

The IBM System/360 Model 91: Some Remarks on System Development by M. J. Flynn and P. R. Low, p. 2.

The IBM System/360 Model 91: Machine Philosophy and Instruction-Handling by D. W. Anderson, F. J. Sparacio, and R. M. Tomasulo, p. 8. The System/360 Model 91 central processing unit provides internal computational performance one to two orders of magnitude greater than that of the IBM 7090 Data Processing System through a combination of advancements in machine organization, circuit design, and hardware packaging. The circuits employed will switch at speeds of less than 3 nsec, and the circuit environment is such that delay is approximately 5 nsec per circuit level. Organizationally, primary emphasis is placed on (1) alleviating the disparity between storage time and circuit speed, and (2) the development of high speed floating-point arithmetic algorithms.

This paper deals mainly with item (1) of the organization. A design is described which improves the ratio of storage bandwidth and access time to cycle time through the use of storage interleaving and CPU buffer registers. It is shown that history recording (the retention of complete instruction loops in the CPU) reduces the need to exercise storage, and that sophisticated employment of buffering techniques has reduced the effective access time. The system is organized so that execution hardware is separated from the instruction unit; the resulting smaller, semiautonomous "packages" improve intra-area communication.

An Efficient Algorithm for Exploiting Multiple Arithmetic Units by R. M. Tomasulo, p. 25. This paper describes the methods employed in the floating-point area of the System/360 Model 91 to exploit the existence of multiple execution units. Basic to these techniques is a simple common data busing and register tagging scheme which permits simultaneous execution of independent instructions while preserving the essential precedences inherent in the instruction stream. The common data bus improves performance by efficiently utilizing the execution units without requiring specially optimized code. Instead, the hardware, by 'looking ahead' about eight instructions, automatically optimizes the program execution on a local basis.

The application of these techniques is not limited to floating-point arithmetic or System/360 architecture. It may be used in almost any computer having multiple execution units and one or more 'accumulators.' Both of the execution units, as well as the associated storage buffers, multiple accumulators and input/output buses, are extensively checked.

The IBM System/360 Model 91: Floating-Point Execution Unit by S. F. Anderson, J. G. Earle, R. E. Goldschmidt, and D. M. Powers, p. 34. The principal requirement for the Model

91 floating-point execution unit was that it be designed to support the instruction-issuing rate of the processor. The chosen solution was to develop separate, instruction-oriented algorithms for the add, multiply, and divide functions. Linked together by the floating-point instruction unit, the multiple execution units provide concurrent instruction execution at the burst rate of one instruction per cycle.

The IBM System/360 Model 91: Storage System by L. J. Boland, G. D. Granito, A. U. Marcotte, B. U. Messina, and J. W. Smith, p. 54. This paper discusses the design concepts employed in the development of the IBM System/360 Model 91 storage system. Particular attention is paid to the exploitation of System/360 capabilities in the areas of large storage capacity, concurrent operation, and flexibility, as they apply to the highly overlapped Model 91 system.

An interleaved set of main storage modules is used with the Model 91 to help mask the difference between machine cycle time and storage access time. The set is connected to the central processor, peripheral storage control element and maintenance console by three time shared busses—one for addresses, one for data-in, and one for data-out. The main storage control element (MSCE) controls these busses to maximize the storage access rate. To achieve minimum access time, requests are normally sent directly to the storage modules. The proper module is selected by the MSCE, the address gated in, and the storage cycle started. If the module is busy from a previous request, the request is stored in a request stack for a later attempt. If the request is accepted, it is stored in an accept stack. This stack controls the data-out gating of the storage modules, and notifies the CPU of the destination of returning data. It also furnishes module busy information which controls the recycling of rejected requests.

An important feature is the ability of the MSCE to logically sequence store/fetch requests, by interlocking the rejected requests with the current request without any degradation of minimum access time. Additionally, each address sent to the MSCE is compared with the addresses of waiting and in-process requests. This allows serial fetching of two adjacent single words of a double-word storage cycle. Fetches following stores to the same location can be executed without waiting for a fetch storage cycle.

Peripheral storage is provided in the system for both block transfers of data and individual word fetches and stores. All requests to peripheral storage are sent via the peripheral storage control element.

The MSCE is synchronized with the CPU and uses the same machine cycle. Ideally, a request can be honored each machine cycle, but the actual rate is determined by storage module conflicts. The storage system performance is measured in access rate and access time. The MSCE has been simulated to measure the effects of storage speeds, degree of interleaving, and changes in MSCE controls.

Design of a High-Speed Transistor for the ASLT Current Switch by J. L. Langdon and E. J. Van Derveer, p. 69. The evolution of a high-speed current switch transistor design is described from initial design considerations through final optimization of horizontal geometry. It was found that a very narrow geometry was desirable, in order to produce the desired low base resistance ($\sim 40 \Omega$). Other characteristics of this design include low capacitance, well-controlled emitter forward voltage, and high-frequency cutoff. Compatibility with the SLT form factor assures manufacturability. This transistor when used in ASLT circuits yields circuit delays of 1.8 nsec.

ASLT Circuit Design by R. F. Sechler, A. R. Strube, and J. R. Turnbull, p. 74. The full switching-speed potential of high performance transistors is difficult to realize in a current switch configuration because of the instability which exists when many circuits are interconnected in a system. With a phase compensating network in the emitter current source, however, it has been possible to design a stable circuit using 1 Gc/sec transistors. Design techniques and engineering aspects of the circuit which result in a 5-nsec in-the-environment propagation delay are described. Particular attention is given to the dc design, stability analysis, switching performance, evaluation and specification of the circuit.

ASLT: An Extension of Hybrid Miniaturization Techniques by R. H. F. Lloyd, p. 86. The hybrid miniaturization technique of applying active and passive components separately to a packaging substrate enables independent customization of components and minimizes stray capacitance between components. Manufacturing advantages result because all components can be pretested, and the critical component joining operation can be performed as a continuous operation. This paper describes IBM's Advanced Solid Logic Technology (ASLT) wherein the capabilities of hybrid circuit technology have been extended to produce a high-speed, high-density digital logic module compatible with automated production. Design considerations and assembly processes are detailed. A development of the power handling capability reviews the various thermal paths within the module.

Review of Wall Creeping in Thin Magnetic Films by S. Middelhoeck and D. Wild, p. 93. Domain wall creeping in thin magnetic Ni-Fe films has been studied as a function of the film thickness, field pulse amplitude, duration and repetition frequency, and bias fields in the hard direction. The experimental results are reviewed and compared with the three existing theories, which ascribe wall creeping to a) Bloch line motion, b) wall structure changes, and c) changing magnetic charges along the walls, respectively. Based on the first theory, methods are indicated by which a reduction of creep sensitivity of magnetic films might be obtained.

A Rapid Method for Determining Compound Composition of Cement Clinker: Application to Closed Loop Kiln Control by P. K. Mehta and M. J. Shah, p. 106. A procedure for determination of phase composition of commercial cement clinker using quantitative x-ray powder diffraction analysis is described. An external standard and comparison of peak heights rather than the peak areas are used for rapid analysis. Several standard curves were prepared using diffraction patterns from known mixtures of previously prepared pure components which exist in cement clinker. For purposes of comparison, both the suggested external standard method and the internal standard method which is generally accepted for quantitative X-ray diffraction analysis were used. It was found that the faster external standard method gives analysis of important clinker constituents with accuracy adequate for quality control in a cement plant. With the use of suggested grinding procedure and an automatic sample changer attachment to standard X-ray diffraction equipment, it is possible to obtain an on-line analysis of clinker in one half hour. This analysis can then be deployed in performing closed loop control of a cement kiln with a proposed algorithm.

On the Necessity to Examine D-Chains in Diagnostic Test Generation—An Example by P. R. Schneider, p. 114.

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Laser-pumped Stimulated Emission from Organic Dyes: Experimental Studies and Analytical Comparisons by P. P. Sorokin, J. R. Lankard, E. C. Hammond, and V. L. Moruzzi, p. 130. Stimulated emission spectra of two organic dyes, chloro-aluminum phthalocyanine (CAP) and 3,3'-diethylthiatricarbocyanine iodide (DTTC) are compared. Giant-pulse ruby laser excitation was used in both cases. An end pumping configuration employed with DTTC resulted in narrow beam divergences and high conversion efficiencies. For CAP, the oscillating transition is one which terminates on an excited vibrational level of the ground electronic state. For DTTC, stimulated emission at the lowest concentrations occurs at the peak of the Franck-Condon-shifted fluorescence band but moves to longer wavelengths as the concentration is increased. The transient behavior of the CAP laser, pumped in a transverse geometry, was observed and compared with computer solutions of the rate equations. Polarization measurements of the laser beams were also made. An analysis is given of requirements for achieving optimal pumping by means of flashlamps. [The paper concludes with an addendum reporting recent observations of stimulated emission from dye solutions lasing at wavelengths ranging from blue (4385 Å) to orange (6000 Å)].

Flashlamp Excitation of Organic Dye Lasers: A Short Communication by P. P. Sorokin and J. R. Lankard, p. 148.

A 110-Nanosecond Ferrite Core Memory by G. E. Werner, R. M. Whalen, N. F. Lockhart, and R. C. Flaker, p. 153. The

design of a large, very-high-speed ferrite memory is described. The memory has a capacity of 8192 words, 72 bits per word, and has a cycle time of 110 nanoseconds and an access time of 67 nanoseconds. The storage devices are miniature ferrite cores, 0.0075 by 0.0123 by 0.0029 inches, and are operated in a two-core-per-bit destructive read-out mode. A planar array geometry with cores resting on a single ground plane is used to control drive line parameters. Device switching speed and bit line recovery are treated as special problems. The design criteria and operational characteristics of the core, and the approach taken on the bit line recovery problem, are also presented.

A Very-High-Speed, Nondestructive-Read Magnetic Film Memory by G. Kohn, W. Jutzi, T. O. Mohr, and D. Seitzer, p. 162. A very-high-speed thin magnetic film memory has been designed and built as a cross sectional test model for 140,000 bits. It can be operated in the NDRO mode with a 20-nsec read cycle time and a 30-nsec access time, and it can be read 65 nsec after the beginning of a write operation.

Device and Array Design for a 120-Nanosecond Magnetic Film Main Memory by E. W. Pugh, V. T. Shahan, and W. T. Siegle, p. 169. Device and array design considerations are described for a manufacturable 120-nsec cycle magnetic film memory containing 600,000 bits in the basic operating module. Worst-case testing is done in such a way as to provide quantitative values for such effects as adjacent bit-line stray field, ground-plane current spreading, flux trapping in metallic ground planes and strip lines, and magnetic-keeper efficiency. Worst-case output signals exceeding 3.8 mV are achieved with a 8-nsec rise-time word pulse of 510 mA. Bit current is 100 mA.

Direct Digital Processor Control of Stepping Motors by T. R. Fredriksen, p. 179. This paper describes the concept for implementing direct computer control of stepping motors. The design approach is based on using the computer to close a minor loop around the motor. The discussion includes both full and partial computer control, and the results show that the closed-loop stepping motor is well suited to such applications.

Digital Simulation Applied to a Photo-Optical System by R. B. Edwards, D. T. Hodges, Jr., W. D. Hopkins, and D. P. Paris, p. 189. The validity of the Image Forming Systems Simulator, IMSIM/1, as a means of simulating multiple-stage photo-optical systems has been determined. IMSIM/1 was used to simulate a three-stage system consisting of a microfilm camera (first stage), followed by the photo-optical subsystem of a developmental image storage and retrieval system (second and third stage). Fine line targets were processed through the camera and the storage and retrieval system. Microdensitometer scans of the targets were then processed through the simulator. To compare the output of the real system with the output of the simulator, it was necessary to measure carefully those system and camera data used in the simulator. After this was done, a satisfactory

agreement between experimental result and simulator output was achieved.

On the Partial Difference Equations of Mathematical Physics by R. Courant, K. Friedrichs, and H. Lewy, p. 215.

Editor's note: This paper, which originally appeared in *Mathematische Annalen* **100**, 32-74 (1928), is republished by permission of the authors. We are also grateful to the Atomic Energy Commission for permission to republish this translation, which had appeared as AEC Report NYO-7689, and to Phyllis Fox, the translator, who did the work at the AEC Computing Facility at New York University under AEC Contract No. AT(30-1)-1480. Professor Eugene Isaacson had made suggestions on this translation.

Hyperbolic Difference Equations: A Review of the Courant-Friedrichs-Lewy Paper in the Light of Recent Developments by P. D. Lax, p. 235. The portion of the Courant-Friedrichs-Lewy paper [*Math. Ann.* **100**, 32 (1928)] that was devoted to hyperbolic difference equations is critically reviewed in terms of its basic contribution to the numerical solution of partial differential equations. Some subsequent developments are then discussed, including recent literature related to the von Neumann condition, some irreversible schemes, generalizations of the energy method, some new difference schemes, and mixed initial boundary value problems.

On Difference Methods for Parabolic Equations and Alternating Direction Implicit Methods for Elliptic Equations by O. B. Widlund, p. 239. Some aspects are discussed of the development of the theory of difference approximations to parabolic equations in its relation to the basic development of difference methods for hyperbolic and elliptic equations by Courant, Friedrichs and Lewy, [*Math. Ann.* **100**, 32 (1928)]. The present paper also deals with the related problem of establishing the convergence of alternating direction implicit methods for elliptic problems.

Elliptic Equations by S. V. Parter, p. 244. A brief review is given of the literature on numerical methods for elliptic problems as related to the ideas introduced by Courant, Friedrichs and Lewy in the fundamental paper published in *Math. Ann.* **100**, 32 (1928). The discussion shows how the finite-difference methods have subsequently been extended and applied to higher order elliptic problems and how the recent literature has reported methods for solving large algebraic systems. In addition, there is a discussion of the relation between the Dirichlet problem and the problem of the random walk.

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On the Mathematical Theory of the Linearly-Graded P-N Junction by D. P. Kennedy and R. R. O'Brien, p. 252. This paper presents a numerical analysis of the mechanisms of operation within a linearly-graded p - n junction. Considered

in this analysis are three important modes of junction operation: equilibrium, forward bias, and reverse bias in the collector junction. In addition, calculations of electrical space-charge layer capacitance are presented for the forward-biased linearly-graded junction. The conclusions derived are compared, in graphical form, with the results of previous investigations of the linearly-graded junction.

Precipitation of Phosphorus, Arsenic, and Boron in Thin Silicon Foils by M. L. Joshi and S. Dash, p. 271. Diffusion of high concentrations of P, B, and As in thin foils of silicon of (111), (110), and (100) orientations is shown to result in extensive precipitation. Observation of the precipitates through a transmission electron microscope has indicated that phosphorus diffusion gives rise to precipitate platelets. Boron precipitates were found to be of various shapes—rod, platelet, and three-dimensional. Matrix contrast observation showed that small coherent platelets of P and B are both of the "vacancy" type—this is in accordance with the smaller size of B and P atoms in the silicon matrix. Contrast studies for arsenic precipitates were inconclusive. Helical dislocations oriented along $\langle 220 \rangle$ directions and originating from precipitate regions were observed in the phosphorus-diffused foils; boron precipitates showed no such helices. Boron rods and three-dimensional structures, however, were invariably found to be enveloped by dislocation spirals, with Burgers vector different from the usual $a/2 \langle 110 \rangle$ type. These dislocation envelopes are thought to be interfacial dislocations. It is concluded that the precipitates are not identifiable as discrete SiP or Si₃B₂ phases, since these phases would be expected to cause compression in the matrix because their specific volume is higher than that of silicon.

On the Velocity of a Domain Wall in an Applied Magnetic Field by W. Palmer and R. A. Willoughby, p. 284. A numerical study is made of a moving magnetic domain wall. It is assumed that the wall moves with a uniform velocity V under the influence of an applied magnetic field of magnitude H_0 . This leads to a boundary value problem on a doubly infinite line. By using a symmetry in the problem, the inherent difficulty of a two-dimensional search on a doubly infinite line is bypassed. For each V the problem is solved as a sequence of initial value problems involving a one-dimensional search. A limiting velocity is determined by means of an eigenvalue analysis. The curve representing the relation between V and H_0 is determined for a particular case.

Characteristics of the Chain Magnetic Film Storage Element by P. Geldermans, H. O. Leilich, and T. R. Scott, p. 291. This paper reports results of a detailed performance evaluation of the chain magnetic film storage element. The chains are made from copper strips which have been plated with a Ni-Fe film and are used to carry word current. The bit/sense signals are carried in wires which pass through the holes in the "links" of the chain. The memory element thus formed will operate in a rotational switching mode and can be used for a word-organized memory.

The results indicate both the advantages and the shortcomings of the device. Because of the complete flux closure, comparatively high output signal flux (200 mV-nsec) can be obtained from small, densely packaged devices which require less than 200 mA of word current and less than 100 mA of bit current. The chain shows high magnetic stability and can be operated in both a destructive and a nondestructive mode. The main problem is the difficulty in handling the delicate self-supporting magnetic devices, for testing, packaging, and wiring; this difficulty determines the limit of miniaturization.

Experimental results, including a large-scale reproducibility study, verify theoretical expectations.

Design Considerations for the Chain Magnetic Storage Array by S. A. Abbas, H. F. Koehler, T. C. Kwei, H. O. Leilich, and R. H. Robinson, p. 302. A computer storage design using the chain store device as both a DRO and an NDRO storage element is discussed for an array organization of one megabit capacity and 500-nsec cycle time. The bit/sense system and schemes for minimizing the longitudinal fields inside the array during the "write" portion of the cycle are presented.

Noise due to difference in the information states of the device is studied experimentally and through evaluations of computer solutions of simulated bit/sense lines. The word-line characteristic impedance and its dependence on the magnetic behavior of the device during the "read" portion of the cycle and on the sending and receiving end terminations are examined with consideration given to long word lines. Sources of noise and bit-to-bit interaction are discussed and comparisons between calculated and experimental results obtained from a small model of the array are given.

A Computer Model for Global Study of the General Circulation of the Atmosphere by D. A. Quarles, Jr. and K. Spielberg, p. 312. A mathematical model is developed for global prediction of large-scale movements and mean properties of the atmosphere from simulated initial weather conditions. A novel feature is the development of the formulation—one of considerably greater complexity than those for previous weather models adapted to machine calculation—in a concise tensor form. The organization of the computational task illustrates how a very complex problem with vast data requirements may be solved on a computer with limited high-speed storage.

A New Current Instability in N-type Germanium by J. C. McGroddy and M. I. Nathan, p. 337. This paper reports the observation of a new oscillatory phenomenon in n -type Ge at 77K. The effect is a coherent oscillatory component of the current through a bar of n -type Ge with ohmic n^+ contacts initiated when the average electric field in the sample exceeds some threshold value which is in the region where the electron drift velocity is nearly saturated. The frequencies of the oscillations vary from a few hundred MHz to 2.8 GHz. The

effect depends on sample orientation, temperature, and carrier concentration. Some possible mechanisms for this effect are discussed. At somewhat higher fields a second, not necessarily related instability, is also observed.

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A Generalized Legendre-Clebsch Condition for the Singular Cases of Optimal Control by *H. M. Robbins*, p. 361. For certain optimal control problems, some of the extremal trajectories generated by simultaneous solution of the state and adjoint equations may include arcs of a special character, called "singular" arcs. The optimality of singular arcs has been the subject of considerable uncertainty, since the classical criteria are inapplicable or inconclusive. This uncertainty has recently been reduced by the discovery of additional necessary conditions for the optimality of singular arcs. The principal result of this paper is a general statement and proof of these conditions, in the form of a "generalized Legendre-Clebsch condition" which reduces to the classical Legendre-Clebsch condition when applied to nonsingular arcs, and gives additional necessary conditions when applied to singular arcs. Other results include a classification of the possible singular arcs, a useful extension of the conventional optimal-control formalism (by the introduction of "generalized Hamiltonians" and "generalized control transformations"), and some interesting variational formulae.

Rapid Computation of Optimal Trajectories by *K. R. Brown, Jr. and G. W. Johnson*, p. 373. A generalized "indirect" method of solving two-point boundary value problems is discussed in application to the problem of computing optimal trajectories in a vacuum. Improved numerical techniques make the method extremely fast when a good initial estimate of the solution is available, but it also converges, more slowly, from initial estimates that are far from the solution. Transversality conditions are combined with final-value constraints enabling the method to solve directly problems defined by constraints on arbitrary functions of final state.

Section 1 defines the differential equations and initial and terminal conditions for optimal rocket trajectories in a central gravitational field. The differential equations are given a particularly simple form and transversality conditions are formulated analytically for typical orbital injection missions. Section 2 defines efficient numerical procedures for solving the initial value problem of optimal trajectories and so reduces the boundary value problem to a multidimensional zero-finding problem. Section 3 describes the generalized version of Newton's method used to solve this multidimensional zero-finding problem. Section 4 summarizes the results of an IBM 7094 implementation, giving execution times and convergence properties.

Some Results in Two-Point Boundary Value Problems by *S. M. Roberts and J. S. Shipman*, p. 383. Two new results in

two-point boundary value problems are presented. The first is a modified method of adjoints which, under certain circumstances, will solve numerically two-point boundary value problems faster than the standard method of adjoints. The second result shows that Friedrichs' solution of the operator equation $P(x) = 0$ is really the modified Newton method. Kantorovich's sufficiency conditions for the convergence of the modified Newton's method are compared with Friedrichs' sufficiency conditions; it appears that, for most applications, the former conditions allow more leeway.

Computer Control of a Paper Machine—an Application of Linear Stochastic Control Theory by *K. J. Åström*, p. 389. This paper describes an attempt to apply linear optimal control theory to computer control of an industrial process. The applicability of the theory is discussed. Particular attention is given to the problem of obtaining a mathematical model of process dynamics and disturbances. Results of actual measurements as well as results from on-line control experience are presented.

On-Line Identification of Process Dynamics by *E. B. Dahlin*, p. 406. Two methods similar to regression analysis are applied to the estimation of parameters in a dynamic process equation. One method uses a residual based directly on the differential equation for the process model. The second method forms the residual from the integro-differential equations derived by integration of the original differential equation with respect to time. The two methods are shown to be complementary in their sensitivity to process and measurement disturbances as well as to errors in the estimate of the process variable reference values. Certain parameters that are very sensitive with one method are shown to be much less sensitive with the other method. A combined method is developed which utilizes each one of the constituent techniques to estimate the parameter for which it has the highest accuracy. This not only permits identification with higher overall parameter accuracy, but also under many practical circumstances gives a convergent solution when one of the constituent methods would give a diverging solution having no practical value for updating control coefficients in an adaptive controller. It is shown that the estimate of the magnitude of a pole in a transfer function can be significantly improved by prefiltering the process input and output data with the same lowpass filter.

The paper presents a theoretical and experimental evaluation of the identification methods. Formulas are derived for the variances of the parameters permitting an estimation of the parameter accuracy in a particular test. The test data used has been collected from different control loops on paper machines. The disturbance level on some of the variables is very strong and a test signal-to-noise ratio as low as 0.5 can be encountered. The method is currently used in routine operation in adaptive paper machine control. It is in use on four control loops and has been tested on several other loops as well.

Sensitivity Constrained Optimal Control Synthesis by W. J. Budurka, p. 427. A constraint on the sensitivity to plant parameter uncertainties is introduced in the synthesis of optimal linear controls by adding a sensitivity function to a quadratic form performance criterion. The synthesis is carried out in the frequency domain using both conventional and Bode sensitivity functions; open-loop and closed-loop controls are of necessity treated separately because the sensitivity functions are different for each case. The optimal control based on the closed-loop Bode sensitivity is shown to satisfy a scalar Wiener-Hopf equation; the same type of equation is also satisfied by the optimal control based on the open-loop conventional sensitivity, but the response characteristics are different. Using the conventional closed-loop sensitivity, the optimal control is shown to satisfy an equation analogous to the Wiener-Hopf equation, but which is more difficult to solve because the control enters quadratically rather than linearly. Examples illustrate the application of derived results.

Synchronization of Traffic Signals in Grid Networks by A. Chang, p. 436. A method of synchronizing traffic signals interconnected in an arbitrary network is presented. The procedure consists of using a simplified mathematical model for traffic to relate the vehicular delay within the network to the signal parameters and then searching over these parameters to minimize the delay. The technique has been used to synchronize traffic signals in San Jose, California and has yielded a ten percent reduction in the average delay per car in comparison with the signal settings determined by the city traffic department with conventional engineering methods.

Design Principles for Sampled-Data Systems with Application to Attitude Control of a Large, Flexible Booster by L. A. Gilson, E. F. Harrold, and F. G. Kilmer, p. 442. This paper reviews Z-transform and W-transform theory and discusses in detail its application to dynamic compensation of linear sampled-data control systems. Both sampled-data (digital) and continuous-data (analog) compensator synthesis methods are discussed. With respect to digital compensator design, w -plane closed-loop pole positions are related to time response characteristics, analogous to the well known relationships between s -plane pole positions and time response parameters for continuous-data systems. An example is given which illustrates the design technique wherein time and frequency response characteristics are compared. A digital stabilization filter is derived for the attitude control system of a missile typical of the Saturn class.

A Computer-Operated Manufacturing and Test System by J. E. Stuehler and R. V. Watkins, p. 452. A computer system utilizing duplexed central processors and three types of satellite computer terminals has been developed for the control of manufacturing processes and product tests. The system was designed for use in a plant producing data processing

equipment. The prime objectives of the project were (1) to reduce the time required for the plant to accept new products or product changes, (2) to reduce control and test equipment costs by using standard control and test equipment, and (3) to improve product quality through more uniform processes and tests. The objectives were met by using small, stored-program computer terminals to control individual tests and processes. These terminals are connected to a central computer system which assists with data processing and serves as an input/output device for the terminals.

The design and implementation of the system occurred in two phases. During the first phase the stored-program test terminal, a high-speed data transmission system, and a multiplexer were designed and installed on an IBM 1460 Data Processing System. A programming system was developed concurrently with the hardware. This system included a real-time monitor and application and utility programs which were written for operation in a time-shared environment. During the second phase of development a process control terminal, a data acquisition terminal, and a new multiplexer for duplexing two 1460 Data Processing Systems were designed and implemented. Also developed were shared file control units, an improved transmission system, and programming designed to effectively utilize the power of two computer systems on a real-time basis.

Properties of Insulating Thin Films Deposited by RF Sputtering by W. A. Pliskin, P. D. Davidse, H. S. Lehman, and L. I. Maissel, p. 461. The use of RF sputtering for the deposition of thin insulating films at relatively low temperatures (50° to 500°C) has been shown to yield films of very high quality. Methods for investigating the properties of RF-sputtered films are discussed in detail, and these indicate that such films are excellent stable insulators. Potential utility as an encapsulant for transistor structures has been demonstrated. Data for RF-sputtered SiO₂ and GSC-1 (an alumina borosilicate glass) are presented as examples of the properties obtained by this technique.

The Magnetization Mechanism in Single-Crystal Garnet Slabs Near the Compensation Temperature by C. D. Mee, p. 468. The magnetization mechanism has been studied in detail in single-crystal slabs of (111), (110) and (100) samples of gadolinium iron garnet (GdIG) near the compensation temperature. Using Faraday-effect and induction-type hysteresisgraphs, the hysteresis loops have been measured in the sample plane and perpendicular to it, respectively. Measurements have been made at various temperatures, thus allowing the effects of variation of the saturation magnetization to be studied. In this way different relative magnitudes of shape and crystal anisotropy are obtained. Also, the effects of strain anisotropy variation are studied on the (111) sample. The hysteresis loops are correlated with the observed domain structures and a satisfactory theoretical model is described. Based on these studies, it is possible to estimate the approximate domain wall thickness and energy

in GdIG. Finally, an estimate of the exchange constant is made which is comparable with other estimates.

