relative humidities and at room temperature. This application demonstrates the flexibility of the computational approach. The method we have used is very general; namely, it is not limited to a biological system but is valid for any organic or inorganic problem requiring systematic simulation on a class of compounds interacting either as a few molecules or as a large ensemble of molecules.

Positive First-Order Logic Is NP-Complete *by D. Kozen, p. 327.* The decision problem for positive first-order logic with equality is NP-complete. More generally, if Σ is a finite set of atomic sentences (i.e., atomic formulas of the form $t_1 = t_2$ or $Rt_1 \ldots t_n$ containing no variables) and negations of atomic sentences and if ϕ is a positive first-order sentence, then the problem of determining whether ϕ is true in all models of Σ is NP-complete.

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The Architecture of IBM's Early Computers *by C. J. Bashe, W. Buchholz, G. V. Hawkins, J. J. Ingram, and N. Rochester, p. 363.* Most of the early computers made by IBM for commercial production are briefly described with an emphasis on architecture and performance. The description covers a period of fifteen years, starting with the design of an experimental machine in 1949 and extending to, but not including, the announcement in 1964 of System/360.

System/360 and Beyond *by A. Padegs, p. 377.* The evolution of modern large-scale computer architecture within IBM is described, starting with the announcement of System/360 in 1964 and covering the latest extensions to System/370. Emphasis is placed on key attributes and on the motivation for providing them, and an assessment is made of the experience gained in the implementation and use of the architecture. The main approaches are discussed for obtaining implementations at widely differing performance levels, and a number of significant implementation parameters for all processors are listed.

IBM Data Communications: A Quarter Century of Evolution and Progress *by D. R. Jarema and E. H. Sussenguth, p. 391.* This paper describes the evolution of technological development in data communications at IBM. Rather than attempting to present a complete history, it emphasizes the changing environment and describes the more significant innovations that were incorporated in IBM's line of data communications products. Evolutionary developments in this area are traced from point-to-point batch transmission, to on-line batch communications, to interactive systems, and finally to networking. Although several aspects are treated, the primary focus of this account is on systems architecture, applications, and technology.

Real-Time Systems for Federal Applications: A Review of Significant Technological Developments *by P. F. Olsen and R. J. Orrange, p. 405.* The Federal Systems Division of IBM has been heavily involved in complex, on-line, real-time systems for over twenty-five years. In this paper a representative sample of these programs are reviewed, and an evaluation of the significant lessons learned from this wealth of experience is presented. The key issues which differentiate real-time systems from their more conventional data processing counterparts are identified and their implications are discussed. This leads to some conclusions regarding the kind of commitment that is necessary in order to succeed in the area of real-time applications.

Evolution of Real-Time Computer Systems for Manned Spaceflight *by S. E. James, p. 417.* This paper describes the evolution of ground-based command and control systems used

to support NASA's manned spaceflight program; it is an encapsulation of twenty years of development of real-time command and control systems at NASA's Real-Time Computer Complex (RTCC) in Houston, Texas. A brief description of manned spaceflight programs, their accomplishments, and IBM's involvement is provided as background information. Emphasis is given to the development of RTCC systems, as well as to the technological and architectural changes affecting this development. Also described are experiences gained in the management of complex, real-time software systems and the tools and techniques used in the development process.

Low-End General-Purpose Systems *by R. L. Taylor, p. 429.* Since the announcement of the IBM System/3 in 1969, IBM has been incorporating leading-edge technology in products referred to as small general-purpose systems. With the many models of the System/3, System/32, System/34, and System/38, IBM has introduced many technological advances addressing the needs of diverse customers, from the novice, first-time user to the experienced user in the distributed data processing account. By identifying the goals, objectives, design themes, major salient features, and development constraints, this paper reviews and highlights the technical evolution of these products in terms of their systems layout, processor architecture, machine structure, and programming support.

