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Domain Orientation in Barium Titanate Single Crystals *by D. P. Cameron, p. 2.* An acid etching technique makes visible the domain structure of barium titanate crystals as reported by Hooton and Merz. Earlier observations by Merz of the mechanism of switching are confirmed by experiments using this technique. A discussion of domain wall formation in the orthorhombic state leads to the explanation of observed domain patterns. Photomicrographs are shown and discussed.

Design of Logic for Recognition of Printed Characters by Simulation *by E. C. Greanias, C. J. Hoppel, M. Kloomok, and J. S. Osborne, p. 8.* A logic for the recognition of printed characters employing a "proportional parts" method has been tested extensively by simulation. The proportional parts method relates the identity of a character to the relative size and position of character elements detected by optical scanning along closely spaced vertical lines. The video information from each scan is coded to designate the number, size, and position of inked areas detected by the scanner. The time sequence or order of occurrence of this coded information is tested by logical circuitry against prescribed sequences for character recognition. A set of coding definitions, a prescribed sequence for the recognition of a given character, and the methods of simulative testing of the recognition logic on the IBM Type 650 Magnetic Drum Data Processing Machine are discussed.

On the Theory of Relaxation Processes *by A. G. Redfield, p. 19.* A general procedure is given for finding the equation of motion of the density matrix of a system in contact with a thermal bath, as for example a nuclear spin system weakly coupled to a crystal lattice. The thermal bath is treated both classically and quantum mechanically, and the theory is similar to, and a generalization of, conventional theories of time proportional transition probabilities. Relaxation of the system by the thermal bath is expressed by a linear matrix operator, and it is stressed that elements of this operator can be regarded as secular or nonsecular perturbations on the equation of motion and can be treated accordingly. When the motion of the system is slow compared to that of the thermal bath, the equation of motion can be expressed in an operator form which is independent of representation. If the system has a time-dependent Hamiltonian which varies slowly compared to the motion of the thermal bath, the same equation of motion is obeyed and the system is relaxed by the bath toward a Boltzmann distribution with respect to its instantaneous Hamiltonian. If the time variation of the Hamiltonian is more rapid, higher order corrections to the equation of motion must be applied. The theory is applied to spin-lattice relaxation of a coupled nuclear spin system in a metal, for arbitrary externally applied fixed magnetic field.

A Three-Dimensional Printed Back Panel *by E. R. Wyma, p. 32.* A new design for interconnections of printed circuit packages in the IBM 608 Transistorized Computer is described. The three-dimensional arrangement for connections among circuit cards is shown to be flexible in design and adaptable to a highly mechanized manufacturing method. An arrangement for automatic cabling is discussed briefly. The various relationships among the design problems for circuit packaging, back panel connections and cabling are shown.

Clarification of First-Order Semiconduction Effects through Use of Electrochemical Potentials *by J. A. Swanson, p. 39.* When deviations from equilibrium conditions are small, the net rate at which electrons are interchanged between two groups of electrons which are separately in states of thermodynamic equilibrium is proportional to the difference of the Fermi levels applying to the two groups. With the help of this principle the first-order treatment of conduction effects in semiconductors (appropriate when carrier concentration

deviations are small) is considerably simplified. Poisson's equation is shown to be ignorable in the first-order treatment of steady-state effects. Application is given to the Hall effect and to the characterization of probes.

A Survey of Contact Resistance Theory for Nominally Clean Surfaces *by W. B. Ittner III and P. J. Magill, p. 44.* While the theory of electrical contact resistance is, for the most part, well known, it is difficult to apply directly to the prediction of experimental results since, in general, the theory involves microscopic parameters beyond the control of the investigator. Recent measurements of contact resistance as a function of the applied contact load, carried out under specified conditions, have yielded results which are in excellent agreement with the general theory. In contrast, however, to a number of previous publications, the results indicate that the contact area is determined completely by the applied load and an effective plastic yield pressure. Under conditions where contact wipe and vibration are held to a practical minimum, the contact area can be specified in terms of a plastic yielding mechanism down to pressures as low as 0.1 gram. In this region the bulk of the contact resistance is seen to be attributable, for nominally clean contacts, to an absorbed gaseous monolayer approximately two angstroms thick.

Development of the Electrostatic Clutch *by C. J. Fitch, p. 49.* A brief historical review of the electrostatic clutch operating on the Johnsen-Rahbek effect is presented. Mechanical design of a clutch, special lubrication, and the fabrication of electronically conductive clutch facing material are described. A high-speed, high torque-to-inertia ratio test model with bi-directional shaft control is described. With the clutch operating at 2500 rpm on 30 milliamperes at 150 volts, torques over 80 inch-pounds are available. The most useful single property of the electrostatic clutch is its fast response time. It can actuate levers, interposers, print hammers, optical gates, etc., in fractions of a millisecond; it can accelerate shafts to high rpm's with moderate loads in a few milliseconds from extremely low input control energy.

An Analysis of Diffusion in Semiconductors *by S. Zaromb, p. 57.* In the experimental determinations of the coefficients of diffusion of impurities in semiconductors reported to date, it has usually been assumed that these coefficients do not vary with concentration. This assumption is questioned here. Interactions between acceptors, donors, electrons, and holes may lead to complicated diffusion equations, as shown by an analysis based on Onsager's theory. In particular, appreciable covalent compound formation is likely to occur between some substitutional donors and acceptors. This alone may lead to a marked dependence of diffusion coefficients on concentration, and to diffusion of acceptors induced by concentration gradients of donors and vice versa. Such effects are suggested by some discrepancies in the experimental results reported thus far.

The Random-Access Memory Accounting Machine—I. System Organization of the IBM 305 *by M. L. Lesser and J. W. Haanstra, p. 62.* The design features of a new automatic data processing machine for business applications, utilizing a random-access memory system, are described. Unlike the usual "batch" method of machine-processing business transactions, the technique used permits transfer of information between any two points in the system and allows multi-choice decisions according to the current status of the information. The "in-line" operational concept is discussed in detail and the data transfer routes and processing controls are shown. Employing punched-card input and printed-record output, the IBM 305 accounting machine is designed to handle 10,000 line-transactions per day.

The Random-Access Memory Accounting Machine—II. The Magnetic-Disk, Random-Access Memory *by T. Noyes and W. E. Dickinson, p. 72.* The design features are described of a new large-capacity memory device having random access to information stored magnetically on rotating disks. The mechanical arrangement of an array of 50 disks is shown, and details are given of the pair of magnetic recording heads, which are spaced accurately from the disk surface by air jets. The access mechanism and the timing system for positioning the heads on the disk tracks are described. The total storage capacity of the system is 5,000,000 alphanumeric characters.

Logical Design of the Digital Computer for the SAGE System *by M. M. Astrahan, B. Housman, J. F. Jacobs, R. P. Mayer, and W. H. Thomas, p. 76.* Special design features and performance criteria are described for the logical system in the digital computer used in the SAGE (Semi-Automatic Ground Environment) air defense system. Design details are given for the arithmetic element, high-speed multiply, index registers, input-output control, and magnetic drum buffer. The system is designed according to special military application requirements of speed, capacity, reliability and flexibility.

Simple Constant-Temperature Oven and Control System *by G. R. Gunther-Mohr and S. Triebwasser, p. 84.* A number of laboratory measurements require a constant and uniform ambient temperature. A thermocouple-monitored system consisting of an oven, a stable reference source and a chopper-amplifier controller unit has been developed. This system provides a stable and uniform temperature, ±0.1°C from 200° to 1050°C in a cylindrical region 5 cm in diameter and 12 cm long. Each of the parts of the system is discussed and their operation as an integrated whole considered.

Lattice Parameters of Zn_3As_2 *by H. Cole, F. Chambers, and H. Dunn, p. 90.*

A General Theory of Multiple Spin Echoes *by J. W. Horton, p. 93.*

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A 32,000-Word Magnetic-Core Memory *by E. D. Foss and R. S. Partridge, p. 102.* The development of the IBM 738 magnetic core storage unit is described and associated engineering problems are discussed, including the electrical and mechanical arrangements for packaging more than one million magnetic cores and their circuits. This paper describes the driver circuits and the sense amplifier used for this system.

Computation of e^N for $-\infty < N < +\infty$ Using an Electronic Computer *by E. G. Kogbetliantz, p. 110.* Rational R and polynomial P approximations to the exponential function e^N are studied. They allow e^N to be computed for any value of the exponent N in the infinite range from minus infinity to plus infinity a minimum number M of multiplications (and divisions, for the rational approximations). This minimum is attained without unduly increasing the number PC of precomputed and stored constants and also without limiting the number Dg of the first correct significant digits.

The Multipurpose Bias Device—Part I: The Commutator Transistor *by B. Dunham, p. 116.* It is suggested that multipurpose devices will provide economy in both number and assortment of basic computer building blocks. A study is made of the Rutz commutator transistor largely in application to three-input, one-output logical situations. A basis is thereby provided for a more general analysis to be published at a later date.

Addressing for Random-Access Storage *by W. W. Peterson, p. 130.* Estimates are made of the amount of searching required for the exact location of a record in several types of storage systems, including the index-table method of addressing and the sorted-file method. Detailed data and formulas for access time are given for an "open" system which offers high flexibility and speed of access. Experimental results are given for actual record files.

The Lorenz Number *by P. J. Price, p. 147.* The theory of the Lorenz number of a conducting crystal is developed for the common models of the electron assembly. For the one-electron model it is shown that, provided scattering is elastic to an approximation which is examined, the Lorenz number is equal to the square fluctuation of the thermoelectric power. For the phenomenological band model an equivalent result is obtained. It is hypothesized that these results are special cases of a more general one. Some applications, including the theory of the bipolar anomaly for semiconductors, are discussed.

A Positive-Integer Arithmetic for Data Processing *by R. W. Murphy, p. 158.* It is hypothesized that positive numbers suffice for the expression of quantities in accounting. New arithmetic operations are devised that yield non-negative results in computation, and the applicability of these operations to data processing is studied. These operations permit a wide variety of functions to be computed with fewer and less complex steps and imply the feasibility of constructing less complex data-processing machines.

Irredundant Disjunctive and Conjunctive Forms of a Boolean Function *by M. J. Ghazala, p. 171.* A thorough algebraic method is described for the determination of the complete set of irredundant normal and conjunctive forms of a Boolean function. The method is mechanical and therefore highly programmable on a computer.

A Mathematical Model for Determining the Probabilities of Undetected Errors in Magnetic Tape Systems *by M. Schatzoff and W. B. Harding, p. 177.* Mathematical models for evaluating the relative efficiencies of vertical and longitudinal redundancy-bit checking in magnetic tape systems are derived. Although these types of validity checking have been in use for some time, this is, to the authors' knowledge, the first quantitative statement of the probabilities associated with them.

A Self-Clocking System for Information Transfer *by L. D. Seader, p. 181.* This paper describes a circuit which generates a continuous train of clock pulses bearing a fixed phase relationship to information pulses. By switching two gated oscillators, the information pulses continuously correct the phase of the clock pulses.

A Symmetrical-Transistor Steering Circuit *by J. L. Walsh, p. 185.*

Determination of Transient Response of a Drift Transistor Using the Diffusion Equation *by H. B. von Horn and W. Y. Stevens, p. 189.*

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Development of the Permissive-Make Relay *by B. J. Greenblott and J. E. Wallace, p. 198.* The development of a new relay is described which meets the need for an improved general-purpose relay for use in existing and future business machines. Long life, reliability, higher speed, low power input and manufacturing economy are realized in the Permissive-Make Relay through the following factors: a new contact system; a balanced force system; optimum magnet design; limited tolerance buildup; adjustment-free assembly design.

Two-Collector Transistor for Binary Full Addition *by R. F. Rutz, p. 212.* Details are given of the design and operational features of two versions of a new multielectrode transistor which serves as a full adder for binary numbers in computer circuits. This transistor in a simple circuit connection performs the logical operations "and," "or," "exclusive or," "if-and-only-if," "neither-nor," "not both," and "not." The point-contact design utilizes two collectors with high current multiplication factors to provide signal amplification during

the logical operation at very high speeds. The "all-junction" design utilizes *p-n* hook collectors to give much higher values of intrinsic alpha. The paper describes the nature of the internal positive-feedback action in the two-collector transistors and illustrates the function of these transistors as logic devices.

Spatial Variation of Currents and Fields Due to Localized Scatterers in Metallic Conduction *by R. Landauer, p. 223.* Localized scatterers can be expected to give rise to spatial variations in the electric field and in the current distribution. The transport equation allowing for spatial variations is solved by first considering the homogeneous transport equation which omits electric fields. The homogeneous solution gives the purely diffusive motion of current carriers and involves large space charges. The electric field is then found, and approximate space charge neutrality is restored, by adding a particular solution of the transport equation in which the electric field is associated only with space charge but not with a current. The presence of point scatterers leads to a dipole field about each scatterer. The spatial average of a number of these dipole fields is the same as that obtained by the usual approach which does not explicitly consider the spatial variation. Infinite plane obstacles with a reflection coefficient r are also considered. These produce a resistance proportional to $r/(1-r)$.

Microwave Amplification by MASER Techniques *by W. V. Smith, p. 232.* A new amplification principle, that of Microwave Amplification by Stimulated Emission of Radiation (MASER), has already demonstrated its potentialities for low-noise, narrow-band amplification. The present note presents an elementary analysis of MASER operation, including its potentiality for broadband, short-transit-time amplification.

The Linear Hall Effect *by P. J. Price, p. 239.* A new method for handling the Boltzmann equation is used to obtain, without approximation, a general formula for the linear Hall effect in a solid electronic conductor. Expressions for the conductivity in no magnetic field and for the quadratic magnetoconductivity are also obtained. These formulas introduce a vector mean free path, not in general parallel to the electron velocity, which is related to the velocity by an integral equation. Some possible cases of the formula for the Hall effect are analyzed. The solution of the integral equation for the vector mean free path is discussed, and methods of approximation are proposed.