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Reverberation Chamber Determination of the Acoustic Power of Pure-Tone Sources by G. C. Maling, Jr. and K. S. Nordby, p. 492. A method was developed that is used to determine the acoustic power radiated by pure-tone and "nearly-pure-tone" sources in a reverberation chamber. The 3-dimensional standing wave sound field generated by a pure-tone source is sampled by a microphone that slowly sweeps a circular path in the chamber. The method relates the average value of the sound pressure at the peaks of the "sample" to its effective rms pressure. The acoustic power of the source is then readily calculated from the effective rms pressure, the volume of the chamber and its absorption.

The Electron Beam Scanlaser: Theoretical and Operational Studies by R. A. Myers and R. V. Pole, p. 502.

This paper presents the theory, design, and initially observed operating parameters of the Electron Beam Scanlaser, a scanning laser device in which a modified electro-optic display tube selects one of many degenerate transverse modes of a flat-field conjugate resonator. The version considered uses a KDP crystal in the mode selector and an ionized mercury hollow cathode discharge as active element. Some observations reported are resolution (10 lines/mm); sweep rate (100 μ sec/line); light decay time (2 msec, minimum); and power/spot (1W pulsed). Laser output power is about 30 dB greater than electron beam power.

Multiple-Curie-Point Capacitor Dielectrics by R. A. Delaney and H. D. Kaiser, p. 511. This paper reports an experimental study of the preparation of screened printed dielectric materials having high dielectric constants and a controlled temperature characteristic. The technique uses mixtures of sintered bodies which have different Curie points and which retain their identity after processing. Barium-strontium and barium-lead titanate mixtures have been prepared having a dielectric constant of about 500. This process has been used to produce negative-positive-zero, negative, and positive thermal coefficient bodies over various temperature ranges.

Two Interconnection Techniques for Large-Scale Circuit Integration by A. E. Brennemann, A. V. Brown, M. Hatzakis, A. J. Speth, and R. F. M. Thornley, p. 520. Studies of the feasibility of custom-interconnected, large-scale integrated circuits required the development of means for converting computer-generated wiring instructions into metallic conductors on a semiconductor wafer. The resulting equipment took two forms. In one, ultraviolet light serves to expose photoresists on a mechanically translated wafer; the other employs an electron beam. Both systems were adequate to produce two-mil-wide conductors, but differ in their potential for achieving high production rates or very thin lines.

Estimation of Temperature Rise in Electron Beam Heating of Thin Films by T.-P. Lin, p. 527. Expressions are given for estimating the transient temperature distribution in a thin film heated by an electron beam. Graphical presentations in terms of dimensionless (reduced) variables are included to aid in specific calculations for designing an electron beam for use as a heating tool.

A Numerical Integration Technique for Ordinary Differential Equations with Widely Separated Eigenvalues by M. E. Fowler and R. M. Warten, p. 537. An explicit nonlinear numerical integration method is presented for the solution of certain large systems of ordinary differential equations in which there is a large spread of time constants, the smallest one being real. The integration formulas are derived and some local truncation error data given for small step sizes. Some applications are discussed where the new technique saves considerable computation time over classical methods.

Power Conversion in Nonlinear Resistive Elements Related to Interference Phenomena by E. M. Philipp-Rutz, p. 544.

This paper derives the power conversion in a nonlinear resistive element that is in series with linear resistors. The derivation of the power conversion is analogous to the Manley and Rowe analysis. The power at the fundamental and intermodulation frequencies is defined as the product of the Fourier coefficients of the current and voltage components at these frequencies. In the analysis, the Fourier coefficients are derived as functions of the generator voltage in a lumped-element circuit. To evaluate the Fourier coefficients, the relationship between current and generator voltage is expressed by a power series. The coefficients of the power series are given in the form of polynomials that are valid for nonlinear resistive elements with exponential characteristics.

For the investigation of interference phenomena, the equivalence between the lumped-element circuit and a microwave circuit is derived and the generator voltage is related to the power flux density carried by the incident waves intercepted by support structures. The transfer of power at the intermodulation frequencies to radiating structures is then described. Finally, the power at the intermodulation frequencies is evaluated numerically for different power levels in the incident waves. The computed values were verified experimentally.

On the Equation $i = i_0 [\exp \alpha (v - Ri) - 1]$ by H. D. Mills, p. 553.

Domain Wall Energy Measurements using Narrow Permalloy Strips by J. M. Daughton, G. E. Keefe, K. Y. Ahn, and C.-C. Cho, p. 555.

Propagation of Signals in Nonlinear Transmission Lines by S. K. Mullick, p. 558. This communication reports the

results of a theoretical investigation of the propagation of signals in transmission lines whose nonlinear parameters are distributed capacitance and conductance. Such lines have their physical counterpart in lossless transmission lines that are loaded with closely spaced transistor bases or junction diodes, and in waveguides filled with certain ferroelectric ceramic materials. The analysis is carried out by conventional perturbation theory, and therefore the nonlinearities and dissipation are necessarily assumed to be small. The conditions for the formation of shock waves in such lines are also derived.

On the Magnetic Properties of Sputtered NiFe Films by B. L. Flur, p. 563. Reproducibility and control of magnetic properties have been significant problems in the preparation of Permalloy films by cathodic sputtering. The data presented in this paper illustrate the reduced sensitivity to gaseous impurities that can be achieved by applying a suitable negative bias to an 81% Ni-19% Fe Permalloy film that is being deposited by dc sputtering. Results are shown which compare the magnetic properties as a function of deposition rate achieved with and without a bias potential applied to the film during deposition. Data are also presented showing the effect of film bias on magnetic properties when known concentrations of oxygen and nitrogen are present in the atmosphere during deposition. The evidence shows that the effect of the bias is to reduce the quantity of system atmosphere impurity included in the film. The bias technique has permitted, with good reproducibility, accurate experimental determination of the effect of such control parameters as substrate temperature on magnetic properties. (Wall motion threshold H_0 , anisotropy field H_{k0} , and dispersion α_{90} are plotted as a function of substrate temperature.) In addition, data are shown which demonstrate the compositional control and simplicity of film thickness and deposition rate control which are inherent in the sputtering process.

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Some Computer Aspects of Meteorology by H. G. Kolsky, p. 584. A long history of large-scale scientific computing is associated with numerical weather prediction. Recently, interest in this field has been renewed as a result of international studies concerning the feasibility of a global observation and analysis experiment preliminary to the World Weather Watch. This paper describes the physical phenomena occurring in the atmosphere and the problems of modeling them for computer analysis. The numerical methods commonly used in general circulation models are described briefly and the relative advantages discussed. Finally, an analysis of the computer requirements for global weather calculations is developed and the need pointed out for very fast computers capable of executing the equivalent of hundreds of millions of instructions per second.

Some Studies in Machine Learning Using the Game of Checkers. II—Recent Progress by A. L. Samuel, p. 601. A

new signature table technique is described together with an improved book learning procedure which is thought to be much superior to the linear polynomial method described earlier. Full use is made of the so called "alpha-beta" pruning and several forms of forward pruning to restrict the spread of the move tree and to permit the program to look ahead to a much greater depth than it otherwise could do. While still unable to outplay checker masters, the program's playing ability has been greatly improved.

Similar Motion of Two-Degree-of-Freedom Nonlinear Vibrating Systems with Nonsymmetric Springs by K. E. Haughton, p. 618. If similar motion occurs, it is demonstrated by a straight line (linear trajectory) in the configuration space whose orthogonal coordinates are the displacements of the masses in the vibrating system. Since the systems considered are conservative, all solutions of the equations of motion must satisfy the Principle of Least Action and its Euler-Lagrange equation. The solution of this equation defines a trajectory in configuration space, thus reducing the problem to one of geometry.

If the trajectory is linear, the Euler-Lagrange equation assumes a simple form. The form is further simplified if the coordinates of the configuration space are rotated and translated so that one axis coincides with the linear trajectory. Hence, if linear trajectories exist, it is necessary that the equation can be so simplified; it is sufficient that the rotation and translation be real.

One application of this analysis is shown for the case of a system whose anchor springs are air bearings, as used in a disk store.

SCEPTRE: A Program for Automatic Network Analysis by S. R. Sedore, p. 627. This paper describes the mathematical formulation of a computer program for automatic transient analysis of electronic networks. The formulation is based on the "state-variable" approach to network analysis and differs from other such programs primarily in the way that the network equations are manipulated to produce a solution. SCEPTRE includes a number of features aimed at providing greater flexibility and convenience for users of the program. Important among these features is that no prescribed equivalent circuit for active elements is required for program operation. Also, linearly dependent voltage and current sources in a network can be handled by the program, and provision has been made to allow a free-form format for input data. The paper includes a discussion of the program's ability to solve networks containing time-varying passive elements, and considers the factors that influence program running time.

Synthesis of Transfer Functions in a Prescribed Frequency Band by W. R. Remley, p. 638. A signal-processing system for synthesizing complicated transfer functions in a prescribed frequency band is described. The system consists of a multiplier followed by a closed loop containing a delay line

and phase modulator in series. One of the inputs to the multiplier is the signal to be filtered. The second input to the multiplier is periodic, the period being equal to the loop delay. One cycle of the periodic waveform is identical to the real part of the transfer function over a prescribed frequency band of width equal to the reciprocal of the loop delay. The imaginary component of the transfer function is the negative of the Hilbert transform of the real part, as in all physically realizable filters. Two applications of the system are discussed. It is shown how a continuously variable delay line and chirp filter can be synthesized using these techniques.

Exposure Control in a Multi-Stage Photographic System
by J. W. Boone and H. S. Todd, p. 643. The use of controlled

exposure in microfilming original documents offers a practical method for producing high-contrast images at subsequent printing stages with constant exposure times. This type of control, used for the three-stage generation of images in a developmental photo-image retrieval system, has given excellent results for documents which have uniform line-density contrast. For variable contrast documents, an analysis of the variations and variable exposures used in microfilming is necessary. The details of the analysis are described in this paper.

Two Remarks on the Reconstruction of Sampled Non-Bandlimited Functions by C. J. Standish, p. 648.

The IBM SELECTRIC Composer: Philosophy of Composer Design by G. A. Holt, p. 3. The IBM SELECTRIC® Composer is a new kind of printing machine, much like a typewriter. This paper outlines the philosophy of design of the significant systems and mechanisms within the Composer and the primary elements needed to satisfy composition requirements, i.e., good print quality in a variety of classical type styles and sizes; variable vertical line spacing; justification; and an output of final copy that can be judged subjectively by printing experts and laymen alike.

The IBM SELECTRIC Composer: The Evolution of Composition Technology by A. Frutiger, p. 9. In this paper a discussion is presented on how the IBM SELECTRIC® Composer fits into the evolution of composition technology—from the calligraphers of the Middle Ages to the modern photocomposers. The advantages and limitations of the machine are discussed briefly with emphasis being placed on their meaning for the typographer.

The IBM SELECTRIC Composer: Letter Keyboard by B. T. Crutcher and D. E. Sederholm, p. 15. This paper describes the design of the letter keyboard for the IBM SELECTRIC® Composer. The design requirements were to provide an information transfer mechanism not only for character selection using the SELECTRIC Typewriter printing system, but also for proportional escapement selection and print impact velocity control. The keyboard was required to be exceptionally reliable, to have the positive SELECTRIC Typewriter touch characteristics, and to be consistent with the keyboard layout standards that are familiar to the operator or typist.

The keyboard that has been developed has a completely serial operating sequence. Each event in a sequence is positively latched as it occurs, and remains latched until its function is completed. This insures reliable information transfer without compromising speed or input-signal storage capability.

The IBM SELECTRIC Composer: Type Font Compatibility by H. Pijlman, p. 26. Because of the large number of type fonts required to support the IBM SELECTRIC® Composer program, it would not have been economical to manufacture separate type elements for each country in which the machine would be marketed. Also, because the total of the standard alphanumeric characters and the typical basic language requirements for all countries is much greater than could possibly be fitted on the Composer's 88-position type element, special Composer fonts had to be developed for various language group classifications. This paper describes the SELECTRIC Composer's development from a single-language system to a multilingual concept and details the problems involved in achieving compatibility, and thus type font interchangeability.

The IBM SELECTRIC Composer: Dead Key and Dead Key Disconnect Functions by G. E. Siemer, p. 32. Because diacritical marks are needed for the Latin and French-Latin type fonts, the IBM SELECTRIC® Composer required a means for printing certain characters without carrier escapement. This note discusses the "dead key" and "dead key disconnect" functions designed to fulfill this requirement.

The IBM SELECTRIC Composer: Mechanical Print Quality by G. T. Slaughter, p. 34. The design of an impact printing device (one which produces aesthetically pleasing copy) must include an optimal combination of mechanical design and supplies (ribbon and paper). This paper describes the evolution of design for both mechanisms and supply parameters which has led to the present standards of mechanical print quality in the IBM SELECTRIC® Composer.

The IBM SELECTRIC Composer: Statistical Evaluation of Printing Alignment by M. Prewarski, p. 41. This paper describes the measurement and evaluation of print alignment for the SELECTRIC® Composer, and discusses the suitability of statistical techniques for achieving both. This paper deals extensively with techniques and procedures for collecting data; however, it is not intended to define a generalized method for statistical evaluation. Printing alignment is shown to be described objectively and precisely by the distribution of measured misalignment; misalignment is precisely defined.

The IBM SELECTRIC Composer: Proportional Escapement Mechanism by B. W. Miles and C. C. Wilson, p. 48. The IBM SELECTRIC® Composer's escapement system employs rotating elements, rather than the conventional rack system, to provide the required displacement. This permits the basic unit of escapement to be varied, and allows the number of units per escapement cycle to vary in proportion to character width. In this paper the authors discuss the machine requirements that led to this approach and describe the elements that have evolved. The analysis used to evaluate the design (and modify it to some extent) is also recorded, in a separate section.

The IBM SELECTRIC Composer: Memory Backspace by C. N. Van Avery, p. 60. This paper describes the design of the memory backspace system as it now appears in the IBM SELECTRIC® Composer. The memory backspace system employs a sensing pawl mechanism in conjunction with the escapement pinwheel and the unit backspace mechanism to provide character-by-character backspace capability. By sensing set pins on the pinwheel, the mechanism "remembers" the location of previously typed characters and permits the carrier to be returned precisely to any print position within the memory "length" without operator measurement or visual alignment.

The IBM SELECTRIC Composer: Development of the Rebound Governor by N. Cail, p. 65. Rebound of the escapement system of the SELECTRIC® Composer after

escapement is limited by the rebound governor, a device consisting of an overrunning clutch and a mass that is coupled to the system only during rebound. The development of the rebound governor is described in this paper and its effect on the escapement system is shown by oscilloscope traces of system displacement versus time.

The IBM SELECTRIC Composer: Justification

Mechanism by J. S. Morgan and J. R. Norwood, p. 68. This paper describes the development and design history of the SELECTRIC® Composer justification mechanism. The authors present a brief definition of justification and how it relates to the printing industry; the requirements imposed upon a justification device that are peculiar to the SELECTRIC Composer; a description of the justification mechanism and its design, development and testing; and a final evaluation of the design relative to the attainment of its designated objectives, both as a mechanism and as a component of the SELECTRIC Composer.

The IBM SELECTRIC Composer: Multiple Index

Mechanism by R. D. Mathews, p. 76. When high-quality printed copy is desired, the ability to use variable styles of type in one printing system is a fundamental requirement. This feature has existed to a limited extent for some time in low-cost, cold-type printing equipment and typewriters, and has been notably realized in the changeable typehead of the IBM SELECTRIC® Typewriter. The ability to vary type size, however, is rarely found in such systems and has been restricted for the most part to commercial hot-type equipment or to manual methods. To remove this restriction in the IBM SELECTRIC Composer, it was necessary to design an index mechanism which would provide variable line-to-line increments. Increment selection was to be flexible enough to accommodate several sizes of type, but it had also to be reliable and easily controlled by the operator. The design which has resulted and is described in this paper is a dual-ratchet, planetary gear system. Platen increments of from 5 to 20 "points" can be selected, and the platen can be indexed manually one point at a time. Other features are also provided, including a "carriage-return, no-index" which permits changing styles on the same line of type without manual "rollback."

The IBM SELECTRIC Composer: Carbon Ribbon Feed

Mechanism by J. W. Spears and J. C. Rogers, p. 87. High quality impact printing requires that a sufficient supply of printer ink be presented to the print element for each character. It is also required that this supply of ink last for a reasonable length of time. To enable the IBM SELECTRIC® Composer to meet the standards considered necessary under these criteria, it was necessary to increase the character yield per ribbon by a factor of two over that which was provided by the IBM SELECTRIC Typewriter. To do this a new constant ribbon tension control device had to be designed to eliminate the inertia and geometry effects associated with the

larger composer ribbon spools. It was also necessary to eliminate ribbon feeding on no-print or spacebar operations and to provide various load controls.

Force-Frequency Coefficient of Singly Rotated Vibrating Quartz Crystals by J. M. Ratajski, p. 92.

Frequency perturbations in vibrating quartz crystals, caused by externally applied forces, have been investigated for some time. The parameters affecting the force-frequency sensitivity were recently established and evaluated, making possible the derivation of a normalized coefficient K_f . An empirical chart, showing the coefficient K_f for all singly rotated crystals, $(yx\ell)\theta$, is presented for all directions of force in the azimuth angle ψ . The maximum force-frequency coefficient is found to be $|K_f| \approx 30 \times 10^{-15} (msN^{-1})$ for angles $\theta = +17^\circ, +26.5^\circ$ and $+64^\circ$. A crystal cut $(yx\ell) - 18.5^\circ$ shows a constant coefficient $K_f = +5.3 \times 10^{-15} (msN^{-1})$ for all angles of ψ . Coefficients $K_f(\psi)$ for BT-, Y- and AT-cut crystals are also shown on separate graphs.

The force-frequency behavior of every crystal cut in the singly rotated Y-cut group can be determined from the chart. The chart is a useful tool for the design of frequency standards and precise force-sensing elements. More significantly, the chart provides normalized experimental data to form a basis for a theoretical treatment of the force-frequency effect.

Some Magnetic Properties of Vacuum-deposited Coupled

Films by K. Y. Ahn and J. F. Freedman, p. 100. The magnetic properties of vacuum-deposited multilayer films constructed in a closed-flux configuration in an integrated structure have been studied as a function of: a) film thickness; b) substrate temperature, and c) the character of the conductor metals. It is found the static magnetic properties of the magnetic layers depend on the material in the previous layers as well as the thickness and deposition temperature of those layers. Techniques of optimizing and controlling the magnetic properties are discussed.

Shear Stresses in a Notched Circular Disk by T.-C. Ku, S. S. So, and W. E. Nickola, p. 110.

The Resonistor: A Frequency Selective Device Utilizing the Mechanical Resonance of a Silicon Substrate by R. J.

Wilfinger, P. H. Bardell, and D. S. Chhabra, p. 113. This communication describes an approach to tuned monolithic circuitry which utilizes the mechanical resonance of a silicon substrate. The proposed device is compatible with monolithic technology and will operate from a few hundred cycles to hundreds of kilocycles. The basic device consists of a silicon cantilever mechanically deflected by electrically induced thermal expansion. Diffused silicon piezo-resistive elements are used to detect stress in the cantilever and provide an electrical output. Maximum stress and electrical output occur when the cantilever is driven at its mechanical resonant frequency.

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Method for Estimation and Optimization of Printer Speed Based on Character Usage Statistics by *E. B. Eichelberger, W. C. Rodgers, and E. W. Stacy*, p. 130. Many high-speed printers now in the field and under development use a constantly moving chain or train containing the characters required in the printing process. Generally they skip to the next line whenever the last character on a given line is printed. Since individual character usage varies widely, it may be possible to increase the printing speed by repeating high-usage characters more frequently on the chain than low usage ones.

This paper presents an analytic method of accurately estimating the printing speed of a chain printer for any character arrangement and describes a technique for determining the number of copies each character should have on the chain so that the printer will operate at or near maximum speed. Using these methods, significant increases in printing speeds have been obtained for actual applications.

Polymer Dielectric Films by *L. V. Gregor*, p. 140. Polymer dielectric films, ranging in thickness from less than 100 Å to several microns, have become increasingly useful for basic investigations of surface phenomena and thin film electrical conductivity and for thin film electronic device and circuit development. The preparation and characterizing properties of thin polymer films are discussed with particular emphasis on recent developments in such areas as ultraviolet surface photolysis, electron bombardment, gaseous electrical discharge, and special chemical processes. Previously unpublished data on certain aspects of polymer dielectric films are presented, and present and potential applications are briefly reviewed.

Computer Algorithm for Spectral Factorization of Rational Matrices by *W. G. Tuel, Jr.*, p. 163. An algorithm is derived for the numerical spectral factorization of matrices arising in optimal filter design. The method uses a bilinear transformation to convert the factorization problem into a stable nonlinear difference equation of the Riccati type. The computer solution of several examples is presented to illustrate the technique.

Automatic Focus Control of Charged-Particle Beams by *M. H. Dost*, p. 171. The focusing mechanism for charged-particle beams is analyzed and its mathematical model is derived. Two control concepts for focusing electron beams are shown and the details of the feedback system for automatic focus control in the electron-beam recorder of an IBM photo-digital mass storage system are described (Fig. 9). Included are a representation of the mathematical system and the computer simulation results obtained from the digital simulation program DSL/90.

Application of Finite Geometry in File Organization for Records with Multiple-Valued Attributes by *S. P. Ghosh*

and *C. T. Abraham*, p. 180. The schemes for organizing binary-valued records using finite geometries have been extended to the situation in which the attributes of the records can take multiple values. Some new schemes for organizing records have been proposed which are based on deleted finite geometries. These new schemes permit the organization of records into buckets in such a manner that, by solving certain algebraic linear equations over a finite field, it is possible to determine the bucket in which records, pertaining to two given values of two different attributes, are stored. Since the bucket identification required for the storage of record accession numbers is based on the combination of attribute values, the file does not require any reorganization as new records are added. This is a definite advantage of the proposed schemes over many key-address transformation procedures wherein the addition of new records may lead to either a drastic revision of the file organization or significant reduction of retrieval effectiveness. The search time for the new schemes are very small in comparison to other existing methods.

The Study of Laser-induced Absorption of a Secondary Light Beam in Molecular Liquids and Solutions by *M. W. Dowley and W. L. Peticolas*, p. 188. New techniques are shown for determining the change in absorption spectrum of molecular liquids when a laser beam is passed through the sample. Two-photon absorption measurements are shown for α -chloronaphthalene. The experimental arrangement (Fig. 3) features a high signal-to-noise ratio and permits study of explicit time dependence of the absorption signal.

Reflectivity Thickness Corrections for Silicon Dioxide Films on Silicon for VAMFO by *W. A. Pliskin and R. A. Wesson*, p. 192.

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Computation of Molecular Properties and Structure by *A. D. McLean and M. Yoshimine*, p. 206. A discussion of general-purpose computer programs in theoretical chemistry is given, followed by a description of the procedures adopted in one such program written by the authors. Specific details on the use of the program for computing molecular wave functions and properties for closed-shell linear molecules are presented. The details of a method for computing the axial components of the static electric polarizability and shielding factor tensors are given. A "Table of Linear Molecule Wave Functions" is available, on request to the authors, as a supplement to the paper. This tabulation was made with the program described in the paper and is the most extensive compilation of molecular wave functions currently available.

Redundant Alphabets with Desirable Frequency Spectrum Properties by *E. Gorog*, p. 234. When alphabets of digital symbols are used to represent information for data processing, storage, and transmission, redundancy in the alphabets is traditionally used for the purpose of error compensation. This paper deals with alphabets of redundant codes, both binary

and higher level, where the emphasis is on using redundancy to produce code alphabets with unique properties in their frequency spectra that can be exploited in the design of the system in which they are used.

In particular, techniques are presented for synthesizing alphabets that produce spectral nulls at frequencies $1/kT$, where T is the duration of a word element. Some of the interesting alphabets are a 10-word, 5-bit alphabet with spectrum zero at $1/2T$; a 10-word, 6-bit alphabet with spectrum zero at $1/3T$; a 36-word, 8-bit alphabet with zero at $1/4T$; and a 36-word, 8-bit alphabet with zeros at both 0 and $1/2T$.

A Two-Dimensional Mathematical Analysis of the Diffused Semiconductor Resistor by D. P. Kennedy and P. C. Murley, p. 242. A two-dimensional mathematical analysis is presented of the electrical properties of the diffused semiconductor resistor. An important conclusion is that substantially more electric current crowding exists within this semiconductor device than heretofore suspected, particularly in the vicinity of the ohmic contacts. Considered in this analysis is the influence on the electrical characteristics of various impurity atom distributions arising from a two-step diffusion process. The results of this investigation are presented graphically.

High-resolution Positive Resists for Electron-beam Exposure by I. Haller, M. Hatzakis, and R. Srinivasan, p. 251. This paper examines the utility of four newly proposed positive resists whose processing combines electron-beam-induced degradation of certain polymers and, subsequently, *in situ* fractionation according to molecular weight. Positive-resist action in four systems formulated on this concept has been demonstrated. Typical sensitivity in electron-beam exposure is 10^{-4} coulomb/cm². Two resists exhibit resolution better than 1 micron. One resist investigated in detail yields extremely clean edges in electron-beam exposure, is resistant to hydrofluoric acid etching baths, and appears otherwise applicable to the fabrication of circuit elements of submicron size.

Effects of Lasers on the Human Eye by W. L. Makous and J. D. Gould, p. 257. In dealing with the relationship between human vision and lasers, this largely theoretical paper places particular emphasis upon the use of lasers within the normal operating range of the visual system, and upon the mechanisms by which laser radiation can cause threshold damage to the eye. Parallel but subordinate sections present some fundamentals of laser radiation, of the relevant aspects of the visual system, and of unit systems for the specification of laser output. A new approach to understanding laser radiation damage to the eye is developed by means of a model limited to conditions existing only at the threshold of damage. It is shown that such threshold damage to the visual system is primarily due to the effects of heat alone, but that photochemical effects and acoustic shockwaves can potentially be a cause of the threshold damage that cannot be

entirely rejected under all conditions. A theoretical estimate of retinal irradiance for threshold damage is made and shown to be consistent with empirical findings. A survey of empirically determined damage thresholds is presented. A valid method of computing retinal irradiance from a laser is given, and the direction and magnitude of errors in earlier formulations are pointed out.

Room Temperature Delay Times in Diffused Junction GaAs Injection Lasers by J. C. Marinace and K. L. Konnerth, p. 272. One nanosecond room temperature delay times at current levels slightly above threshold have been obtained in GaAs injection lasers using a two step diffusion process. Copper contamination is found to leave the delay time unchanged, but increases the rise time.

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Automatic Dynamic Response Analyzer by P. E. Stuckert and G. F. Bland, p. 286. The Automatic Dynamic Response Analyzer (ADRA) is a laboratory tool for developing improved methods of characterizing and measuring the dynamic performance of integrated circuit logic packages. ADRA consists of ensembles of computer controlled electronic equipment which provide a suitable electrical environment for the logic unit under examination, subject the unit to appropriate patterns of shaped pulses, measure and digitize the input/output waveforms, and process the resulting data. This paper describes the ADRA system, its organization and hardware characteristics, and an example of its use.

An Application of the Automatic Dynamic Response Analyzer by K. Maling and H. D. Schnurmann, p. 300. An experiment to obtain the coefficients of a circuit delay equation was designed and implemented on the ADRA/M44 system in order to gain experience in the system's use. The process involves automatic calibration and diagnostic procedures, data collection under computer control and multivariate regression analysis. Some conclusions are drawn about the planning and use of computer controlled instruments such as ADRA.