Evolution of Small Real-Time IBM Computer Systems *by T. J. Harrison, B. W. Landeck, and H. K. St. Clair, p. 441.* In parallel with the development of data processing applications for computers, effort was directed to other areas in which computers might provide benefits for the user. One early effort was the application of computers to the monitoring and control of industrial processes such as those used in oil refinery units, steel plants, and paper machines. Over time, these early efforts were generalized to a broader class of applications in which the computer was connected directly into an external *process* which placed time response requirements on the computer system. These systems have become known as *real-time systems*. In this paper, the evolution of IBM small real-time systems is traced from the late 1950s to the present. Emphasis is placed on a few features and requirements which characterize these systems.

Reliability, Availability, and Serviceability of IBM Computer Systems: A Quarter Century of Progress *by M. Y. Hsiao, W. C. Carter, J. W. Thomas, and W. R. Stringfellow, p. 453.* Computer systems have achieved significant progress in the areas of technology, performance, capability, and RAS (reliability/availability/serviceability) during the last quarter century. In this paper, we shall review the advances of IBM computer systems in the RAS area. This progress has for the most part been evolutionary; however, in some cases it has been revolutionary. RAS developments have been driven primarily by technological advances and by increases in functional capability and complexity, but RAS considerations have also played a leading role and have improved technological and functional capability. The paper briefly reviews the progress of computer technology. It points out how IBM has maintained or improved its systems RAS capabilities in the face of the greatly increased number of components and system complexity by improved system recovery and serviceability capability, as well as by basic improvements in intrinsic component failure rate. The paper also covers the CPU, tape, and disk areas and shows how RAS improvements in these areas have been significant. The main objective is to provide a comprehensive view of significant developments in the RAS characteristics of IBM computer systems over the past twenty-five years.

The Evolution of the MVS Operating System *by M. A. Auslander, D. C. Larkin, and A. L. Scherr, p. 471.* The mechanization of computer operations and the extension of hardware functions are seen as the basic purposes of an operating system. An operating system must fulfill those purposes while providing stability and continuity to its users. Starting with the data processing environment of twenty-five years ago, this paper describes the forces that led to the development of the OS/360 system design and then traces the evolution which led to today's MVS system.

The Origin of the VM/370 Time-Sharing System *by R. J. Creasy, p. 483.* VM/370 is an operating system which provides its multiple users with seemingly separate and independent IBM System/370 computing systems. These virtual machines are simulated using IBM System/370 hardware and have its same architecture. In addition, VM/370 provides a single-user interactive system for personal computing and a computer network system for information interchange among interconnected machines. VM/370 evolved from an experimental operating system designed and built over fifteen years ago. This paper reviews the historical environment, design influences, and goals which shaped the original system.

The IBM History of Memory Management Technology *by L. A. Belady, R. P. Parmelee, and C. A. Scalzi, p. 491.* The history of memory management technology in IBM during the period between the 1950s and the early 70s is discussed in this paper. The paper concentrates on the programming and operating system aspects of the problem, rather than the hardware technology involved.

Data Base Technology *by W. C. McGee, p. 505.* The evolution of data base technology over the past twenty-five years is surveyed, and major IBM contributions to this technology are identified and briefly described.

History of IBM's Technical Contributions to High Level Programming Languages *by J. E. Sammet, p. 520.* This paper discusses IBM's technical contributions to high level programming languages from the viewpoint of specific languages and their contributions to the technology. The

philosophy used in this paper is that it is the appropriate collection of features in a language which generally makes the contribution to the technology, rather than an individual feature. Those IBM languages deemed to have made major contributions are (in alphabetical order) APL, FORTRAN, GPSS, and PL/I. Smaller contributions (because of lesser general usage) have been made by Commercial Translator, CPS, FORMAC, QUIKTRAN, and SCRATCHPAD. Major contributions were made in the area of formal definition of languages, through the introduction of BNF (Backus-Naur Form) for defining language syntax and VDL (Vienna Definition Language) for semantics.