Literary Data Processing *by P. Tasman, p. 249.* A method is presented for rapid compilation of analytical indexes and concordances of printed works, using either a conventional punched-card system or an electronic data processing machine. A detailed description of the procedures used in automatically analyzing and indexing the *Summa Theologica* of St. Thomas Aquinas is given. Reference is also made to the indexing of the Dead Sea Scrolls using an IBM 705.

An Experimental 50-Megacycle Arithmetic Unit *by R. M. Walker, D. E. Rosenheim, P. A. Lewis, and A. G. Anderson, p. 257.* An experimental 50-megacycle arithmetic unit has been built which performs a repetitive multiplication program and checks the results for errors. The unit uses pulse circuitry which has been developed to perform digital operations at a 50-megacycle pulse-repetition rate. This paper describes the arithmetic system and the circuits which perform the required functions. These circuits include a full binary adder, a phase-locked frequency divider which provides a 3.125-megacycle secondary timing source, a reshaping and retiming circuit using germanium diodes and capacitive storage, a high-speed shift register, a high-speed indicator register, and a binary word generator.

Various novel features of a digital system operating at these high speeds are described. These include the use of coaxial delay lines for the distribution of signals and as storage elements, and the use of secondary emission tubes in amplifier and multivibrator circuits.

In a 50-megacycle system the interdependence of the space and time dimensions is marked, and although this introduces problems which are not ordinarily encountered in computing systems, it may be used advantageously to provide features such as the variable-phase clock system used in the arithmetic unit.

The performance and reliability of the arithmetic unit are discussed as well as the reliability of the components and circuits which make up the system. Although the techniques and circuitry discussed here have been applied only to a relatively simple arithmetic unit, it is felt that they could be useful in a variety of high-speed computing and measurements applications.

Microsectioning: A Metallographic Technique for Semiconductor Devices *by J. S. Hanson, p. 279.* A microsectioning technique is described that enables metallographic sectioning of fragile semiconductor devices without the difficulties and specimen damage associated with the use of conventional techniques. Major advantages are (a) maintenance of a planar surface on specimens having adjoining areas of widely varying physical characteristics, (b) preservation of boundary details between such areas by elimination of rounding-off effects, and (c) precise positioning of the sectioning plane by direct micrometer caliper measurement. Choice of sectioning plane, specimen mounting, machine lapping of mounted specimens, polishing, etching, and panoramic microphotographic techniques are described. The effectiveness with which data can be gathered from the resulting microphotographs is demonstrated by an analysis and evaluation of selected specimen photographs.

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Preface *by D. R. Young, p. 294.*

Trapped-Flux Superconducting Memory *by J. W. Crowe, p. 294.* A memory cell based on trapped flux in superconductors has been built and tested. The cell is constructed entirely by vacuum evaporation of thin films and can be selected by coincident current or by other techniques, with drive-current requirements less than 150 ma. The short transition time of the trapped-flux cell indicates its possible use in high-speed memories. The superconductive film memory does not exhibit the problems of "delta noise" in core memories resulting from the difference in half-select pulse outputs.

An Analysis of the Operation of a Persistent-Supercurrent Memory Cell *by R. L. Garwin, p. 304.* From a thin-film persistent-supercurrent memory cell is abstracted a particular theoretical model which is discussed exactly and in detail. The behavior predicted is in good agreement with that of experimental devices built to be as closely like the model as was possible at the time. Partly because of the simplicity of the analysis and the rather complete understanding thus gained, this model may prove to be useful for the design of large-scale memory and computing systems. For a single cell, a memory cycle time of 5 millimicroseconds should be achievable, and for a large memory perhaps 10 millimicroseconds.

A Statistical Approach to Mechanized Encoding and Searching of Literary Information *by H. P. Luhn, p. 309.* Written communication of ideas is carried out on the basis of statistical probability in that a writer chooses that level of subject specificity and that combination of words which he feels will convey the most meaning. Since this process varies among individuals and since similar ideas are therefore relayed at different levels of specificity and by means of different words, the problem of literature searching by machines still presents major difficulties. A statistical approach to this problem will be outlined and the various steps of a system based on this approach will be described. Steps include the statistical analysis of a collection of documents in a field of interest, the establishment of a set of "notions" and the vocabulary by which they are expressed, the compilation of a thesaurus-type dictionary and index, the automatic encoding of documents by machine with the aid of such a dictionary, the encoding of topological notations (such as branched structures), the recording of the coded information, the establishment of a searching pattern for finding pertinent information, and the programming of appropriate machines to carry out a search.

The Effect of an Electric Field on the Transitions of Barium Titanate *by M. E. Drougard and E. J. Huibregtse, p. 318.* A review is presented of the effects of electric fields on the ferroelectric phase transitions of barium titanate at 120°C and 5°C. The double hysteresis loop observed at the Curie point and the triple hysteresis loop and dielectric constant measured at the 5°C transition are examined in the light of Devonshire's thermodynamic theory of ferroelectricity in barium titanate. The data and various published experimental results are shown to agree with calculations based on the Devonshire free-energy function. The discrepancy between the coercive fields predicted by the theory and those actually observed is discussed.

A Mechanical Heart-Lung Apparatus *by R. Taylor, p. 330.* An apparatus is described for taking over the functions of the human heart and lungs for short periods of time to permit a surgeon to perform certain open-heart surgical procedures in a blood-free field. This equipment is capable of receiving venous blood from the patient, removing excess carbon dioxide and restoring the proper oxygen content, and finally of pumping the blood back into the patient's arterial system. The heart-lung apparatus is provided with controls that automatically maintain the pH of the blood at its correct value, maintain proper blood temperature and safeguard the patient against unwanted changes in blood volume and against excessive blood pressure during the course of the operation. The machine requires the attention of only two persons during normal surgical procedures.

The Formalization of Scientific Languages—Part I: The Work of Woodger and Hull *by B. Dunham, p. 341.* The extent to which scientific languages can be formalized is an important problem, especially if it is assumed that a theorem-proving machine will deal most effectively with formal systems. In Part I, the axiomatic attempts of Woodger in genetics and of Hull in the theory of rote learning are examined. In Parts II and III, to be published later, the more prominent efforts to formalize physical theory will be considered and a general study will be made of related questions.

A Radiant-Energy Heater Using an Ellipsoidal Reflector *by E. H. Nicollian, G. R. Gunther-Mohr, and L. R. Weisberg, p. 349.* The effectiveness of a radiant-energy heater employing a hemi-ellipsoidal aluminum reflector and an incandescent lamp as radiation source is illustrated by application to the zone-melting of germanium. The factors affecting the design and performance of this heater are discussed.

A Binary-Weighted Current Decoder *by E. J. Smura, p. 356.* A novel method for driving cathode-ray-tube deflection yokes from digital equipment has been found. The system is compared with other methods and outstanding features are described. The important design parameters are outlined and their effect on circuit operation noted. A printed-circuit-package assembly of a typical converter using this system is shown.

Radio-Interference Control as Applied to Business Machines *by J. M. Sarley and R. J. Hendery, p. 363.* This paper discusses certain known characteristics and sources of radio interference and methods used to reduce the interference levels present in business machines. Particular attention is given to electro-mechanical machines ranging from a simple card perforator, operated by an electrical contact and an electromagnet, to electronic data-processing machines. The sources of interference in these machines are found in a wide variety of components and circuit configurations, such as electrical contacts, gas tubes, unterminated transmission lines and motors.

Some of the problems encountered in reducing this interference to a satisfactory level are described. Testing methods are also considered. A description is given of the development of a universal line filter which has been most successful in reducing noise transmission over power cables.

The development of reinforced plastic machine covers presents a special problem in radio-interference control. A discussion is given of experimental solutions to this problem through the use of such techniques as copper screening, copper spray, and imbedded metallic foils.

Superconducting Connections to Films *by J. A. Kurtz, p. 373.*

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A Learning Machine: Part I *by R. M. Friedberg, p. 2.* Machines would be more useful if they could learn to perform tasks for which they were not given precise methods. Difficulties that attend giving a machine this ability are discussed. It is proposed that the program of a stored-program computer be gradually improved by a learning procedure which tries many programs and chooses, from the instructions that may occupy a given location, the one most often associated with a successful result. An experimental test of this principle is described in detail. Preliminary results, which show limited success, are reported and interpreted. Further results and conclusions will appear in the second part of the paper.

An Error-Sampled Sweep-Position Control System *by C. H. Knapp, E. Shapiro, and R. A. Thorpe, p. 14.* This paper illustrates the application of sampled-data theory to the synthesis of a feedback control system using forward-path digital compensation to achieve high accuracy and fast response. It also presents a detailed description of the design and operation of a transistor system prototype. Developed for the specific purpose of controlling the position of an instantaneous portion of a cathode-ray-tube trace, the system has a number of unusual characteristics such as transport lag, digital integration, and numerous sampling rates. The practical manner in which these characteristics are implemented and the mathematical techniques used for system analysis should prove applicable to a wide variety of control-system problems.

Magnetic-Recording-Head Selection Switch *by L. D. Seader, p. 36.* A switch for selecting one out of 100 magnetic recording heads for reading or writing is described. The recording heads are arranged in a 10 by 10 matrix and the switching is accomplished by semiconductor devices. The problem of obtaining suitably fast current rise time during writing is discussed, and the problem of crosstalk from unselected recording heads during reading is analyzed. Experimental results illustrate the performance of the switch.

Computation of Arctan N for $-\infty < N < +\infty$ Using an Electronic Computer *by E. G. Kogbetliantz, p. 43.* Rational (R) and polynomial (P) approximations to Arctan N are studied with the aim of computing this function, to any prescribed accuracy and without unduly increasing the number PC of stored constants, in a minimum number M of multiplications (and divisions for R approximations). The number Dg of first correct *significant* digits in principle is not bounded. The results corresponding to the values 8, 10, 18 and 20 of this number are as follows: (Table of results is given for M ranging in value from 4 to 10.)

If M is increased, subroutines with smaller PC are easily deduced from our general results. Thus, for instance, rational approximations with $Dg = 6$ can be obtained in three multiplications only, if $PC = 19$ (combination $m^* = 3$, $q = 10$); but the same accuracy $Dg = 6$ characterizes also the cases $M = 4$ with $PC = 11$ and $M = 5$ with $PC = 7$ (combinations $m^* = 4$, $q = 6$ and $m = 5$, $q = 4$).

If polynomial approximations are used, $Dg = 6$ is obtained for $M = 5$, $PC = 7$, but also for $M = 4$ and $PC = 11$. No subroutines with a stored table of values of Arctan x are considered.

Effects of Low Temperatures on Transistor Characteristics *by A. B. Credle, p. 54.* The four-pole parameters of a group of similar *pnp* alloy junction transistors were measured in the frequency range from 0.5 to 5 mc and from room temperature down to that of liquid nitrogen. The measured parameters are translated into simple electrical networks for application in these frequency and temperature ranges.

Theoretical expressions for the transistor parameters are evaluated. This evaluation utilizes the effects of temperature on surface-recombination effects, on hole mobility, and on carrier lifetime that have been reported in the literature.

The transistors were subjected to grounded-emitter pulse tests in which the transistors were driven from beyond cutoff to the edge of saturation. These tests show that, for a given output pulse current, rise time decreases with temperature. The tests with the transistor in liquid nitrogen show further that rise time decreases as the output current pulse increases. Under these conditions it is possible for a 30 mw, 3 mc alloy-junction transistor to deliver a one-ampere output current pulse with a rise time of a few tenths of a microsecond and with a grounded-emitter gain of about 20.

A New Approach to Small-Computer Programming and Control *by J. J. Lentz, p. 72.* A novel approach to computer programming and control, used in the IBM 610 computer, allows the solution of complex problems by an operator whose only previous experience with computing has been the desk calculator. The machine's command structure is designed so that the operator can at all times communicate with the computer by a series of short sentence-type instructions closely resembling the steps of manual arithmetic solution. A type of floating-decimal operation called the "auto-point" mode permits entry of data into storage locations with automatic positioning of the decimal point, without elaborate programming. The decimal point is automatically re-positioned during subsequent computation.

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High-Resolution Magnetic Recording Structures *by A. S. Hoagland, p. 90.* Design concepts are established for several high-resolution magnetic recording structures, and their application demonstrated. The conventional ring head is treated and two new devices are described. A probe-type unit

is discussed which shows promise in high-density vertical magnetic recording. A wire-grid array is also advanced to outline a unique conceptual approach to the achievement of higher resolution.

Programs as a Tool for Research in Systems Organization *by J. Jeenel, p. 105.* A program for the solution of a problem by a data-processing system constitutes a conceptual link between the problem and the machine. It is proposed that both problems and machine organization be studied in terms of programs. A data-processing system may for this purpose be considered a collection of units such as arithmetic units and stores of different types and characteristics. A standard representation of programs is proposed for studying the organization of systems composed of processing units and stores. This approach may lead to more efficient and systematic design of data-processing systems as well as to improved programming methods for existing machines.

On the Statistical Mechanics of Impurity Conduction in Semiconductors *by P. J. Price, p. 123.* The statistical mechanics of the impurity electron states for a semiconductor with a low density of donors, and a small amount of acceptor compensation, is analyzed. Expressions are obtained for the number of dissociated donor ion states according to the Mott model, and for the effects of multiple trapping, and of dispersion of the trapping energies, on this number. An expression for the thermoelectric power according to the Mott model is obtained. If a small proportion of "minority" donors, of a different chemical species with a smaller electron binding energy than the majority donors, were added to the impurity content they should act as additional traps for donor ion states: The statistical mechanics of this system is analyzed.