A Balanced Capacitor Read-Only Storage by S. A. Abbas, J. K. Ayling, C. E. Gifford, R. G. Gladu, T. C. Kwei, and W. J. Taren, p. 307. The design of a control storage system of 90 nsec access time and 200 nsec cycle time with permanently stored microinstructions is described. The storage medium used is the capacitive coupling between two groups of orthogonal conductors forming an information plane and a sense plane. There are 2816 words of 100 bits each, divided over two gates. The selection of an address line in the information plane is achieved through a transistor selection matrix. The output signal is sensed differentially at the mid-point of the sense line, which is matched at both ends. The sense amplifier output plus a "strobe" pulse set a latch for a portion of the cycle time and this provides the necessary inputs to the central processing unit. The major contributions

to noise, such as sneak-path noise and select noise, are discussed and evaluated. The timing of the different pulses necessary to drive the array and the resulting outputs are explained and the marginal effects of time and amplitude variations are considered. Information can be changed off-line by replacing bit planes. Transcription of information in the bit planes is fully automated and can be speedily accomplished.

A New Technique for Wide-Band Video Recording by *W. T. Frost and C. T. Masters*, p. 318. An efficient means for distributing the information contained in a wide-band analog signal over two limited bandwidth channels is provided by using frequency modulation and "zero-crossing counting." The new technique should accommodate at least twice the bandwidth that can be recorded or transmitted by the usual FM methods. Experimental results with a two-channel magnetic tape system confirm this expectation.

Pressurized High-Speed Development of Diazo Films by *J. W. Boone and R. B. Mulvaney*, p. 323. The combination of a new high-speed process and developer unit which uses pressurized anhydrous ammonia gas offers a significant increase in the speed of developing diazo photomaterials. In addition to being up to 100 times faster than conventional ambient-pressure ammonia development processes, the new process and developer provide both flexibility and uniformity of sensitometric characteristics.

The unpleasant odor and corrosive character of ammonia gas required a means for positively sealing the film surface to the processing device and a means for disposing of residual ammonia gas remaining in the device at the end of the processing cycle. A developer platen, designed to meet these needs, also achieves uniform image development by utilizing the entering flow of ammonia gas to wash entrapped ambient air from the film surface and into a small reservoir. The process and its relatively simple hardware have been incorporated into an experimental photo-image converter to provide "on-line" input and output of photo-images from a random access image file. The process and a wash-type developer are used in the IBM 9950, 9954 and 9955 diazo aperture card copiers.

An Application of the Cooley-Tukey Algorithm to Equalization by *B. Meister*, p. 331. A new method is proposed to determine the tap settings of a delay-line filter for distortion correction of digital data after transmission by a voice line. The procedure described achieves approximately the optimal tap settings by solving a system of linear equations with a circulant matrix of coefficients. When the fast Fourier transform algorithm of Cooley and Tukey is used, the resulting quantity of computations is considerably smaller than in other known methods. Therefore, much faster equalization can be achieved.

Implicit Implementation of the Weighted Backward Euler Formula by *H. H. El-Sherif*, p. 335. This communication describes how the weighted backward Euler formula, as applied to analyze electromechanical systems, can be implicitly implemented by replacing capacitors and inductors by resistors and voltage or current sources, respectively, and by replacing the driving functions by their first differences. This replaces the set of differential equations, which describes the capacitive voltages and the inductive currents, by a set of algebraic first difference equations.

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The IBM 1975 Optical Page Reader Part I: System Design by *R. B. Hennis*, p. 346. The IBM 1975 Optical Page Reader, specially built for the Social Security Administration, reads over 200 fonts from quarterly employer reports printed by electric and manual typewriters, business machines, and high-speed printers. Since the SSA has no control over the means used by employers to prepare the reports, many variations in print quality are present. This paper discusses the problems involved in planning and developing a system to read these reports and summarizes the design of the specialized video signal processing circuits and the character recognition logic that are used in the system. Two companion papers treat the latter topics in more detail. Also discussed in the paper is a management information system that permitted detailed analysis of experimental data and accelerated the development process.

The IBM 1975 Optical Page Reader Part II: Video Thresholding System by *M. R. Bartz*, p. 354. An adaptive video thresholding system is used in the Page Reader to minimize recognition failures due to contrast and line width variation. The main threshold operator is a linear function of the average contrast over a specified area. Adjustments to the threshold level are made by circuits that compute the average line width in a character, and by circuits that filter out spatial noise in the vicinity of the character. The different types of print quality distortions predominant in typewriter printing and business machine printing are handled by switching between different sets of threshold operators.

The IBM 1975 Optical Page Reader Part III: Recognition Logic Development by *D. R. Andrews, A. J. Atrubin, and K.-C. Hu*, p. 364. The design approaches which were used to specify feature measurement logic, recognition reference standards, and decision functions for a multifont character recognition system are discussed. The importance of an intuitive approach to design, as opposed to a fully automated approach, is emphasized. The nature of the problem required an intimate interaction between the designers, who investigated complex pattern recognition problems and proposed design alternatives, and the computer, which relieved the designer of routine testing and evaluation of the tentative design.

Time-Optical Control of a Moving-Coil Linear Actuator by C. J. Brown and J. T.-S. Ma, p. 372. The time-optimal control problem for a moving-coil linear actuator has been worked out by means of functional analysis and a related graphical procedure requiring only data from an impulse response. On the basis of experience with a test model, there is good correlation between the theoretical and the experimental methods. While the latter is accurate over only very short distances, the usefulness of the technique can be extended as needed by operating the system in piecewise linear fashion. The nonlinearity of the coil inductance can be handled under computer control by including in the program the inductances for successive segments of travel.

Development of the IBM Magnetic Tape SELECTRIC Composer by D. A. Bishop, R. S. Heard, R. E. Hunt, J. E. Jones, and R. A. Rahenkamp, p. 380. The IBM Magnetic Tape SELECTRIC® Composer (MT/SC) is a direct-impression (or "cold-type") typesetting system that combines the recording capabilities and automatic operation of the Magnetic Tape SELECTRIC Typewriter with the proportional spacing, justification and multiple-type-size features of the SELECTRIC Composer. Intended to permit high-volume, high-quality composition at moderate cost for users of offset printing methods, its design and development are described in this paper.

On the Measurement of Impurity Atom Distributions in Silicon by the Differential Capacitance Technique by D. P. Kennedy, P. C. Murley, and W. J. Kleinfelder, p. 399. A mathematical analysis is presented on the measurement of an impurity atom distribution in silicon by the differential capacitance technique. This analysis shows some inherent errors that can arise when the technique is applied to material containing a small impurity atom density. An important conclusion is that the differential capacitance measurement establishes the distribution of majority carriers, rather than the distribution of impurity atoms; therefore this measurement technique is applicable only in regions of semiconductor material exhibiting charge neutrality.

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Error Detection and Correction in a Photo-Digital Storage System by I. B. Oldham, R. T. Chien, and D. T. Tang, p. 422. An error-correction system has been implemented for data stored in the IBM Photo-Digital Storage System. Hardware is used for encoding and error detection, and a processor-controller is used, on a time-sharing basis, for error correction. A Reed-Solomon code is used to obtain a very low error rate in spite of flaws affecting the recorded bits. This approach is applicable to systems which require complex codes and have a data processor available on a time-sharing basis.

Small-signal Stability Criterion for Electrical Networks Containing Lossless Transmission Lines by R. K. Brayton,

p. 431. A stability criterion is derived for networks containing lossless transmission lines as well as the usual lumped electrical elements. The criterion is stated in terms of the transmission line parameters and scattering matrix measurements made at the terminals of the lumped part of the network. The mathematical proof of the stability theorem involves some new results concerning a special system of difference-differential equations. Another stability criterion is derived in terms of more general input-output measurements.

Calculation of Liquid Droplet Profiles from Closed-Form Solution of Young-Laplace Equation by T.-C. Ku, J. H. Ramsey, and W. C. Clinton, p. 441. A closed-form solution is obtained for a two-dimensional version of the Young-Laplace equation governing the shape of the interface between immiscible liquids. This solution enables designers of liquid junctions (in, for example, soldering or ink printing applications) to calculate profiles using certain junction dimensions as boundary conditions in the equations. Calculated profiles are superimposed on silhouettes of liquid junctions to show the accuracy of the solutions ($\pm 5\%$). The paper also introduces a parameter called the coefficient of retardation which was found convenient in accounting for all the factors that permit variable contact angles to be observed in a given solid-liquid-air system.

X-ray Diffraction Topography of Germanium Wafers by A. P. Segmüller, p. 448. X-ray diffraction topography in transmission and reflection has been employed to analyze crystal faults and stresses in germanium wafers caused by deposition of oxide layers, epitaxy and planar diffusion. Localized diffusion of arsenic, gallium and phosphorus normally does not introduce stresses sufficiently high to generate dislocations in germanium (011) wafers. However, heat treatment of germanium wafers covered with a SiO_2 film causes high stresses which are often relieved by plastic deformation.

Photo-*n-p* Junctions in ZnTe by F. F. Morehead and B. L. Crowder, p. 458. We have demonstrated ZnTe devices with efficient (about 1%) light emission at 77K in which the injection mechanism is a forward-biased photo-*n-p* junction. In one, Al and Cd are diffused into highly *p*-type ZnTe:P to produce an Al-doped region 70 μm deep with a 20 μm surface layer of average composition $\text{Zn}_{0.6}\text{Cd}_{0.4}\text{Te}$. Light emission (575 nm) is observed for 2.5 V. Similar results are obtained when Al alone is diffused in from an evaporated layer to a depth of about 50 μm . This latter device was earlier thought to operate by avalanche injection. Both structures with In contacts to the Al layer give open-circuit photovoltages of over 1.8 V at 77K. The all-ZnTe device, however, requires over 7 V to sustain light emission. While it is possible that efficient ZnTe devices made by vapor diffusing the Al are avalanche injection structures, efficient avalanche injection in a II-VI device has yet to be conclusively demonstrated.

Algebraically Generalized Recursive Function Theory by *H. R. Strong, p. 465*. The Uniformly Reflexive Structure (URS) introduced by E. G. Wagner is, for this paper, a nonassociative algebra consisting of a domain and a binary operation satisfying the following axioms:

$$0. (\exists*)(\forall a)[a \cdot * = * \cdot a = *];$$

$$1. (\exists\psi)(\forall a, b, c, d)$$

$$\times [\psi \neq * \& ((a \neq * \& b \neq * \& c \neq * \& d \neq *) \rightarrow$$

$$((a = d \& (((\psi \cdot a) \cdot b) \cdot c) \cdot d = b) \text{ or}$$

$$(a \neq d \& (((\psi \cdot a) \cdot b) \cdot c) \cdot d = c)); \text{ and}$$

$$2. (\exists\alpha)(\forall b, c, d)[\alpha \neq \psi \& ((b \neq * \& c \neq * \& d \neq *) \rightarrow$$

$$((\alpha \cdot b) \cdot c \neq * \& ((\alpha \cdot b) \cdot c) \cdot d = (b \cdot d) \cdot (c \cdot d))].$$

Wagner showed that these structures generalize much of Recursive Function Theory (RFT).

In this paper the functions "computed" by a URS are the functions given by left multiplications by elements of the URS. A family of functions is said to form a URS if it is the family of left multiplications of some URS. Axioms for Basic Recursive Function Theory are given characterizing those families of functions which form URS's. The Partial Metarecursive Functions and the Computable Functionals of McCarthy are shown to form URS's.

An investigation of notions analogous to the "recursively enumerable" notion in RFT shows that if any splinter ("successor set") of a URS is semicomputable, then all are. A partial analogue to the Rice-Myhill-Shapiro Theorem is proved for URS's satisfying an axiom corresponding to Kleene's "indefinite description." Finally, a study of pairing

functions leads to work analogous to Rogers' on Gödel numberings and generalizes similar work of Wagner.

Design and Fabrication of Subnanosecond Current Switch and Transistors by *V. A. Dhaka, p. 476*. A junction-isolated integrated circuit in silicon is described, having a switching speed of 320 picoseconds in a package which by itself causes a 120 ps delay. The design of the transistor used in this circuit was obtained by simulating the transistor as a computerized, two-dimensional distributed model. The improvements required in the transistor technology were thus predetermined and the design was realized without a large number of iterations. It is shown that the primary parameters affecting the performance of the transistor are (a) mobile carrier storage in the emitter-base junction; (b) emitter crowding; (c) stretching of the base into the collector at high forward-current densities and (d) conductivity modulations in the active base region. The resulting transistors have a cut-off frequency of 7.15 GHz at $V_{CB} = 2$ V and $I_C = 20$ mA. The total number of impurity atoms forming the emitter and the base region are 5.57×10^9 and 5.7×10^5 , respectively.

New Annealing Effects on the Bulk Corrosion Potential of Germanium by *R. Gereth and M. E. Cowher, p. 483*. The corrosion potential (U_k) of *n*-type Ge with donor concentrations less than 10^{18} cm^{-3} was drastically changed (" ΔU_k effect") by heat treatments between 600 and 800°C. The formation of recombination centers due to Cu contamination is probably the principal cause.

Foreword by J. D. Swalen, p. 2.

Computer-operated X-ray Laboratory Equipment by H. Cole, p. 5. Many instruments in research laboratories are now operated under varying degrees of computer control, not merely to accumulate and store data, but to obtain information about the sample sooner. The need for the scientist to interact with the computer is then as important as the instrument-computer interaction. This requirement leads to strong differences in implementation between laboratory automation and process control, and also suggests that the scientist must consider his over-all information needs as well as his instrument needs. A control computer shared by several people doing x-ray diffraction and fluorescence work is used as an example to illustrate some of these aspects of laboratory automation.

Automation of a Wide-range, General-purpose Spectrophotometric System by P. M. Grant, p. 15. The application of an IBM 1800 computer to the control and data acquisition functions of a wide-range spectrophotometric system is described. The optical part of the system is designed primarily for solid-state spectroscopy in the reflectance mode, the energy range of interest being roughly 1 to 12 eV (10^4 to 10^5 cm⁻¹). The operations of the computer include regulation of the wavelength setting, determination of the system gain, analog-to-digital conversion of the output signal, and positioning of the sample and detector. Two experimental configurations are employed, depending on whether or not the sample and detector are to remain stationary or to be repositioned during a run. The former holds for electrophotometry, fluorescence, and photoconductivity studies, while the latter pertains to ordinary reflectance and transmittance measurements. The principal advantage to be derived from on-line computer control of such experiments, besides more rapid accumulation and reduction of data, is the improvement in signal-to-noise ratio by averaging many repetitive scans over the same energy range. The emphasis in this paper is on the software used to implement these operations.

New Research Techniques for the Life Sciences by G. D. McCann, p. 28. A data collection and analysis system, using a high-speed, general-purpose digital computer, has been developed at the California Institute of Technology and applied to the study of visual processes of pattern recognition in living nervous systems. The experimental technique employs a rapid, flexible method of neural network modeling that permits an analysis of network functional behavior and a comparison with experimental data. Some details are given of research on neural activity in the visual system of the insect order *Diptera*.

Computer-assisted Spectroscopy by B. Johnson, T. Kuga, and H. M. Gladney, p. 36. The logical and timing

requirements and the control circuitry of spectrometers in all energy ranges, chromatographs, scanning interferometers and microdensitometers, and a large class of related experimental apparatus are very similar. From the standpoint of on-line computation and control, they can be considered parametric variations of a single experiment. With a magnetic resonance spectrometer as an example, we describe briefly the central, common elements of the necessary computer-instrument interface and of adequately flexible and open-ended control programs. Some examples of results follow.

Combination of On-line Analysis with Collection of Multicomponent Spectra in an On-line Computer by N. P. Wilburn and L. D. Coffin, p. 46. A digital computer has been interfaced to four 256-channel analyzers. All functions of normal multichannel analyzers have been reproduced by suitable coding. In addition, a weighted least-squares method for estimating on line the contribution of individual radionuclides in a multicomponent pulse height spectrum has been incorporated. Details of the mathematics and coding methods, which include special modifications to an existing FORTRAN system for on-line use, are described.

An Interactive Graphics System for Nuclear Data Acquisition by J. Birnbaum, T. Kwap, M. Mikelsons, P. Summers, J. F. Schofield, and F. Carrubba, p. 52. The graphics terminal described was developed for low-energy nuclear-physics data acquisition and control, and is currently in use at the Yale University Wright Nuclear Structure Laboratory as part of an IBM System/360 Model 44-based system. It is comprised of dual cathode ray tube displays, a light pen, and function keyboard, and includes character generation, display simulation, and photographic facilities. It is capable of plotting 200,000 points per second with variable intensity. The display programming structures, which support highly interactive communication between physicist and computer, are discussed in detail. A data acquisition programming system permits the creation and manipulation of self-describing global data and display entities. Examples of the resultant increased experimental sophistication and efficiency are presented.

Simulation and Experimental Research by J. J. Byerley and T. Z. Fahidy, p. 61. The usefulness of computer simulation in interpreting and extending experimental information is presented via a practical example taken from the area of chemical metallurgy.

Computer Facilities for the Laboratory by T. R. Lusebrink and C. H. Sederholm, p. 65. Digital computers have become indispensable aids for many laboratory disciplines, allowing the performance of experiments which would be infeasible without the aid of a computer. Until recently, these computations have usually been carried out off-line, i.e., experimental data has been acquired in real time and subsequently processed on a large central computer. Small, relatively inexpensive digital computers first entered the

laboratory as a substantial aid in real-time acquisition of data and control of experiments. Such computers, however, suffer severe limitations with regard to ultimate processing of the data. Hence the data processing must still generally be done on a large computer.

To realize the full potential of computer-instrument interaction, one should use the computer to: acquire data while performing requisite control of an experiment; calibrate, reduce, and compare the data with files of known physical parameters or theoretical calculations; and finally, produce desired reports and documentations of the experiment. In order to obtain results soon enough to effect the next experiment, i.e., in minutes, or at most, tens of minutes, all of the foregoing steps should preferably be carried out in a single computer.

Fulfilling all of these needs requires a computer too large and expensive to be dedicated to most single experiments. Therefore, a computer shared among several instruments is required. A computer system which simulates the independence of small dedicated computers, but which is also capable of performing medium- to large-scale computations when they are required, is most desirable.

Of course, many of these statements are controversial, and in order to investigate the validity of this approach an experimental computer system has been designed and implemented specifically for automation of multiple laboratory instruments in a time-shared mode. Experience gained from the simultaneous operation of a mass spectrometer, a nuclear magnetic resonance spectrometer, and two gas chromatographs is presented. The application programs and some proposed augmentation of these programs are also discussed.

Use of a Time-sharing Computer in Nuclear Chemistry by J. Fryklund and W. Loveland, p. 75. The Oregon State University computer-analyzer system couples the advantages of on-line data acquisition and analysis with the low cost of a time-sharing computer. The system operates in two modes. In Mode A, a 4096-channel analyzer serves as a data acquisition and buffer storage device with the contents of the analyzer memory being transmitted via telephone lines to the Oregon State University computer for analysis. In Mode B, the correlated outputs of N analog-to-digital converters (corresponding to an N -parameter event) are transmitted to the computer in real time for storage and analysis. Additional information, programming and computations may be entered at any time from a remote terminal console. The results of the data analysis can be returned immediately to the remote terminal console or to any regular computer output device. This system has the advantages of being able to utilize the full facilities of a large computer, its FORTRAN compiler, etc., for on-line data acquisition and analysis while avoiding the responsibilities of hardware maintenance and systems programming for the nuclear chemists.

Computer-controlled Optical Spectrometer by D. M. Hannon, D. E. Horne, and K. L. Foster, p. 79. Hardware developed to implement the computer control of a single-beam monochromator operating under a time-sharing system is described. A stepping motor and associated circuitry yield very precise wavelength positioning in an open loop configuration and with a minimum of computer use. The circuits used to position and step the wavelength are described in detail.

Growth of a Laboratory Computer System for Nuclear Physics by J. F. Mollenauer, p. 87. A computer system may typically be expected to progress through a cycle terminating in overloading. The experience with an early system at the author's nuclear physics laboratory serves as an example. The original computer and a similar machine later installed with it are now overloaded and a new system is under construction. The success of the interactive data analysis on the original system has made it desirable to enhance the display and light pen facilities while reducing the computer time involved in generating the displays. The use of a data storage/display disc effectively provides off-line displays but requires more manipulation in data acquisition. The solution is found in the large number of processing units economically feasible with third-generation equipment. Two linked computers will perform data acquisition and analysis, the smaller performing data acquisition under the control of the larger, which will run a fairly simple time-sharing system. Together with several I/O processors, this hierarchy of processors will provide ease of program development and a very high degree of computational power and data acquisition capability.

Measuring Optical Transfer Functions of Lenses with the Aid of a Digital Computer by J. B. Davis and H. H. Herd, p. 93. The problems involved in lens testing, as opposed to the testing of one lens under one set of conditions, are of sufficient magnitude and complexity that the use of a computer is almost imperative to make the job practical. A machine and method for evaluation of lenses is described which employs a digital computer as a major component, has no restrictions as to the quality of lenses which may be accommodated, and requires no precision targets or auxiliary optics of any type. The results are in a form directly applicable to predictions of performance of complicated systems where the lens is one of several linear dissipators.

The reader is introduced to lens testing considerations and a brief discussion of methods, followed by a detailed description of a specific implementation and computerized approach. Next, the basic mathematics involved, including a practical procedure for truncating a Fourier series, are explained in some detail. Finally, examples of measured output and machine accuracy and stability examination are given.

The Use of Computers at CERN by R. T. Bell and H. Øverås, p. 104. This paper surveys the many ways computers

and connected special devices are used in the laboratory of high energy nuclear physics research of CERN (European Organization for Nuclear Research) in Geneva, Switzerland.

An Experimental System for Time-shared, On-line Data Acquisition by *H. A. Reich, p. 114*. With the increasing availability of terminal-oriented, time-shared computers, it now becomes feasible to extend the method of use to include real-time, on-line data acquisition and data reduction. Here described is a particular embodiment of such a system, using an IBM 1050 terminal and the IBM Research M44/44X and the APL/360 Model 50 computers. Reasons leading to the choice of equipment, special devices, programming considerations, data rates and some economic factors are considered.

Real-time Reduction of Nuclear Physics Data by *P. R. Bevington, p. 119*. Small scientific computers have been widely used in research laboratories for on-line data acquisition to improve the efficiency of data collection and to perform sophisticated data manipulation before storage. An equally productive use of such computers is for the subsequent reduction of these data in real time, permitting interaction between investigator and computer and providing immediate interpretation of masses of data. This report describes the philosophy and techniques developed for the SCANS (Stanford Computers for the Analysis of Nuclear Structure) system for the reduction in real time of multichannel pulse-height spectra, which comprise the bulk of data in Nuclear Physics. The programming language for users is FORTRAN, to provide flexibility and ease in introducing and modifying sophisticated concepts such as nonlinear least-squares fitting. Software interface to specific real-time hardware devices such as oscilloscope display and light pen is accomplished via library subroutines which perform a variety of general purpose services. Several different applications of this approach to various types of data spectra are discussed to illustrate the degree of mutual interaction achieved between investigator and computer and the resultant optimization of reduction techniques to suit particular types of data.

The Use of a Control Computer in a Chemistry Department by *Y. Okaya, p. 126*. The Chemistry Department of the Stony Brook Campus of the State University of New York is composed of a number of faculty members whose research experiments fall generally into two categories; (1) steady data acquisition and control tasks with relatively small data and demand rates, and (2) continuous scan-type measurements of various data rates. An IBM 1800 control system is employed as the nerve center of a computer-based experiment complex.

This paper discusses the multi-experiment control system used at Stony Brook Chemistry, giving some details of experiments performed by faculty members as examples of its application. It is pointed out that one of the objectives of this computerized

department is creation of a course in the use of computers in chemistry. With a data-acquisition computer available in the department, the course can include actual bench practice in data acquisition and control tasks.

Use of a Terminal System for Data Acquisition by *K. L. Konnerth, p. 132*. The application of a mathematically-oriented conversational computing system to data collection and computer control for a specific experiment is described. Relatively simple interfaces are used between the experiment and computer terminal to provide for voltage analog inputs and outputs to the experiment. The terminal is connected to the computer by way of conventional voice-grade telephone lines. It is concluded that this type of data acquisition system is quite useful for experiments in which several-second computer response time can be tolerated, data reduction is necessary and the computer load is insufficient to justify the use of a local computer. An additional facility which provides for the ability to plot data was found to be extremely useful.

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The Kinoform: A New Wavefront Reconstruction Device by *L. B. Lesem, P. M. Hirsch, and J. A. Jordan, Jr., p. 150*. A new, computer-generated, optical element called a kinoform is described. This device operates only on the phase of an incident wave and forms a single image by wavefront reconstruction without the unwanted diffraction orders characteristic of holograms. The kinoform is also more efficient in the use of spatial frequency potential and reconstruction energy and can be synthesized in considerably less computer time than the digital hologram.

Associative Holographic Memories by *D. Gabor, p. 156*. Recently Longuet-Higgins modeled a temporal analogue of the property of holograms that allows a complete image to be constructed from only a portion of the hologram. In the present paper a more general analogue is discussed and two two-step transformations that imitate the recording-reconstruction sequence in holography are presented. The first transformation models the recall of an entire sequence from a fragment while the second is more like human memory in that it provides recall of only the part of the sequence that follows the keying fragment. Both models require only the three operations: shift, multiplication and addition.

Computer-generated Binary Holograms by *B. R. Brown and A. W. Lohmann, p. 160*. Holograms synthesized by computer are used for constructing optical wavefronts from numerically specified objects. Elimination of the need for a physical object has made new applications possible, for example, three-dimensional computer output displays, synthetic prototypes for interferometric testing, and filters for various optical data processing operations. Our computer holograms differ from a normal hologram in that the transmittance is

binary, yet they are able to construct general wavefronts and images efficiently and have several practical advantages over holograms with a continuous range of transmittance. Recent improvements that simplify the production of binary holograms and improve their performance are described and experimental work showing reconstruction of two- and three-dimensional images is presented.

Electron Beam Writing of Spatial Filters by H. Wieder, R. V. Pole, and P. F. Heidrich, p. 169. A method is described for the generation of optical spatial filters using electron beam-addressed crystals of KDP. Some examples of simple filters which have been successfully written by this method are presented.

Graphic Computer-assisted Design of Optical Filters by F. Gracer and R. A. Myers, p. 172. An interactive graphic system is described in which a designer using a light pen creates an optical filter design at an IBM 2250 Graphic Console controlled by an IBM 1130 computer. The designer can observe the reflectivity (or some other property) of the filter as a function of wave number plotted on the CRT. The application was developed using an experimental graphic version of the 1130 Continuous System Modeling Program (CSMP), a general purpose, block-oriented simulation language in which the functional blocks represent the elements and organization of an analog computer. The designer has available a full set of operators for further analyzing the behavior or modifying the design of the filter. In addition to providing a highly flexible analytic tool, the system is intended to explore means for making the interactive computer terminal an important element in the inventive process.

Switchable Total Internal Reflection Light Deflector by M. E. Rabedeau, p. 179. A new digital light deflector, capable of being switched in less than 35 μ sec with less than 300 V, uses the principle of switchable total internal reflection. The deflector produces high-quality, high-contrast images and its low cost and high light transmittance make it potentially well suited for use in optical-beam-addressable memory systems as well as for other applications in which random deflection is desirable.

Efficiencies and Bandwidths of Intracavity Acousto-optic Devices by E. G. Lean, M. L. Dakss, and C. G. Powell, p. 184. Acousto-optic devices based on isotropic and anisotropic acoustic Bragg diffraction will be discussed in terms of their efficiency and bandwidth. The conflicting requirements on the width W of the acoustic column with regard to efficiency and bandwidth determine the basic limitations of the devices. A scheme using the acousto-optic devices within a flat-field conjugate (FFC) angularly degenerate laser cavity has been experimentally demonstrated. The bandwidth of the new scheme is limited by the field angle of the FFC cavity instead of by W^{-1} . The width W can be made as large as possible to increase the diffraction efficiency without decreasing the bandwidth. The new scheme provides means for high

efficiency and large bandwidth in optical deflection and signal processing systems.