The History of Language Processor Technology in IBM *by F. E. Allen, p. 535.* The history of language processor technology in IBM is described in this paper. Most of the paper is devoted to compiler technology; interpreters, assemblers, and macro systems are discussed briefly. The emphasis is on scientific contributions and technological advances from a historical perspective. The synergistic relationship between theory and practice is a subtheme.

Formal Semantics of Programming Languages: VDL *by P. Lucas, p. 549.* The history of ideas that led to the first formalization of the syntax and semantics of PL/I is sketched. The definition method and notation are known as the Vienna Definition Language (VDL). The paper examines the relationship between VDL and both denotational semantics and the axiomatic approach to programming language definition.

IBM Contributions to Computer Performance Modeling *by Y. Bard and C. H. Sauer, p. 562.* Performance modeling can be used throughout the life of a computer system, from initial design, through implementation, configuration (and reconfiguration) and even tuning. Performance models are usually solved by numerical techniques, where possible, and by simulation, otherwise. This paper summarizes IBM's contributions to performance modeling and the solution of performance models.

Computer Modeling in Energy and the Environment *by H. P. Flatt, p. 571.* Computer modeling has played a significant role in the evaluation of possible sources of energy as well as the consequences of the use of energy on the environment. In this paper the contributions of IBM scientists to improve models in the fields of air pollution, solar energy, plasma physics, coal gasification, and energy conservation are summarized. These contributions include not only better numerical and programming techniques but improved mathematical models based upon advances in understanding of the physical processes involved.

Solid State Memory Development in IBM *by E. W. Pugh, D. L. Critchlow, R. A. Henle, and L. A. Russell, p. 585.* Memory technology in IBM processors has undergone a 280,000-fold increase in density, a 20,000 times decrease in power per bit, and a 10 to 100 times increase in speed during the last twenty-five years. These improvements have brought many advantages to users of information processing equipment, including a 650-fold reduction in the cost per bit of memory. During this period, processor memory technology evolved from cathode ray storage tubes in the early 1950s, through ferrite cores and thin magnetic films in the 1950s and 1960s, to bipolar and MOSFET semiconductor memories in the late 1960s through the 1970s. This paper describes these developments and the technical innovations that made them possible. It also describes continuing exploratory efforts, including work on magnetic bubbles—the newest solid state memory technology.

Semiconductor Logic Technology in IBM *by E. J. Rymaszewski, J. L. Walsh, and G. W. Leehan, p. 603.* In the last twenty-five years the performance of integrated circuits has improved by more than three orders of magnitude and the unit cost has been reduced by approximately the same factor. This paper describes the evolution of semiconductor logic technology in IBM from its early replacement of vacuum tubes in the mid-1950s to the beginnings of VLSI. It highlights the major challenges and accomplishments in the development of bipolar and field-effect transistor technologies and their embodiment in components for a wide spectrum of IBM products.

Electronic Packaging Evolution in IBM *by D. P. Seraphim and I. Feinberg, p. 617.* A quarter century of innovation in the development of packaging for semiconductors has culminated in the announcement of the IBM 4300 Series of computers and the IBM 3081. This technology has been built on a broad and expanding base starting with packaging for the 1400 Series in the late 1950s. In the next series, System/360, IBM chose to follow a unique approach which employed solder joints for the semiconductor connections, allowing ultimately a higher density and total number of interconnections compared to the rest of the industry. This has driven the packaging at the module level to achieve extremely high density and has led to multichip interconnections and multilayers on this first level of package. The dramatically increasing circuit function at the module level requires area arrays of pins to be able to get enough of them in a small area. Thus the next level (second level) of packaging has likewise been driven to provide many layers of dense interconnections to link to the module pins. New types of plated through holes join the many layers of interconnection. The highlights of the technical approaches which have been developed over the twenty-five-year period are discussed briefly in this paper.