Pulse Time Displacement in High-Density Magnetic Tape *by R. A. Skov, p. 130.* In computer magnetic tape systems, a primary factor in character rate is recording density. Pulse time displacement places a direct limit on the maximum bit density which may be used in parallel NRZI recording systems in which recovery of the information on readback depends on correct synchronism of all tracks. Measurement techniques for evaluation and analysis of pulse time displacement are described. A sawtooth oscilloscope display is particularly useful for observing time displacement as a function of time. The various components of time displacement and their causes, such as skew and pulse crowding, and methods used to reduce them are discussed. This study led to the adoption of a recording density exceeding 500 bits per inch for the IBM 729-III Magnetic Tape Unit.

Reliability Improvement by the Use of Multiple-Element Switching Circuits *by W. E. Dickinson and R. M. Walker, p. 142.* Physical devices used for switching have finite probabilities of failure. Circuits which make use of redundancy to achieve resultant reliabilities greater than that of their elements have been proposed and have been analyzed for the case of intermittent failures. The present paper extends certain of these results to the case of permanent failures of the elements, assuming that the reliability of these elements is known. It is shown that, for operating periods which are short compared to the mean time to failure of the elements, a substantial increase in reliability can be obtained by such redundancy.

Reliability Improvement through Redundancy at Various System Levels *by B. J. Flehinger, p. 148.* Improvement in computing machine reliability through redundancy is studied as a function of the level at which the redundancy is applied. The reliability achieved by redundancy of complete, independent machines is compared to that achieved by redundancy of smaller units.

A machine unit is termed m times redundant when the following conditions exist:

1. m independent identical units operate simultaneously with a common input.

2. A failure detector is associated with each unit.

3. A switch is connected to the outputs of the units, so that the output is taken from some one unit until failure occurs in that unit. Then the switch steps so that the output is taken from the next redundant unit, if that unit is operating correctly. The process continues until the assigned task is completed or all m units fail.

The reliability of m redundant units is expressed in terms of the reliability of one unit and the probabilities of correct operation of the failure detectors and switch.

It is assumed that a complete machine may be broken up into p units, $p = 1, 2, 3, \ldots, 24$, of equal reliability. The reliability achieved by redundancy of these units is calculated as a function of p and m, $m = 1, 2, 3, 4$, with single-machine reliabilities of 0.2, 0.5, 0.9 and 0.99. These results are calculated for perfect failure detection and switching devices as well as for moderately unreliable devices. The resultant system unreliability is plotted as a function of p on linear and on logarithmic scales.

The Automatic Creation of Literature Abstracts *by H. P. Luhn, p. 159.* Excerpts of technical papers and magazine articles that serve the purposes of conventional abstracts have been created entirely by automatic means. In the exploratory research described, the complete text of an article in machine-readable form is scanned by an IBM 704 data-processing machine and analyzed in accordance with a standard program. Statistical information derived from word frequency and distribution is used by the machine to compute a relative measure of significance, first for individual words and then for sentences. Sentences scoring highest in

significance are extracted and printed out to become the "auto-abstract."

On Checking an Adder *by W. W. Peterson, p. 166.* It is widely known that a computer adder can be checked by a completely independent circuit using check symbols that are residues of the numbers modulo some base. This paper describes such a residue checking system and shows, moreover, that independent adding and checking circuits are possible only with systems of this type. The discussion includes a method of handling residue-class check symbols when overflow occurs.

A Note on the Computation of Eigenvalues and Vectors of Hermitean Matrices *by T. C. Chen and R. A. Willoughby, p. 169.*

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A Direct-Reading Printed-Circuit Commutator for Analog-to-Digital Data Conversion *by C. A. Walton, p. 178.* A novel direct-readout printed-circuit commutator has been incorporated in the design of a shaft-to-digital converter system for analog-to-digital data conversion. The design avoids the use of supplementary coding or additional translation circuitry required to operate other shaft-to-digital converters. Methods are described for ensuring logical progressions of numerical data despite gearing errors and the analog nature of the input-shaft position. Some applications of the commutator are discussed.

Phase Equilibria in the Ferrite Region of the System Manganese-Iron-Oxygen *by M. W. Shafer, p. 193.* An important factor in growing crystals from the melt is an understanding of the phase relationships for systems involving the necessary elements. This investigation deals with the determination and interpretation of these relationships in the ferrite region of the system Mn-Fe-O and points out the conditions necessary to grow crystals along with the Mn_3O_4-Fe_3O_4 join.

The results are presented in terms of a phase diagram which shows isotherms, isobars, and fractionation curves, the data necessary to predict the exact crystallization path of compositions which fall in the ferrite region.

Several crystallization paths are discussed and their relationship to crystal growth pointed out. Liquids falling on the Mn-Fe side of the Mn_3O_4-Fe_3O_4 join are deficient in oxygen and on cooling will precipitate a lower oxide phase in addition to a stoichiometric ferrite. On the other hand, ferrite crystals separating from liquids whose compositions fall on the oxygen side of the join can have excess oxygen (cation vacancies).

The Physical Interpretation of Mean Free Path and the Integral Method *by P. J. Price, p. 200.* In previous papers, general expressions for the linear electronic transport constants of solids were obtained in terms of a conjugate function $\psi^\dagger$ related, by a linear inhomogeneous integral equation, to the function (of electron state) ψ measured by the "flux." It is now shown that

$$\tau\psi^\dagger = \int_0^\infty \psi(t)\, dt\,,$$

where the integrand is the expectation of ψ for an electron which at time t earlier was in the specified state (of which $\psi^\dagger$ is a function) and $1/\tau$ is the collision frequency. In particular, the vector mean free path $\tau v^\dagger$ is: "the limit, after a virtually infinite time, of the mean displacement, in Brownian motion, of the position of an electron initially in the specified state." If there is a force (e.g. that due to a magnetic field) accelerating the electrons between collisions, then a linear transport constant is the same functional of an "extended conjugate" $\psi^{\dagger e}$ as it is of $\psi^\dagger$ in the absence of the force. It is shown that $\tau\psi^{\dagger e}$ is obtained (instead of $\tau\psi^\dagger$) when the integrand in the integral above is replaced by the "expectation after time t" as modified by the accelerations between collisions. The relation of the present formalism to the Shockley-Chambers theory is discussed.

A Load-Sharing Matrix Switch *by G. Constantine, Jr., p. 204.* A matrix-switch winding pattern has been developed which allows the power from several pulse generators to be combined into a single high-power pulse to drive a computer core memory. This pulse may be directed into one of a group of outputs. The method of operation, including the logical basis for changes in number of outputs, is described.

The device is suitable for the *X-Y* drivers of a transistor-driven core memory because one switch allows a group of fast, low-power transistors to deliver a large drive pulse to one drive line on one side of the memory. A 16-output load-sharing matrix switch has been used in the *X-Y* drive system for a 2-μsec memory.

Study of the Second-Order Ferroelectric Transition in Tri-Glycine Sulfate *by S. Triebwasser, p. 212.* Results of measurements of the dielectric constant, dielectric nonlinearity and spontaneous polarization of tri-glycine sulfate are given. These data demonstrate clearly that this material exhibits a second-order ferroelectric transition. The properties discussed are described in terms of the usual expansion of the free energy in even powers of the polarization

$$F(P,T) = F(O,T) + A(T - T_0)P^2 + BP^4 + CP^6,$$

where A, T_0, B and C are constants and T and P are the temperature and polarization, respectively. From the various data taken it is found that $A = 1.96 \times 10^{-3}\ (°C)^{-1}$, $T_0 = 49.8°C$, $B = 2.0 \times 10^{-10}\ (\text{esu/cm}^2)^{-2}$ and $C = 8.4 \times 10^{-19}\ (\text{esu/cm}^2)^{-4}$. From these results the nonlinearity of the dielectric constant above the Curie point is calculated at various temperatures.

Computation of Arcsin N for $0 < N < 1$ Using an Electronic Computer *by E. G. Kogbetliantz, p. 218.* All known subroutines for Arcsine are based on the relation Arcsin N = Arctan $[N/(1 - N^2)^{1/2}]$. Therefore, Arcsine is not computed as such but as an Arctangent.

To avoid the loss of machine time caused by the computation of $N/(1 - N^2)^{1/2}$, a direct computation of Arcsine is proposed. A subroutine yielding the first six correct significant digits in only five multiplications and divisions is described in detail to illustrate the new method's rapidity. The same number of five operations is necessary to compute, knowing N, the number $N/(1 - N^2)^{1/2}$.

A Full Binary Adder Employing Two Negative-Resistance Diodes *by J. W. Horton and A. G. Anderson, p. 223.* Full binary pulse addition may be performed using only two negative-resistance diodes. Amplified Sum and Carry outputs can be provided which are virtually in coincidence with the input signals. A full adder is described, employing Reeves-Cooke positive-gap diodes which operate with pulses of 20-millimicrosecond duration.

Curve Fitting for a Model of Applied Research and Development Scheduling *by P. V. Norden, p. 232.* Analysis of the research and development process has suggested improved techniques for estimating the anticipated effort requirements for engineering projects. Logistic growth curves have been fitted to the time distribution of cumulative man-hours, and an effort-distribution array permits the extraction of meaningful information from historical cost records. These provide a consistent basis for adjusting current project schedules and making further estimates.

The Bipolar Righi-Leduc Effect *by P. J. Price, p. 249.*

Magnetic Field Plotter for Superconducting Films *by H. E. Kronick, p. 252.*

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Communication Sciences in a University Environment *by J. B. Wiesner, p. 268.* Information processes and information processing systems are the principal concerns of investigators in many fields, including electrical engineering, neurophysiology, psychology, linguistics, genetics and mathematics. Studies in each of these fields contribute to understanding in the others, and each has a need for mathematical models and mathematical methods for describing and analyzing these processes. Studies of electrical communication and computational systems have provided the mathematical tools and understanding which are useful to the other fields. The related interests of this diverse group of scientists are examined and the activities of several groups in the Communication Sciences Center at M.I.T. are described.

Problems in Scientific Communication *by E. de Grolier, p. 276.*

How Much Science Can You Have at Your Fingertips? *by I. J. Good, p. 282.* Numerous suggestions are presented for helping men to learn and retrieve scientific information, with or without artificial aids.

In a discussion of how much information can be stored in a human brain, and how this compares with the amount of scientific information that has been published, it is argued that the number of "conceivable" states of the brain is much larger than the number of attainable states. It is necessary here to use a definition for the number of effective states of a brain or of any record.

It is mentioned that access to published literature is not the only problem in the communication of scientific information.

A discussion of how a man might acquire an encyclopedic knowledge emphasizes, for example, that a vital principle in learning and teaching is an explicit belief in the importance of general principles.

Knowledge is compared with a network having various impedances in the connections between the nodes, somewhat like a nervous system. Difficulties in classification (and in organization) appear when networks depart very much from having a tree-like structure. Some tentative suggestions for learning arise out of this model.

Possible new fields of research, such as *saporology*, and of new periodicals, such as *Half-Baked Ideas*, are touched upon.

A discussion of the value of mechanical aids concludes with a list of probable new advances in consulting scientific literature in the near future. Sixteen applications are listed for tape recordings of books.

The paper concludes with a warning that some of the world's greatest scientists have done their best work when they were given plenty of time to think their own thoughts.

Channels with Side Information at the Transmitter *by C. E. Shannon, p. 289.* In certain communication systems where information is to be transmitted from one point to another, additional side information is available at the transmitting point. This side information relates to the state of the transmission channel and can be used to aid in the coding and transmission of information. In this paper a type of channel with side information is studied and its capacity determined.

Artificial Auditory Recognition in Telephony *by E. E. David, Jr., p. 294.* Machines which automatically recognize patterns from a stream of acoustic events, for example a spoken command, would have great utility in both communications and data processing. This paper reviews two

applications of an elementary recognizer to the problem of actuating certain logical functions, and indicates how more ambitious recognizers might be utilized. In this regard, the automatic measurement of a talker's voice pitch and voicing dynamics appears fundamental to speech analysis, and hence to many recognition schemes. Visual inspection of spectral data taken from different speakers supports this contention.

Segmentation of speech into discrete units suitable for recognition, including the possibility of overlapping elements, is discussed. There is reason to expect that such segments will span several elementary speech sounds (phonemes). To illustrate this approach, a set of rules is presented for associating visual spectral displays (sound spectrograms) with the perception evoked by the corresponding utterances. These rules are specifically tailored for a limited vocabulary consisting of ten spoken numbers, and were validated by naive subjects who used them to identify the utterances of 33 people. In a further experiment, spectrograms of the same material from 14 talkers were simplified by reducing them to binary elements. It was found that master patterns for each number, compiled from the ensemble of talkers, could identify the utterances with over 99% success. These results emphasize a "diversity" approach to speech recognition which operates on relations between gross spectral features and does not depend exclusively on any one property.

The Role of Large Memories in Scientific Communications *by M. M. Astrahan, p. 310.* Large memories provide automatic reference to millions of words of machine-readable coded information or to millions of images of document pages. Higher densities of storage will make possible low-cost memories of billions of words with access to any part in a few seconds or complete searches in minutes. These memories will serve as indexes to the deluge of technical literature when the problems of input and of the automatic generation of classification information are solved. Document files will make the indexed literature rapidly available to the searcher. However, memory capacity is currently well ahead of our ability to use it, and much work remains in this area. Machine translation of languages and recognition of spoken information are two other areas which will require fast, large memories.

A Business Intelligence System *by H. P. Luhn, p. 314.* An automatic system is being developed to disseminate information to the various sections of any industrial, scientific or government organization. This intelligence system will utilize data-processing machines for auto-abstracting and auto-encoding of documents and for creating interest profiles for each of the "action points" in an organization. Both incoming and internally generated documents are automatically abstracted, characterized by a word pattern, and sent automatically to appropriate action points. This paper shows the flexibility of such a system in identifying known information, in finding who needs to know it and in disseminating it efficiently either in abstract form or as a complete document.