High Performance Reduction Lenses for Microelectronic Circuit Fabrication by R. E. Tibbetts and J. S. Wilczynski, p. 192. Data are presented for three families of objective lenses useful in making high resolution plates and improving the process of photoresist exposure. These lenses have 7 to 10 elements each, spherical surfaces only, and were designed with the aid of computers. Many of the lenses have been fabricated and these have confirmed the soundness of the design methods, assessment criteria, and manufacturing techniques.

Mechanisms of Stress Relief in Polycrystalline Films by P. Chaudhari, p. 197. The stress required to operate dislocation sources within a grain, at a grain boundary, and at surfaces is found to be larger than the intrinsic stresses observed in polycrystalline films. It is therefore unlikely that a dislocation flow mechanism can relieve stresses in films. Grain boundary sliding and diffusional creep can, however, relieve stresses in films and equations describing the kinetics of stress relaxation are derived. It is suggested that stress relief occurs primarily by a diffusion-creep mechanism. Growth of hillocks during annealing of a film is briefly discussed in terms of the diffusion-creep mechanism.

Effects of Bending Stiffness in Magnetic Tape by R. E. Norwood, p. 205. The elasticity of magnetic tape is an important factor in determining the shape of a tape loaded over a magnetic head. Over a single apex the radius of curvature of the tape is inversely proportional to the wrap angle and to the square root of the ratio of tape tension to bending stiffness. If a constant-pressure support is assumed instead of a knife edge, the radius of curvature increases considerably. A chart is provided for use in calculating the radius of curvature under different loading conditions.

Over a double apex the results are the same as for a single apex except when the distance between apexes becomes small. By increasing the radius of curvature of the head to conform to the radius of curvature of the tape, the rate of head wear can be greatly reduced.

Symbolic Polynomial Operations with APL by A. J. Surkan, p. 209. A recursive calculation of polynomial coefficients is used to demonstrate how functions performing polynomial algebra and differentiation may be written concisely in Iverson notation and executed by an on-line, time-sharing implementation of APL. These functions will operate on symbolic polynomials with constant coefficients and display in a superscripted format results having up to 116 variables.

On the Measurement of Impurity Atom Distributions by the Differential Capacitance Technique by D. P. Kennedy and R. R. O'Brien, p. 212.

SLT Device Metallurgy and its Monolithic Extension by P. A. Totta and R. P. Sopher, p. 226. The glass-passivated, face-down semiconductor chip joining technology employed in IBM's SLT (Solid Logic Technology), has become not only a fundamental element in the hybrid circuitry of System/360 but also the basis for later metallurgical designs. The "flip-chip," copper ball terminal, solder reflow technique is comprehensively reviewed and a discussion is given of its extension, through the use of ductile, all-solder terminals, to monolithic applications.

Controlled Collapse Reflow Chip Joining by L. F. Miller, p. 239. Solder reflow connection of semiconductor devices to substrates has been shown to be a reliable, effective, and readily automated technique. Rigid copper spheres, which remain rigid during solder reflow, have been used successfully for some time as a major element of the contact joint. However, to expand the capability of such joints to larger devices such as multiple-transistor chips in hybrid components, ductile metallic joining pads can be used on the devices instead of the copper spheres to reduce mechanical strains and permit multi-pad devices to make proper contact to module lands during reflow. This paper describes a technique that prevents these solder pads from collapsing and permits large scale production. Termed "controlled collapse," the method is based on limiting the solderable area of the substrate lands and chip contact terminals so that surface tension in the molten pad and land solder supports the device until the joint solidifies. The result is a sturdy, testable connection of high reliability (bond strength 30-50 gm, pilot-production yields exceeding 97%, predicted failure rate—based on laboratory tests—considerably lower than that of copper ball contacts). The process is economically adaptable to automation and offers considerable latitude in fabrication and control tolerances.

Geometric Optimization of Controlled Collapse Interconnections by L. S. Goldmann, p. 251. This paper deals with the mechanical reliability of controlled collapse solder joints in modules subjected to the thermal fatigue conditions of machine usage. Particular emphasis is placed on design variability and how the shape and dimensions of the joint and chip affect reliability. A systematic technique is presented to optimize pad dimensions. A new experimental method to characterize chip-to-substrate interconnections—the torque test—is described and analyzed. Its applicability to design evaluation is discussed and representative data are analyzed. The relationship between torque test measurements and fatigue is discussed.

Reliability of Controlled Collapse Interconnections by K. C. Norris and A. H. Landzberg, p. 266. The use of solder pads to join multi-pad integrated circuit chips to modules provides a highly reliable, rugged interconnection technology. This paper reports some important aspects of the reliability

evaluation that was carried out on the "controlled chip collapse" interconnection system developed by IBM. Included are an analysis of the mechanics of the system, a model to establish the relationship among different thermal fatigue testing conditions, and experimental verification of the model. In the course of this work, the chip failure rate of the interconnection as used in present designs was predicted to be better than $10^{-7}\%$ /1000 hours for the mechanism studied.

Parametric Study of Temperature Profiles in Chips Joined by Controlled Collapse Techniques by S. Oktay, p. 272.

Parameters governing the temperature profiles of typical semiconductor chips joined to circuit module substrates by controlled chip collapse (flip-chip bonding) techniques are discussed. These include the physical and geometric properties of various layers of metals and non-metals that form the chip-to-substrate interconnection. The importance of the bond between the interconnection and the substrate from the point of view of interfacial thermal resistance is indicated. Also, the "thermal pinch" effects of voids in controlled chip collapse interconnections are discussed. The various thermal impedances as obtained from computer simulated temperature profiles are given graphically as functions of the parameters. The derivation of a semi-empirical expression for predicting the transient response of junctions on joined chips is shown.

Studies of the SLT Chip Terminal Metallurgy by B. S. Berry and I. Ames, p. 286. The thin film metallurgy used for SLT chip terminal contacts has been studied with respect to the soldering procedure used for chip-to-module joining. A simple solder immersion test was used to study wetting and dewetting effects on Cr films overlaid with films of Cu and other metals. It was found that the initial soldering reaction (consisting of the conversion of the Cu film to a Cu-Sn metallic layer) proceeds to completion in only a few seconds. Thereafter, the intermetallic layer starts to disintegrate and become thinner by a mechanism identified as solution-assisted spalling. Removal of the intermetallic layer by this mechanism is not limited by simple solubility considerations. From metallographic observations and the inability to produce direct wetting of Cr films by solder, it was concluded that the basic cause of solder dewetting is the excessive loss of intermetallic from the underlying Cr film. Dewetting is accelerated if the Cu film is deposited on an oxidized Cr surface. These observations underscore the importance of the manufacturing practice of overlapping the Cr and Cu depositions so as to obtain an adherent and interlocked structure which is resistant to spalling. Other studies have show that Al films are relatively inert to molten pure Pb-5% Sn solder, but are susceptible to rapid attack if gold is added to the solder. Appreciable delay of such attack is afforded by an overlying film of Cr, provided both surface and edge coverage are achieved.

Parallel Methods for Approximating the Root of a Function by W. L. Miranker, p. 297. We present a class of

methods for approximating the root of a function. The methods are designed for execution on a parallel processor and when they are so executed, the speed of the approximation process is increased. The increase in speed is estimated analytically by computations of the order of convergence of the various methods presented.

Scattering of Electromagnetic Radiation by a Large, Absorbing Sphere by *J. V. Dave*, p. 302. Details are provided for two subroutines with which one can compute the various characteristics of the electromagnetic radiation scattered by an absorbing, homogeneous sphere of any reasonable size. The necessary expressions for this purpose were first derived by Mie. The method of computations used is the so-called method of logarithmic derivative of one of the complex functions, introduced by Infeld. The main difference between the two subroutines is in the procedure used in computations of one of the functions. This function is computed by an upward recurrence procedure in one subroutine and by a downward recurrence procedure in the other.

Sufficient results for demonstrating the reliability of these programs are presented and discussed for a sphere of $10\mu\text{m}$ radius illuminated by an unpolarized radiation of $0.4\mu\text{m}$ wavelength.

A General Method for Obtaining Impedance and Coupling Characteristics of Practical Microstrip and Triplate Transmission Line Configurations by *Y. M. Hill, N. O. Reckord, and D. R. Winner*, p. 314. In order to design an interconnection system for nanosecond-risetime logic circuitry, it is necessary to obtain a balance between impedance variations, propagation velocities, and crosstalk levels so as to achieve the best system speed as well as system speed control. To accomplish this, it is necessary to relate the electrical material properties and physical dimensions of the connections to characteristic impedances, propagation velocities, and crosstalk coupling coefficients.

Two practical transmission line configurations: the microstrip line, which is coated for physical protection, and the offset or unsymmetrical triplate line, are being fabricated by mass production techniques. Because of the close control required and the many factors affecting impedance and coupling, these configurations require accurate means for predicting their characteristics.

An improved "subintervals" technique and a series approximating the Green's function have been combined to yield a single practical computer algorithm. Excellent agreement has been obtained in comparing the results of computations with large scale-model transmission line measurements. The method is quite general because dimensions, conductor shapes, and dielectric properties may vary widely.

Thermal Expansion in a Constrained Elastic Cylinder by *J. F. Janak*, p. 323. The stress developed in an elastic cylinder of finite length undergoing thermal expansion with one end clamped is expressed in terms of a series expansion of a biharmonic function, appropriate derivatives of which give the displacements and stresses within the cylinder. The coefficients in this series are determined by a least-squares fit to the boundary conditions at the ends of the cylinder and values of the stress on various surfaces are found as functions of the height-to-radius ratio. All components of the stress tensor become infinite at the circumference on the clamped end. A tabulation is included of quantities of interest in any cylindrical problem in which the curved surface is a free surface.

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Stochastic Model for Manufacturing Cost Estimating by *C. T. Abraham and R. D. Prasad*, p. 343. The unit manufacturing cost (i.e., its estimator) for a given manufacturing program with stochastic demand and operation yield is assumed to be a random variable. For a simple series production line the probability distribution of the unit manufacturing cost has been derived by either the transform method, which uses Mellin and Laplace transforms, or the method of moments, which uses either the Gram-Charlier series approximation or the Pearson system of frequency curves. The estimates and 90%-confidence intervals for the base manufacturing cost are computed for two device-component products. The model cost estimates are very close to the actual values and the confidence intervals are sufficiently narrow to be useful in applying contingencies to the predictions.

Dynamic Inventory Models and Stochastic Programming by *M. N. El Agizy*, p. 351. A wide class of single-product, dynamic inventory problems with convex cost functions and a finite horizon is investigated as a stochastic programming problem. When demands have finite discrete distribution functions, we show that the problem can be substantially reduced in size to a linear program with upper-bounded variables. Moreover, we show that the reduced problem has a network representation; thus network flow theory can be used for solving this class of problems. A consequence of this result is that, if we are dealing with an indivisible commodity, an integer solution of the dynamic inventory problem exists. This approach can be computationally attractive if the demands in different periods are correlated or if ordering cost is a function of demand.

Programmed Automatic Customer Engineer (PACE) Dispatch by *W. H. Evers and S. S. Thakur*, p. 357. An experimental real-time system is described for assigning customer engineers (servicemen) to requests for service, preventive maintenance and engineering- and sales-change activities. The system, which can be applied to service organizations of many kinds, is viewed as a stochastic

programming formulation. The resultant mathematical programming problem is structured as a control system, an inner control loop and an outer adaptive feedback loop in which system parameters are adjusted based on a performance index. Tests of the system have been made using data from the Brooklyn, New York and Washington, D.C. IBM Field Engineering Division branch offices.

Model of Competition in a Two-seller Market by *D. Savir*, p. 366. In this model of sellers' competition we are concerned with the transition from a single-seller market to a two-seller market, the effects of transition on the first seller, his likely reactions and the thereby changed market situation that awaits the entering competitor. The decision variables considered in this model are the sizes of the two sales forces. We show that the enterer should not view the market as it stands prior to his entry, but as changed by the first seller to accommodate or oppose his entry. Upon the entrance of the competitor, both sellers must increase their sales forces to attain the levels of profit anticipated prior to entry, if indeed these can be attained. Equilibrium strategies are shown to be maximal sales effort on the part of the first seller and either maximal sales effort or abstention from entry on the part of the enterer. A finite series is derived to express the exact expectation of a class of rational functions of a binomially distributed random variable.

Maximal Biflow in an Undirected Network by *J.-C. Arinal*, p. 373. In this network flow problem we deal with two distinct commodities, each commodity being identified by a pair of source and sink nodes. The problem consists of maximizing the total flow (biflow) of the two commodities. It is solved by an inductive algorithm which starts with a maximal multiterminal flow from the set of sources to the set of sinks in the network, yields the value of the maximal biflow and terminates with the construction of the maximal biflow itself. Computational experience shows that this algorithm can also be used in the three-commodity flow problem to obtain a good lower bound for the value of a maximal three-commodity flow.

Algorithm and Average-value Bounds for Assignment Problems by *W. E. Donath*, p. 380. A new suboptimal intermediate-speed algorithm which uses n^2 in n steps is developed for the assignment problem. Upper and lower bounds are derived, using this algorithm and other methods, for the average values of three classes of $n \times n$ assignment problems:

1. When the elements of the matrix are random numbers uniformly distributed over the range 0 to 1, the average optimal value is smaller than 2.37 and larger than 1 for problems with large n . Experimentally the value is about 1.6.
2. When the elements of the matrix are random numbers such that the probability of being less than x is x^{k+1} ($k \neq 0$), asymptotic expressions for the upper and lower bounds of the

average optimal value are $C_1 n^{k/(k+1)}$ and $C_2 [(k+1)/k] n^{k/(k+1)}$, respectively.

3. When each column of the matrix is a random permutation of the integers 1 to n , asymptotic upper and lower bounds are $2.37n$ and $1.54n$, respectively. Experimentally the value is about $1.8n$.

Shortcut in the Decomposition Algorithm for Shortest Paths in a Network by *T. C. Hu and W. T. Torres*, p. 387.

The problem considered is that of finding the shortest path between the two nodes of every pair in a large n -node network. A decomposition algorithm is proposed for use when the number of arcs is less than $n(n-1)$. The network is first decomposed into several overlapping subnetworks. Next, with each subnetwork treated separately, conditional shortest paths are obtained using triple operations. Finally, these conditional shortest paths are used to obtain the shortest paths between paired nodes in the original network by matrix mini-summation. This decomposition algorithm requires less computer storage and fewer arithmetic operations than other known algorithms.

Minimaximal Paths in Disjunctive Graphs by Direct Search by *J.-F. Raimond*, p. 391.

The problem of finding a minimaximal path in a disjunctive network is stated in terms of both graph theory and linear programming with mixed-integer variables. It is solved in both formulations using a "direct search" scheme with additional dynamic features, which seems to be a more efficient algorithm than those based on other methods. Although it yields an optimal solution, the algorithm can be used as such or with very few changes to find suboptimal solutions for larger problems. Computational experience on the general machine scheduling problem is described.

Heuristic Algorithm for the Traveling-salesman Problem

by *T. C. Raymond*, p. 400. The classical traveling-salesman problem is to determine a tour that will minimize the total distance or cost involved in visiting several cities and returning to the starting point. This paper describes a new heuristic algorithm that has been programmed for a digital computer and that obtains optimal or near-optimal solutions to the problem. The author's general approach was derived from an existing algorithm developed by Karg and Thompson in 1964. Computational results for five multi-city tours are presented and the algorithm is shown to be competitive with other existing heuristic techniques.

IBM 2750 Voice and Data Switching System:

Organization and Functions by *B. Corby*, p. 408. This paper reviews the functions of private automatic branch exchanges (PABX's) and describes the organization of the IBM 2750 Voice and Data Switching System. This system has two main functional areas: (1) line switching, transmission and signaling, and (2) common control. The switching network uses a new integrated electronic crosspoint. The common

control is performed by a built-in duplexed computer with stored programs dedicated to line switching.

The IBM 2750 offers a variety of normal and advanced voice features, and some entirely new data features, and is designed for interconnection with an IBM System/360. Four companion papers describe the electronic switching network, the network control program, and the integrated crosspoint in greater detail.

Electronic Switching Network of the IBM 2750 by R. E. Reynier, p. 416. A description of the voice and data switching network of a fully electronic private automatic branch exchange (PABX) is given, including a description of the crosspoint device and its principles of operation. Some related circuitry is described, including the terminal and service circuits, supervision circuits and a loss-compensation device.

Operational Program for the IBM 2750 by J.-D. Colas, p. 428. This paper describes the operational program of the IBM 2750 Voice and Data Switching System. The program runs in the supervisor unit of the two network controllers used in the 2750. This program controls: (1) the duplexing of the network controllers; (2) the switching network; (3) the data collection and transmission operations passing through the system, including interconnection with IBM System/360; (4) the on-line error handling and system testing.

The IBM program uses all available core storage. It is flexible, is tailor-made to each customer's requirements, and runs continuously without customer assistance.

Semiconductor Crosspoints by L. L. Rosier, C. Turrel, and W. K. Liebmann, p. 439. The design considerations for a semiconductor crosspoint consisting of an SCR-diode-resistor circuit are presented and the fabrication process is briefly reviewed. These crosspoints have an ON-resistance of three to four ohms and a capacitance of approximately three picofarads. They can be interconnected on ceramic modules to form matrix arrays for use in telephone line switching applications.

Response Time of Thyristors: Theoretical Study and Application to Electronic Switching Networks by E. Y. Rocher and R. E. Reynier, p. 447. After restating the experimental definition of the response time of a low-power thyristor by assuming a well-defined dc triggering current, the authors show that the equivalent two-transistor representation of the thyristor leads to a theoretical interpretation of the triggering condition under certain simplifying assumptions. The accuracy of this theoretical model is shown to be satisfactory.

A practical definition of the response time of a thyristor is proposed, and the literal expression of the response time as a function of the parameters of both constituent transistors is given. Examples of application are then given in the design

of the switching networks of the IBM 2750, where thousands of thyristors are used as crosspoints arranged in matrices and connected in series.

Data Recovery in a Photo-Digital Storage System by R. L. Griffith, p. 456. A data-recovery feature has been developed for recovering electron-beam recorded information which is microscopic in dimension and has been partially obliterated by flaws in a photographic-film recording medium. This feature provides (1) backup procedures that exploit redundancies in the recording format for the synchronization and identification of data, (2) coding for error detection and correction of 5 independent characters in 50 data character lines, (3) variation of machine parameters that affect reading performance, and (4) statistically optimized schedules for applying a variety of recovery techniques. Error rate is reduced from one error line in about 100 lines to less than one error line in 2.7×10^6 lines.

Modeling Plasma Effects on Radar Cross Section of Reentry Vehicles by F. H. Mitchell, Jr., W. R. Mahaffey, and R. F. Jacob, p. 468. In order to design a radar to detect, track, and identify unknown targets, models of the expected electromagnetic scattering properties of the targets must be developed. This communication begins with a qualitative discussion of interactions between an incident wave and a plasma-clad body in order to give the general reader a heuristic understanding of the problem background. Then rigorous calculations of normalized backscatter cross section for a spherical, plasma-clad body, and the limitations of this model, are presented in context with earlier background material.

A plasma simulation technique is described as a means for modeling a diverse range of reentry bodies and plasmas that are not amenable to analytic solution. The theoretical analysis can be used to validate the simulation technique in a spherical configuration after which the technique can be used to simulate many other plasma shapes around a variety of bodies.

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A Perspective on Acoustoelectric Instabilities by R. Bray, p. 487. The acoustoelectric instabilities appear in diverse forms and seem complex because of the large number of factors which influence them. A perspective on the instabilities is provided in terms of experiments on the III-V semiconductors, selected to limit or control the variables. Detailed evidence is presented that the source of the acoustic flux is the thermal equilibrium phonon spectrum. The individual contributions of various factors to the instabilities are identified and discussed; e.g., 1) circuit conditions (constant current or constant voltage) which determine the degree of feedback between buildup of flux and gain everywhere in the sample, 2) boundary conditions, including destruction or reflection of flux, 3) inhomogeneities in resistivity of the samples, to which the current oscillations and

initial stages of domain formation are particularly sensitive, and 4) the form of the acoustoelectric gain curve, which determines whether the feedback on the gain is positive or negative when the current is changed by the flux buildup. Also, several aspects of deviation from small signal theory are identified. In strong flux, 1) the peak of the frequency spectrum of the flux is shifted down, 2) the acoustoelectric gain coefficient is changed, and 3) the carrier distribution function may become hot in the high field of the domain. It is concluded that the strong flux effects modify but do not basically determine the form of the resistance instabilities.

Parametric Amplification and Frequency Shifts in the Acoustoelectric Effect by S. Zemon and J. Zucker, p. 494.

Mechanisms for the downshift in the frequency of maximum acoustic intensity f_{mi} for high flux domains in piezoelectric semiconductors are reviewed. For the simple case where an externally introduced acoustic wave (pump) produces a single-frequency domain in photoconducting CdS, clear evidence is given that the downshift in f_{mi} is due to parametric amplification of thermal acoustic noise. For a pump of 990 MHz, after some initial growth ($v_d = 1.14 v_s$), the pump is found to be depleted. In the pump depletion region, signals in a 200 MHz band about the even subharmonic (445 MHz) are found to grow. At pump strains of about 10^{-6} the signals propagated at angles to the pump equal to those that give phase matching according to the dispersion of linear theory. For higher pump strains, however, the collinear process is dominant. The signal domain is narrower than the pump domain, as expected, because the parametric growth is exponentially dependent on pump strain. The downshifting of f_{mi} in the region where deviations from linear theory are still small is discussed in terms of a parametric interaction model, with the initial acoustic strain distribution considered as an incoherent pump.

A Brillouin Scattering Study of Acoustoelectric Domain Formation in *n*-GaAs by D. L. Spears, p. 499.

Brillouin scattering measurements in *n*-GaAs show (1) that the initial formation of acoustoelectric domains is the consequence of spatially inhomogeneous amplification produced by resistivity inhomogeneities, and (2) that the subsequent stages of domain evolution involve flux-dependent processes which further shape the domain; an important process appears to be parametric frequency conversion.

Off-axis Acoustoelectric Domains in CdS by A. R. Moore, R. W. Smith, and P. Worcester, p. 503. In CdS crystals oriented with the electric drift field parallel to the *c* axis, acoustoelectric domains consist of off-axis shear waves. This is because there is no acoustoelectric gain for shear waves traveling along the hexagonal axis, while the gain may be large in an off-axis direction. The particular angle at which the gain is a maximum depends on the angular dependence of the electromechanical coupling coefficient and the component of the electron drift velocity along that angle. These factors combine to make the angle of maximum gain a

function of drift velocity along the *c* axis. Using a stroboscopic strain-birefringent method, we observed the off-axis domains directly. The domain tilt angle has been found to depend on drift velocity in roughly the same way as predicted from the small-signal angular dependence theory. Discrepancies may be the result of large-signal effects or of angular dispersion.

Acoustoelectric Amplification in InSb by R. K. Route and G. S. Kino, p. 507. It was demonstrated by Kikuchi that two modes of acoustoelectric domain oscillation occur in InSb in a transverse magnetic field. Using lithium niobate transducers on an acoustic amplifier, we have measured linear acoustic gain as a function of electric and magnetic field and frequency. At high magnetic fields ($B \geq 3000$ gauss) the results are in good agreement with White's theory. However, at low magnetic fields, the wavelength of the sound waves is less than the mean free path of the electrons, and the macroscopic theories break down. We have extended a microscopic theory of magnetacoustic interactions, due to Spector, to include electron drift. We find excellent agreement between theory and experiment over the whole range of magnetic field. Moreover, the results account very clearly for the two modes of acoustic domain formation.

Characteristics of Semiconducting Glass

Switching/Memory Diodes by A. D. Pearson, p. 510.

Semiconducting glass diodes can exhibit at least three conducting states: a high-resistance, or "off" state; a low-resistance, or "on" state; and a negative resistance state. When appropriately pulsed they can also display a memory function. The laboratory operation of simple diodes and the methods of inducing transitions among the various states are described. In addition, the possible role of phase changes in the mechanism of device operation is discussed, and new evidence in support of a filamentary conduction hypothesis is presented.

Physics of Instabilities in Amorphous Semiconductors by

H. Fritzsche, p. 515. A four-fold classification of the current-controlled instabilities in amorphous semiconductors is proposed. The experimental evidence supporting a simple band model for the amorphous covalent alloys is given. The present understanding of the reversible switching effects and of the switching with memory is discussed.

Current Filaments in Semiconductors by A. M. Barnett, p.

522. A current filament is a non-uniform radial distribution of current in the presence of a uniform electric field in a uniform sample. These filaments can have diameters in the 0.005 inch range. The current density at the center of the filament can be several orders of magnitude higher than the background current density in the rest of the sample. Filaments have been studied in devices exhibiting the current-controlled negative resistance associated with specific cases of two-carrier space-charge-limited current double injection. Electrons and holes are injected from opposite

contacts into a semi-insulator in which the lifetime of carriers of one sign is much longer than the lifetime of carriers of the opposite sign. When forward biased this device exhibits a high-voltage, high-impedance (10^8 ohms) pre-breakdown region and a low-voltage, low-impedance (1 to 10^3 ohms) post-breakdown region. In the post-breakdown region current increases at a nearly constant voltage followed by a high-current power-law region. Current filaments have been studied throughout the post-breakdown region by recording the recombination radiation observed through one of the injecting contacts. Experimental and analytical studies of current filaments in silicon at 77K and GaAs at 300K are reviewed.

Current Oscillations in Deep-level Doped Semiconductors

by B. G. Streetman and N. Holonyak, Jr., p. 529. We observe current oscillations in *p-i-n* (and optically excited *n-i-n*) devices containing deep levels. The oscillations occur in the positive resistance region of the space-charge-limited (SCL) current regime of the *I-V* characteristics, before the occurrence of double-injection breakdown. This is a general effect, occurring in Si, Ge, and GaAs compensated with various deep-level impurities and in electron-irradiated devices. The oscillations are sinusoidal at threshold, with frequency strongly dependent on the recombination kinetics of the *i*-region, and on the deep level density, but are essentially independent of device length. The frequency and amplitude of the oscillations are affected by temperature and optical excitation. Various models have been proposed to account for oscillations in semiconductors containing deep levels, but no existing model describes fully the various aspects of the effect reported here. Because the device length exceeds carrier diffusion length, any model for the oscillation mechanism must include the existence of space charge and the kinetics of recombination, but may not depend essentially upon a traveling domain which imposes a length dependence on the oscillation frequency. Tentatively, we favor a model in which the recombination process unbalances the steady or dc space charge.

Space-charge-limited Current Instabilities in $n^+-\pi-n^+$

Silicon Diodes by A. K. Hagenlocher and W. T. Chen, p. 533. If the strength of a pulsed electric field of about 10^3 volts/cm is exceeded in a nickel-doped 25,000 ohm-cm π -type silicon sample with n^+ contacts, a transient charge distribution is established that leads to a current instability. When the critical applied field is reached a current-controlled negative resistance is observed. The sample impedance decreases by several orders of magnitude, with a switching time in the nanosecond range, and microwave oscillations are produced. Below the threshold a space-charge-limited current flows, and voltage profile measurements show the presence of the expected negative space charge near the cathode. As the field is increased this space charge extends further into the sample. At the threshold the nickel centers become ionized, and a positive space charge is created in the center of the sample. This non-equilibrium distribution, which persists for a period

of 200 to 300 microseconds, has properties similar to those of a gaseous plasma.

Time Response of the High-field Electron Distribution Function in GaAs by H. D. Rees, p. 537. Numerical

calculations have been made of the high-field electron distribution function for GaAs, its small-signal frequency response and its behavior in large sinusoidal electric fields. The response speed is limited by the low scattering rate within the $\langle 000 \rangle$ valley. With increasing frequency the threshold field for negative conductivity rises and the negative mobility and oscillator efficiency fall. The free-electron dielectric constant is positive at high-fields, with a peak near the threshold field.