Design Automation in IBM *by P. W. Case, M. Correia, W. Gianopulos, W. R. Heller, H. Ofek, T. C. Raymond, R. L. Simek, and C. B. Stieglitz, p. 631.* Within the context of the changing design requirements of digital systems spanning the semiconductor era, this paper describes the significant steps in the development of Design Automation technology in IBM. We cover the design tools which support the design of the

electronic portion of such systems. The paper emphasizes the systems approaches taken and the topics of design verification, test generation, and physical design. Descriptions of the technical contributions and interactions which have led to the unique characteristics of IBM's Design Automation systems are included.

Semiconductor Manufacturing in IBM, 1957 to the Present: A Perspective *by W. E. Harding, p. 647.* Over the past twenty-five years we have witnessed the transition from germanium-based, individual transistors in their hermetically sealed enclosures to VLSI silicon devices interconnected in modular packages containing more than 50,000 logic circuits or as many as 500,000 bits of random-access memory. During this progression, manufacturing facilities producing these modern products have become more complex and technologically more sophisticated than those of any other industry. This review traces these fast-moving changes as they have occurred in IBM, emphasizing the continuous expansion of manufacturing skills and disciplines and how these, in turn, have contributed to the development of today's products and their respective manufacturing systems.

The Evolution of Magnetic Storage *by L. D. Stevens, p. 663.* Since delivery of the first vacuum-column magnetic-tape transport in 1953 and the first movable-head disk drive in 1957, tape and disk devices in many configurations have been the principal means for storage of the large volumes of data required by data processing systems. Magnetic drums and other device geometries have also been important system components, but to a lesser extent. Over the past twenty-five years significant developments have been made that increase the capacity, reduce the cost, and improve the performance and reliability of these devices. With each improved device the range and nature of the applications undertaken have expanded and, in turn, led to a need for further device improvement. This paper gives a general review and historical perspective of magnetic storage development within IBM and is an introduction to the subsequent papers on disk, diskette, and tape technology and on disk manufacturing.

A Quarter Century of Disk File Innovation *by J. M. Harker, D. W. Brede, R. E. Pattison, G. R. Santana, and L. G. Taft, p. 677.* This paper traces the development of disk file technology from the first disk drive to the present. A number of innovative advances are reviewed in the evolution of mechanical design, materials, and processes. These advances constitute the technological base that has permitted almost four orders of magnitude of improvement in areal density; they are discussed from four interrelated aspects: the magnetic head and its air bearing support; the head positioning actuator; the disk substrate and its magnetic coating; and the read/write signal detection and clocking electronics.

Innovations in the Design of Magnetic Tape Subsystems *by J. P. Harris, W. B. Phillips, J. F. Wells, and W. D. Winger, p. 691.* This paper explores the selection of magnetic tape as an input/output medium for electronic computers and reviews the innovations in the development of magnetic tape and tape handling machines since their introduction in the early 1950s.

The IBM Diskette and Diskette Drive *by J. T. Engh, p. 701.* The diskette and diskette drive have had a major influence on data processing. They provide a low-cost, compact, high-performance solution to the need for a reusable magnetic medium and have largely replaced the punched card in many applications. Early applications were simple program-load functions. Today these have expanded to a wide range of medium exchange, information storage, and data processing applications. This paper examines the history of the development of these products within IBM. The discussion includes some of the alternatives considered and some of the problems encountered during these developments.

Innovations in Disk File Manufacturing *by R. B. Mulvany and L. H. Thompson, p. 711.* This paper discusses the important innovations in disk file manufacturing at IBM over the past twenty-five years. Technology advances in the key components of disk files—the magnetic read/write head, its air bearing support, and the disk substrate and magnetic coating—have permitted almost four orders of magnitude increase in areal recording density since the first disk file, the IBM 350, was shipped in 1957. Manufacturing capability for these basic recording technology components has been the key to realizing the cost/performance promise of each new technology. The evolution of this manufacturing capability is discussed with an emphasis on important innovations in processes, materials, tools, and testing techniques.