Chess-Playing Programs and the Problem of Complexity *by A. Newell, J. C. Shaw, and H. A. Simon, p. 320.* This paper traces the development of digital computer programs that play chess. The work of Shannon, Turing, the Los Alamos group, Bernstein, and the authors is treated in turn. The efforts to program chess provide an indication of current progress in understanding and constructing complex and intelligent mechanisms.

Intelligent Behavior in Problem-Solving Machines *by H. L. Gelernter and N. Rochester, p. 336.* As one step in the study of intelligent behavior in machines, the authors consider the particular case of a machine that can prove theorems in elementary Euclidean plane geometry. The device uses no advanced decision algorithm, but relies rather on rudimentary mathematics and "ingenuity" in the manner, for example, of a clever high-school student.

This paper discusses heuristic methods and learning machines and introduces the concept of a theory machine as an extension of a theorem-proving machine.

Computation in the Presence of Noise *by P. Elias, p. 346.* The behavior of a system consisting of a preliminary coder, an unreliable computer, and a decoder is investigated. Coding input blocks of k binary digits into output blocks of $n>2k$ binary digits, it is shown that a simple combinational computer which can take the *and* or *or* of k or more input blocks can only be made arbitrarily reliable by making n/k arbitrarily large, so that the capacity for computation, in an information theory coding sense, is zero. Incomplete results for a single *and* or *or* circuit give the same result if the output gives no information about the inputs except for the information about their *and* or *or*; if this is not demanded, then for $n>2k$, reliable computation through noisy computing circuits is possible, but the computing is done in the decoder.

Machine-Made Index for Technical Literature—An Experiment *by P. B. Baxendale, p. 354.* Machine techniques for reducing technical documents to their essential discriminating indices are investigated. Human scanning patterns in selecting "topic sentences" and phrases composed of nouns and modifiers were simulated by computer program. The amount of condensation resulting from each method and the relative uniformity in indices are examined. It is shown that the coordinated index provided by the phrase is the more meaningful and discriminating.

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Automatic Failure Recovery in a Digital Data Processing System *by R. H. Doyle, R. A. Meyer, and R. P. Pedowitz, p. 2.* This paper describes a program which will enable a complex digital data processing system to give "first aid" to itself. Ordinarily, when an error occurs during system operations, the computer must be stopped for corrective maintenance. The FIX program, however, automatically compensates for computer malfunctions so that recovery from errors may be effected with a negligible loss of operational time. Some equipment features used by the FIX program are briefly outlined prior to a detailed discussion of the structure and function of the program itself. In its initial application in the SAGE system, FIX provided automatic recovery from more than 90% of all failures occurring during the period studied.

Diffusion Attenuation, Part I *by J. A. Swanson, p. 13.* Perturbation methods are applied to the problem of calculating the attenuation of signals consisting of compensated space charges moving in an electric field of general, but prescribed, form. Asymptotic formulas for attenuation and phase shift are derived which apply when the diffusion currents giving rise to attenuation are small compared to the field-induced currents. Alternate expansions of the continuity equation, e.g., in terms of the frequency, are discussed in a mathematical appendix.

Diffusion Attenuation, Part II *by J. A. Swanson and K. Y. Sih, p. 18.* The amount of diffusion attenuation has been computed as a function of frequency for the case of uniform electric field. Application to drift transistors is discussed.

On the Mathematical Theory of Error-Correcting Codes *by H. S. Shapiro and D. L. Slotnick, p. 25.* Hamming considered the problem of efficient, faultless transmission of binary data over a noisy channel. For a channel which corrupts no more than one binary digit in each sequence of length n, he constructed alphabets, the so-called Hamming codes, which permit error-free signalling. The authors study the analogous problem for channels which can corrupt a greater number of digits. Non-binary channels are also studied, and analogues of the Hamming codes are constructed. It is perhaps of interest that some of the techniques employed derive from algebraic and analytic number theory, mathematical disciplines not generally associated with the type of applied problems considered in this paper.

The Thermal Equivalent Circuit of a Transistor *by P. R. Strickland, p. 35.* An exact electrical analogue is given for the thermal system between the collector junction and the constant-temperature environment of a transistor. For this circuit analogue, the voltage response to an applied current is equivalent to the temperature response of the collector junction to an applied-power dissipation. The objective of this paper is (1) to prove that this thermal equivalent circuit is entirely consistent with the rigorous, academic approach to the problem, which is to solve a boundary-value problem for heat flow in the transistor system; (2) to present an experimental method for obtaining the circuit parameters in the thermal equivalent circuit; and (3) to demonstrate the utility of the thermal equivalent circuit for the circuit designer and the transistor designer.

The Multipurpose Bias Device—Part II: The Efficiency of Logical Elements *by B. Dunham, D. Middleton, J. H. North, J. A. Sliter, and J. W. Weltzien, p. 46.* The efficiency of a logical element can be equated with the set of subfunctions it realizes upon biasing or duplication of inputs. Various classes of elements are considered, and optimum or near-optimum examples are presented. Some related areas of study are suggested.

An Analysis of Adequate Inventory Levels *by J. J. Sopka, p. 54.* An analytical procedure for determining adequate stock levels for an inventory system with random demand and replenishment functions is presented.

Two-Parameter Lifetime Distributions for Reliability Studies of Renewal Processes *by B. J. Flehinger and P. A. Lewis, p. 58.* Probability functions are defined for use in reliability studies of equipments which are maintained over a long period of time through replacement of components. These are: *lifetime distribution function, lifetime density function, probability of survival, hazard, expected number of replacements,* and *renewal rate.* Theoretical results of renewal theory are adapted to reliability studies of complex systems.

The "exponential law" is equivalent to the assumption that survival probability for any given time interval is independent of the age of a component at the beginning of the interval. It seems more realistic, however, to assume that this survival probability is a monotonically *decreasing* function of initial age, or, equivalently, that the hazard is a monotonically *increasing* function of the age of the component. Consequently, three two-parameter models of distribution functions, with the properties: (1) initial lifetime density greater than zero, and (2) monotonically increasing hazard, are proposed and discussed. The lifetime behavior associated with these models ranges from complete determinacy to complete randomness. An entropic measure of this randomness is introduced.

The expected number of replacements is numerically calculated and plotted as a function of time for several different parameter values in each model.

An Experimental Modulation-Demodulation Scheme for High-Speed Data Transmission *by E. Hopner, p. 74.* An experimental low-cost system was designed to determine speed and reliability limitations on transmitting binary data over private telephone lines. A brief review of alternative

approaches is given, with a description of the laboratory model. Performance of the equipment is reported with the reliabilities experienced at 600, 1000, 1600, and 2400 bits per second.

Application of Phase-Contrast Metallography in a Production Laboratory *by G. Koves, p. 85.*

Observations of Rotational Switching in Ferrites *by W. L. Shevel, Jr., p. 93.*

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Direct Measurement of the Angular Dependence of the Imaginary Part of the Atomic Scattering Factor of Germanium *by L. P. Hunter, p. 106.* In the dynamical theory of the anomalous transmission of x-rays through perfect thick crystals, the ratio of transmitted intensity to incident intensity depends upon $[1 - Kf'_{Ge}\ (\theta_{hkl})/f'_{Ge}\ (0°)]$ exponentially. Here K is the polarization factor and the $f'_{Ge}\ (\theta_{hkl})$ and $f'_{Ge}\ (0°)$ are the imaginary parts of the atomic scattering factors of germanium at the angle θ_{hkl} and 0°, respectively. This paper describes the measurement of the ratio $f'_{Ge}\ (\theta_{hkl})/f'_{Ge}\ (0°)$ for several different sets of planes in nearly perfect germanium crystals.

Finite Automata and Their Decision Problems *by M. O. Rabin and D. Scott, p. 114.* Finite automata are considered in this paper as instruments for classifying finite tapes. Each one-tape automaton defines a set of tapes, a two-tape automaton defines a set of pairs of tapes, et cetera. The structure of the defined sets is studied. Various generalizations of the notion of an automaton are introduced and their relation to the classical automata is determined. Some decision problems concerning automata are shown to be solvable by effective algorithms; others turn out to be unsolvable by algorithms.

Interatomic-Force Constants from a Central-Force Law *by H. Cole, p. 126.* Interatomic-force constants may be predicted from standard central-force laws using thermodynamic data. For the three cases where diffraction data are available (aluminum, copper, and iron) the predicted values agree within an order of magnitude for aluminum and iron, but differ strongly in the case of copper. It is suggested that Jacobsen's α_1, for copper, represents the strongest departure from a central-force model and should therefore be the most promising point for further theoretical work.

On the Transition from Superconducting to Normal Phase, Accounting for Latent Heat and Eddy Currents *by A. J. W. Duijvestijn, p. 132.* A rigorous solution is given for the superconducting transition of a semi-infinite slab held at a point below the critical temperature T_c when a constant magnetic field above the critical value H_∞ is applied. The solution accounts for both the absorption of latent heat and the dissipation of eddy-current heat during the transition. A numerical example is calculated for the case of constants close to those of tantalum.

Geometric Effects in the Superconducting Transition of Thin Films *by M. D. Reeber, p. 140.* A study is made of the effect of geometric factors and field orientation on the superconducting transition of bulk material whose dimensional ratios are comparable to those of thin evaporated films. An expression is derived for an effective demagnetizing coefficient in the direction of the applied field for an elliptic cylindrical superconductor, and it is shown that this deviates from 1 by quantities of the order of 10^{-2} or smaller for experimentally realizable conditions with typical films. These small coefficients give rise to surface fields sufficiently large for transition to the intermediate state. The shape of the transition for various field orientations has been obtained experimentally, and these curves are analyzed qualitatively on the basis of Landau's and Andrew's theory of the intermediate state. For temperatures below the transition point, and in the absence of fields other than the earth's magnetic field, the possibility that these films are in the intermediate state is explored.

Computation of Sin N, Cos N, and $\sqrt[n]{N}$ Using an Electronic Computer *by E. G. Kogbetliantz, p. 147.* Rational Padé approximations to Sin N in the interval $0 \le N \le 41\pi/256$ and to Cos N in $0 \le N \le 87\pi/256$ allow the computation of both functions in $0 \le N \le \pi/2$ with the first ten correct significant digits in four multiplications and divisions only. If the infinite range $0 \le N < \infty$ is considered, one more multiplication reduces it to the range $0 \le N \le \pi/2$ so that the total number of operations is five. The method is flexible and gives any desired accuracy. Thus if eighteen first correct significant digits are required, they are obtained in seven operations for any N in $(0, \infty)$.

The same method applied to $\sqrt{N}$ and $\sqrt[3]{N}$ yields a very accurate first guess which then is improved by Newton's method. For the radicals $\sqrt[m]{N}$ with $m > 4$, Newton's method is too slow, and rational Padé approximations studied in this paper yield better subroutines.

Microwave Resonance in Gadolinium-Iron Garnet Crystals *by W. V. Smith, J. Overmeyer, and B. A. Calhoun, p. 153.* Ferrimagnetic resonance has been observed in single crystals of gadolinium-iron garnet at 9479 and 23,725 mc. The resonance behavior is discussed in terms of a two-sublattice theory. The gadolinium g-factor is equal to 2.006 above $-90°C$ and increases at lower temperatures. The gadolinium ions contribute to the anisotropy below $-40°C$. The assignment of separate damping constants to each sublattice explains the sharp variation in over-all damping with temperature near the compensation point.

On Codes for Checking Logical Operations *by W. W. Peterson and M. O. Rabin, p. 163.* Two types of codes for checking logical operations digit by digit on two vectors of

binary digits are studied. The first type attaches a check symbol to each vector of binary digits and requires that the check symbol for the logical function of two vectors can be determined from the check symbols of the two input vectors. The second type of coding is ordinary block coding into vectors of binary digits, with the added requirement that the coded vectors be processed digit by digit.

The constraints on the codes resulting from the assumptions for the coding system are studied by typical algebraic arguments. It is shown that for both types of coding and for all nontrivial logical functions of two variables, except "exclusive or" and its complement, there is no system of checking simpler than duplication. For "exclusive or" and its complement, group alphabets can be used, and for the block coding these are the only codes which can be used.

Extension of Moore-Shannon Model for Relay Circuits *by M. Kochen, p. 169.* The Moore-Shannon model for switching circuits is extended to show how the number of redundant relays needed to improve reliability depends on the logical function of the entire circuit. The reliabilities of AND, OR, and EXCLUSIVE-OR relay circuits are studied as a function of the number of relays, the network topology, and the distribution of inputs. For the case of intermittent failures, a procedure is developed for calculating the reliability of combinational switching circuits, defined as the probability that the circuit will function as specified, averaged over all possible inputs, and subject to the idealizing assumptions of the Moore-Shannon model. The redundancies required to achieve a specified increase in reliability, although considerably smaller than for alternative methods, are still enormous. It is shown that a good way to improve an AND circuit, for example, is to use a series-parallel network in which the number of parallel lines varies with the logarithm of the number of basic AND circuits connected in series to form each line.

Numerical Solution of Laplace's Equation, Given Cauchy Conditions *by I. Sugai, p. 187.*

A Cryogenic Oscillator *by G. B. Rosenberger, p. 189.*

Noise Theory for Hot Electrons *by P. J. Price, p. 191.*

Doubling the Efficiency of the Load-Sharing Matrix Switch *by M. P. Marcus, p. 194.*

Elementary Divisors of Normal Matrices *by P. Erdös, p. 197.*

The Reduction of Two-Way Automata to One-Way Automata *by J. C. Shepherdson, p. 198.*

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Some Studies in Machine Learning Using the Game of Checkers *by A. L. Samuel, p. 210.* Two machine-learning procedures have been investigated in some detail using the game of checkers. Enough work has been done to verify the fact that a computer can be programmed so that it will learn to play a better game of checkers than can be played by the person who wrote the program. Furthermore, it can learn to do this in a remarkably short period of time (8 or 10 hours of machine-playing time) when given only the rules of the game, a sense of direction, and a redundant and incomplete list of parameters which are thought to have something to do with the game, but whose correct signs and relative weights are unknown and unspecified. The principles of machine learning verified by these experiments are, of course, applicable to many other situations.