Negative Conductivity Effects and Related Phenomena in Germanium. Part I by J. C. McGroddy, M. I. Nathan, and

J. E. Smith, Jr., p. 543. This paper is the first part of a two-part review of recent work on current instabilities and related properties of germanium in high electric fields. In this part we discuss the general subject of high field transport in *n*-Ge with emphasis on the concept of saturated drift velocity. The oscillations which result from bulk negative differential conductivity (BNDC) in $[100]$ and $[110]$ directions at low temperatures are discussed and related to the saturation effects. A discussion of theoretical and experimental evidence with regard to the BNDC effects is presented.

Finally, the anisotropy of the high-field conductivity is discussed and related to the Erlbach instability.

Negative Conductivity Effects and Related Phenomena in Germanium. Part II by J. E. Smith, Jr., M. I. Nathan, and

J. C. McGroddy, p. 554. This paper is the second part of a two-part review of recent work on current instabilities and related properties of germanium in high electric fields. In this part the transferred carrier mechanism for producing bulk negative differential conductivity (BNDC) in a semiconductor is discussed. Experimental work on instabilities related to three realizations of this effect, in uniaxially compressed *n*- and *p*-type Ge, and in *n*-type Ge at low temperatures with field and current in a $\langle 111 \rangle$ direction, is reviewed. Theoretical understanding of these effects, which is largely qualitative at this time, is discussed. In an appendix a list of materials in which BNDC effects have been observed is presented, with some of the relevant properties of these materials.

Bulk Negative Differential Conductivity in Germanium:

Theory by E. G. S. Paige, p. 562. Two mechanisms have been proposed for the bulk negative differential conductivity of *n*-type germanium first observed by Elliott et al. These are discussed with reference to recent Monte Carlo calculations in which effects due to intravalley acoustic phonon scattering, $\langle 100 \rangle$ and $\langle 000 \rangle$ minima and ellipsoidal constant energy surfaces are explored. Strong evidence is presented that electron transfer to $\langle 100 \rangle$ minima causes this negative

conductance. The origin of its temperature and orientation dependence is discussed.

Wave Propagation in Negative Differential Conductivity Media: n-Ge by A. C. Baynham, p. 568. A study has been made of transverse electromagnetic wave propagation in the negative differential resistance medium provided by suitably oriented *n*-type germanium at 77K. The wave frequency is chosen to fall below the critical scattering rates in this system (1 GHz), and the sample dimensions are maintained below the critical length for domain formation. Thus when the electric vector is oriented parallel to the dc biasing field, and the propagation vector is normal to the biasing field, growth of the wave is to be expected and evidence of it is presented. In addition, the real and imaginary parts of the conductivity are evaluated throughout the dc bias field range from zero to 3.5 kV/cm, for a range of resistivities.

Trap-controlled Field Instabilities in Photoconducting CdS Caused by Field-quenching by K. W. Böer, p. 573. The formation of stationary high-field domains adjacent to cathode or anode, dependent on the contact potential of the electrodes, their widening with increased applied voltage and their transition into two types of moving domains are discussed. Domains which move under deformation of the domain profile and usually dissolve before they reach the anode, and nearly undeformed moving domains are described. The structure and kinetics of these domains are directly observed using the Franz-Keldysh effect and photographs of typical domain forms are presented.

The Effects of Hydrostatic Pressure on Hot-electron Phenomena in n-InSb by J. C. McGroddy, M. I. Nathan, W. Paul, S. Porowski, J. E. Smith, Jr., and W. P. Dumke, p. 580. The effect of hydrostatic pressure on the Gunn effect (high pressures) and bulk avalanche breakdown (low pressures) in *n*-InSb is studied. The measured generation rates of electron-hole pairs at 77K and 195K at several pressures are compared with the theory of Dumke.

Location of the <111> Conduction Band Minima in the Ga_{1-x}In_xSb Alloy System by M. R. Lorenz, J. C. McGroddy, T. S. Plaskett, and S. Porowski, p. 583. Pressure dependence of the resistivity and optical absorption by conduction band electrons are used to determine the position of the <111> (*L*₁) conduction band minima in the Ga_{1-x}In_xSb alloy system. These experimental data permit a more precise estimate of the position of the *L*₁ minima than had been possible using Gunn effect data alone.

The Influence of Boundary Conditions on Current Instabilities in GaAs by M. P. Shaw, P. R. Solomon, and H. L. Grubin, p. 587. We obtain excellent agreement among experiments eliciting a variety of GaAs current instabilities and the results of a computer simulation of GaAs with various fields imposed at the cathode boundary. When the cathode field is below around 4 kV/cm theory and experiments show

that the *I-V* characteristics of the active element are linear up to about 3 kV/cm where the current saturates and no transit-time oscillations occur. Experimentally this element gives rise to severe noise in a resistive circuit and sometimes tunable oscillations in a resonant circuit. When the cathode field is in the differential negative resistivity regime the *I-V* characteristics of the active element are nearly linear up to a threshold field (determined by the boundary field) where current drop, voltage rise and transit-time oscillations occur. For cathode fields above about 15 kV/cm the *I-V* characteristics are nonlinear and the element exhibits tunable oscillations in a resonant circuit.

A Topological Theory of Domain Velocity in Semiconductors by J. B. Gunn, p. 591. A theory is given for the velocity of a free, steadily travelling domain of high electric field in a semiconductor exhibiting a negative differential conductivity. Explicit results are derived for the cases for which the domain behavior is dominated either by the (electric-field dependent) diffusion of electrons, or by the rate of transfer of electrons between states having different mobilities. It is shown that the solution for the electric-field distribution has the required properties only if the system of differential equations involved possesses singular points with special topological properties; this requirement serves to fix the domain velocity. The velocity depends only on the properties of the semiconductor at that high electric field where the effective drift velocity of electrons is equal to that outside the domain.

Avalanche Shock Fronts in p-n Junctions by D. J. Bartelink and D. L. Scharfetter, p. 596. The conditions necessary for the formation of avalanche shock fronts, narrow layers of avalanche moving through a diode depletion layer faster than the carrier saturated drift velocity, are shown to be related to the large-signal limits of Read and more general avalanche transit time diode theory. Analysis of shock fronts by a simple analytic method has been used to interpret computer simulations of high efficiency microwave oscillator diodes. The oscillation mode, called the Trapatt mode, involves a compensated electron-hole plasma that is trapped in the depletion layer for a portion of each cycle.

Coherent Microwave Emission from an Electron-hole Plasma by B. B. Robinson and G. A. Swartz, p. 601. Coherent microwave radiation, 6.5 to 44 GHz, is generated by InSb at 77K with an injected electron current transverse to a magnetic field. The maximum output power is about 10 microwatts for input power levels of one to five watts. Grooves cut into the Suhl surface of the rod-shaped InSb samples impose the coherence and determine the frequency range of coherent operation. Wavelength measurements of a surface wave show that the effective groove width is equal to about a half-wavelength. A theory of double-stream interaction in a thin plasma layer with a magnetic field transverse to the current flow predicts instabilities in the observed frequency range. The theory predicts all of the qualitative and several

of the quantitative features of the observed emission. Noise emission is predicted and observed at temperatures up to room temperature with appropriate onset magnetic fields. The theoretical analysis and concurrent experimental evidence demonstrate the existence of an instability in a thin-layer plasma in the absence of a magnetic field at 77K.

Negative Differential Mobility in Nonparabolic Bands by G. Persky and D. J. Bartelink, p. 607. A strong NDM (negative differential mobility) in *n*-InSb at low temperatures is predicted from a single non-parabolic band model. Calculations allowing for the anisotropy of the distribution function have been made using (1) a drifted Maxwellian, and (2) a "two-temperature" model. The calculated NDM threshold field of 550 V/cm is in an observable field range in *p-n* junctions. In bulk samples, where breakdown occurs at $E \approx 200$ V/cm, domain nucleation may take place at high-field inhomogeneities and contribute to the dynamics of the breakdown process and attendant microwave emission.

The Role of Acoustic Wave Amplification in the Emission of Microwave Noise from InSb by C. W. Turner, p. 611. The experimental evidence for the generation of microwave emission from InSb by acoustic amplification of thermal noise is reviewed. The conditions in which the electron-phonon interaction is likely to dominate over other possible physical mechanisms are discussed, with particular reference to crystallographic orientation and crystal geometry. The application of the small signal acoustic amplification theory is shown to lead to qualitative agreement between constant gain loci and emission threshold curves.

Noise Emission from InSb by A. H. Thompson and G. S. Kino, p. 616. This paper gives a new explanation of the low-field noise emission from InSb. Theoretical predictions and experimental measurements with a fine tungsten probe (10- μ m definition) show that there are very large fields at one corner of the cathode contact in the presence of a transverse magnetic field. Our experiments show that avalanching occurs near this point and the noise amplitude has a strong maximum there. In a longitudinal magnetic field all samples measured have shown inhomogeneities near the cathode contact, which are the source of noise.

Microwave Emission and High-frequency Oscillations in *n*-Type InSb by D. K. Ferry and W. A. Porter, p. 621. Microwave emission from *n*-InSb at 77K in the presence of electric and magnetic fields was studied. Rectangular InSb samples were cut so that the long dimension and the applied electric field were parallel to one of the crystallographic axes $\langle 100 \rangle$, $\langle 110 \rangle$, or $\langle 111 \rangle$ and so that the position of all other axes was known. It was observed that instabilities in the voltage across the InSb sample accompanied the microwave emission and that, for a limited range of electric and magnetic fields, these instabilities were in the form of coherent oscillations. Both effects showed their lowest electric field thresholds when the magnetic field was parallel to one, but

not a specific one, of the crystallographic axes. Both effects were shown to occur at electric fields below those expected for an electron-hole plasma and a close correspondence between the two effects was demonstrated.

Summary of Microwave Emission from InSb: Gross Features and Possible Explanations by M. Glicksman, p. 626. This paper reviews the experimental observations of microwave emission from InSb and the theories proposed to explain these. Two sources for some of the radiation, the acoustoelectric interaction and a collision-induced plasma instability, appear reasonably well established. Experiments are proposed to clarify a number of still unanswered questions.

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Energy Diagram Method for Bragg Reflections in Low Energy Electron Diffraction (LEED) Spectra by P. M. Marcus, F. P. Jona, and D. W. Jepsen, p. 646. A point of view and a method of calculation derived from energy band theory are applied to the problem of finding energies of Bragg reflections from a given crystal. Energy curves are defined and calculated which describe the behavior of individual diffracted electron beams for a given set of beams incident on a particular face of the crystal. Intersections of these curves correspond to and identify the Bragg reflections associated with each beam. Energy diagrams and Bragg peak positions are shown for simple cubic and face-centered cubic lattices for various angles of incidence. We discuss the method in some simple cases and then solve the problem of finding Bragg reflections from the general crystal lattice with an arbitrary surface plane and arbitrary incident beams. The effect of the surface in producing well-defined diffracted beams for any incident beam and in grouping the Bragg reflections into these beams is described. Tables and formulas, which apply to any direction of incidence, are given for the Bragg reflections from the (001), (110) and (111) faces of the face-centered cubic lattice.

Two-dimensional Mathematical Analysis of a Planar Type Junction Field-effect Transistor by D. P. Kennedy and R. R. O'Brien, p. 662. A two-dimensional mathematical analysis is presented of the steady-state mechanisms of operation within a planar type junction field-effect transistor (JFET). This analysis shows that the potential distribution within the source-drain channel follows from solutions of Poisson's equation rather than from Laplace's equation. In particular, velocity-limited carrier transport produces a region of carrier accumulation in a region of the source-drain channel previously assumed to be depleted of carriers by the gate junction space-charge layers. The results of this two-dimensional mathematical analysis are presented in graphic form.

Fast Sequential Decoding Algorithm Using a Stack by F. Jelinek, p. 675. In this paper a new sequential decoding algorithm is introduced that uses stack storage at the receiver.

It is much simpler to describe and analyze than the Fano algorithm, and is about six times faster than the latter at transmission rates equal to R_{comp} , the rate below which the average number of decoding steps is bounded by a constant. Practical problems connected with implementing the stack algorithm are discussed and a scheme is described that facilitates satisfactory performance even with limited stack storage capacity. Preliminary simulation results estimating the decoding effort and the needed stack size are presented.

RF Sputtered Strontium Titanate Films by W. B. Pennebaker, p. 686. Two deposition parameters are important in rf sputtering of SrTiO_3 films: the oxygen-argon content ratio, and the substrate temperature. More than 1% oxygen is needed to produce insulating films; the exact percentage required depends on system cleanliness. Both dielectric constant and crystallite size increase with increasing substrate temperature.

Films of 2400 Å deposited at 500°C on gold have a dielectric constant of 200. The dc conductivity closely follows the Poole-Frenkel model. Two dielectric loss peaks are believed to be caused in part by an oxygen deficient region near one electrode. The variation in the dielectric constant κ with electric field is similar to that observed in bulk material.

Cation Deficiencies in RF Sputtered Gadolinium Iron Garnet Films by E. Sawatzky and E. Kay, p. 696. RF sputtering of stoichiometric, polycrystalline gadolinium iron garnet material results in films significantly deficient in iron content. The cation deficiency is shown to be quite sensitive to preparatory conditions and reflects itself markedly in the magnetic and structural properties of the resultant films. Temperature dependent sticking probabilities and selective resputtering at the growing film surface are thought to be the most likely causes for the observed deficiencies. A simultaneously operated rf-dc two-target sputtering system is described in some detail, which allows an expeditious study of and subsequent compensation for the observed cation deficiency. Films with essentially the bulk garnet composition

and bulk structural and magnetic properties were prepared in this two target system.

A Nonlinear Digital Filter for Industrial Measurements by B. Pehrson, p. 703. A simple algorithm is presented for nonlinear filtering of a time series composed of a gaussian component, pulses and steps. The method used is a combination of simple statistical techniques. The main advantage is claimed to be a scheme for adaptation of the filter parameters.

Strain and Temperature Distributions in a Thermally Activated Cantilever by A. Sugerman, S. Schmidt, and Y.-O. Tu, p. 711.

Mathematical Model for Pattern Verification by R. C. Dixon and P. E. Boudreau, p. 717. Pattern verification is mathematically defined, an appropriate decision function derived, and a measure for system evaluation is given. Two basic postulates are set forth to fully define a verification system: each known class is expected, with nonzero probability, to be verified under the correct class label; and the pattern vector extracted during verification should be descriptive of the given class, independent of which class label was entered into the system. Through appropriate use of a priori probabilities, three types of information can be incorporated into the theory: the expected number of times a given class will require verification, the expected use of each class label by a given class, and the likelihood that a particular class is susceptible to "impostor" patterns.

Optical Damage to LiNbO_3 from GaAs Laser Radiation by E. P. Harris and M. L. Dakss, p. 722. We have observed optical damage to LiNbO_3 at room temperature from focused cw GaAs laser radiation at a wavelength of 8450 Å. Visible damage was apparent after a 20-sec exposure corresponding to an energy flux of about $1.2 \times 10^5 \text{ J/cm}^2$ and was observed by changes in the diffraction pattern of the crystal. This is believed to be the first report of such damage in the potentially useful wavelength range of 0.8 to 0.9 μm . No damage was observed at a wavelength of 9030 Å in a similar but pulsed-laser experiment.

Dielectric Films for Ge Planar Devices by T. O. Sedgwick, J. A. Aboaf, and S. Krongelb, p. 2. A series of passivating and masking films was developed and evaluated for use in a Ge planar transistor technology. In the search for satisfactory films, silicon dioxide, aluminum oxide, silicon nitride and multilayer combinations of these films, as well as some doped and mixed-composition films, were studied. The films, formed by pyrolytic deposition or by sputtering, were evaluated and compared with respect to the following properties: etch rate; dopant masking; mechanical stress; oxygen, hydrogen and water permeability; stability with respect to elevated temperature electrical-bias stressing; and Ge-insulator interface electrical condition.

The most important results of our experiments are the following: Silicon nitride appears to be the only satisfactory mask for Ga diffusions, although silicon dioxide is adequate for As, P and Sb diffusion masking. The dielectric properties of pyrolytically deposited SiO_2 can be made to approach those of thermal SiO_2 by high temperature densification. The surface electrical properties of the Ge- SiO_2 interface are more stable to thermal annealing than is any other Ge-insulator combination. However, aluminum oxide has been shown to be much less permeable to oxygen, hydrogen and water vapor than is SiO_2 . Since the Ge-insulator interface electrical properties are sensitive to these ambient gases, a satisfactory passivating film structure for Ge consists of an underlayer of SiO_2 and an overlayer of Al_2O_3 , silicon nitride or other relatively impermeable film.

The Theory of Hot Electrons by P. J. Price, p. 12. This is a survey of methods of analysis of the hot-electron phenomenon in semiconductors. The earliest method depended on three basic assumptions: smallness of the deviation of $f(p)$, the carrier distribution function, from $f_0(E(p))$, the distribution in energy E ; the conventional relaxation-time relation between $f - f_0$ and df/dE ; and smallness of df/dE . More general methods are associated with giving up, successively in the reverse order, these assumptions. Procedures for obtaining and solving equations involving f_0 only, based on a new approach due to Levinson, are developed. An inherently precise method for calculating f and related treatment of differential mobility, which requires computer implementation and which has recently come into use, is expounded. Test calculations for the case of n -germanium are reported.

On-line Far-infrared Michelson Interferometry in a Time-shared Mode by J. N. Gayles, Jr., W. L. Honzik, and D. O. Wilson, p. 25. A method is described for implementing real-time far-infrared Fourier spectroscopy in a time-shared environment. The system makes use of the IBM 1800 TSX-based General Experimental Monitor (GEM) and reduces by at least an order of magnitude the time between experiment initiation and the display of useful spectral frequency and

intensity information. The key feature of the system includes conversational mode operation with the incomplete data array. This feature enables one to review at any interval the Fourier transform of the partially acquired data without in any way disturbing the process of data collection. Procedures are illustrated also for performing signal averaging and several comparatively routine spectroscopic tasks.

On the Equations of Holland in the Solution of Problems in Multicomponent Distillation by D. S. Billingsley, p. 33.

Holland developed certain equations to be used to accelerate or induce convergence in multicomponent distillation calculations. In practice this procedure has been the most successful of any adjunct to the basic Thiele-Geddes or Lewis-Matheson procedure for solving these problems. It is of importance, therefore, to ascertain the conditions under which the Holland equations can be guaranteed to possess the required type of solution at each iteration. The types of specifications which fulfill these conditions are determined.

On the Maximum Likelihood Method of Identification by T. Bohlin, p. 41.

The maximum likelihood principle of estimation applied to the linear black-box identification problem gives models with theoretically attractive properties. Also, the method has been applied to industrial data (various processes in paper production) and proved able to work in practice.

This paper presents further developments of the method in the case of a single output. The reliability and speed of the identification algorithm have been improved, and the method has been made easier to use. A rather sophisticated computer program, however, was needed. It employs a generalized model structure, an improved hill-climbing algorithm, and an automatic procedure for determining model orders and transport delays. Some statistics from performance tests of the program are presented.

Argon Content of SiO_2 Films Deposited by RF Sputtering in Argon by G. C. Schwartz and R. E. Jones, p. 52.

When SiO_2 is deposited by sputtering in an argon rf glow discharge, the films so produced contain considerable amounts of trapped argon, as determined by x-ray fluorescence analysis. This argon content was measured as a function of various sputtering parameters: argon pressure, rf power, electrode spacing, substrate temperature, and magnetic field, the latter two being most influential. A simple theoretical model for the capture and release of argon is presented which explains an observed linear decrease of the argon concentration in SiO_2 with increasing temperature. Incorporation of argon into the sputtered SiO_2 film does not seem to impair the film's ability to act as a good passivating and insulating layer.

Superlattice and Negative Differential Conductivity in Semiconductors by L. Esaki and R. Tsu, p. 61.

We consider a one-dimensional periodic potential, or "superlattice," in monocrystalline semiconductors formed by a periodic

variation of alloy composition or of impurity density introduced during epitaxial growth. If the period of a superlattice, of the order of $100 \text{ \AA}$, is shorter than the electron mean free path, a series of narrow allowed and forbidden bands is expected due to the subdivision of the Brillouin zone into a series of minizones. If the scattering time of electrons meets a threshold condition, the combined effect of the narrow energy band and the narrow wave-vector zone makes it possible for electrons to be excited with moderate electric fields to an energy and momentum beyond an inflection point in the E - k relation; this results in a negative differential conductance in the direction of the superlattice. The study of superlattices and observations of quantum mechanical effects on a new physical scale may provide a valuable area of investigation in the field of semiconductors.

Calculation of the Current Density in the Contacts of a Thin Film Resistor by J. Overmeyer, p. 66. The two-dimensional boundary value problem appropriate to current flow in a film resistor is examined. A simple closed-form solution for current density into the contact is found to exist for the important case of a thin film resistor with extended lands. The spatial dependence of the current density into the contact is found to be similar to that obtained by Kennedy and Murley for the diffused resistor, with film thickness entering the functional dependence in a role analogous to the diffusion length of the dopant ion in the diffused resistor.

Indium-mercury Alloy as a Low-toxicity Liquid Electrode by S. S. Russell and S. L. Levine, p. 70.

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Dynamic Performance of Schottky-barrier Field-effect Transistors by K. E. Drangeid and R. Sommerhalder, p. 82. The dynamic performance of Schottky-barrier field-effect transistors is discussed, with the aim of finding in a most simple way the physical parameters on which the dynamic properties of a FET depend, how strong they influence the dynamic qualities of FET's, and what recommendations can be given as to proper choice of material or structure for FET's with good high-frequency performance.

Computer Aided Two-dimensional Analysis of the Junction Field-effect Transistor by D. P. Kennedy and R. R. O'Brien, p. 95. A two-dimensional analysis is presented of the mechanisms of operation for a junction field-effect transistor. Particular emphasis is placed upon the process of electric current saturation in both wide gate and narrow gate structures. It is shown that velocity saturated carrier transport in a source-drain channel produces heretofore unreported mechanisms of device operation. Comparisons made between the conclusions derived from this two-dimensional analysis and the conventional one-dimensional theory of JFET operation are presented in graphic form.

Projection Masking, Thin Photoresist Layers and Interference Effects by S. Middelhoek, p. 117. Projection masking is used for producing microwave semiconductor devices with micrometer or submicrometer structures. In contrast to contact masking, the mask is projected onto the silicon wafer by means of a high quality microscope objective. Since the chromatic errors of such a lens cannot be fully corrected, monochromatic light has to be employed. This, however, causes standing light waves to occur in the SiO_2 and photoresist layers, leading to unexpected effects. This report describes some of these effects and the experimental conditions under which satisfactory masking results can be obtained.

Microwave Properties of Schottky-barrier Field-effect Transistors by P. Wolf, p. 125. The microwave properties of silicon Schottky-barrier field-effect transistors (MESFET's) with a gate-length of one micrometer are investigated. The scattering parameters of the transistors have been measured from 0.1 GHz up to 12 GHz. From the measured data an equivalent circuit is established which consists of an intrinsic transistor and extrinsic elements. Some of the elements of the intrinsic transistor, notably the transconductance, are strongly influenced by the saturation of the drift velocity. Best performance of the intrinsic transistor is obtained with highly doped and thin channels. The measured power-gain is in good agreement with theoretical values deduced from the equivalent circuit. The best device has a maximum frequency of oscillation f_{max} of 12 GHz. The investigation reveals that the extrinsic elements, especially the resistance of the gate-metallization and the gate-pad parasitics, degrade the power-gain considerably. Without them a value of f_{max} close to 20 GHz is predicted.

Silicon and Silicon-dioxide Processing for High-frequency MESFET Preparation by T. O. Mohr, p. 142. Silicon wafer processing is described which provides submicrometer epitaxial layers on top of high-resistivity silicon substrates for fabrication of high-frequency metal-semiconductor field-effect transistors. Silicon-dioxide underetching at the border of an oxide window, performed in hydrogen at elevated temperatures, is one method of realizing 1-micrometer device structures.

Metallization Processes in Fabrication of Schottky-barrier FET's by S. Middelhoek, p. 148. The metallization processes necessary for the production of microwave Schottky-barrier field-effect transistors are described. Since the gate contact is only 1 micrometer wide, the holes and the metallization of the source, drain and gate contacts are produced simultaneously. Then in a subsequent process, the source and drain contacts are converted to ohmic contacts by the evaporation of Au-Sb onto these contacts. Mask alignment is not a problem because the Au-Sb spreads across the surface after suitable heat treatment.

Minimal Energy Dissipation in Logic by R. W. Keyes and R. Landauer, p. 152. Minimal energy dissipations for the logic process based on thermodynamics and general phase space considerations are known. The actual availability of these minimal dissipations has not, however, been demonstrated. These minimal dissipation sources in a computing system also act as noise sources and thereby lead to questions about the ultimate available reliability of the computing process. A new and hypothetical device is presented in this paper and used to construct a physically analyzable computing system. It is demonstrated that this system has dissipations larger than, but of the same order of magnitude as, the original minimal quantities. It is also shown that any required reliability can be obtained with this device, without increased energy expenditure, but at the expense of an increasing time per computational step.

Thermal Problems of the Pulsed Injection Laser by R. W. Keyes, p. 158. Heat is produced in short periods of time during pulsed operation of an injection laser. The temperature of the laser at the beginning of any pulse due to the heating caused by preceding pulses is calculated for several simple model cases. The results are applied in the description of performance deterioration caused by heating.

Application of RF Discharges to Sputtering by H. R. Koenig and L. I. Maissel, p. 168. The operation of rf discharges is described and the internal distribution of voltages is considered. The significance of this with respect to sputtering, particularly of insulators, is then discussed. An equivalent circuit for the discharge is presented and the influence of such parameters as pressure and magnetic field on the components of this circuit is described. Finally, energy distributions for positive ions, electrons, and negative ions incident at the substrate during deposition are given.

Control of RF Sputtered Film Properties Through Substrate Tuning by J. S. Logan, p. 172. A means has been found to control the rf potential of the substrate during rf sputtering. The application of this technique to the deposition of silica films has been investigated in detail. The technique can be described as the use of an adjustable rf impedance between the substrate holder and ground electrodes, which generates an rf potential by virtue of the flow of rf current through it. Adjustment of the rf potential of the substrate results in a controlled dc bias potential developed at the film surface, which correlates directly with the physical properties of the deposited films. In general, the most desirable film properties are obtained when the dc substrate bias (obtained by adjusting the substrate-holder rf impedance) is at a high negative potential. The effect of substrate bias on etch rate, pinhole breakup thickness, and argon content has been measured.

Re-emission of Sputtered SiO₂ During Growth and Its Relation to Film Quality by L. I. Maissel, R. E. Jones, and C. L. Standley, p. 176. An improved technique for measuring

re-emission coefficients is described and data on the effect of temperature are presented. These are discussed in the light of a physical model of film growth during sputtering wherein constant re-emission of material throughout deposition occurs. Evidence is then presented that such re-emission is essential if films of high quality are to be obtained. To help assess "quality" in a quantitative fashion use has been made of the PBUT (pin-hole breakup thickness) phenomenon, which is described in some detail. The influence on PBUT of several system parameters such as sputtering pressure and impurity content is discussed and related to the re-emission coefficient.

Metal Edge Coverage and Control of Charge Accumulation in RF Sputtered Insulators by J. S. Logan, F. S. Maddocks, and P. D. Davidse, p. 182. The successful application of rf sputtered SiO₂ in the passivation of silicon semiconductor devices depends in part on the proper control of ionic charge migration in the insulator during sputtering, and on the adequate coverage of metal line edges by the insulator. It is shown that an appropriate combination of target purity, substrate temperature control and phosphosilicate blocking layer thickness can be used to achieve ionic charge densities at the silicon-SiO₂ interface of less than 1×10^{12} charges per square centimeter. The effects of argon ion bombardment are shown to be acceptably low for typical operating conditions. In a conventional system, the adequate coverage of metal line edges is shown to be influenced primarily by argon pressure and magnetic field. In a special system where the substrate potential can be varied, it has been shown that adequate edge coverage can be obtained at sufficiently negative potentials. These data are consistent with a mechanism requiring some resputtering to obtain the desired film coverage.