IBM Typewriter Innovation *by H. S. Beattie and R. A. Rahenkamp, p. 729.* The evolution of the writing machine from early eighteenth-century concepts to the modern electronic typewriter represents a rich history of innovative efforts by many individuals in several countries. This paper briefly highlights several significant early milestones and then draws particular attention to typewriter developments within the IBM Corporation. After entering the typewriter business in 1933, IBM expanded the applicability of electric typebar machines and introduced proportional spacing to electric typewriters. The IBM SELECTRIC® Typewriter single-print-element concept represented a major departure from traditional typewriter design. Since the introduction of the SELECTRIC Typewriter, it has evolved in several directions that resulted in the following: a typewriter to produce high-quality printing for cold-type composing applications; an input/output writer for use in terminals, computer consoles, and word processing machines; a typewriter that can correct errors by mechanically removing them from the page or covering them up; and electronic typewriters, using microcircuitry, that provide more memory and computing power than some early computers.

IBM Word Processing Developments *by F. T. May, p. 741.* IBM has been the leader in a variety of word processing

innovations since the introduction of the Magnetic Tape/SELECTRIC Typewriter in 1964 by the Office Products Division (OPD). Since then the basic approach of combining quality printed output and magnetic storage with new functions has been followed by OPD, while other IBM divisions have concentrated on new applications with data processing systems and shared-logic word processing systems. This article summarizes the major technical contributions by IBM that have supported the growth of an area of business that today is widely recognized as one of great potential for increased productivity in the modern office environment.

Printer Technology in IBM *by T. Y. Nickel and F. J. Kania, p. 755.* Major developments in printer technology have occurred during the past twenty-five years. Improvements in such areas as performance, reliability, and product cost are described in this paper, along with many of the IBM impact printer products embodying these developments, beginning with the well-known 1403 Line Printer.

Laser Electrophotographic Printing Technology *by C. D. Elzinga, T. M. Hallmark, R. H. Mattern, Jr., and J. M. Woodward, p. 767.* This paper describes the development of a non-impact printing technology—electrophotography with laser imaging—and explains its implementation, in both office product and system output devices. The key technical advances made during the development of the two devices are shown.

Semiconductors at IBM: Physics, Novel Devices, and Materials Science *by R. W. Keyes and M. I. Nathan, p. 779.* Work on semiconductor physics, devices, and materials science carried on at IBM in the last twenty-five years is reviewed. Topics covered include hot electrons, inversion layers, the injection laser, electroluminescence, the Gunn effect, MESFETs, solar cells, superlattices, and amorphous materials and effects.

Electronic Structure Theory *by P. S. Bagus and A. R. Williams, p. 793.* This paper reviews the history of IBM contributions over the last quarter century to electronic structure theory. The two main sections of the paper deal with large-scale computations in quantum chemistry and the study of the electronic structure of solids. The paper briefly discusses the methods of ab initio quantum chemistry, a field in which IBMers have devoted major effort and made substantial innovative, scientific contributions. Partly as a result of these contributions, it is now possible to use these methods to address theoretically problems of practical importance in chemistry. Major contributions toward understanding the electronic structure of solids, particularly with regard to metallic bonding, surface electronic structure, the nature of magnetism, and semiconductor defects, are discussed as well as pioneering efforts in the analysis of photoemission and low-energy electron diffraction data.

Phase Transitions *by K. A. Müller and E. Pytte, p. 811.* This paper presents a selective review of some of IBM's major contributions in the area of phase transitions during the last twenty-five years. It is separated into three main sections covering ferroelectric and structural transitions, magnetism, and nonequilibrium phase transitions.

Algebraic Complexity Theory *by N. Pippenger, p. 825.* Algebraic complexity theory, the study of the minimum number of operations sufficient to perform algebraic computations, is surveyed with emphasis on the general theory of bilinear forms and two of its applications: polynomial multiplication and matrix multiplication. Though by no means exhausting algebraic complexity theory, these topics illustrate well its development and its methods, and provide examples of its most striking successes.

