

Quarterly Progress Report

Division 2

Data Systems

15 May 1964

Prepared under Electronic Systems Division Contract AF 19(628)-500 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



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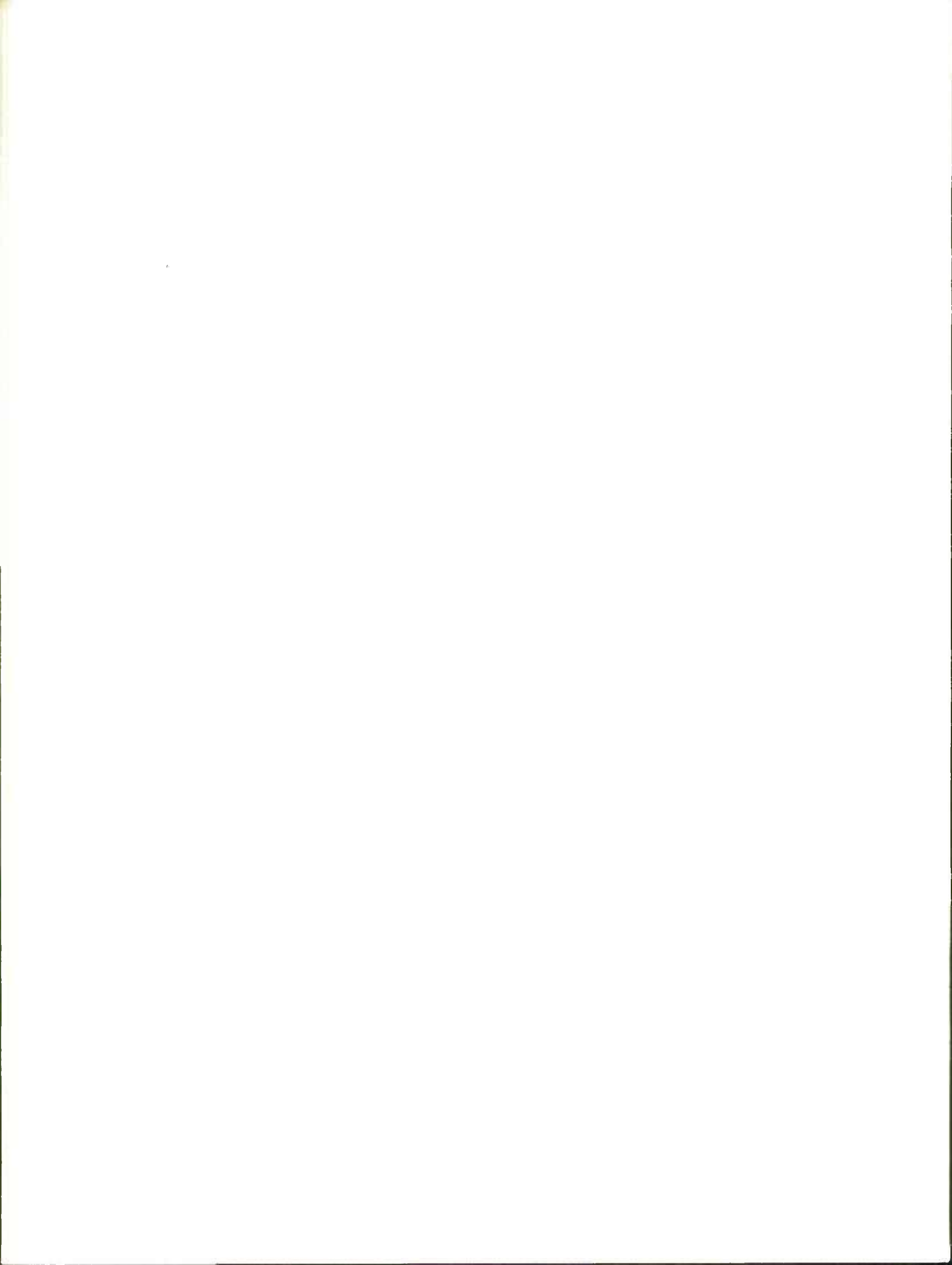
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts





INTRODUCTION

This report reviews progress during the period 1 February through 30 April 1964 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems and Project Apollo describe other work in the Division during the period. This results in separate reporting of all the work of Groups 21 and 22, and some of the work of Group 28.

Detailed reports of research will continue to be available in the form of Technical Reports, Group Reports, and Journal Articles. A list of the reports issued during the present reporting period is included here.