Automatic Impedance Matching System for RF Sputtering by N. M. Mazza, p. 192.

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Survey of the Field of Magnetic Semiconductors by S. Methfessel, p. 207. Magnetic semiconductors are materials with good band conductivity as well as magnetic order. Since each phenomenon requires a different description of the relevant electron states, the band structure of these materials is very complicated, containing band states as well as localized states. An important condition for strong interaction between the magnetic and the conducting electrons appears to be the existence of high densities of states at the Fermi energy, providing large carrier polarizations in the magnetized state.

Exchange Mechanisms in Europium Chalcogenides by T. Kasuya, p. 214. Superexchange mechanisms, which are mostly responsible for the nnn exchange constant I_2 in Eu chalcogenides, are investigated in detail. In contrast with the usual 3d transition metal compounds, the Kramers-Anderson mechanism is estimated to be one order of magnitude too small to explain the experimental results due to a small $4f \rightarrow$

2p transfer energy. The mechanism by which a p electron is transferred to a 5d state through the d-f exchange interaction gives the correct order of magnitude for I_2 , with a negative sign, even though it is a sixth-order perturbation. The cross term between the above two mechanisms is shown to be nearly as important as the second mechanism and may have a positive sign. The indirect exchange mechanisms, in which the anion p level has no important role, are responsible for the nn exchange constant I_1 . The phonon-assisted mechanism proposed by Smit is estimated to be more than one order of magnitude smaller than the experimental value. The d-f mixing term is proved to be responsible for I_1 , in good agreement with experiment.

Long-range Magnetic Interactions (RKKY-type) in the UP-US Solid Solutions by *M. Kuznietz*, p. 224. UP, US, and the UP-US solid solutions have the NaCl-type structure and are good conductors of electricity. UP is anti-ferromagnetic of type I; US is ferromagnetic. Assuming U^{4+} cations, P^{3-} and S^{2-} anions, and RKKY interactions between the uranium localized 5f-electrons via the conduction electrons (≈ 1 in UP and ≈ 2 in US), the observed magnetic structures are accounted for, although these structures are also predicted by molecular field theory. A neutron diffraction study of the UP-US solid solutions has revealed two new magnetic structures, the type IA (2+, 2-) antiferromagnetic structure and the antiphase (5+, 4-) ferrimagnetic structure, which are of long range (several lattice parameters) and are typical of long-range RKKY-type interactions, as assumed in the simple model for these compounds. Further experimental evidence is given for the long-range magnetic interactions in uranium mononitrides and monochalcogenides and their solid solutions. The situation in these uranium compounds is compared with the corresponding lanthanide compounds, and the role of covalency and superexchange in the case of heavier anions is discussed.

Ordered Moment of NiS_2 by *J. M. Hastings and L. M. Corliss*, p. 227. The transition metal dichalcogenides exhibit a wide variety of both electrical and magnetic properties, from insulators to superconductors and from ferromagnetism through antiferromagnetism to diamagnetism. NiS_2 is a semiconductor with an anomalous paramagnetic behavior which leaves in doubt the existence of a local moment. Previous neutron diffraction data have failed to show any ordering down to 4.2K. Our neutron powder diffraction data on stoichiometric NiS_2 show a transition at 40K to a structure which can be described as ordering of the first kind. This is followed by an abrupt transition at 30K in which additional diffraction peaks appear and these are consistent with ordering of the second kind. Despite the fact that the powder data cannot indicate an unambiguous magnetic structure, the magnitude of the ordered moment can be fixed. The rms moments associated with ordering of the first and second kinds are 1.0 and 0.60 μ_B per nickel atom, respectively, and the total moment is 1.17 μ_B per nickel atom.

Specific Heat of SnTe-MnTe System from 2 to 25°K by *M. P. Mathur, D. W. Deis, C. K. Jones, A. Patterson, and W. J. Carr, Jr.*, p. 229. The low-temperature specific heat of a series of semiconductor alloys of the SnTe-MnTe system, for Mn to Sn ratios of 0 to 0.1 has been measured in the temperature range 2 to 25K. Large anomalies are observed due, presumably, to the ordering of the Mn^{2+} spin system. The temperature region over which these anomalies occur is roughly the region in which ferromagnetism is observed.

Localized and Itinerant Electrons in Oxides by *J. M. Honig*, p. 232. Recent work concerning the electrical properties of ReO_3 , PrO_x , ($1.5 \leq x \leq 2.0$), TiO_2 , $SrTiO_3$, perovskites, CrO_2 , NiO , $Li_xZn_{1-x}V_2O_4$, V_2O_3 , and Ti_2O_3 has been selectively reviewed in attempts to elucidate the conduction properties of the charge carriers. A number of controversial issues are pointed out: Frequently it is not known whether mobilities are activated or not, nor whether a given material should be classified as a polaronic or mixed-carrier material; neither is there agreement on the nature of electrical transitions. Discrepancies in electrical properties can generally be traced to insufficient control over preparation and characterization of samples.

Hall Mobility Measurements on Magnetite above and below the Electronic Ordering Temperature by *W. J. Siemons*, p. 245. Hall effect measurements were made on a single crystal of magnetite in the temperature range 65 to 373K. The Hall voltage was positive over the whole temperature range. The results can be explained by assuming that magnetite is a normal semiconductor below the transition point and a degenerate one above that temperature.

Transport Properties of Iron-nickel Ferrites by *P. Nicolau, I. Bunget, M. Rosenberg, and I. Belciu*, p. 248. The mechanism of electrical conduction in the magnetic semiconductors $Ni_xFe_{3-x}O_4$ with $0.6 < x \leq 1$ was investigated. The electrical properties of these compounds are extremely sensitive to the presence of $\alpha-Fe_2O_3$ as a second phase. The exponential temperature dependence of the electrical resistivity ρ and the temperature-independent thermoelectric power θ are in good agreement with an electron-hopping model. The electrical conduction occurs by thermally activated electron hopping between octahedral Fe^{2+} and Fe^{3+} ions with an activation energy q . The values of ρ , q and θ depend on the Fe^{2+} concentration only, and are not sensitive to small deviations from stoichiometry due to the presence of cation or anion vacancies.

Metal-insulator Transition in Transition Metal Oxides by *T. M. Rice and D. B. McWhan*, p. 251. The metal-insulator transition in the V_2O_3 system is discussed. A recent series of experiments on V_2O_3 and $(V_{1-x}Cr_x)_2O_3$ is reviewed. The phase diagram for the system is described. The Cr-doped mixed oxides are insulating at room temperature for $x \geq 0.009$ and transform to a metal with the application of pressure. This phase transition is identified as a Mott transition. A

comparison is made between the experimental results and theoretical predictions of the Mott transition.

Magnetic and Electrical Properties of $(\text{La}_{1-x}\text{Ca}_x)\text{MnO}_3$ by G. Matsumoto, p. 258. Samples of polycrystalline $(\text{La}_{1-x}\text{Ca}_x)\text{MnO}_3$, where x takes values ranging from 0.005 to 0.3, have been studied experimentally. Specimens were carefully prepared in the stoichiometric forms by changing the oxygen partial pressure conditions for each value of x . For specimens having x smaller than 0.1, the Néel temperature T_N is almost constant, 141K, while the paramagnetic Curie temperature θ increases as x increases. On the other hand, for specimens in which x is greater than 0.1, both T_N (or T_C) and θ are almost equal and increase with the value of x . The Mn^{55} NMR spectra associated with Mn^{3+} and Mn^{4+} ions were observed in specimens having x smaller than 0.175, while motionally narrowed Mn^{55} spectra were observed where the values of x were 0.2 or 0.3. All the experimental results could be qualitatively explained by postulating that the d holes at the sites around Ca^{2+} ions contribute to both the electrical conduction and the magnetic interaction. The ferromagnetic interaction induced by mobile d holes can not be ascribed to the double-exchange interaction, if this interaction has the usual form $b \cos(\theta/2)$.

Band Structure of Magnetic Semiconductors by D. Adler, p. 261. The band structure of materials in which both localized and itinerant outer electrons are simultaneously present is discussed. The Franck-Condon Principle is applied, and small and large polaron formation is taken into account. A scheme for estimating the densities-of-states of perfect crystals and doped or non-stoichiometric crystals is suggested, based on the ionic many-body states as a starting point. Screening, covalency, crystalline-field and overlap effects are quantitatively considered. In particular, the band structures of both pure and Li-doped NiO are derived and found to be in agreement with the experimental observations. It is shown that conclusions which are based on ordinary donor and acceptor techniques fail to account for the effects of doping even in a qualitatively correct manner, due to the neglect of important correlation effects.

Transport Properties of the Europium Chalcogenides by S. von Molnar, p. 269. Transport properties of pure and doped Eu chalcogenides are reviewed to determine the mechanisms responsible for the anomalous behavior near T_C , the Curie temperature. It is found that, whereas the scattering theory of simple metals accounts for the behavior of materials containing impurities in excess of $2 \times 10^{20} \text{ cm}^{-3}$, several models for transport have been proposed for smaller concentrations. The impurity hopping model appears to be consistent with the data for very dilute systems.

Temperature and Magnetic Field Dependence of the Conductivity of EuO by M. R. Oliver, J. O. Dimmock, and T. B. Reed, p. 276. The conductivity of EuO has been measured as a function of temperature from 30 to 300K in

magnetic fields up to 50 kG. The zero-field resistivity exhibits a sharp elbow at about 50K, and increases as much as 10^8 between 50 and 70K to a broad maximum between 75 and 80K. In an applied magnetic field, the broad maximum is rapidly decreased and the elbow is shifted to higher temperatures. These data are interpreted in terms of a transfer of electrons between a conduction band and an electron trap. In the model the energy separation between the band and trap level depends on the magnetic energy of the crystal and is thus a strong function of temperature and magnetic field. At low temperatures the trap level is assumed to be above the conduction band edge such that the electrons lie in the band. As the temperature is increased the energy of the band edge increases such that it crosses the trap level at about 50K. The large increase in resistivity with increasing temperature and the effects due to the magnetic field are explained by the transfer of electrons from the energy band into the trap states.

Tunneling Spectroscopy in Ferromagnetic Semiconductors by W. A. Thompson, F. Holtzberg, and S. von Molnar, p. 279. The observation of zero-bias anomalies in tunneling has received much attention but their interpretation has suffered from a lack of definition of the character of the tunneling barrier. Junctions formed from a metal with Eu-chalcogenide ferromagnetic semiconductors offer a potential means of overcoming this difficulty. We have made rectifying junctions of EuS:Eu on In. The results indicate: 1) a large resistivity peak at zero-bias voltage which, in the ferromagnetic region, has a strong magnetic-field dependence, and 2) a resistance maximum near 30 mV which has been tentatively assigned to excitation of collective modes in the bulk of the semiconductor. We interpret the present results by considering excitation of ferromagnetic magnons in the barrier region.

Spin-disorder Scattering and Band Structure of the Ferromagnetic Chalcogenide Spinels by C. Haas, p. 282. Magnetic semiconductors are characterized by the presence of charge carriers and magnetic moments. The interaction between the charge carriers and the magnetic moments leads to a spin splitting of the energy bands, and to spin-disorder scattering of the charge carriers. The result is a strong influence of magnetic properties on the transport properties. The theory of these effects is discussed in the first part of this paper. In the second part two models for the band structure of CdCr_2Se_4 are discussed, and compared with experimental data on the optical properties and the transport properties.

Hole and Electron Bands in n -type CdCr_2Se_4 by L. R. Friedman and A. Amith, p. 289. A phenomenological model is presented to explain the anomalous temperature dependencies of the electrical resistivity and the Hall and Seebeck coefficients of indium-doped CdCr_2Se_4 , with selenium deficiencies. The model postulates the existence of a hole band below localized donor levels, well above the intrinsic valence band. The assumed relative motions of the hole band and the donor level as the temperature is lowered, together

with the optically deduced downward motion of the conduction band, are adequate to explain the data in a consistent manner. It is hypothesized that the hole band as well as the donor levels are related to the combination of indium ions and selenium deficiencies.

High-field Nonohmic Behavior of the *p*-type

Ferromagnetic Semiconductor $\text{Ag}_x\text{Cd}_{1-x}\text{Cr}_2\text{Se}_4$ by B. Vural, p. 292. The high-field longitudinal magnetoresistance of the ferromagnetic (polycrystalline) *p*-type semiconductor $\text{Ag}_x\text{Cd}_{1-x}\text{Cr}_2\text{Se}_4$ has been measured as a function of temperature and applied magnetic and electric fields. It is suggested that the observed "anomalies" may be related to the possible spin wave-carrier wave interactions in these materials.

Comments on Electronic Transport in Transition Metal

Oxides by H. P. R. Frederikse, p. 295. Several aspects of electronic transport in nonmagnetic and magnetic transition metal oxides are reviewed. These include high- and low-temperature measurements of conductivity, the Hall effect and the Seebeck effect, and their analysis in terms of the electronic energy structure. Particular emphasis is put on the temperature dependence of the Hall mobility, which gives essential information concerning the correct description of the energy states and the scattering of the charge carriers. The second half of the paper discusses the relation between the transport properties and the magnetic ordering. The properties of LaCoO_3 together with an interpretation suggested by Goodenough are presented to illustrate this point.

Optical Properties of the Europium Chalcogenides

by J. O. Dimmock, p. 301. The measured optical properties of the Eu chalcogenides are surveyed in an attempt to determine those aspects of the electronic structure of these materials that have been established. Optical absorption as well as optical and magneto-optical reflectivity data are discussed, along with the results of photoconductivity, photoluminescence and photoemission measurements and of magneto-optical measurements in the vicinity of the absorption edge. It is concluded that the fundamental absorption edge is due to the onset of $\text{Eu}^{++} 4f$ to $5d$ transitions of the type $4f {}^7({}^8S_{7/2}) \rightarrow 4f {}^6({}^7F_1)5d(T_{2g})$ and that a higher energy reflectivity peak is primarily due to $4f {}^7({}^8S_{7/2}) \rightarrow 4f {}^6({}^7F_1)5d(E_g)$ transitions, although anion *p*-valence band to Eu conduction band transitions may also be involved. The principal unanswered questions involve the relative positions of the Eu *6s* and $5d(T_{2g})$ states, the breadth of the *5d* levels and the role played by exciton effects in the *4f* to *5d* optical transitions.

Optical Reflectance Study of Magnetic Ordering Effects in

EuO , EuS , EuSe and EuTe by C. R. Pidgeon, J. Feinleib, W. J. Scouler, J. O. Dimmock, and T. B. Reed, p. 309. The reflectivity of the ferromagnetic semiconductors EuO , EuS and EuSe has been measured as a function of temperature and light polarization in an orienting magnetic field. In the energy range from just above the absorption edges to about 5.0 eV,

there are two prominent features, E_1 and E_2 , which change with the magnetic order, indicating exchange splittings of the *5d* states. Antiferromagnetic EuTe shows a different structure in the E_1 and E_2 peaks. However, with a large magnetic field applied (> 40 kOe) the spectrum becomes characteristic of the other ferromagnetic europium chalcogenides suggesting a phase transition to parallel spin alignment at $H \approx 80$ kOe. The effect provides direct experimental confirmation of the band theory prediction that there are superlattice splittings in the band structure of an antiferromagnetic crystal.

Magneto-optical Investigation of the Band Edge of CdCr_2S_4 and Related Absorption Measurements on

Cr-doped CdIn_2S_4 by S. Wittekoek and P. F. Bongers, p. 312. The 4T_1 and 4T_2 crystal-field transitions of Cr^{3+} have been observed in the absorption spectrum of $\text{CdIn}_2\text{S}_4(\text{Cr})$. From the similarity between the temperature dependence of the 4T_2 band and the reported blue shift of the absorption edge of CdCr_2S_4 , it is concluded that in CdCr_2S_4 this edge is caused by the 4T_2 absorption band of the Cr^{3+} ions. The polar magneto-optic Kerr effect between 560 and 700 nm and the Faraday rotation between 800 and 8000 nm are reported for CdCr_2S_4 . The Kerr effect spectrum indicates that the intrinsic band edge of CdCr_2S_4 is at 1.91 eV at 60K and shifts to lower energies with decreasing temperature.

Influence of Magnetic Ordering on the Faraday Effect in

CdCr_2Se_4 by D. Kuse, p. 315. Measurements of the magneto-optical rotation in CdCr_2Se_4 at wavelengths between 0.9 and 1.3 μm are reported. In the paramagnetic state, the rotation passes a minimum with decreasing wavelength and changes sign at the absorption edge. The Verdet constant is proportional to the paramagnetic susceptibility ($V = -18 \text{ deg/kOe-cm}$ at 300K and $\lambda = 1.05 \mu\text{m}$). In the ferromagnetic state the Faraday effect is large and the sign reversal very pronounced; e.g., the rotation changes by $6.5 \times 10^4 \text{ deg/cm}$ in a wavelength interval of 400 Å in saturated material at 93K. The photon energy at which the sign reversal occurs shows a strong temperature-dependent red shift; the temperature dependence is similar to that of the absorption edge. At low temperatures an additional rotational minimum appears that is subject to the same red shift.

Magnetic Field Dependence of Indirect Transitions in

Ferromagnetic Semiconductors by R. M. White, p. 318. The optical absorption coefficient for magnetic semiconductors has been calculated for indirect transitions in which the intraband scattering arises from an *s-d* or *s-f* exchange interaction instead of the usual phonon mechanism. The temperature and magnetic field dependence of the resulting absorption coefficient are discussed.

Photoinduced Magnetic Effects in $\text{YIG}(\text{Si})$

by E. M. Gyorgy, J. F. Dillon, Jr., and J. P. Remeika, p. 321. This paper summarizes the recent investigations of photoinduced effects in magnetic materials. To date it has been shown that the uniaxial anisotropy, strain, linear dichroism, coercive force

and initial permeability can be modified by infrared radiation. The theory interpreting the coercive force and permeability experiments differs from the model used to describe the first three effects and is not discussed here. The first three effects can be interpreted fairly well in terms of a model which has single Fe^{2+} ions preferentially occupying inequivalent octahedral sites. It is shown that with polarized light more than half of the available Fe^{2+} ions can be selectively moved among specific types of sites. Irradiation with unpolarized light essentially leads to a distribution appropriate for thermal equilibrium at the temperature of the sample.

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Coding for Error Control in a Computer-Manufacturer's Environment: A Foreword by R. T. Chien, p. 342.

Coding Schemes for Reduction of Intersymbol Interference in Data Transmission Systems by H. Kobayashi, p. 343. Various coding schemes and their effects on intersymbol interference in pulse amplitude modulation systems are discussed. First, the relation between imperfections in the baseband-equivalent channel and intersymbol interference is clarified and applied to explain the effect of correlative level coding and Gorog's frequency concept codes in reducing intersymbol interference. Another coding scheme is then introduced: construction of codes in the time domain with intersymbol interference directly in mind. A decimal code of length 4 and an alphanumeric code of length 6 are proposed as practical codes and their properties are discussed. Simulation results are presented to give quantitative comparison of these coding techniques. Curves of the vertical eye-opening vs transmission rate have been produced and we show that codes designed in the time domain achieve better performance than both the frequency concept codes and the conventional codes for a wide class of channel characteristics.

Introduction to Pseudoternary Transmission Codes by A. Croisier, p. 354. This paper describes many of the pseudoternary (PT) codes (twinned, bipolar, partial response, etc.) used in data transmission. In these, binary information is transmitted through three-level rather than binary pulse codes for controlling the power distribution in the frequency spectrum, improving clock recovery, allowing error detection or for just increasing the binary data rate. Linear and nonlinear PT codes are considered, the latter being divided into alphabetic and nonalphabetic codes. Among the nonalphabetic codes, emphasis is given to the modified bipolar codes used in pulse code modulation systems. Two recently developed codes of this type are described: High Density Bipolar (HDB) and Compatible High Density Bipolar (CHDB). They are particularly suitable for PCM transmission on repeated lines.

Another nonalphabetic code, the Transparent Interleaved Bipolar (TIB) is presented for the first time. This code

features all the advantages of partial-response (or Interleaved Bipolar) signalling and, in addition, guarantees a minimum density of pulses, regardless of the data.

Application of Partial-response Channel Coding to Magnetic Recording Systems by H. Kobayashi and D. T. Tang, p. 368. A magnetic recording channel can be regarded as a "partial-response" channel because of its inherent differentiation in the readback process. The conventional NRZI method of recording is shown to be equivalent to the "precoding" of this particular partial-response channel, the purpose of which is to limit the propagation of error in the channel output. Using this new viewpoint, one can readily adopt an error detection scheme (developed for general partial-response channels) that takes full advantage of the inherent redundancy in the three-level channel output. The detection scheme is optimum in the sense that it detects all detectable errors with minimum delay.

The paper also describes a new high-density recording method, named the "Interleaved NRZI," which is obtained by molding an ordinary recording channel into a different type of partial-response channel, resulting in a potential increase in information density. Implementation of the corresponding optimum error detection scheme is also presented.

Finally, performance of these error detection schemes is evaluated in terms of probabilities of detecting single and double errors within a certain finite delay.

Sequence-state Methods for Run-length-limited Coding by P. A. Franaszek, p. 376. Methods are presented for the encoding of information into binary sequences in which the number of ZEROS occurring between each pair of successive ONES has both an upper and a lower bound. The techniques, based on the state structure of the constraints, permit the construction of short, efficient codes with favorable error-propagation-limiting properties.

Error Correction for IBM 800-bit-per-inch Magnetic Tape by D. T. Brown and F. F. Sellers, Jr., p. 384. The 800-bit-per-inch magnetic tape units that are components of IBM System/360 can correct error bursts of unlimited length in any one of their nine tape tracks. The correction technique employs a modified cyclic code in conjunction with a parity bit in each nine-bit character. There are nine check bits in the modified cyclic code and these form a check character at the end of every record. To perform the correction, a record in which an error has been detected must be reread. Errors involving more than one track within the same record are detected but are not correctable. This error correction technique operates during both read-forward and read-backward operations, and on records of any length.

Orthogonal Latin Square Codes by M. Y. Hsiao, D. C. Bossen, and R. T. Chien, p. 390. A new class of multiple-error correcting codes has been developed. Since it belongs to the

class of one-step-decodable majority codes, it can be decoded at an exceptionally high speed. This class of codes is derived from a set of mutually orthogonal Latin squares. This mutually orthogonal property provides a class of codes having a unique feature of "modularity." The parity check matrix possesses a uniform pattern and results in a small number of inputs to modulo 2 adders. This class of codes has m^2 data bits, where m is an integer, and $2tm$ check bits for t -error correcting.

A Class of Optimal Minimum Odd-weight-column

SEC-DED Codes by *M. Y. Hsiao*, p. 395. The class of codes described in this paper is used for single-error correction and double-error detection (SEC-DED). It is equivalent to the Hamming SEC-DED code in the sense that for a specified number k of data bits, the same number of check bits r is used. The minimum odd-weight-column code is suitable for applications to computer memories or parallel systems. A computation indicates that this code is better in performance, cost and reliability than are conventional Hamming SEC-DED codes.

b -Adjacent Error Correction by *D. C. Bossen*, p. 402. A high-speed method is derived for single-symbol error correcting Reed-Solomon and Hamming type codes. A matrix description is used for implementation of the codes, in which single-error correction in the Galois field 2^b corresponds to correcting a block of b bits in a binary field. The resulting codes correct not only single-bit errors but also single clusters of b -adjacent-bit errors.

Error Control for Terminals with Human Operators

by *D. T. Tang and V. Y. Lum*, p. 409. The man-machine interface at any terminal in a computer system is a likely source of error and can be regarded as a noisy channel. Certain data, such as ID numbers, can be precoded to protect against most-likely errors, including transposition of adjacent symbols and substitutions, as well as deletions and insertions. This paper first considers certain basic requirements for error detection with minimum redundancy. An efficient special coding scheme designed for decimal terminals is described next. Finally, certain cyclic codes are shown to be adaptable to transposition error control when appropriate decoding schemes are implemented.

Three Measures of Decoder Complexity

by *J. E. Savage*, p. 417. Three measures of the complexity of error correcting decoders are considered, namely, logic complexity, computation time and computational work (the number of logical operations). Bounds on the complexity required with each measure to decode with probability of error P_e at code rate R are given and the complexity of a number of ad hoc decoding procedures is examined.

An Analysis of the Effectiveness of Hybrid Transmission

Schemes by *E. Y. Rocher and R. L. Pickholtz*, p. 426. A comparison is made of the performance of pure

retransmission, forward error correction and hybrid (error detecting/correcting) schemes for data transmission in a noisy (probability of error, $P > 10^{-4}$) binary symmetric channel. The performance calculations are based on the use of BCH codes for error detection and correction up to the full correction capability of the code. It is shown that a probability of undetected error of less than 10^{-9} error/bit, can be achieved by correcting only a few errors while retaining a reasonable throughput and a very low retransmission rate. The best codes in the class considered are specified and the complexity of instrumentation is estimated. Finally, various combinations of possible systems employing half duplex and reverse channel operation are used in a comparison of the transmission schemes. For line error rate worse than 10^{-4} error/bit, a hybrid system operating with a reverse channel is superior to the other possibilities.

Maximal Group Codes with Specified Minimum Distance

by *A. M. Patel*, p. 434. All n -digit maximal block codes with a specified minimum distance d such that $2d \geq n$ can be constructed from the Hadamard matrices. These codes meet the Plotkin bound. In this paper we construct all maximal group codes in the region $2d \geq n$, where d is a specified minimum distance and n is the number of digits per code word. Unlike the case of block codes, the Plotkin upper limit, in general, fails to determine the number of code words $B(n, d)$ in a maximal group code in the region $2d \geq n$. We show that the value of $B(n, d)$ largely depends on the binary structure of the number d . An algorithm is developed that determines $B(n, d)$, the maximum number of code words for given d and $n \leq 2d$. The maximal code is, then, given by its modular representation, explicitly in terms of certain binary coefficients and constants related to n and d . As a side result, we obtain a new upper bound on the number of code words in the region $2d < n$ which is, in general, stronger than Plotkin's extended bound.

Low Energy Electron Diffraction (LEED) Spectra:

Aluminum by *F. P. Jona*, p. 444. The intensities of low energy electron beams specularly and nonspecularly diffracted from $\{100\}$, $\{110\}$ and $\{111\}$ surfaces of aluminum have been measured in a display-type LEED system as functions of electron energy, angle of incidence and azimuthal angle. Several of the measured and normalized spectra are presented, and the procedures followed in aligning the sample, reducing stray magnetic fields, and collecting and normalizing the data are described.

Silicon Defect Structure Induced by Arsenic Diffusion and

Subsequent Steam Oxidation by *S. Dash and M. L. Joshi*, p. 453. Misfit dislocation nets are known to occur when very high amounts of phosphorus and boron are diffused into silicon single-crystal wafers. Diffusion of arsenic in silicon is not known to produce such dislocations. Through transmission electron microscopy it is shown in this paper that diffusion of high amounts (up to 1.6×10^{21} atoms/cm³) of arsenic creates Frank hexagonal loops on (111) planes parallel

to the diffusion surface, and stacking faults on the inclined {111} planes, instead of misfit dislocation nets (the latter are still not observed). These faults and loops are found to be extrinsic, and are thought to be due to insertion of extra silicon layers in the matrix where the stacking fault energy is decreased by arsenic atoms. The driving force for the generation of loops and faults is shown to be the concentration gradient rather than fast cooling.