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Design of Experiments in Computer Performance Evaluation *by M. Schatzoff, p. 848.* Techniques of statistical design of experiments have been successfully employed for many decades in a variety of applications in industry, agriculture, medicine, psychology, and other physical and social sciences. Their aim is to provide scientific and efficient means of studying the effects, on one or more variables of interest, of varying multiple controllable factors in an experiment. These techniques have not been widely used in the study of computer systems, although they can potentially have as large an impact as they have had in other fields. The purpose of this paper is to review some of the basic concepts underlying the statistical design and analysis of experiments and to illustrate them by means of examples drawn from studies of computer system performance. The examples include comparisons of alternate page replacement and free storage management algorithms, optimization of a scheduler, and validation of a system simulation model.

Adaptive Spectral Methods for Simulation Output Analysis *by P. Heidelberger and P. D. Welch, p. 860.* This paper addresses two central problems in simulation methodology: the generation of confidence intervals for the steady state means of the output sequences and the sequential use of these confidence intervals to control the run length. The variance of the sample mean of a covariance stationary process is given approximately by $p(0)/N$, where $p(f)$ is the spectral density at frequency f and N is the sample size. In an earlier paper we developed a method of confidence interval generation based on the estimation of $p(0)$ through the least squares fit of a quadratic to the logarithm of the periodogram. This method was applied in a run length control procedure to a sequence of batched means. As the run length increased the batch means were rebatched into larger batch sizes so as to limit storage requirements. In this rebatching the shape of the spectral density changes, gradually becoming flat as N increases. Quadratics were chosen as a compromise between small sample bias and large sample stability.

In this paper we consider smoothing techniques which adapt to the changing spectral shape in an attempt to improve both the small and large sample behavior of the method. The techniques considered are polynomial smoothing with the degree selected sequentially using standard regression statistics, polynomial smoothing with the degree selected by cross validation, and smoothing splines with the amount of smoothing determined by cross validation. These techniques were empirically evaluated both for fixed sample sizes and when incorporated into the sequential run length control procedure. For fixed sample sizes they did not improve the small sample behavior and only marginally improved the large sample behavior when compared with the quadratic method. Their performance in the sequential procedure was unsatisfactory. Hence, the straightforward quadratic technique recommended in the earlier paper is still recommended as an effective, practical technique for simulation confidence interval generation and run length control.

The Software-Cache Connection *by J. Voldman and L. W. Hoevel, p. 877.* This paper describes an adaptation of standard Fourier analysis techniques to the study of software-cache interactions. The cache is viewed as a "black box" Boolean signal generator, where "ones" correspond to cache misses and "zeros" correspond to cache hits. The spectrum of this time sequence is used to study the dynamic characteristics of complex systems and workloads with minimal *a priori* knowledge of their internal organization. Line spectra identify tight loops accessing regular data structures, while the overall spectral density reveals the general structure of instruction localities.

Approximate Solution of Queueing Networks with Simultaneous Resource Possession *by C. H. Sauer, p. 894.* Queueing networks are important as performance models of computer and communication systems because the performance of these systems is usually principally affected by contention for resources. Exact numerical solution of a queueing network is usually only feasible if the network has a product form solution in the sense of Jackson. An important network characteristic which apparently precludes a product form solution is simultaneous resource possession, *e.g.*, a job holds memory and processor simultaneously. This paper extends previous methods for approximate numerical solution of queueing networks with homogeneous jobs and simultaneous resource possession to networks with heterogeneous jobs and simultaneous resource possession.