Some Properties of Experimental 1000-Mc Transistors *by R. F. Rutz and D. F. Singer, p. 230.* Experimental transistors designed to operate above 1000 Mc are described and measurements of their electrical parameters discussed. The design is a diffused-base drift transistor structure with minimized bulk resistances and junction capacitances. Measurements of the short-circuit current gain ($-h_{21b}$) with both emitter and collector reverse-biased, indicated that the passive circuit comprising extrinsic parameters only could produce a gain greater than unity. Interpretation of measurements using a simplified equivalent circuit shows that reduction of bulk resistances leads to an appreciable passive or feed-through current. An oscillator is described in which the transistors operated up to 1550 Mc.

A Gas Film Lubrication Study—Part I: Some Theoretical Analyses of Slider Bearings *by W. A. Gross, p. 237.* The Reynolds differential equation describing flow in a compressible lubricating film is developed. Important characteristics of such films are determined directly from the Reynolds Equation. Pressure, load, velocity, and geometry characteristics are presented for many compressible slider bearing films based upon computer solutions of a Reynolds difference equation as derived in Part II. Part III cites experimental verification of computer solutions and describes experimental techniques.

A Gas Film Lubrication Study—Part II: Numerical Solution of the Reynolds Equation for Finite Slider Bearings *by W. A. Michael, p. 256.* This paper presents a finite-difference technique for obtaining approximate numerical solutions to the Reynolds partial differential equation of gas film lubrication theory. A digital computer program is described, and discretization errors and stability of the difference equations are discussed.

A Gas Film Lubrication Study—Part III: Experimental Investigation of Pivoted Slider Bearings *by R. K. Brunner, J. M. Harker, K. E. Haughton, and A. G. Osterlund, p. 260.* The results of experimental measurements on pivoted slider bearings are presented, the experimental methods are described, and the experimental data are compared with data obtained from a numerical solution of the Reynolds differential equation for a compressible fluid.

Experiments on the Relation of the Operator to the Control Loop of an Airborne Digital Computer *by C. A. Bennett, p. 275.* Some laboratory experiments were performed over a period of three years to provide design information for digital computer systems for error correction in aircraft navigation. In a simulated digital control loop, the operator observed crosshair error and fed control signals to the computer. The studies showed relationships between recovery time and solution rate, transmission delays, hand-control sensitivity, sampling rate, and scanning rate.

A Learning Machine: Part II *by R. M. Friedberg, B. Dunham, and J. H. North, p. 282.* An effort is made to improve the performance of the learning machine described in Part I, and the over-all effect of various changes is considered. Comparative runs by machines without the scoring mechanism indicate that the grading of individual instructions can aid in the learning process. A related study is made in which automatic debugging of programs is taken as a special case of machine search. The ability to partition problems and to deal with parts in order of difficulty proves helpful.

Indexing and Control-Word Techniques *by G. A. Blaauw, p. 288.* In large-scale computers the details of data handling, such as indexing, transmission and ordering, may be performed either by programming or by built-in machine operations. An analysis of the most frequently performed functions justifies the expansion of single-valued index quantities to three-valued control words and the specification of built-in increment, count and refill operations to be used with these control words. STRETCH, the large-scale computer which is being developed by IBM for the Los Alamos Scientific Laboratory, provides these control-word functions for data-handling operations.

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Some New Aspects of Color Perception *by M. M. Woolfson, p. 312.* A mathematical analysis is made of Land's recent experiments which showed that fully colored pictures can be produced by a two-color projection system. Although Land's results apparently had been at variance with the classical theories of color perception, it has now been found possible to explain the experiments within the framework of those theories and in conjunction with well-known phenomena in the field of experimental psychology. The results are interpreted in terms of a mechanism of color transformation.

Algebraic Topological Methods for the Synthesis of Switching Systems, Part III: Minimization of Nonsingular Boolean Trees *by J. P. Roth and E. G. Wagner, p. 326.* An algorithm is given for solving a general problem in combinational switching-circuit minimization theory. The circuits considered consist of a disjunction (OR-ing together) of trees of any set of logical elements, with the restriction that in any given tree no input appears more than once. To each logical element is attached a positive cost. A method is presented for designing a minimum-cost circuit of this variety for any given logical function. Two parallel treatments are given, one viewing it as an abstract mathematical problem, the other considering it as an engineering problem.

Theory of a Fast-Switching Electron-Beam Frequency Divider *by N. M. Kroll and I. Palócz, p. 345.* A velocity-modulated electron-beam microwave tube is described which can be operated as a frequency divider. Its operation is analyzed in terms of velocity-modulation bunching theory, neglecting space-charge forces. Because of the existence of two stable states opposite in phase, such a divider can be advantageously employed in a microwave logical system. The transient behavior of the device is discussed, particularly with reference to the time required to switch the device from one of its stable states to the other. Factors involved in the minimization of this time interval are analyzed.

On the Reduction of Continuous Problems to Discrete Form *by J. Greenstadt, p. 355.* A continuous problem, defined as one involving derivatives or integrals, is to be reduced to a discrete problem, involving only algebraic or evaluative operations. An approach involving cells instead of points is taken, and the unknown function is approximated by functional representations, each associated with one cell and an associated set of parameters. Suitable operations are then defined, each associated with a particular cell. These operations remove the configuration coordinates from the problem, leaving only the parameters. Similar operations are defined which link the approximations in adjacent cells, and which translate certain interface conditions to relations between parameters associated with cells. The entire set of relations is then the equivalent of the usual difference equations.

A variational algorithm is introduced in order to circumvent certain difficulties associated with matching equations and unknowns. This also permits the convenient retention of certain "exact conditions" associated with the continuous problem. Some illustrative examples are given.

Esaki Tunneling *by P. J. Price and J. M. Radcliffe, p. 364.* Tunneling, between propagating electron states, at a semiconductor junction is discussed in terms of customary quantum transition theory for the matrix elements of the hamiltonian between the states representing reflection of an

electron (in either band) from the junction. The coordinate representation for the wavefunctions of these states is investigated, and tunneling probabilities (ratios of transmitted to incident current) are found for the "elastic" process proposed by Esaki and for the "phonon-assisted" processes. It appears that the tunneling may be described as taking place in a central region of the junction thinner than the space charge region. Current-voltage characteristics are calculated both for elastic and for phonon-assisted tunneling.

A 3000-Mc Lumped-Parameter Oscillator Using an Esaki Negative-Resistance Diode *by R. F. Rutz, p. 372.*

Millimicrosecond Magnetization Reversal in Thin Magnetic Films *by W. Dietrich and W. E. Proebster, p. 375.*

Germanium PNPN Thyratron *by M. Klein and A. P. Kordalewski, p. 377.*

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Toward Mechanical Mathematics *by H. Wang, p. 2.* Results are reported here of a rather successful attempt of proving all theorems, totalling near 400, of *Principia Mathematica* which are strictly in the realm of logic, viz., the restricted predicate calculus with equality. A number of other problems of the same type are discussed. It is suggested that the time is ripe for a new branch of applied logic which may be called "inferential" analysis, which treats proofs as numerical analysis does calculations. This discipline seems capable, in the not too remote future, of leading to machine proofs of difficult new theorems. An easier preparatory task is to use machines to formalize proofs of known theorems. This line of work may also lead to mechanical checks of new mathematical results comparable to the debugging of a program.

A Thermodynamic Treatment of Dilute Superconducting Alloys *by R. E. Jones, Jr., p. 23.* The effect of adding small concentrations of an impurity to a superconducting metal is analyzed by thermodynamic methods. Two possible types of variation of the Gibbs free energy with composition are then discussed, utilizing a number of simplifying assumptions. For the case in which alloys have a superconducting second-order transition, there is a long-range interaction among solute atoms, even in limits of high dilution.

A Proof Method for Quantification Theory: Its Justification and Realization *by P. C. Gilmore, p. 28.* A program is described which can provide a computer with quick logical facility for syllogisms and moderately more complicated sentences. The program realizes a method for proving that a sentence of quantification theory is logically true. The program, furthermore, provides a decision procedure over a subclass of the sentences of quantification theory. The subclass of sentences for which the program provides a decision procedure includes all syllogisms. Full justification of the method is given.

A program for the IBM 704 Data Processing Machine is outlined which realizes the method. Production runs of the program indicate that for a class of moderately complicated sentences the program can produce proofs in intervals ranging up to two minutes.

The Wave Equation in a Medium in Motion *by W. L. Miranker, p. 36.* A model for the transverse vibrations of a tape moving between a pair of pulleys is devised using a variational procedure. It is shown by means of energy-type integrals that the energy of that portion of the tape between the pulleys is not conserved, but that there is a periodic transfer of energy into and out of the system. The solution for the wave equation is then constructed by a method which makes use of functional equations. The solution is observed to be periodic in time, and a modal decomposition of it is derived. A solution is also derived for the case of forced vibrations at the pulleys, and a class of forcing vibrations which cause unbounded solutions as time increases is isolated. In an appendix, a boundary layer effect is considered which occurs when the velocity of the tape through the pulleys approaches the sound speed of the tape.

Design Methods for Maximum Minimum-Distance Error-Correcting Codes *by J. E. MacDonald, p. 43.* In error-correcting codes for combating noisy transmission channels, a central concept is the notion of minimum distance. If a code can be constructed with minimum distance between code points of $2m+1$, then any number of errors per code word which does not exceed m can be corrected, thus increasing the reliability of transmission above that to be expected with no redundancy in the code.

An upper bound on minimum distance is derived which depends on g (the number of code points or messages required) and n (the number of binary symbols per code point). This bound is complementary to a bound due to Hamming and uses an argument which is essentially due to Plotkin.

Construction methods are presented for codes which actually achieve the upper bound on minimum distance for any g and an infinite class of integers n which depend on g. Sixteen code types are described: three for $g = 2h-1$, six for $g = 2h$, and seven for $g = 2^k$.

A New Group of Codes for Correction of Dependent Errors in Data Transmission *by C. M. Melas, p. 58.* Multiple related errors of any configuration can be automatically corrected by a class of codes having the property of using two groups of parity bits, one defining the error pattern, the other determining the location of the errors within the block.

In particular, error bursts can be corrected with a minimum amount of redundancy. Because each parity-bit group is derived by using maximum-length shift-register sequences, rather than by storing a decoding table, the implementation of these codes is relatively simple, as shown in an example of a three-bit-wide burst-correcting code. An example is given of an application of these codes in a data transmission system where only an even number of bits is likely to be corrupted by a noise burst.

Information Theoretical Analysis of Multivariate Correlation *by S. Watanabe, p. 66.* A set λ of stochastic variables, $y_1, y_2, \ldots, y_n$, is grouped into subsets, $\mu_1, \mu_2, \ldots, \mu_k$. The correlation existing in λ with respect to the μ's is adequately expressed by

$$C = \sum_{i=1}^{k} S(\mu_i) - S(\lambda) \geq 0,$$

where $S(\nu)$ is the entropy function defined with reference to the variables y in subset ν. For a given λ, C becomes maximum when each μ_i consists of only one variable, $(n = k)$. The value C is then called *the total correlation in* λ, $C_{tot}(\lambda)$. The present paper gives various theorems, according to which $C_{tot}(\lambda)$ can be decomposed in terms of the partial correlations existing in subsets of λ, and of quantities derivable therefrom. The information-theoretical meaning of each decomposition is carefully explained. As illustrations, two problems are discussed at the end of the paper: (1) redundancy in geometrical figures in pattern recognition, and (2) randomization effect of shuffling cards marked "zero" or "one."

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Foreword *by E. W. Pugh, p. 94.*

Domain Walls in Thin Ni-Fe Films *by S. Methfessel, S. Middelhoek, and H. Thomas, p. 96.* Observations of domain walls in Ni-Fe films as a function of thickness demonstrate the strong influence of magnetic stray fields on the wall structure, hence on the coercivity for wall motion. In order to reduce the stray-field energy, the Bloch walls in films thicker than 1000 Å are subdivided into sections with alternating polarity which are separated by Bloch lines. In thinner films, the domain walls are of the Néel type. The position of Bloch lines in such walls is indicated by crosswalls. The motion of Bloch lines in an applied field can be observed particularly easily on scratches in negative magnetostrictive material; such scratches display properties corresponding to Néel walls. Crosswalls are also present at the ends of domains and around holes in the film material. A crosswall is distinguished from ordinary domain walls by the continuous change of the angle of magnetization along both sides of it.

Measurement of Magnetic-Field Attenuation by Thin Superconducting Films *by E. Erlbach, R. L. Garwin, and M. P. Sarachik, p. 107.* The dependence of the field attenuation on temperature and superimposed dc magnetic field is measured with a sensitive rf bridge. It is shown theoretically that the penetration depth λ can be derived from the attenuation measurements, and the experiment therefore yields λ as a function of temperature and dc magnetic field. Changes in λ can be detected to an accuracy of $\pm 0.03\%$. Preliminary data on the temperature dependence of λ for lead are compared with the predictions of the Bardeen-Cooper-Schrieffer theory and are shown to be consistent with an energy gap between 4.9 kT_c and 5.4 kT_c at 0K. Detailed descriptions are given of the apparatus and of the preparation of the samples.