Reduction of Electromigration in Aluminum Films by Copper Doping by I. Ames, F. M. d'Heurle, and R. E. Horstmann, p. 461. We have found that the lifetime of aluminum films subjected to high current densities at elevated temperatures can be increased by the addition of copper. Previous studies have indicated that the failure mechanism is a combination of electromigration-induced phenomena, including nucleation and growth of voids, which are gated primarily by material transport along grain boundaries. On the basis of the present study, it appears that the presence of copper causes an appreciable retardation in the rate at which this overall combination of processes takes place, thereby producing a considerable increase in lifetime.

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The Conference on Holography and the Computer by J. A. Jordan, Jr., p. 476.

Some Effects of Fourier-domain Phase Quantization by J. W. Goodman and A. M. Silvestri, p. 478. If the Fourier transform of a function $g(x)$ is quantized, the function recovered by inverse transformation differs from $g(x)$. By means of a biased limiter model, the effects of Fourier-domain phase quantization are studied. Amplitude information is assumed fully retained, while phase is quantized to N equally spaced levels. The recovered function is shown to consist of several different contributions, the relative strengths of which depend on the number of phase quantization levels. Several specific examples are given. Motivation and interpretation are presented in terms of digitally constructed holograms.

Incoherent Filtering Using Kinoforms by J. C. Patau, L. B. Lesem, P. M. Hirsch, and J. A. Jordan, Jr., p. 485. Incoherent optical filtering with the kinoform used as a filtering element is discussed. Kinoform theory is briefly reviewed and initial results with "fan" and correlation filters are presented.

Acoustic Holography with Crossed Linear Arrays by D. M. Milder and W. H. Wells, p. 492. This paper is an analysis of how acoustic (or microwave) holography can be applied to large masses, such as natural bodies of water or the earth, by means of a linear array of microphones and by scanning with one or more transmitters to produce holographic phase shifts. This type of hologram, in which the phased array has a conical antenna pattern, is shown to be superior to the area hologram for computing images in the near field. Computer simulations are given of virtual holograms and image reconstructions for

specular and diffuse reflectors; simulations are also made for the case of pulse holography, which yields genuine three-dimensional images with reduced highlight distortions.

Structural-information Storage in Holograms by J. T. Winthrop, p. 501. The number of degrees of freedom, or structural-information content, of the object wave field recorded in a Leith-Upatnieks hologram is expressed in terms of the resolving power and dimensions of the recording medium, the coherence properties of the primary illumination and the position of the point reference source. In contrast with previous studies, the calculation does not involve the paraxial approximation. It is shown that of all holograms, the Fourier-transform hologram makes the most efficient use of available resolving power and coherence length.

Laser Speckle and Its Elimination by D. Gabor, p. 509. "Objective" speckle arises from the uneven illumination of an object with a multiplicity of waves that interfere at its surface. "Subjective" speckle arises at rough objects even if they are illuminated evenly by a single wave. The noise in the image is caused by the interference of the point-figures, which have random phases. Subjective speckle cannot be reduced except by extending the aperture. On the other hand the "objective" speckle in a plane, for instance in the plane of a transparency, can be reduced, and in the limit made invisible, by a special type of wide-angle illumination. This consists of a one-parameter family of plane waves, which can be produced by diffraction at a special grating, or two crossed gratings, close to the object plane. This makes it possible to produce multiple holograms, with the same insensitivity to dust or scratches as diffused holograms, but without any visible speckle in the reconstruction.

A Theory of Granularity and Bleaching for Holographic Information Recording by H. W. Lorber, p. 515. The Kelly three-stage model of photographic information recording is a mathematical model of black-and-white silver-halide film with granularity neglected. In the work reported here, the theory is extended for use in phase-holographic applications. Granularity effects are contained in the fourth and final stage, a two-dimensional, nonhomogeneous, filtered Poisson process. The output of this stage is a sample function of the random process that describes the pattern of modification of the emulsion. Formulas for the signal-to-noise ratio of a hologram and the optimum granular behavior are derived as examples of the use of the granularity model.

Noise and Distortion in Photographic Data Storage by D. G. Falconer, p. 521. Noise and distortion limit the usefulness of the photographic transparency as a data-storage medium. The noise, which tends to be multiplicative, derives from the random distribution of silver grains in the photographic image, as well as from thickness variations in the developed emulsion. Distortion, on the other hand, results from 1) the nonlinear relation between transmittance and exposure, 2) the finite width of the emulsion's point-spread function and 3) the

existence of an adjacency-enhancement function. Although grain noise remains intrinsic and untreatable, nonlinear distortion—both global and local—may be treated by lowering the contrast of the exposure pattern or, preferably, by recording the data in the form of a phase-modulated carrier wave, as in holography. A solution to the remaining difficulty, namely, linear-global distortion, is obtained through the use of high-resolution, Lippmann-type emulsions.

Characteristics of Dielectric Holograms by J. Upatnieks and C. D. Leonard, p. 527. The diffraction efficiency and signal-to-noise ratio for two-dimensional and volume diffuse-signal-beam holograms are calculated and experimentally determined. Calculations are based on the statistical properties of the signal beam, and exact integrals rather than series approximations are used. High signal-to-noise ratio and high diffraction efficiency are possible, with the peak calculated diffraction efficiency being 22% for two-dimensional and 64% for volume holograms. The experimentally achieved efficiencies were 12% for two-dimensional and 36% for volume holograms.

High-efficiency Phase-hologram Gratings by A. Schmackpfeffer, W. Järisch, and W. W. Kulcke, p. 533. Optimum conditions for the generation of high-efficiency hologram gratings are presented. The most efficient phase holograms were obtained for exposures 10 to 20 times larger than those for optimally exposed amplitude holograms. Hologram gratings produced on Agfa Gevaert 8 E 70 recording plates diffracted 40 percent of the incident radiation into the holographic image. This experimentally obtained efficiency is 60 percent of the theoretical maximum for a hologram with a geometric parameter Q of 4.6.

A Statistical Mechanical Approach to Systems Analysis by A. E. Ferdinand, p. 539. The maximum entropy principle is used as the criterion for calculating the equilibrium state probabilities of a queuing or network system in which service rates are exponentially distributed. A configuration-independent partition function is given as the solution to this network problem; from this function the important properties of the system may be derived. Simple and well known examples are used to illustrate the method. A phenomenon similar to the phase transition of statistical mechanics is observed in a queuing model.

Moment Normalization of Handprinted Characters by R. G. Casey, p. 548. Handprinted characters can be made more uniform in appearance than the as-written version if an appropriate linear transformation is performed on each input pattern. The transformation can be implemented electronically by programming a flying-spot raster-scanner to scan at specified angles rather than only along specified axes. Alternatively, curve-follower normalization can be achieved by transforming the coordinate waveforms in a linear combining network. Second-order moments of the pattern are convenient properties to use in specifying the transformation.

By mapping the original pattern into one having a scalar moment matrix all linear pattern variations can be removed. Comparison experiments with three sets of handprinted numerals showed that error rates were reduced by integral factors if the patterns were normalized before scanning for recognition.

Performance Equivalence of Suboptimally Controlled Nonlinear Systems by R. C. Durbeck, p. 558. A procedure is described that shows how a technique used to develop performance bounds for a large class of nonlinear dynamic systems with state-dependent control policies can be extended to determine whether a nonlinear system can be controlled so that it is at least "performance equivalent" to an associated optimally controlled linear system. A procedure for generating one or more control policies to attain this equivalence is also discussed. An example illustrates the fact that more than one control policy may satisfy the equivalence criterion.

Concurrent Error Detection for Group Look-ahead Binary Adders by G. G. Langdon, Jr. and C. K. Tang, p. 563. This paper presents an evaluation of the relative merits of two schemes for performing concurrent error detection in group look-ahead adders. One of the schemes is a residue mod 3 check and the other is a parity prediction check. The Boolean statements that define the operation of group look-ahead adders, concurrent error detection and the Boolean difference serve as background for interpreting the results of the study. The Boolean difference is a tool for calculating the "coverage" of elements in a logical network by error-checking schemes. Some weaknesses in prior studies of coverage calculation are brought to light. Tables showing the number of circuit elements in the various portions of adder and error-checking circuits are given. It is shown that the residue mod 3 check adder is not economical unless the addition operands are already provided with the mod 3 check bits. Thus, a worthwhile comparison of the checking schemes should not proceed without considering the overall data flow checking strategy. In machine organizations with three or more data transfer checks, the parity-checked adder seems to offer a cost advantage.

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Plant automation in IBM: a Preface by R. M. Neudecker, p. 588.

Integrated Manufacturing Systems: Architectural Considerations by C. Kinberg and B. W. Landeck, p. 589.

This paper is divided into two main parts. The first is concerned with definitions of concepts and terms of importance to the architect of integrated manufacturing systems. It describes the operational environment, how the manufacturing systems are going to be used, and a variety of system requirements. Priorities are established and a set of guiding principles for system design are proposed. In the

second part, three basic system structures are analyzed and evaluated in terms of the previously stated priorities and guiding principles. The relation of integrated manufacturing systems to other complex systems is shown to illustrate how generally applicable many of the findings derived from knowledge of the manufacturing environment are to the design of systems for other application fields.

The paper concludes by restating the key requirements and formulates what appears to be the greatest challenge for the system architect. That is, the creation of an architectural framework within which the system designers can structure manufacturing systems capable of handling besides the planned tasks a variety of unforeseen applications. Readers familiar with the plant environment and the terms and concepts associated with it may skip the first sections and start with System Requirements. We would, however, advise even the experienced reader to review the definition of real-time systems, which we believe is new.

An Integrated Manufacturing Process Control System: Implementation in IBM Manufacturing by *J. E. Stuehler*, p. 605. An integrated manufacturing process control system has been developed and implemented in several of IBM's manufacturing facilities to control process and test equipment used in the manufacture of IBM products. The system architecture consists of a central, on-line, IBM 360 Data Processing System operating under OS/360 which communicates via high-speed data channels to satellite IBM 1800, 1130 and System/360 processors.

These satellite processors control various types of process and test equipment. The central system serves as a common data bank and an input/output device for the satellite processors. In addition, the central system performs data analysis and management reporting on information obtained from the manufacturing floor. This paper discusses the general system requirements and specifications along with the hardware and software required to implement those requirements and specifications. Also discussed are problems which were encountered after initial development and plans for future development.

A Transmission Control Unit for High-speed Computer-to-computer Communication by *F. W. Thoburn*, p. 614. An integral part of a process control and testing system used in several IBM plants is the transmission control unit (TCU). This paper discusses the design of the TCU, which provides the communication link between as many as 512 satellite computers and a central computer. It uses a microprogrammed polling scheme to establish connection with the satellites that need service and it permits messages of unrestricted length to be transmitted in either direction at the rate of 2.5×10^6 bits/sec over coaxial cables. With the aid of noise suppression circuits, it operates in the electrically noisy factory environment at an error rate of less than 10^{-8} .

PCOS: A Process Control Extension to Operating System/360 by *J. R. Calva*, p. 620. This paper discusses the design and implementation of an extension to IBM Operating System/360 that is called PCOS and is intended specifically for use in "real-time" control of IBM manufacturing processes and testing. The most important part of PCOS is a Real-Time Control Program (RTCP) which is initiated at system start-up time as a "never-ending" task. The RTCP controls the execution of application programs and permits system response to requests for their execution within a time on the order of 100 msec. Other contributions are an "express path" for handling input/output operations, an "interpartition communication" program that provides common core storage for use during the execution of application programs, and an appendage to the OS/360 supervisor program to serve a specially designed high-speed multiplexor called the "transmission control unit."

Computer-aided Testing and Fabrication of Magnetic Tape Heads by *R. B. Fischer, C. M. Cox, and C. Holdinsky*, p. 633. A data collection and analysis system has been developed to control magnetic tape head testing and provide data analysis for manufacturing process control. Data collection is achieved by a system of test terminals controlled by an IBM 1130 computer, which is a satellite of an IBM System/360 Model 50 computer. The data base made possible by this system provides a means of tracing recurring failures and leads to a better understanding of the effects of process variables on the completed product.

Precision Automatic Measuring of X-Y Coordinates by *M. R. Radio, S. A. Schmitt, S. H. Lewis, T. G. Merry, and J. L. Evjen*, p. 641. This paper reports the development of a computer-controlled machine for non-contact inspection of manufactured parts. The machine, called PAMM (Precision Automatic Measuring Machine), is capable of providing "on-the-fly" measurements accurate to within 100 microinches. The intersection of a rotating spiral slot with a stationary linear slot produces a moving aperture for scanning in small increments over a projected, enlarged image of a part. The scanner assembly moves along an overhead cantilever beam in the x direction, and the part being inspected moves in the y direction along the machine base; position in each direction is monitored by a separate laser interferometer.

In the paper conventional methods of coordinate measuring are briefly reviewed, the details of the new design are presented, some experimentally obtained measurements are given, measurement errors induced by photodetector shot noise and aperture roughness are analyzed, and the computer-control and data-analysis techniques are discussed.

IBM System/7 and Plant Automation by *T. J. Harrison, R. L. Homiak, and G. U. Merckel*, p. 652. The recently announced IBM System/7 was developed for use in a broad range of data acquisition and control applications and provides the foundation for comprehensive plant automation

applications. Its unique modular structure and broad spectrum of features satisfy the basic plant automation requirements described in the paper by Kinberg and Landeck in this issue. In the present paper the functional characteristics, important design features, and the basic architectural concepts of hardware and software are discussed. An example of the use of this new system in the automation of the System/7 manufacturing process itself is provided to illustrate its use in the testing of complex electronic assemblies as part of an integrated plant automation system.

IBM 2790 Digital Transmission Loop by *R. O. Hippert, Jr.*, p. 662. A tandem connection of terminals for a data collection system has certain desirable advantages over the more common radial configuration. To make use of these advantages, high-speed transmission links are required. This paper describes the transmission capability necessary for a high-speed digital data repeater when it is restricted to an in-house environment. The transmission techniques discussed are implemented in the IBM 2790 Data Communication System.

The Percus-Yevick Theory and the Equation of State of the 6:12 Fluid by *D. J. Henderson, J. A. Barker, and R. O. Watts*, p. 668. The Percus-Yevick theory can be used to calculate the pair distribution function and from this the equation of state. The conventional method is to calculate the pressure of compressibility directly, unfortunately yielding poor results for the 6:12 fluid at low temperatures. In this paper results are obtained using an indirect method, in which the energy is calculated from the pair distribution function, and the equation of state is obtained by thermodynamic identities. These results are virtually in exact agreement with the machine calculation results for the 6:12 potential and with experimental results for argon.

Iterated Consensus Method for Multiple-output Functions by *M. P. Marcus and W. H. Niehoff*, p. 677. The iterated

consensus method for obtaining prime implicants of Boolean functions has several advantages with respect to the conventional tabular method. However, when one attempts to apply the iterated consensus method to multiple-output functions using the rules set forth in the existing literature, it is possible that some of the prime implicants will not be produced. This communication presents an algorithm which assures that all prime implicants of multiple-output functions will be found.

On the Correlation Matrices of Trigonometric Product Functions by *R. F. Filipowsky*, p. 680. Sets of waveforms called TPF's, which are products of trigonometric functions, may have application in communications technology, network analysis and signal processing. This communication briefly reviews the characteristics of TPF's and presents methods for calculating their cross-correlation coefficients when 1) all TPF's in a set have harmonic factors with the same set of values, and 2) the harmonic factors have different values.

Man-made Superlattice Crystals by *A. E. Blakeslee and C. F. Aliotta*, p. 686. Multiple closely spaced layers of $\text{GaAs}_{1-x}\text{P}_x$, which approximate a one-dimensional crystalline superlattice, have been created by periodically pulsing PH_3 into an $\text{AsH}_3\text{-PH}_3\text{-Ga-HCl}$ vapor-growth apparatus. The phosphorus mole fraction varies between maximum and minimum values with a period typically less than 200 Å. Structures with up to 150 such layers have been produced. The crystal growth process and methods of characterization are discussed briefly.

Comment on "A Topological Theory of Domain Velocity in Semiconductors" by *E. J. Aas*, p. 689. Recently Gunn presented a simple formula for the domain velocity in a "diffusion-controlled" semiconductor, based on topological arguments. It is shown that these arguments are generally not valid. The apparent agreement between Gunn's formula and Hauge's computer simulation is briefly discussed.

Digital Simulation of the Global Transport of Carbon Monoxide by H.-C. W. Kwok, W. E. Langlois, and R. A. Ellefsen, p. 3.

A numerical model of the general atmospheric circulation is used to simulate the global transport of carbon monoxide. The sources are estimated from gasoline consumption data. Since the strongest sources lie in the northern hemisphere belt of strong prevailing westerly winds, "chaining" effects are quite pronounced. Emissions generated in one populous area are soon superimposed upon those of the next area downwind. Subscale cumulus convection, which is parameterized in the model, accounts for a significant fraction of the vertical CO transport.

A New Technique for Gas-phase Kinetic Spectroscopy of Molecules in the Triplet State by H. E. Hunziker, p. 10. A recently developed experimental method is described to populate by Hg photosensitization and observe by absorption spectroscopy the triplet states of polyatomic molecules in the gas phase; detailed discussion and analysis of the experiment are given. The technique can be used to investigate triplet states that cannot be populated efficiently by the intersystem crossing process and to detect triplet absorption bands located within the wavelength range of ground-state absorption of a molecule. A modulation scheme, based on a novel type of Hg resonance light source—an rf-driven toroid capable of modulation frequencies up to 250 kHz—is used for monitoring the optical absorption (by phase-sensitive detection) and measuring the lifetime of the transient species. Sensitivity is comparable with that of flash spectroscopy for transients that decay by a second-order process. Results obtained for several aromatic hydrocarbons are reviewed. New transitions were detected by this method for triplet-state naphthalene, and the absorption spectra and decay kinetics of triplet-state benzene and toluene were measured for the first time. Some applications of the technique to problems other than triplet-state spectroscopy are illustrated or outlined.

Photoconduction in Aromatic Hydrocarbons by G. Castro, p. 27. Photoconduction has been observed in single crystals of benzene, naphthalene, biphenyl and pyrene using the pulse technique. Experimental procedures have been found for the purification and crystal growth of the materials that produce specimens whose charge carrier lifetimes are sufficiently long to allow the measurement of drift mobilities, and thus to determine the number of charge carriers produced per pulse. A single-photon generation mechanism was observed only in pyrene. The other materials exhibited a photogeneration mechanism that depended quadratically on light intensity and was determined to be exciton-exciton collision ionization.

Photochemical Addition of Benzene to Cyclobutene by R. Srinivasan, p. 34. The major products of the photochemical addition at 253.7 nm of benzene to cyclobutene in solution were found to be tetracyclo[5.3.0.0^{2,10}.0^{3,6}]-decene-8 and tricyclo[4.2.2.0^{2,5}]deca-7,9-diene, which arise from 1,3- and

1,4-additions. The quantum yields for both reactions were independent of benzene concentration below 2M but decreased at higher concentrations. The maximum quantum yields that were obtained are 0.81 and 0.09 for the 1,3- and 1,4-reactions, respectively, indicating that the former reaction is a very efficient process.

The 1,3-addition may occur from the singlet (¹B_{2u}) state of benzene, as has been suggested in the literature. The origin of the 1,4-addition is not clear, but it seems unlikely that it occurs from the triplet state of benzene.

Preparation and Thermodynamics of Some Homologous Nitrones, a New Group of Liquid Crystals by W. R. Young, I. Haller, and A. Aviram, p. 41. To investigate the mesomorphic behavior of aldonitrones, a series of 13 homologs of N-(p-alkoxyphenyl)-α-anisyl nitrones was prepared and characterized. Although most of these substances exhibit normal nematic or smectic mesophases, the trend in nematic-isotropic transition temperatures to increase as a function of alkoxy chain length is an exceptional occurrence. Comparison of our data with that of analogous compounds previously reported indicates that thermal persistence of the nematic phase of these compounds increases in the following order: 4,4'-dialkoxybenzylideneaniline, 4,4'-dialkoxyazobenzene, N,α-di-(4-alkoxyphenyl)-nitron, 4,4'-dialkoxyazoxybenzene. In addition, the phase transitions were investigated by means of differential scanning calorimetry. The entropies of the mesophase-isotropic transitions of the nitrones imply that the long alkoxy chains, in contrast to a widely held belief, are not restricted to a single conformation in the mesophase.

Polymorphism in Cholesteryl Esters: Cholesteryl Palmitate by M. J. Vogel, E. M. Barrall II, and C. P. Mignosa, p. 52. The thermal transitions in cholesteryl palmitate, an ester having liquid-crystalline states, have been evaluated and compared to previously reported data. A sample synthesized from carefully purified cholesterol and palmitic acid using p-toluene sulfonic acid compared directly with previously reported data. A sample of recrystallized ester from a commercial source showed a slightly depressed solid-to-mesophase transition temperature. However, the mesophase proved to be smectic, commonly reported as monotropic with respect to the solid phase. Both smectic-to-cholesteric and cholesteric-to-isotropic-liquid transitions were sharp, indicating a pure material. It is postulated that a specific impurity, possibly an isomeric cholesterol ester, is responsible for this previously unreported effect. This effect of related compound interaction has been reported for nematic-mesophase-forming compounds. Thin layer chromatography, microscopy, depolarized light intensity analysis, differential scanning calorimetry and NMR spectroscopy data are offered in support of this postulate.

On Measuring Nuclear Magnetic Shielding Anisotropies in Liquid Crystal Solvents by C. S. Yannoni, p. 59. Up to the

present time nuclear magnetic shielding anisotropies ($\Delta\sigma$) have been determined in nematic liquid crystal solutions by comparing the chemical shifts in the isotropic and nematic phases. Unknown changes in solvent-induced shifts arising from the isotropic $\rightarrow$ nematic phase transition constitute a serious problem in the interpretation of the results. To avoid the ambiguities inherent in these shifts, a method is described for measuring $\Delta\sigma$ in the nematic phase alone. This technique has been used to determine $\Delta\sigma$ in a variety of ^1H - and ^{19}F -containing molecules and the results are compared with those obtained by the two-phase method.

Application of Probabilistic Decoding to Digital Magnetic Recording Systems by *H. Kobayashi*, p. 64. A digital magnetic recording system is viewed in this paper as a linear system that inherently includes a correlative level encoder. This encoder can be regarded as a linear finite-state machine like a convolutional encoder. The maximum likelihood decoding method recently devised by Viterbi to decode convolutional codes is then applied to digital magnetic recording systems. The decoding algorithm and its implementation are discussed in detail.

Expressions for the decoding error probability are obtained and confirmed by computer simulations. It is shown that a significant improvement in the performance with respect to other methods is achievable by the maximum likelihood decoding method. For example, under the Gaussian noise assumption the proposed technique can reduce raw error rates in the 10^{-3} to 10^{-4} range by a factor of 50 to 300. These results indicate that the maximum likelihood decoding method gains as much as 2.5 dB in signal-to-noise ratio over the conventional bit-by-bit detection method.

A New High-sensitivity Organic Photoconductor for Electrophotography by *R. M. Schaffert*, p. 75. A new organic photoconductor has been developed, consisting essentially of a 1:1 molar ratio of one molecule of 2, 4, 7-trinitro-9-fluorenone (TNF) to one monomer unit of poly-N-vinylcarbazole (PVCz). This photoconductor (1:1 TPC) is nearly panchromatic in the visible range of the spectrum and has a white-light sensitivity approximately equal to that of amorphous selenium when used for electrostatic imaging. The photosensitivity, which is due mainly to the TNF-PVCz complex, is greater for negative corona charging than for positive charging. Charge acceptance of the 1:1 TPC is high, ≈ 1200 volts for a $13\mu\text{m}$ film, indicating good dielectric strength. Dark decay of the charge is affected by substrate materials and substrate surface conditions. In general dark decay is slower for negative charging than for positive charging. Quantum efficiency (Q.E.) is nominally about 0.15 in the range of 400 to 500 nm but decreases somewhat for shorter and longer wavelengths. The Q.E. increases rather markedly with field strength, but decreases somewhat at high light intensities. Field-controlled photogeneration of carriers is indicated, and thermal measurements show a field-dependent activation energy in the

range of 0.06 to 0.20 eV. The absence of residual potentials in light decay curves and the lack of a thickness effect in photodischarge currents indicate that no deep traps are present in the 1:1 TPC layers.

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Preface to papers on Mechanics of Materials by *J. L. Hibbard*, p. 102.

Wear of Electrical Contacts due to Small-amplitude Motion by *R. G. Bayer and J. L. Sirico*, p. 103. The "IBM wear model," which has previously been used to describe the wear of electrical contacts as a result of gross sliding motion, is used to describe contact wear in the case of small-amplitude sliding motion. This model was applied to a particular contact configuration on which a series of wear tests was performed. The empirical results of the tests are compared to the theoretical expressions and good agreement is found, thus indicating that the wear mechanism is essentially the same for both large- and small-amplitude sliding contact.

Effect of Hammer Length and Nonlinear Paper-ribbon Characteristics on Impact Printing by *A. L. Jones and A. J. Lavin*, p. 108. An analysis of the impact process in a particular type of high-speed printer was undertaken to determine the effect of hammer length on the contact time. The hammer is modeled as a one dimensional wave propagation medium and the paper-ribbon combination as a dissipative, nonlinear medium with hysteresis. The integrated macroscopic viscoelastic parameters for a particular impact geometry and hammer momentum were determined from a combination of the analytical model and the experiments run on an instrumented printer robot. Permanent deformation of the paper-ribbon caused by character penetration was also determined in this manner. The simulated model was then used to predict the change in dynamic behavior of such a system due to variations of the hammer length. The hammer length is shown to have only a tertiary effect on contact time in such a dissipative deformable nonlinear system. This result demonstrates that the widely discussed use of hammer length as a design parameter to control contact time in impact printing is invalid for such a dissipative system.

Adhesion and Partial Slip between Normally Loaded Round Surfaces by *P. A. Engel and H. D. Conway*, p. 116.

A simple mechanism is sought to account for the frictional energy losses encountered in the mutual contact surface of two bodies pressed normally against each other. The mathematical model of Coulomb friction is assumed valid, and it is shown that slip between the contacting surfaces develops in the outlying regions of contact. This model, used in conjunction with a numerical scheme, leads to a set of nonlinear simultaneous algebraic equations in the surface tractions. Two specific cases are computed: those of a rigid sphere and of a rigid roller each pressed against an elastic medium. The relative size of the slip region is shown to depend on the

material properties. Energy dissipation during a half contact cycle is calculated, and the influence of the secondary adhesive tractions on the contact stresses is discussed.

Analysis of Defect Distribution in Transistor Structures with Reflection and Transmission X-Ray Topography by *J. K. Howard and P. J. Smith*, p. 123. Reflection and transmission x-ray topography can be combined to isolate and identify dislocations that penetrate the active junctions of transistor structures in integrated circuit wafers. This is accomplished by reconstructing the defect distribution normal to the surface as viewed in transmission (volume-sensitive) and reflection (surface-sensitive) x-ray topography. The combination of surface and bulk observations is exploited to demonstrate the effect of dislocation density on pipes (low-resistance paths from emitter to collector). A method is also described for estimating the depth of defect visibility in reflection x-ray topography.

Effect of Extremely Thin Nitrogenous Surface Films on Phosphorus-impurity Profiles in Silicon by *J. Makris, A. Ferris-Prabhu, and M. L. Joshi*, p. 132. In open-tube diffusion furnaces, nitrogen is often used as a carrier gas for impurities. Nitrogen flowing over silicon wafers at the diffusion temperature creates extremely thin surface films, which act as strong diffusion barriers. Similar barriers are formed on silicon wafers even in capsule-diffusion systems because of the residual atmosphere. Phosphorus-impurity profiles are found to be kinked due to these diffusion barriers. The position and dependence of the kinks on various diffusion parameters such as time, temperature and impurity concentration in the carrier gas are discussed. The kinks are eliminated if the formation of the thin-film barriers is avoided through use of argon or other noble gases. A mathematical model is presented to explain the kinked behavior of the profiles.