Collision-Free Local Area Bus Network Performance Analysis *by V. C. Hamacher and G. S. Shedler, p. 904.* This paper deals with port access control for local area computer communication bus networks. Emphasizing properties of the algorithms and delay-throughput performance, we focus on two collision-free access control schemes recently proposed by Eswaran, Hamacher, and Shedler. We also provide a comparison of these schemes to other available bus access techniques. The performance analysis is based on representation of the bus network as a closed queueing system with nonpreemptive priority service.

Delay Analysis of a Two-Queue, Nonuniform Message Channel *by S. B. Calo, p. 915.* A Message Channel is defined as a tandem connection of single server queues in which the successive service times experienced by any particular customer are scaled versions of the same random variable, and thus it serves as a model for sparsely connected store-and-forward data communications networks (or network segments) where messages typically preserve their lengths as they traverse the system. A particular instance of such a nonstandard queueing model is analyzed in this paper. The system consists of two single server queues in tandem subject to a Poisson arrival process (at the first queue) and providing service according to scaled versions of a sequence of two-level, discrete random variables. A set of recursive equations that can be used to solve the model for any given scaling factor at the second queue (normalized with respect to the first queue service) is explicitly derived. In addition, complete solutions are displayed for several cases of interest, and the equilibrium mean cumulative waiting times for these instances are compared as a method of indicating the impact of the scaling factor on the operation of the system. The extension of several results to systems with more general service time processes is discussed.

Message Reassembly Times in a Packet Network *by G. Stroebel, p. 930.* This paper addresses the problem of computing the reassembly time of a multipacket message. All packets from a single message are assumed to flow in sequence along the same physical path. The analysis includes the effects of contention between messages in the network on the delay time at each station along the path and its impact on message reassembly time.

Fleshing Out Projections *by M. A. Wesley and G. Markowsky, p. 934.* In an earlier paper, the authors presented an algorithm for finding all polyhedral solid objects with a given set of vertices and straight line edges (its *wire frame*). This paper extends the Wire Frame algorithm to find all solid polyhedral objects with a given set of two dimensional projections. These projections may contain depth information in the form of dashed and solid lines, may represent cross sections, and may be overall or detail views. The choice of labeling conventions in the projections determines the difficulty of the problem. It is shown that with certain conventions and projections the problem of fleshing out projections essentially reduces to the problem of fleshing out wire frames. Even if no labeling is used, the Projections algorithm presented here finds all solutions even though it is possible to construct simple examples with a very large number of solutions. Such examples have a large amount of symmetry and various accidental coincidences which typically do not occur in objects of practical interest. Because of its generality, the algorithm can handle pathological cases if they

arise. This Projections algorithm, which has applications in the conversion of engineering drawings in a Computer Aided Design, Computer Aided Manufacturing (CADCAM) system, has been implemented. The algorithm has successfully found solutions to problems that are rather complex in terms of either the number of possible solutions or the inherent complexity of projections of objects of engineering interest.

An Emulation System for Programmable Sensory Robots *by J. Meyer, p. 955.* This paper describes EMULA, an experimental interactive system for the emulation of sensory robots. EMULA was constructed as a bridge between an existing language for driving actual robots and an existing geometric modeling system. The modeling system was extended to handle mechanisms, such as robots, and an emulation language was introduced to indicate certain specific physical effects, including sensory feedback, grasping and releasing of parts, and gravity. EMULA allows manipulation programs to be tested by users in interactive terminal sessions or in batch mode. Monitoring functions are provided to record actions, store selected views, and check for collisions.

Impact of a Liquid Drop Against a Flat Surface *by S. E. Bechtel, D. B. Bogy, and F. E. Talke, p. 963.* Lagrangian methods are used with an assumed flow field and a truncated sphere model to analyze the dynamical process of a liquid drop impacting a flat, rigid surface. The resulting differential equation for drop height as a function of time during contact is solved numerically for several values of the three parameters: Weber number of the incoming drop, ratio of the surface tension in air to that at the contact surface, and the viscosity parameter. The drop contact radius as a function of time is also calculated and compared with some experimental results in the literature.