Magnetic Anisotropy in Single-Crystal Thin Films *by E. L. Boyd, p. 116.* Thin, single-crystal films of Ni, Fe, Ni-Fe and Ni-Co have been grown by vacuum deposition onto heated rock salt. The cubic crystalline anisotropy constant, K_1, of these films has been measured at room temperature by a torque method. In the case of the Ni-Fe alloys, K_1 was found to be the same for thin films as for bulk materials of the same composition. The measured anisotropy in the Ni-Co films differs quantitatively but has the same qualitative variation with composition as is reported for bulk crystals. The results of one magnetic annealing experiment on a 75% Ni - 25% Fe film lends support to the short-range ordering model of uniaxial anisotropy in alloys. Pure nickel films exhibit a pronounced uniaxial anisotropy superimposed on the crystalline anisotropy. This uniaxial term disappears after the film is removed from the substrate, indicating that its origin is in an anisotropic stress in the deposited film.

Analysis of the Residual Gases in Several Types of High-Vacuum Evaporators *by H. L. Caswell, p. 130.* A mass spectrometer study is made of the residual gases in several types of vacuum evaporators ranging from oil-diffusion-pumped, conventional systems to an oil-free, ultra-high-vacuum chamber. Partial pressures of water vapor, hydrogen, carbon monoxide, carbon dioxide, nitrogen, oxygen, argon and hydrocarbon vapors varied appreciably in the evaporators studied.

The performance of a conventional system was improved by using special low-vapor-pressure gasket materials to minimize hydrocarbon contamination, a liquid-nitrogen trap to reduce water vapor, titanium gettering for oxygen and nickel-iron gettering for hydrogen. For thin-film deposition, the importance of thoroughly outgassing the source materials is pointed out.

Electrical Properties of Thin-Film Semiconductors *by F. S. Ham and D. C. Mattis, p. 143.* The theory of the electrical properties of metal films as given by Fuchs and Sondheimer is extended to nondegenerate semiconductors with ellipsoidal energy surfaces. A change of variables reduces the problem to a simpler one with spherical energy surfaces but with electric and magnetic fields which are tilted with respect to the film. This is solved to first order in the applied fields. The effective mobility and Hall coefficient vary with film thickness much as for a metal but show an anisotropy with film orientation, even for cubic crystals. Anisotropy is observed for both diffuse and specular surface scattering and for surface channels as well as films, and it provides a means of measuring the effective mass ratio of the carriers.

Anisotropic Conduction in Solids Near Surfaces *by P. J. Price, p. 152.* A reduction in the electrical conductivity of a solid results from "diffuse" reflection of electrons from the surfaces. The effect occurs for specular reflection also, if the operative electron-energy surfaces are not spherical. A theory of the latter case is given here. The average conductivity of a thin crystal tends to a finite limit (rather than zero) as the thickness tends to zero. The Hall effect for the same circumstances is also treated.

Size Effects for Conduction in Thin Bismuth Crystals *by A. N. Friedman and S. H. Koenig, p. 158.* The size dependence of the electrical conductivity, and preliminary results for galvanomagnetic effects, in thin, single crystals of high-purity bismuth at 4.2K are reported for a range of thicknesses comparable to the electron mean free path. The results, when interpreted according to the theory of Ham and Mattis and of Price (in the accompanying papers), show that the scattering of electrons by the surface is specular, and confirm the novel predictions of the theory for the case of specular reflection and anisotropic surfaces of constant energy.

Angle-of-Incidence Anisotropy in Evaporated Nickel-Iron Films *by E. W. Pugh, E. L. Boyd, and J. F. Freedman, p. 163.* The magnetic anisotropies of iron, nickel, and permalloy films, evaporated onto glass substrates at various incident angles and substrate temperatures, have been measured by a torque method. For all compositions, the largest absolute value for the magnetic anisotropy occurs at the largest incident angle and lowest substrate temperature. A detailed calculation of the anisotropy resulting from a [111] fiber axis is found to fail to agree with the experimental results either in order of magnitude or in direction of the easy axis. The change in the magnetic anisotropies of films after removal from substrates is small enough that macroscopic stress cannot be the source of the anisotropy. A difference in electrical resistance parallel and perpendicular to a direction defined by the vapor stream during deposition is found to vary qualitatively very much like the magnetic anisotropy, both with film composition and incident angle. It is concluded that deposition at an angle of incidence produces an anisotropy in structural imperfections, which are interpreted in terms of shape and surface magnetic anisotropies as well as magnetostrictive effects.

Superconducting Tin Films of Low Residual Resistivity *by G. J. Kahan, R. B. DeLano, Jr., A. E. Brennemann, and R. T. C. Tsui, p. 173.* Evaporated tin films of low residual resistivity have been produced by using very high deposition rates in a conventional vacuum system. The substrates were cooled with liquid nitrogen. After the film edges are removed by mechanical trimming or chemical etching, these films show sharp magnetic and temperature transitions from the superconducting to the normal state, a critical field - temperature characteristic which is close to a modified version of the London theory, a transition temperature very close to the value of bulk tin, and a reversible resistance - critical current characteristic. These characteristics are compared with those of films deposited on substrates at room temperature using low deposition rates. Evidence is presented to indicate that the edge effect in the temperature transition of films is caused by a concentration of impurities in the edges. The low-temperature mean free path, rather than the resistivity ratio, is suggested as a figure of merit for estimating film purity because the size effect limits the resistivity ratio for thin films.

On the Influence of Aggregation on the Magnetic Phase Transition of Evaporated Superconducting Thin Films *by M. E. Behrndt, R. H. Blumberg, and G. R. Giedd, p. 184.* An investigation was made of the magnetic phase transition of thin, superconducting Sn films. In evaporated films, because of the sloping edges, broad magnetic field transitions are generally found. This paper shows that such "penumbra" effects can be eliminated by raising the temperature of the substrate during evaporation. The lack of penumbra effect was due to the aggregation of the film. The transition curves of such films displayed hysteresis.

Nanosecond Switching in Thin Magnetic Films *by W. Dietrich, W. E. Proebster, and P. Wolf, p. 189.* A special pulse equipment including a pulse-sampling oscilloscope with an over-all response time of 0.35 nanosecond (10^{-9} sec) for the observation of the nanosecond flux change in thin permalloy films is described. Film switching signals as short as 1 nanosecond have been obtained and are discussed with respect to the underlying processes. Inverse switching time versus driving-field curves have been plotted for films of different thicknesses. They show that thinner films switch faster than thicker ones. The slopes of these curves have characteristic values in the nanosecond region of about 10^{8} per oersted-second. Coherent rotation and oscillation of the magnetization have been clearly detected by picking up the flux change transverse to the driving field.

The Variation of Cryotron Current Amplification Factor with Temperature *by A. E. Brennemann, p. 197.*

The Influence of Edge Effects on Domain Structure and Coercive Force of Circular Nickel-Iron Films *by M. Beckerman and K. H. Behrndt, p. 198.*

A New Electron Mirror Design *by J. D. Kuehler, p. 202.*

Measurement of Crystallite Size and Strain of Electroplated Films *by R. S. Smith, p. 205.*

Information-Theoretical Aspects of Inductive and Deductive Inference *by S. Watanabe, p. 208.* By a straightforward application of Bayes' theorem of probability, the behavior is discussed of the credibilities (inductive probabilities) of competing hypotheses as functions of an increasing body of relevant empirical data. It is shown how the effect of a priori credibilities persists in the evaluation of credibilities in general, except in the important limiting cases investigated. An "inverse H-theorem" is mathematically demonstrated, according to which the entropy function defined in terms of the credibilities shows a net decrease in time. This decrease is not necessarily monotonous in an individual case, but is monotonous in the "expected" behavior of the inductive entropy function. Three machine-simulation experiments of inductive inference on the IBM 704 are described. The first two concern the classical problem of guessing the ratio of white and black balls in an urn. The third experiment

concerns guessing a hidden pattern obeyed by a sequence of binary numbers.

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Foreword: Vapor Growth *by G. R. Gunther-Mohr, p. 247.*

Epitaxial Vapor Growth of Ge Single Crystals in a Closed-Cycle Process *by J. C. Marinace, p. 248.* The Ge-I_2 disproportionation reaction in a sealed tube will deposit Ge epitaxially upon Ge seeds at a typical rate of 10μ/hr at a typical temperature of 400°C. Dislocations are of the same kind and approximate concentrations as observed in ordinary melt-grown Ge. Chemical purity is comparable to the best melt-grown Ge. The fraction of donors transferred from the source material to the deposited material is nearly unity over a wide range of concentrations, while the fraction of acceptors transferred is considerably less than unity. However, either *n*-type or *p*-type Ge can be deposited, and by using two sources within the same tube alternating layers can be obtained.

Electrical Properties of Vapor-Grown Ge Junctions *by M. J. O'Rourke, J. C. Marinace, R. L. Anderson, and W. H. White, p. 256.* A method of fabricating *p-n* junctions and *p-n* junction devices by a closed-cycle iodide vapor-growth process is described. The electrical characteristics of junctions made by alternately depositing *p*-type and *n*-type germanium onto a germanium substrate compare favorably with those fabricated by other means. Device arrays, such as diode matrices, and multijunction structures have been made by this process. If sufficient control can be achieved, devices having a wide range of impurity distributions and geometric configurations will be possible.

A Vapor-Grown Variable Capacitance Diode *by R. L. Anderson and M. J. O'Rourke, p. 264.* Germanium *p-n* junctions have been made which have a large fractional variation of capacitance with voltage and which have promise of being operable at high frequencies. These diodes are produced by a vapor-growth process in which the doping is switched from *n*-type to *p*-type during growth. Capacitances which vary as the reciprocal of voltage over a considerable range have been observed.

This capacitance variation corresponds to a net donor concentration which decreases from its value at the junction approximately as the reciprocal of distance from the junction. At a position corresponding roughly to the edge of the transition region at breakdown, the net donor concentration abruptly increases. This rapid variation of capacitance with voltage and the low series resistance resulting from the discontinuity in doping level should result in high-frequency diodes, if the magnitude of the discontinuity can be increased sufficiently.

Radiotracer Studies of the Incorporation of Iodine into Vapor-Grown Ge *by W. E. Baker and D. M. J. Compton, p. 269.* Measurements of the incorporation of iodine into single crystals of Ge grown by the disproportionation of GeI_2 have been made using I^{131} as a radioactive tracer. The results show that I is not likely to be a hindrance to device use of this material since the amount incorporated is moderately low ($10^{14} - 10^{15}$ atoms/cm^3), and does not appear to be correlated with electrical effects. It does not diffuse appreciably ($D_{875°} < 10^{-13}$ cm^2/sec). No excess is found at an all-deposited *p-n* junction. The concentration of I incorporated appears to decrease with increasing temperature, to be independent of growth rate on a (111) orientation of the seed, but to vary by a factor of up to 50 from one orientation to another. It is deduced that the I is incorporated by a mechanism intimately connected with the crystal growth.

Incorporation of As into Vapor-Grown Ge *by W. E. Baker and D. M. J. Compton, p. 275.* The incorporation of arsenic into single-crystal germanium grown by the disproportionation of GeI_2 was studied using As^{76} as a radioactive tracer, and using measurements of the Hall effect. The deposition was carried out in a sealed tube using as source material a single crystal of Ge doped to 2.5×10^{19} atoms/cm^3 with As. It was found that all the As incorporated into the vapor-grown Ge was electrically active, at least for material grown on a (211) Ge seed. The concentration of As in the deposited Ge was lower than that in the source, and appeared to depend on the crystallographic orientation of the growing face.

Tunnel Diodes by Vapor Growth of Ge on Ge and on GaAs *by J. C. Marinace, p. 280.*

Germanium - Gallium Arsenide Heterojunctions *by R. L. Anderson, p. 283.*

Epitaxial Growth of Silicon *by E. S. Wajda, B. W. Kippenhan, and W. H. White, p. 288.*

Incorporation of Au into Vapor-Grown Ge *by W. E. Baker and D. M. J. Compton, p. 296.*

Impurity Introduction during Epitaxial Growth of Silicon *by R. Glang and B. W. Kippenhan, p. 299.*

Dislocation Content in Epitaxially Vapor-Grown Ge Crystals *by H. S. Ingham, Jr. and P. J. McDade, p. 302.*

Physical versus Logical Coupling in Memory Systems *by J. A. Swanson, p. 305.* A memory system consisting of bistable static dissipationless units such as ferrites, ferroelectrics, or cryotrons is considered. For a given amount of physical material the memory capacity may be increased by using small volumes of the bistable material for each bit. If made sufficiently small, however, the individual bits will become unreliable because of the influence of thermal agitation and quantum-mechanical tunneling processes. Some

unreliability can be tolerated, since it can be compensated by redundancy. The optimum size of the individual bit, for maximum information storage, is evaluated. If thermal agitation is the prime source of errors, then the optimum-sized bit involves typically less than 100 of the independent cooperating units (electron spins, dipoles, et cetera) which cause the bistability. The maximization process concerns itself only with the preservation of information and not with possible methods of access to the individual bit. In particular, the maximization process neglects complications in the coding equipment needed to read in and out of memory.

Synthesis of a Communication Net *by R. T. Chien, p. 311.* A systematic method is given for the realization of communication nets from their terminal capacity matrices. It is shown that this procedure results in a net whose total branch capacity is minimum for all nets satisfying the same terminal capacity matrix. It is also shown that when the terminal capacity matrix is indeterminate, then, for a given total branch capacity, the total terminal capacity is highest when all terminal capacities are made equal.

Synthesis of Switching Functions by Linear Graph Theory *by W. Mayeda, p. 321.* Techniques of linear graph theory are applied to the study of switching networks. The first part treats the relationships among paths and circuits in a graph which will give a simple method of analyzing switching networks. The necessary conditions are given for the realizability of switching networks consisting of the specified elements. The second part is the synthesis which is accomplished by the use of the decomposition of cut-set matrices.