Molecular Engineering in the Development of Materials for Thermoplastic Recording by *H. R. Anderson, Jr., E. A. Bartkus, and J. A. Reynolds*, p. 140. A number of internally plasticized copolymers and terpolymers have been prepared which are shown to be suitable for thermoplastic recording. These materials were responsive to both in-air and in-vacuum recording techniques, where the electrostatic charge is applied by corona charging or electron beams, respectively. Several of these materials were tailored for Schlieren optical readout while others possessed properties suggesting their use in recording systems requiring electron beam readout.

On the Correlation between Domain Size and Coercive Force in Grain-oriented 3.25% Si-Fe by *J. A. Pesch*, p. 151. A method is described for measuring the size of the largest spike-shaped magnetic domains on surfaces of grain-oriented 3.25% Si-Fe. Values of coercive force, obtained by using measured spike-domain size in a previously derived empirical expression correlating spike size with the coercive force in

silicon-iron, are in close agreement with coercive force values obtained from $B-H$ loop measurements. This technique makes it possible to measure the coercive force on non-toroidal magnetic components used in data processing machines.

Segmentation Methods for Recognition of Machine-printed Characters by *R. L. Hoffman and J. W. McCullough*, p. 153. This paper reports an investigation of some methods for isolating, or segmenting, characters during the reading of machine-printed text by optical character recognition systems. Two new segmentation algorithms using feature extraction techniques are presented; both are intended for use in the recognition of machine-printed lines of 10-, 11- and 12-pitch serif-type multifont characters. One of the methods, called quasi-topological segmentation, bases the decision to "section" a character on a combination of feature-extraction and character-width measurements. The other method, topological segmentation, involves feature extraction alone.

The algorithms have been tested with an evaluation method that is independent of any particular recognition system. Test results are based on application of the algorithm to upper-case alphanumeric characters gathered from print sources that represent the existing world of machine printing. The topological approach demonstrated better performance on the test data than did the quasi-topological approach.

System Validation by Three-level Modeling Synthesis by *K. A. Duke, H. D. Schnurmann, and T. I. Wilson*, p. 166. The experimental three-level system modeling technique discussed in this paper can be used during the design stage of a system for identifying mismatches among the architectural, microprogramming, and hardware logic levels. Compatible switching between modeling levels is emphasized. Execution of an application program by the architectural and microprogramming level models with switching between levels is illustrated.

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Numerical Method for Computing Nonlinear, Time Dependent, Buoyant Circulation of Air in Rooms by *J. E. Fromm*, p. 186. A method is described which solves the dynamic equations for air circulation at Grashof numbers that are in the range of environmental temperatures of rooms. Previous two-dimensional computation techniques were limited to $G \approx 10^5$ but environmental conditions require $G \approx 10^{12}$. The higher Grashof numbers become calculable through the design of a mixed system of nonlinear difference equations which has purely leading-phase-error properties. In addition provision is made for nonlinear stability by explicitly programming cross derivative terms in lieu of employing "time splitting." The isotropic behavior achieved through time splitting is retained by the system of difference equations. Details of the required algorithms are included.

Random-walk Model of Stream Network Development by J. S. Smart and V. L. Moruzzi, p. 197. A random-walk, headward-growth model of stream network development in a region of uniform lithology and uniform slope is proposed. The principal difference from previous models is that the probability of growth is made dependent on the area contributing runoff to the stream tip. Two versions of the model have been studied in detail and shown to give satisfactory results. A major advantage is that all of the important network variables, including drainage density and outlet density, come naturally out of the simulation processes.

Automatic Pulse Parameter Determination with the Computer Augmented Oscilloscope System by A. A. Guido, L. Fulkerson, and P. E. Stuckert, p. 204. The Computer Augmented Oscilloscope System (CAOS) is a special computer terminal facility intended for laboratory experiments involving waveforms and their interpretation. The system provides digital acquisition of waveform data, system control and calibration, data analysis, and graphic and alphanumeric display.

Pulse parameter determination requires the use of all system capabilities since a) hardware and software options must be chosen or controlled, b) the pulse waveform must be digitized, c) the appropriate analytical algorithms must be applied to the data and d) the results of analysis must be displayed. Specific attention is given to the algorithms required for pulse parameter determination and a new procedure for determining base and top magnitude of a pulse waveform is presented.

A Quasi-steady-state Analysis for the Electrophotographic Discharge Process by H. Seki, I. P. Batra, W. D. Gill, K. K. Kanazawa, and B. H. Schechtman, p. 213. A description of the electrophotographic discharge process is presented for a homogeneous photoconductor characterized by constant free-carrier lifetimes and trapping times. The physical model is described by a set of one-dimensional nonlinear differential equations with appropriate boundary conditions. It is shown that a quasi-steady-state approximation can be derived which is valid for most of the decay process under typical electrophotographic conditions. In this quasi-steady state, the photoconductor layer can be described by an equivalent circuit which consists of a capacitance in parallel with a two-terminal element whose current-voltage characteristic is directly related to the field-dependent photoinjection efficiency. A numerical analysis using large-scale computation of the solutions to the differential equations has been done for a hypothetical but typical material. The results of this computation, which describe the initial transient behavior and the subsequent quasi-steady-state behavior of the photoconductor, are presented. The results of the quasi-steady-state analysis agree with the actual behavior of amorphous Se. It is suggested that measurement of the quasi-steady-state photodischarge process can be used as a convenient technique for obtaining the field-dependent characteristics of the photoinjection process.

Interaction Potential between Li^+ and HD : Region for Rotational Excitation Cross Sections by W. A. Lester, Jr., p. 222. The interaction potential between Li^+ and HD (with internuclear separation fixed at 1.4 a.u.) was determined by two different methods using the results of a recent self-consistent-field calculation of the potential energy surface for $\text{Li}^+\text{-H}_2$. In one method, $\text{Li}^+\text{-HD}$ interaction energies were obtained utilizing an analytical representation of the $\text{Li}^+\text{-H}_2$ surface. The second method used *ab initio* $\text{Li}^+\text{-H}_2$ interaction energies directly to yield the $\text{Li}^+\text{-HD}$ potential surface by means of interpolation procedures. The interaction potentials determined by the two methods are essentially identical and have been fit to an analytical form, $V(r, \theta) = \sum v_i(r) P_i(\cos \theta)$, to facilitate scattering studies. For large center of mass distances, perturbation theory is in good accord with the potentials constructed by the two procedures.

A Design Study of Ultrasonic Bonding Tips by S. Z. Dushkes, p. 230. The standing wave on ultrasonic bonding tips and the tendency of the lower end to fold back upon itself, termed "lug-down," have been measured under actual bonding conditions. These phenomena have also been modeled on a computer. Lug-down can be a major contributor to bonding failures in designs having an overly slim tip. One definition of a "bonding failure" is the production of a bond between wire and monolithic circuit pad which lifts, when the wire is pulled at 90° to the pad, under a wire tensile force less than 25% of the ultimate tensile strength of the wire. Improper location of nodes can also contribute to bonding failures. A tapered tip has been shown by mathematical analysis to possess a higher resonant frequency and fewer nodes than a tip of uniform cross section. Using the newly developed taper tip, means were found for minimizing lug-down. With judicious trade-offs, it is now possible to optimize tip geometry for a particular bonding application.

Heat-transfer Calculations at the Tape-head Interface of a Computer Tape Drive by G. M. Lederle, p. 236. Frictional heat generation can develop localized high temperatures at the tape-head interface of a computer tape drive and can seriously affect the performance of the drive. Using standard heat transfer theory, we calculated the magnitude of this "hot spotting" to be of the order of 21°C for an IBM 2400 series tape drive. In general, it is almost impossible to accurately measure hot spotting on a tape drive. A series of calculations was performed to investigate why this is so.

The Common-core Filter as an Electromagnetic Interference-suppression Device by D. R. Bush, p. 242.

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Experimental Fabrication of One-dimensional GaAs Laser Arrays by J. C. Marinace, p. 258. Arrays of GaAs injection lasers have been fabricated for use in an experimental EuO film memory system. Planar-type array structures are formed by diffusing zinc through parallel slots in a diffusion mask on

a GaAs wafer. Details of fabrication are given and some initial test results on operating characteristics and life performance are reported.

Fabrication and Properties of Monolithic Laser Diode Arrays by G. J. Sprokel, p. 265. Monolithic arrays of planar diffused GaAs injection lasers have been fabricated using diffusion masking and photolithography to delineate the junction area. After contact metallization, the arrays are soldered to a sapphire wafer which serves as a heat sink and carries the contacts for each junction. The diodes operate cw at 78 K and the threshold current density, $J_{th} = 700$ to 1100 A cm^{-2} . The dc power output is linear at least to $5 \times J_{th}$ and the power efficiency, η_p , is about 40%. Threshold and power output are quite uniform across the array but the beam polarization varies at random from one unit to the next.

Characteristics of GaAs Laser Arrays Designed for Beam Addressable Memories by H. Wieder and H. Werlich, p. 272. Four properties of GaAs laser arrays i.e., the efficiency, junction width, beam spread, and polarization, are important in assessing the usefulness of such devices in beam addressable memory applications. Measurements made on a series of arrays are presented. It is shown that the first two parameters closely approach the characteristics of an idealized array, while the latter two reduce the energy density at the storage plane to 25 percent of that at the junction surface. With existing devices, information has been written and recovered at a bit rate of 10 MHz.

Dynamics of a Flashlamp-pumped Rhodamine 6G Laser by B. G. Huth and M. R. Kagan, p. 278. In this paper a rate-equation model is developed for a single-wavelength dye laser. The model is unique in that it accounts for the fact that triplet-state lifetimes are not necessarily very long, as has been previously assumed. This modification makes it possible to analyze more accurately the behavior of dye lasers that are pumped with pulse energies above threshold. Computer solutions of the rate equations are obtained and an experimental technique is developed to measure amplifier gain, which is then used to estimate populations of molecules at various energy levels. An experimental study of triplet lifetimes in anthracene is included in an Appendix. These results support the experimental values obtained by Stockman for Rhodamine 6G, which are used in our calculations.

Interleaving Slow- and Rapid-data-rate Experiments with a Time-sharing Laboratory Automation System by P. M. Grant, p. 293. A technique is described for accommodating rapid-transfer-rate experiments within an IBM 1800 Time Share Executive (TSX) laboratory automation monitor designed primarily for slow-scanning, low-drift apparatuses, each having the computer control its independent variable. The slow-scan experiments may be delayed for substantial periods to allow break-in by, and dedication of the computer to, those tasks requiring acquisition of short bursts of high-speed data. The system is structured so that each user

can implicitly and dynamically specify the current maximum time interval for which his experiment may be interrupted.

The break-in on a slow-scan experiment is done on a demand-response basis through the use of interrupt coreloads and masking of all other interrupts that are likely to interfere with a particular high-speed scan that has been initiated. When data acquisition is completed, control is returned to the time-sharing system by unmasking the interrupts and an appropriate data analysis task is queued for later execution.

Automation of Data Acquisition in Transient Photoconductive Decay Experiments by B. H. Schechtman and P. M. Grant, p. 296. The application of a time-shared IBM 1800 Data Acquisition and Control Computer to data acquisition and reduction in transient photoconductive decay experiments is described. These experiments present an interesting problem in laboratory automation, since they involve high data rates (data periods frequently on the submillisecond scale), a free-running independent variable (time), and a mode of operation in which it is possible to amass large quantities of data in a relatively short time. Techniques are described wherein these transient data are collected in real time while the computer simultaneously monitors many timer-based, slower-scanning experiments. The computer is shown to facilitate a variety of otherwise formidable data manipulation and analysis tasks. In addition to improving the quality of the data obtained, automation of these measurements provides data analysis and display of physical results within minutes after each data logging run, permitting the experimenter to interact closely with the data in a fashion not possible under manual operation.

Automation of a Residual Gas Analyzer on a Time-shared Computer by D. L. Raimondi, H. F. Winters, P. M. Grant, and D. C. Clarke, p. 307. The automation of a quadrupole mass spectrometer - residual gas analyzer (RGA) on a time-shared IBM 1800 Data Acquisition and Control Computer is described. The RGA, which is used to determine the partial pressures of various gases in a vacuum system, may be operated up to a maximum data rate of about 20,000 points/sec (pps) in an interleaved manner with multiple slow-scanning (≤ 20 pps) instruments. We review in detail the hardware and software considerations regarding the design and subsequent interfacing of the instrument to the computer. Methods for initiating data collection, entering experimental parameters, and analyzing the experimental data, such as spectrum plotting, smoothing, peak location, mass identification, and calculation of the partial pressures by using a least-squares approximation to fit mass peaks, are discussed with examples.

Equivalent Circuit for Conductivity-Temperature Characteristics of the PdO/Ag-Pd Glaze Resistor by G. J. Kahan, p. 313. It is shown that a reasonable fit of experimental to calculated data can be obtained with a simple model of the PdO/Ag-Pd glaze resistor. An equivalent circuit

describing the temperature characteristics of the glaze resistor is proposed. The experimental measurements can be reproduced quite adequately over a considerable temperature range, using an equivalent circuit consisting of a semiconductor contact resistance in parallel with a metal. A quadratic term in $(1/T^2)$ in addition to the usual linear term with $(1/T)$ for $\ln \sigma$ is used to obtain a good fit at low temperatures. (T = absolute temperature; σ = conductivity.) This parabolic curve approaches the experimentally observed values for palladium oxide.

An Improved Method for Designing Optimal Linear Compensators by *S. G. Greenberg and Y. Bard*, p. 318. In linear dynamical systems with white Gaussian plant and observation noise and quadratic cost criteria the well-known separation theorem of stochastic control holds. The result is that the determination of the system matrix for the compensator depends on the solution of two Riccati equations, one arising from a deterministic regulator problem and the other from a filtering problem. It is shown in this paper that if the given system is single-input, single-output and time-invariant, one can achieve substantial savings in computation time. Assuming controllability and observability and using the standard controllable representation of the system matrix, we show that at each iteration step of the solution of the algebraic matrix Riccati equation by Newton's method the number of variables to be solved for reduces from the customary $n(n+1)/2$ to n . Moreover, the number of operations to determine these n variables is on the order of $n^3/16$ as opposed to $n^3/3$ in ordinary matrix inversion.

The observability matrix is used as a similarity transformation so that the Riccati equation for the filtering problem is placed in the same format and the above procedure may be used again. The results obtained are easily extended to the case in which the system is either single-input or single-output. The system matrix of a fifteenth-order compensator was determined using 0.92 seconds of computer time on the IBM System/360, Model 67.

Some Numerical Results for Iterative Continuation in Nonlinear Boundary-value Problems by *W. E. Bosarge, Jr. and C. L. Smith*, p. 323. In this communication we apply certain continuous analog iterative methods to two sample boundary-value problems. We show that the Euler-Newton and the second-order continuation of the Newton method are both useful algorithms for obtaining solutions to classes of nonlinear boundary-value problems. For a convergence analysis we rely upon a number of convergence theorems presented in earlier work. We indicate, through the numerical results, that the relaxed Newton methods are particularly useful in the iterative solution of "strongly" nonlinear problems where little information is available concerning "good starting values."

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Multi-fluid Subdued Boiling; Theoretical Analysis of Multi-fluid Interface Bubbles by *S. Oktay*, p. 342. The recently discovered boiling phenomenon called "multi-fluid subdued boiling" is discussed. It has been observed that when a beaker containing two immiscible liquids of dissimilar densities is heated at the bottom, the vapor bubbles rise in the lower liquid until they reach the liquid-liquid interface. There the bubbles are trapped, and after a short period of time they collapse. As the heat transfer is increased, however, the bubbles begin to coalesce to form a new set of "interface bubbles," and the latter eventually become large enough to break away from the interface and rise into the upper liquid layer. Upon reaching the liquid-air interface most of the bubbles do not escape into the ambient but suddenly condense, contract and drop back toward the lower liquid level. "Boiling off," or net vapor generation, is subdued.

The prediction of the interface bubble sizes is also discussed. Analysis shows that the properties of the fluids used can be included mathematically in nondimensional parametric forms, by means of which the shapes and sizes of the interface bubbles can be found.

A Procedure for Implementing the Fast Fourier Transform on Small Computers by *J. W. Hartwell*, p. 355. A technique has been developed that adapts the Fast Fourier Transform algorithm for implementation on computers having relatively long multiplication times. The technique is particularly well suited to real-time processing on a small data acquisition computer such as the IBM System/7.

Four basic ideas are utilized to improve the performance of the original Cooley-Tukey algorithm on such a machine:

- 1) The real-valued nature of the input data is exploited.
- 2) The number of multiplications that must be carried out is minimized at the expense of additions.
- 3) The calculations are performed in a carefully ordered sequence.
- 4) Special multiplication algorithms are used.

This technique has reduced by more than an order of magnitude the time required to carry out 1024-point transformations on a small computer. A program is developed for calculating these transforms in real time on an IBM System/7 computer. With this program, a maximum sampling rate in excess of 10 kHz is obtained.

Generation of Synchronous Data Transmission Signals by Digital Echo Modulation by *M. F. Choquet and H. J. Nussbaumer*, p. 364. This paper shows the basic similarities

among various data transmission techniques. It generalizes the concept of how the signal element serves as a unifying feature of various modulation schemes. The present approach permits an extension of the digital echo modulation technique, originally introduced by A. Croisier and J-M. Pierret, to cover most of the cases of digital data transmission. The practical application of digital echo modulation to the design of modems is discussed and examples of digitally implemented modem transmitters are given.

Activation Energy for Electromigration in Aluminum Films Alloyed with Copper by M. C. Shine and F. M. d'Heurle, p. 378. The rate of electromigration in thin films of aluminum and aluminum alloyed with copper has been determined by measuring the changes in resistance of stripes subjected to a current density of 4×10^6 A/cm². At temperatures in the range from 100 to 200°C the activation energy for electromigration has been found to have the same value for both the pure and the copper-alloyed samples, namely, 0.6 eV. However, the rate of migration is much smaller, by a factor as large as 100, in the copper-bearing samples. These results are discussed in terms of grain boundary diffusion and the effect of alloying additions on diffusion mechanisms.

Design of Logic Circuit Technology for IBM System/370 Models 145 and 155 by P. E. Fox and W. J. Nestork, p. 384. Monolithic System Technology (MST) is a microelectronic circuit family consisting of high-density monolithic circuit chips on ceramic substrates. Using current-switch emitter follower (CSEF) logic, the technology is designed to provide a balanced reflection of cost and performance requirements. One version, MST-2, has been developed for use primarily in the middle range of System/370—the Models 145 and 155. The typical package usually consists of a single multi-circuit chip on a 16-pin module substrate, and the design embodies a number of recent interconnection and packaging developments that make it well suited to large-scale automated production.

The IBM 3803/3420 Magnetic Tape Subsystem by J. W. Irwin, J. V. Cassie, and H. C. Oppeboen, p. 391. The design innovations in the IBM 3803 Tape Control Unit and the IBM 3420 Magnetic Tape Unit are discussed. The new design concepts include a full readback parity check, a system of microprogram control that obtains high operating rates through overlap of channel control and motion control functions, a new phase-error detection system, a modified dual-density recording feature and a new interface between the control unit and tape drive. The combination of novel error detection methods, control features and programming support (including an expanded scheme of on-line diagnostics) contributes to greatly improved total system performance over previous models of tape subsystems.

Thermal Problems of the CW Injection Laser by R. W. Keyes, p. 401. We describe the theoretical dependence of

emitted light power on current in a continuously operating *p-n* junction laser, based on an injection laser model previously developed by the author. The analysis relates power output to threshold current, electrical resistance, thermal resistance, and external quantum efficiency of the laser, all quantities that can be independently measured or calculated for particular structures. The equations presented thus constitute a simple analytical model for both thermal design and diagnosis of operation of cw injection lasers.

Ultra-high-speed Operation of Josephson Tunneling Devices by H. H. Zappe and K. R. Grebe, p. 405. Switching times of large Josephson devices have been measured. We report gate switching times of 85 ps and array cycle times of an elementary memory cell of 550 ps. Although these times are expected to be smaller in more realistic miniaturized devices, they represent to our knowledge, the shortest times for such circuits ever reported in any technology.

Synchronization in a Wideband Optical Data Transmission System by E. M. Philipp-Rutz, p. 408. An optical synchronization technique is described for the demultiplexer of a wideband optical data transmission system. In this system, the closely spaced optical pulses of interleaved PCM channels are "space sorted" by a coincidence detection technique using an optical reference waveform generated in the receiver. For synchronization of the reference waveform with a spatial waveform produced by the received laser beam in the demultiplexer, a number of pulses on these two optical waveforms are coded with a pseudo-random sequence. Acquisition of the coded waveforms for synchronization is indicated in an optical matched filter. For automatic tracking, a synchronization error-control circuit is added.

Direct Technique for Improving a Matrix Inverse by G. A. Sitton, p. 413. A method is shown that transforms the problem of inverting an ill-conditioned matrix to one of inverting a diagonally dominant matrix. An error analysis is outlined and the method is compared in theory and in result with the commonly used iterative methods. This direct method is demonstrated to be the limiting case of an *n*th-order iterative procedure as *n* approaches infinity. Examples are given that show the advantages of the direct method even under adverse conditions. The unreliability of the convergence of the iterative technique due to computational errors is also discussed.

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A Self-Isolation Scheme for Integrated Circuits by M. B. Vora, p. 430. A self-isolation scheme is proposed for fabricating transistors in semiconductor integrated circuits. Such integrated circuits with double-diffused transistors require three diffusions and one epitaxial layer in the proposed process. Since no isolation or reach-through diffusions are involved, this technique could reduce the area of a memory or logic cell by 50% or more.

Design and Development of an Ultralow-Capacitance, High-Performance Pedestal Transistor by *H. N. Ghosh, K. G. Ashar, A. S. Oberai, and D. DeWitt*, p. 436.

High-performance transistors with small geometries require a highly doped collector region to produce a large impurity gradient at the collector-base junction. This allows the structure to sustain high current densities and to attain low collector series resistance. However, the resulting increase in collector transition capacitance degrades the ac characteristics of the transistors. A structure is proposed and experimental results are presented in this paper to demonstrate that the conflicting requirements above, which limit the high-performance characteristics of transistors, can be resolved by the planar IC process.

Planar Mesa Schottky Barrier Diode by *N. G. Anantha and K. G. Ashar*, p. 442. Planar silicon technology has been used to fabricate mesa Schottky barrier diodes with high breakdown voltages. This method proves to be superior to alternate methods used to increase the breakdown voltage of Schottky diodes. The processing techniques and characteristics of mesa Schottky diodes are described in this paper.

Electron Beam Fabrication of Micron Transistors by *S. Magdo, M. Hatzakis, and C. H. Ting*, p. 446. For high-speed performance as well as high packing density, it is desirable to make the components in integrated circuits as small as possible. One of the fundamental problems in making smaller components is that of limitations in the optical technology. This paper describes an experimental process and the results obtained by using an electron-optical system to fabricate small transistors. Planar bipolar transistors with emitter and base contact windows one micron wide have been fabricated, with the electron beam exposure system used to open all the diffusion windows as well as to expose the metallization patterns.

Conventional etching techniques are unable to provide 1- μ m wide metal paths in half-to one-micron thick metal layers; therefore the lift-off process is used. The dc and ac characteristics presented compare favorably, for the first time using this fabrication process, with the best bipolar transistors produced by optical masking processes. These characteristics provide a guide for refinement in future micron transistor design.

Experimental Evaluation of High Energy Ion Implantation Gradients for Possible Fabrication of a Transistor Pedestal Collector by *J. F. Ziegler, B. L. Crowder, and W. J. Kleinfelder*, p. 452. The use of ion accelerators to implant impurities in crystals has become the subject of widespread research. Such studies have been limited mainly to low energies with acceleration voltages of 50 to 500 kilovolts. In this energy range, impurities are implanted into the upper micron or less of the surface.

The present work describes certain characteristics of high energy ion implantation. The ions used were boron and phosphorus. They were implanted into silicon with energies of 2 to 4 megavolts. In this energy range, the impurities have a useful positive impurity concentration gradient from the surface. The surface concentration is about $4 \times 10^{16} \text{ cm}^{-3}$, and the peak concentration exceeds 10^{19} cm^{-3} depending on dosage. The peak concentration occurs about 2.5 μ m deep. After annealing the radiation damage introduced into the semiconductor, it was determined that the surface silicon recovered over 90% of its expected maximum conductivity and mobility.

A discussion is given of the concentration gradients required to fabricate a collector pedestal for a high-speed switching transistor, and it is shown that such gradients can be obtained by using high energy ion-implantation. The pedestal may be implanted after the base and emitter diffusions, and annealed at a low temperature, thus keeping a sharp impurity gradient. Also, since it is put into the final epitaxial layer, its vertical position relative to the emitter-base junction will be independent of epitaxial undulations.

An Arsenic Emitter Structure for High-Performance Silicon Transistors by *H. N. Ghosh, A. S. Oberai, J. J. Chang, and M. B. Vora*, p. 457. Arsenic-doped emitters have been shown to produce high performance in bipolar silicon transistors. In comparison with phosphorus, the emitter dopant commonly used in the industry, the use of arsenic results in a steeper gradient ($10^{24}/\text{cm}^4$), less compensation of the base region, no "emitter dip" effect, and a flatter profile with higher sheet conductivity. Since arsenic atoms are a better match to Si than are phosphorus atoms and the arsenic process requires lower surface concentration for a particular diffusion depth and sheet conductivity, fewer crystal defects are generated. As a result the arsenic emitter process results in a higher device yield and is much more reproducible, even for shallow diffusion depths. Arsenic-emitter transistors, both with and without gold doping, are found to be superior in performance, with 1.6 to 2 times higher gain bandwidth, f_t and current gain, β , than those with phosphorus emitters with similar geometry. Also the ability of the arsenic emitter to sustain large current densities, exceeding $30,000 \text{ A-cm}^{-2}$, makes it extremely desirable for high density, small geometry, and high-performance silicon devices.

Arsenic Source Vapor Pressure Kinetics and Capsule Diffusion by *J. S. Sandhu and J. L. Reuter*, p. 464. After diffusion temperature and time, the most important parameters in capsule diffusion source behavior are the dopant vapor pressure characteristics in the capsule. The vapor pressure behavior is a function of the degree of homogenization of the Si-dopant system and hence of the source preparation technology. Various methods of preparing Si-As source material are discussed. Homogenized-source preparation is described as it relates to reproducibility and controlled capsule diffusion behavior. The measurement of the kinetics of

arsenic vapor pressure development in a typical capsule system and the role of vapor pressure in determining capsule diffusion behavior are described. Finally, the dependence of arsenic vapor pressure characteristics, and hence of the diffusion, on source weight-to-capsule volume ratio is described.

A Diffusion Model for Arsenic in Silicon by *T.-L. Chiu and H. N. Ghosh*, p. 472. It is proposed that double acceptor-level vacancies are responsible for arsenic diffusion into silicon. A computer program, which combines this diffusion mechanism with the formation of arsenic clusters and an internal electric field induced by the impurity gradient, is used to calculate arsenic diffusion profiles in wide ranges of diffusion temperatures and surface impurity concentrations. The calculated diffusion profiles are in good agreement with the measured profiles.

On the Relationship of Resistivity to Arsenic Concentration for Heavily Doped *n*-type Silicon by *T.-L. Chiu and H. N. Ghosh*, p. 477.

Numerical Calculation of Magnetic Fields in the Vicinity of a Magnetic Body by *A. E. Ruehli and D. M. Ellis*, p. 478. Static magnetic fields, resulting from an applied field, are calculated in the vicinity of a magnetic body. Specifically, numerical results are given for a rectangular body of constant permeability. The reduction or shielding of the magnetic fields is calculated in the neighborhood of the body. Integral equations are developed which can be solved numerically on a computer. Typical fields are described for rectangles of different thicknesses, and comparisons with known solutions are shown.