Error Correcting Codes for Correcting Bursts of Errors *by J. E. Meggitt, p. 329.* It is observed that the codes of Abramson, Melas and others are essentially described by the characteristic equation that a certain matrix satisfies. Consequently it is found that transformations of these codes are possible provided that the characteristic equation is preserved. These transformations may then be exploited to produce codes that have a simple implementation and, in fact, a general method is indicated by which any code may be implemented when the characteristic equation is known.

A Character-Recognition Study *by W. E. Dickinson, p. 335.* A study of the single-gap-scan approach to character recognition, using an IBM 650 for simulation, is reported. Ten specially designed digits were used in this study. Character recognition is discussed in terms of some simple concepts from n-dimensional geometry. The main contribution is an effective method for using a computer to aid in the design of the type font. This procedure is a natural development of the vector approach. Experimental results show the sensitivity of the system to phasing. An expression is given for a "quality factor." The relationship of this factor to errors and to ink density is illustrated.

On Dimensional Analysis *by R. E. Thun, p. 349.* The dimensions of physical quantities q are interpreted as vectors

$$q_i(\gamma_{i1}, \gamma_{i2}, \ldots, \gamma_{in}) \equiv \gamma_{i1}b_1 + \gamma_{i2}b_2 + \ldots + \gamma_{in}b_n ,$$

where the basic elements b_j generating the vector space represent the basic quantities of the dimensional system and the coefficients γ_j are defined by

$$q_i = \prod_{j=1}^{n} b_j^{\gamma_{ij}} .$$

This interpretation permits the application of the theorems on vector spaces to dimensional analysis. Some results of this approach are simplified rules for the transformation of dimension and unit systems and a physically more transparent derivation of a complete set of dimensionless products by a transformation of bases. The new notation yields a sequential order of physical equations which may lead to a dimensional analysis based on appropriately selected equation groups.

Note on Perturbation of a Uniform Magnetic Field by a Cube of Magnetic Material *by F. Partovi, p. 357.*

Space-Charge-Limited Currents in Resin Films *by R. E. McCurry and R. M. Schaffert, p. 359.*

A Cyclic Code for Double Error Correction *by C. M. Melas, p. 364.*

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Fourier Analysis of the Motion of a Hydraulically Controlled Piston *by H. J. Greenberg, p. 378.* The problem is considered of the motion of a free piston in a finite pipe filled with a compressible liquid and subject to a step in pressure introduced from the two ends. The treatment is in one dimension using the linearized wave equation for the density disturbance and the linearized boundary conditions. A generalized Fourier series expansion leads to the solution of the problem. The mathematical analysis is complicated first by the presence of the interior boundary conditions which lead to a system of discontinuous eigenfunctions, and second, by the step pressure input which results in reflected discontinuities. By studying the properties of the eigenfunctions from a variational characterization, the formal expansions used are established rigorously. The motion of the piston is determined as a function of the input parameters, and the maximum piston excursion and the associated time are tabulated numerically over the ranges of interest of these parameters.

Shock Waves in Nonlinear Transmission Lines and Their Effect on Parametric Amplification *by R. Landauer, p. 391.* The propagation of a periodic signal on a transmission line

with a nonlinearity in the distributed capacitance is examined. The signal is deformed during its propagation and electromagnetic shock waves are generated. It is pointed out that the shock wave will form in a distance which is short for any parametric amplification purposes. The subsequent growth of the shock and its decay, due to the inevitable dissipation associated with a shock, are analyzed assuming that the capacitance variations are small compared to the total capacitance. The propagation of a small deviation from a signal which is perfectly periodic in time is also examined, and it is shown that the small deviation may spread out in time but cannot be changed in its sign. This result was invoked in an earlier paper demonstrating the impossibility of parametric amplification on dispersionless nonlinear lines.

On the Switching Time of Subharmonic Oscillators *by A. H. Nethercot, Jr., p. 402.* The time necessary to change the phase of an idealized subharmonic parametric oscillator from one value to a value differing by 180° is calculated for various values of pump power and switching power. Several conclusions are drawn from the results.

A Duality Theorem for Convex Programs *by W. S. Dorn, p. 407.* A proof is given for a duality theorem for a class of convex programs, i.e., constrained minimization of convex functions. A simple example is included.

A Class of Optimal Noiseless Load-Sharing Matrix Switches *by R. T. Chien, p. 414.*

New Developments in Load-Sharing Matrix Switches *by G. Constantine, Jr., p. 418.*

High-Speed Counter Requiring No Carry Propagation *by W. N. Carroll, p. 423.*

Increasing the Brightness-Voltage Nonlinearity of Electroluminescent Devices *by J. A. O'Connell and B. Narken, p. 426.*

Determining Component Variation for Gradual Transition between Dissimilar Impedances *by C. Becker, C. M. Bruen, and R. B. Turner, p. 430.*

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Foreword: Combinatorial Problems *by A. W. Tucker, p. 454.*

Traces, Term Ranks, Widths and Heights *by D. R. Fulkerson and H. J. Ryser, p. 455.* The notions of widths and heights of (0, 1)-matrices are discussed in the general setting of known results concerning traces and term ranks. Proofs are omitted throughout.

Automorphisms of Steiner Triple Systems *by M. Hall, Jr., p. 460.* This paper treats the following problem in combinatorial analysis: Find an incomplete balanced block design D with parameters b, v, r, k, and $\lambda = 1$, possessing an automorphism group G which is doubly transitive on the elements of D and such that the subgroup H of G fixing all the elements of a block is transitive on the remaining elements. Also find transitive extensions of such groups G. If the block design is a finite projective plane, the plane is necessarily Desarguesian. Thus, these properties of the automorphism group may be considered as a "Desarguesian" property of the designs.

This paper considers the case in which D is a Steiner triple system. The main result is that a "Desarguesian" Steiner triple system is either 1) a projective geometry over $GF(2)$ or 2) an affine geometry over $GF(3)$. Two intermediate results are of interest: 1) A Steiner triple system has for each element an involution fixing only this element, if and only if every triangle generates an $S(9)$, a Steiner triple system with 9 elements; 2) if a Steiner triple system has for each triple an involution fixing only the elements of this triple, then every triangle generates an $S(7)$ or an $S(9)$.

The Enumeration of Trees by Height and Diameter *by J. Riordan, p. 473.* The enumeration of trees which was begun by Harary and Prins, is simplified and elaborated in the interest of obtaining reliable numerical results. Height is a characteristic of a rooted tree, the length in lines of the longest path from the root, while the *diameter* of a (free) tree is the length of the longest path joining two endpoints. The most general enumerations given are for the case where a fixed number of the points of the trees are labeled with distinct labels, which puts in one setting the classical contrast of all points alike and all points unlike. The numerical tables given extend to trees with 20 points, all alike, and to trees with 10 points, all unlike.

Maximal Paths on Rectangular Boards *by R. E. Miller and J. L. Selfridge, p. 479.* A combinatorial approach is made to the problem of obtaining a path on a rectangular board of m by n squares with both terminals at the edges of the board. A square is said to be *covered* when the path enters one edge and leaves an adjacent edge. All other squares are said to be *missed.* Maximal paths are found, i.e., those which cover a maximum number of squares. For $m = n$, $m-2$ squares are missed when m is even, and $m-1$ squares are missed when m is odd. For $m < n$, $m-2$ squares are missed if m is even, and $n-2$ squares are missed if m is odd. The method of proof for m and n even is quite different from that for m or n odd. Certain properties of terminal positions, path length, types of missed squares, and unique paths are also investigated. The dependence of the results on the parity of m and n is again very striking.

On the Exceptional Case in a Characterization of the Arcs of a Complete Graph *by A. J. Hoffman, p. 487.* It is known that a certain simple set of properties characterize the relationship of adjacency of the $n(n-1)/2$ arcs of the complete

graph of order n, when $n \neq 8$, and that these properties are not a sufficient characterization when $n = 8$ (see [1], [2], [3], [4], and [7]). The present paper describes a method for enumerating all counter-examples when $n = 8$.

On Moore Graphs with Diameters 2 and 3 *by A. J. Hoffman and R. R. Singleton, p. 497.* This note treats the existence of connected, undirected graphs homogeneous of degree d and of diameter k, having a number of nodes which is maximal according to a certain definition. For $k = 2$ unique graphs exist for $d = 2, 3, 7$ and possibly for $d = 57$ (which is undecided), but for no other degree. For $k = 3$ a graph exists only for $d = 2$. The proof exploits the characteristic roots and vectors of the adjacency matrix (and its principal submatrices) of the graph.

Inductive Proof of the Simplex Method *by G. B. Dantzig, p. 505.* Instead of the customary proof of the existence of an optimal basis in the simplex method based on perturbation of the constant terms, this paper gives a new proof based on induction. From a pedagogical point of view it permits an earlier and more elementary proof of the fundamental duality theorem via the simplex method. Specifically we shall show that there exists a finite chain of feasible basis changes, which results in either an optimal feasible solution or in an infinite class of feasible solutions, such that the objective form tends to minus infinity.

Solving a Matrix Game by Linear Programming *by A. W. Tucker, p. 507.* This paper presents (1) a new characterization, via linear programming, of extreme optimal strategies of a matrix game and (2) a simple direct procedure for computing them. The first pertains to the neat formulas of L. S. Shapley and R. N. Snow for a "basic solution", and the second to the highly effective "simplex method" of G. B. Dantzig. Both are related to the author's "combinational equivalence" of matrices, the first through an optimal block-pivot transformation and the second through a suitably chosen succession of elementary pivot steps.

Some Combinatorial Lemmas in Topology *by H. W. Kuhn, p. 518.* For many years it has been known that a combinatorial result, called the Sperner Lemma, provides an elegant proof of the Brouwer Fixed Point Theorem. Although the proof is elementary, its complete formal exposition depends upon the somewhat complicated operation of subdividing a simplex. Also, the proof does not show whether the Sperner Lemma can be derived from the Brouwer Fixed Point Theorem.

This central result of this paper is a combinatorial proposition, analogous to the Sperner Lemma, and applying to the n-cube, for which subdivision is a trivial operation. This Cubical Sperner Lemma follows immediately from the Brouwer Fixed Point Theorem and thus opens the possibility of other applications of topology to combinatorial problems. The question of such a topological proof is raised for another cubical analogue of the Sperner Lemma, due to Ky Fan, and for the Tucker Lemma, which is related to the antipodal point theorems. The Cubical Sperner Lemma of this paper implies the Tucker Lemma in 2-dimensions; this suggests that other connections joining these combinatorial results remain to be discovered.

Minimal Complete Relay Decoding Networks *by E. F. Moore, p. 525.* The standard relay-contact-tree network has been used extensively for many years. If n is the number of relays involved, it has always been assumed that the $2(2^n-1)$ contacts used in the standard tree network is the smallest possible number of contacts with which such a network could be made. This paper proves that this is true, provided no sneak paths are allowed. This is in contrast to the result obtained by Lupanov, who showed that when n is five or more it is possible to save contacts below the usual number by permitting sneak paths.

This paper proves further theorems about any network which satisfies the same specifications as an n-relay tree without sneak circuits, and which is built with the minimal number of contacts. In particular, these theorems characterize such a network well enough that it can be shown to be one of the standard forms of relay tree network.

A Bound for Error-Correcting Codes *by J. H. Griesmer, p. 532.* This paper gives two new bounds for the code word length n which is required to obtain a binary group code of order 2^k with mutual distance d between code words. These bounds are compared with previously known bounds, and are shown to improve upon them for certain ranges of k and d. Values of k and d are given for which one of these bounds can actually be achieved; in such cases, the structure of the resulting codes is shown to satisfy a certain condition.

Minimization over Boolean Trees *by J. P. Roth, p. 543.* An algorithm is provided for what might be termed the general problem of logical design of circuits with one output and no feedback. Given a set ß of logical building blocks, each with a positive cost, each with one output, and given a Boolean function f the problem is to prescribe a Boolean tree constructed from the available set of building blocks which realizes f and which has a minimum cost. Actually a more general problem involving *don't care* conditions is treated. The cost of a Boolean tree shall be the sum of the costs of the building blocks of which it is composed. A special case of this problem is the classical logical problem of finding a functional expression for a given logical function which uses a minimum number of conjunctions, disjunctions and negations. Programmed on an IBM 704 computer, the algorithm is believed to be efficient on problems with eight or less variables.

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Periodic Solutions of the Wave Equation with a Nonlinear Interface Condition *by W. L. Miranker, p. 2.* In this paper we consider the problem of the voltage oscillations in a transmission line when a diode represented as a nonlinear capacitance is placed in shunt in that line. In particular we consider the response of this line to periodic driving voltages and study the periodic responses. This physical situation is shown to lead to the mathematical model of the wave equation in the voltage in a domain with an internal boundary (the interface), at which the voltage is required to satisfy a nonlinear jump condition. By an application of Gauss' theorem, the problem is reduced to a nonlinear difference-differential equation. In the case that the generator driving the line is matched to it, this family of equations reduces to a family of nonlinear differential equations. The paper is concerned with a study of the periodic solutions of these two classes of equations.

Theoretical Current Multiplication of a Cylindrical Hook Collector *by D. P. Kennedy, p. 25.* An analysis is given on the mechanisms of operation for a current-multiplying hook collector of cylindrical geometry. Mathematical equations are presented which establish the minority carrier transport efficiency within a cylindrical hook collector region; both surface and bulk recombination are assumed to be present. Also included in this analysis is the influence, upon current multiplication, of the factors determining minority carrier injection efficiency for a diffused hook emitter junction. Numerical evaluation of appropriate hook collector design equations are presented in graphical form throughout a range of geometrical parameters applicable to many practical situations.

Methods of Analysis of Circuit Transient Performance *by L. Hellerman and E. J. Skiko, p. 33.* This paper surveys some numerical methods applicable in obtaining the distribution of performance parameters associated with the transient behavior of switching circuits. The methods considered are: (1) *Monte Carlo,* in which sample circuits are simulated on the IBM 704 and their performance computed and tabulated. (2) *Parameter sensitivity methods,* including propagation of error, in which the first and second moments of the output distribution are estimated from parameter sensitivities; and a method using the total differential of the performance parameter to estimate the deviation of circuit behavior from its component deviations. (3) *A surface fitting method,* in which there is developed a formula for delay time in terms of circuit component values. Each method is used to determine the delay time of a simple system. Their merits and drawbacks are compared and discussed, and estimates are given of the IBM 704 machine time necessary for implementation on a ten-transistor switching circuit.

Analysis of a Constant-Input-Flow Hydraulic System *by S. C. Titcomb, p. 44.* An analysis of the system is discussed and its application to a paper form feeder carriage in a printer is described. A nonlinear differential equation is derived based on stated assumptions and lumped oil parameters. The equation is linearized and solutions for motor velocity and peak pressure, both versus time, are determined. The analytical results show the effect of system parameters on system acceleration, steady state volumetric efficiency, and peak pressure. A limited amount of experimental data has been collected and good correlation between theoretical prediction and experimental results for acceleration time and peak pressure has been achieved.

Solid-State Optical Maser Using Divalent Samarium in Calcium Fluoride *by P. P. Sorokin and M. J. Stevenson, p. 56.*

A Magnetic Associative Memory System *by W. L. McDermid and H. E. Petersen, p. 59.*

Acoustic-Mode Mobilities for "Split-p-Silicon" *by P. J. Price and Y.-H. Kao, p. 63.*

Hydrogen-like Impurity States in Axially Symmetric Crystals *by R. W. Keyes, p. 65.*

Card Capacitor—A Semipermanent, *Read Only* Memory *by H. R. Foglia, W. L. McDermid, and H. E. Petersen, p. 67.*

Safe X-Ray Shutter and Filter System *by F. Chambers, M. Okrasinski, and H. Cole, p. 69.*

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Table Look-up Procedures in Language Processing Part I: The Raw Text *by G. W. King, p. 86.* A method of addressing memories is described which is very powerful in the processing of natural languages, where the arithmetic or logical operations are either nonexistent or do not lend themselves to algorithmic description. The main feature is the guarantee of initiation of an exhaustive search for a linguistic word at a point just beyond the desired address. Sequential search backwards not only locates an address if it is there but also provides identification of a longest match first. The method is further extended to provide "conditional" addressing by prefixing subsequent addresses from information obtained in earlier searches.

Phase Reversal Data Transmission System for Switched and Private Telephone Line Applications *by E. Hopner, p. 93.* A phase reversal data transmission system is described, capable of operating at 2000 bauds over private telephone lines and at 1200 bauds over switched networks. The advantages and limitations of the system are discussed from a theoretical and practical standpoint. The clocking problem in data transmission is considered and several approaches are indicated. A summary is given of extensive field tests over

switched and private lines in Europe and on private (SAGE) lines in the U.S.

A Magnetic Associative Memory *by J. R. Kiseda, H. E. Petersen, W. C. Seelbach, and M. Teig, p. 106.* This paper describes a computer storage system in which data flows in and out of the memory on the basis of content rather than location (address). In addition, a small experimental model of this system is described, using ferrite cores as novel associative memory storage elements.

Acoustic-Mode Scattering of Holes *by M. Tiersten, p. 122.* Matrix elements are calculated for acoustic-mode scattering of holes in the valence band structure typified by germanium. Whitfield's generalization of the deformation potential theorem is used to calculate the electron-phonon interaction; his method is, however, extended to include the spin-lattice coupling. A general expression for the electron-phonon interaction matrix element is obtained, and calculations are presented for some special directions in **k**-space.

Analysis of a Basic Queuing Problem Arising in Computer Systems *by P. E. Boudreau and M. Kac, p. 132.* A model which describes a basic junction, or queuing structure, arising in a general computing system is subjected to a mathematical analysis. The results consist of several formulas describing the performance of various parts of the system. The feasibility in analyzing general queuing problems in this manner is stated, together with the results of a Monte Carlo simulation used for comparison purposes.

A Direct Digital Method of Power Spectrum Estimation *by P. D. Welch, p. 141.* This paper discusses a method of digital power spectrum estimation involving the direct combination of the sample time function with sines and cosines. This treatment is in contrast to the normal indirect digital method which proceeds through the intermediary of the autocovariance function. All the practical design details necessary for the planning of a spectral estimation program are treated.

The Dynamics of a Subharmonic Oscillator with Linear Dissipation *by G. J. Lasher, p. 157.* A mathematical analysis of the dynamic behavior of subharmonic oscillators (parametrons) is made assuming a nonlinear reactance but a linear dissipation or resistance. Simple equations of motion for the subharmonic and pump amplitudes are derived in the quasistatic, or high-Q, approximation. Numerical solutions are obtained for two cases. The first shows the subharmonic amplitude changing from a small value to its steady state value when a constant pump signal is applied. The second shows decay when the pump signal is removed.

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A 0.7-Microsecond Ferrite Core Memory *by W. H. Rhodes, L. A. Russell, F. E. Sakalay, and R. M. Whalen, p. 174.* The design and performance of a newly developed magnetic core memory is described. A two-dimensional array organization and partial switching of toroidal cores were employed in the design of this low-power, high-speed memory. The memory features a unique combination of a current-steering diode matrix and a load-sharing magnetic switch for an economical and high-performance drive system. The operating memory has a storage capacity of 73,728 bits and executes instructions reliably up to a repetition rate of 1.47 mc. The discussion will include a description of the organization, the series-parallel delay line clock, the control of critical timing pulses, and the actual measured performance.

Irreversibility and Heat Generation in the Computing Process *by R. Landauer, p. 183.* It is argued that computing machines inevitably involve devices which perform logical functions that do not have a single-valued inverse. This logical irreversibility is associated with physical irreversibility and requires a minimal heat generation, per machine cycle, typically of the order of kT for each irreversible function. This dissipation serves the purpose of standardizing signals and making them independent of their exact logical history. Two simple, but representative, models of bistable devices are subjected to a more detailed analysis of switching kinetics to yield the relationship between speed and energy dissipation, and to estimate the effects of errors induced by thermal fluctuations.

A Table Look-up Machine for Processing of Natural Languages *by J. L. Craft, E. H. Goldman, and W. B. Strohm, p. 192.* A table look-up machine based upon a photographic memory is being optimized for the processing of natural languages. It makes use of automatic retrieval of lexical information by means of novel addressing features which allow look-up of phrases regardless of length. Linguistic determinations made on the basis of the lexical information retrieved govern subsequent operations. In addition a sentence buffer holds a sentence long enough to make the backward and forward passes which will be required to make grammatical and contextual analyses.

An Approximate Method for Treating a Class of Multiqueue Problems *by M. A. Leibowitz, p. 204.* The following problem is considered: N queues of unrestricted length are served in cyclic order by a single server. Input to each queue is Poisson, the service time distribution may be arbitrary, and a finite time is required by the server to go from one queue to the next. Supposing that at any queue the server serves all units which he finds when he arrives, what is the probability p_n that in a stationary state he finds exactly n units? The method for solving this problem is based on the notion of a "self-consistent" probability distribution and is actually applicable to a general class of multiqueue situations of which the one considered here is typical.

Notes on Cumulative Photovoltages *by J. A. Swanson, p. 210.* It is reasoned that the large photovoltages observed by

Cheroff and Keller on ZnS crystals are theoretically plausible and can result from a wide class of different mechanisms. Conversely, the conditions under which a photoconductor with periodic inhomogeneities does not show a cumulative photovoltage are shown to be very restrictive and improbable. General theorems concerning the magnitude of the photovoltage are proved, and remarks are made on its directionality.

The Use of Radioisotopes to Determine the Chemistry of Solder Flux *by G. J. Sprokel, p. 218.* When rosin flux activated with amine halides is used in soldering printed circuit boards, metal halides are formed; these halides cannot be removed with organic solvents and thus may cause corrosion. The use of alkanol amines as solder fluxes has been investigated. After soldering, the flux can be removed by rinsing with water. Throughout this investigation radioisotopes were used to identify the compounds studied.

Bistable Systems of Differential Equations with Applications to Tunnel Diode Circuits *by J. K. Moser, p. 226.* A mathematical analysis is developed for nonlinear circuits which have at least two stable steady states, and therefore are of interest as computing or memory elements. Circuits containing one or two tunnel diodes will be analyzed in detail as applications of the theory.

The method is based on the study of certain "potential function" whose extrema are the steady states of the circuit and whose minima correspond to the stable switching states. This study leads to a qualitative description of all solutions in the large and results in quantitative restrictions on the parameters (*R, L, C* and nonlinear characteristics) which seem of practical importance.

Minimum Polarized Distance Codes *by M. P. Marcus, p. 241.* The choice of a code for a given application is influenced by many factors, such as economics, compatibility, and reliability. This paper is concerned solely with the reliability of codes, and shows how, for a given number of bits per character and a given minimum distance, the probability of undetected error in an asymmetric channel may be reduced by many orders of magnitude merely by the proper selection of coded characters. For a given minimum distance, an optimum selection of characters requires, as nearly as possible, the same number of "one" and "zero" bit failures to change one character to another. The concept of *polarized distance* is introduced, and it is shown how the probability of undetected error is related to the *minimum distance* of a code only in a symmetric channel, while the probability of undetected error is related to the *minimum polarized distance* in both symmetric and asymmetric channels.

The purpose of this paper is to present new theoretical concepts useful in the evaluation of codes, and not to recommend one code over another. The codes in the paper are used only as examples to illustrate the theoretical concepts involved.

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The Electronic Contribution to the Elastic Properties of Germanium *by R. W. Keyes, p. 266.* Theories of several elastic effects resulting from the contribution of electrons to the strain energy function of germanium are presented. They show that the elastic properties are appreciably changed by doping with donor and acceptor impurities. The properties considered are: (1) volume, (2) elastic constants of degenerate *n*-type material, (3) third-order elastic constants of degenerate *n*-type material, (4) elastic constants of degenerate *p*-type material, (5) elastic constants of material containing electrons bound to donors, (6) elastic constants of material containing electrons bound to pairs of donor atoms. The most striking effect is found for the case of degenerate *n*-type germanium, in which the theory predicts that c_{44} can be lowered by 8% with attainable doping levels.

Dislocations and Plastic Flow in Germanium *by D. Dew-Hughes, p. 279.* Single-crystal specimens of germanium have been tested in tension over a range of temperature and strain rate. Dislocation density has been determined as a function of plastic strain, and some direct measurements of dislocation velocity have been made. From these results the plastic behavior of germanium can be explained in terms of dislocation velocity and dislocation multiplication, and is analogous to the interpretation given by Johnson and Gilman for deformation of lithium fluoride. Effects of crystal purity and orientation have been examined; strain-aging effects were absent. Conjectures are made as to the causes of work hardening.

A High Track-Density Servo-Access System for Magnetic Recording Disk Storage *by A. S. Hoagland, p. 287.* This paper is concerned with an investigation of the feasible track-density potential of random-access magnetic-disk storage where magnetic-head positioning is essential. Primary emphasis is given to a novel, servo-access concept (closed-looped head-positioning control which includes the record member) for track location and registration. This servo concept has been investigated as a means of making possible automatic tracking as well as precision positioning. Inherent in such an access control technique is an enhanced suitability for interchangeable record members. Included in the discussion are design and performance results of an access model operated at 154 tracks per inch.

Lognormal Distribution Function for Describing Anelastic and Other Relaxation Processes I. Theory and Numerical Computations *by A. S. Nowick and B. S. Berry, p. 297.* Such phenomena as dielectric, magnetic, and anelastic relaxation are often described in terms of a distribution of relaxation times. It is shown that a relaxation process which exhibits a Gaussian distribution in the logarithm of the relaxation times

(a "lognormal" distribution) can be specified completely by three parameters. These are: the mean relaxation time (τ_m), the width of the distribution (β), and the magnitude of the relaxation (δJ). The relationships of these parameters to experimentally measurable functions are usually complicated. These relationships were obtained in numerical form by machine computation. Finally, a simple formula is derived which expresses the parameter β in terms of the widths of the distribution of the activation energies and that of the attempt frequencies.

Lognormal Distribution Function for Describing Anelastic and Other Relaxation Processes II. Data Analysis and Applications *by A. S. Nowick and B. S. Berry, p. 312.* The present paper deals with the use of the theory and computations given in Part I for a relaxation process governed by a lognormal distribution of relaxation times. The experimental determination of the basic parameters appearing in the theory is shown to require the application of a number of corrections to the usual type of dynamical data. General expressions are derived for these corrections, and the data necessary for their use are presented in graphical form. Specific examples are given of the application of the theory to the analysis of anelastic relaxation phenomena.

A Study of the Playback Process of a Magnetic Ring Head *by G. J. Y. Fan, p. 321.* The playback process of a magnetic ring head with finite permeability of head and tape are studied, using the theorem of reciprocity. In order to obtain an accurate result for the playback process, the field around a magnetic gap is studied by a Fourier method. The shift of the gap null for infinite permeability of the head as calculated by Westmijze is confirmed, and the new shift is found when the tape permeability is greater than one. A simplified gap-loss function is given for the case of finite parameters for tape and head.

A Note on Hall Probe Resolution *by H. Koehler, B. Kostyshyn, and T.-C. Ku, p. 326.*

The Chargistor, a New Class of Semiconductor Devices *by H.-N. Yu, p. 328.*

Monte Carlo Analysis of Transistor Diffusion Techniques *by D. P. Kennedy, p. 331.*

A Network Minimization Problem *by F. P. Palermo, p. 335.*