30 April 1964

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Head, Division 2
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Accepted for the Air Force
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UNCLASSIFIED REPORTS BY AUTHORS IN DIVISION 2

15 February through 15 May 1964

PUBLISHED REPORTS

Technical Reports

TR No.				<u>DDC and Hayden Nos.</u>
306	The Baseball Program: An Automatic Question- Answerer, Vol.I	A. K. Wolf C. S. Chomsky B. F. Green, Jr.	11 April 1963	DDC*
349	Radar Scattering from a Conducting Cone-Sphere	J. H. Pannell J. Rheinstein A. F. Smith	2 March 1964	DDC*

Group Reports

No.				
1964-1	An Approximate Method for the Calculation of Scalar Scattering by Two-Dimensional Bodies	A. D. MacGillivray A. F. Smith	9 January 1964	DDC 431781 H-564
1964-2	The Angular Resolution of Multiple Targets	J. R. Sklar [†] F. C. Schweppe	14 January 1964	DDC 430185 H-560
1964-3	Backscatter Radar from Some Low Cross-Section Shapes	A. F. Smith	16 January 1964	DDC 431780 H-567
1964-11	Error Analysis of a Digital Monopulse Radar	M. Schneider N. T. Gaarder	30 January 1964	DDC 430297 H-561
1964-12	Fuel-Optimal Singular Control of a Nonlinear Second Order System	M. Athans M. D. Canon	30 January 1964	DDC 430272 H-559

Journal Articles[‡]

JA No.			
2169	An Iterative Procedure for Computing Time-Optimal Controls	H. K. Knudsen	Trans. IEEE, PTGAC <u>AC-9</u> , 23 (1964)
2209	Hazards in Pulse Sequential Circuits	P. E. Wood, Jr.	Trans. IEEE, PTGEC <u>EC-13</u> , 151 (1964)

* Not yet assigned.

† Division 4.

‡ Reprints available.

Published Journal Articles (Continued)

MS No. 707	A New Method of Locating the Maximum Point of an Arbitrary Multipeak Curve in the Presence of Noise	H. J. Kushner	J. Basic Engineering <u>86</u> , 97 (1964)
913A	A Multilayer Dielectric- and Magnetic-Film Memory Cell Designed for Optical Read-Out	D. O. Smith	J. Appl. Phys. <u>35</u> , 772 (1964)
917B	Magnetic Properties of Ni-Fe-Cr Films	M. S. Cohen	J. Appl. Phys. <u>35</u> , 834 (1964)
918	Deposition Temperature and Compositional Dependence of Negative Anisotropy in Nickel-Iron Films	G. P. Weiss D. O. Smith	J. Appl. Phys. <u>35</u> , 818 (1964)
952	Future Developments in Large Magnetic Film Memories	J. I. Raffel	J. Appl. Phys. <u>35</u> , 748 (1964)

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2273	A Direct Constructive Proof of the Criterion for Complete Controllability of Time-Invariant Linear Systems	P. L. Falb M. Athans	Accepted by Trans. IEEE, PTGAC
2324	A Proposal for an Associative Memory Using Magnetic Films	J. I. Raffel T. S. Crowther	Accepted by Trans. IEEE, PTGEC
2331	Evaluation of Likelihood Functions for Gaussian Signals	F. C. Schweppe	Accepted by Trans. IEEE, PTGIT
MS No.			
688A	Sketchpad, A Man-Machine Graphical Communication System	I. E. Sutherland	Accepted by Simulation

Meeting Speeches*

MS No.			
979	High Density Magnetic Film Memory Techniques	T. S. Crowther	Intermagnetic Conference, Washington, 6-8 April 1964
1051	Syllable Segmentation in Voiced Environments	A. N. Stowe	Acoustical Society of America, New York, 6-9 May 1964

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

Unpublished Meeting Speeches (Continued)

MS No.			
1079	The Maximum Principle and Its Applications	M. Athans	Modern Control Theory and Application, Downey, California, 3 March 1964
1092	Deposited Connections and Wiring	E. A. Guditz	IEEE, PTGPEP, Waltham, Massachusetts, 12 May 1964

For convenience in ordering copies of Lincoln Laboratory reports, DDC (formerly ASTIA) and H numbers are listed. Reports assigned H numbers are unclassified (released) and are obtainable at cost as microfilm or photoprint copies from the Microreproduction Laboratory, Hayden Memorial Library, M. I. T., Cambridge, Massachusetts 02139.

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DIGITAL COMPUTERS

GROUP 23

I. COMPUTER SYSTEMS

A. TX-2

1. Optical Input

The image dissector camera has been received from ITT Industrial Laboratories and a system shakedown is about to begin. From the data furnished by ITT, it has been determined that performance is below specification in several areas. More accurate data, obtained using TX-2, will be necessary before we can determine what steps must be taken to achieve desired performance.

2. Multiuser Consoles - Typewriters and Keyboards

Plans to use the IBM Selectric typewriter in the new console design have met difficulties, i.e., creating a "golf-ball" with the Lincoln-Writer type style. Therefore, typewriters have been ordered from Soroban. Keyboard specifications are nearly frozen and orders will be placed shortly. Logic design is progressing, along with an evaluation of a logic system using a small general-purpose computer for typewriter and keyboard control and buffering. The use of a Digital Equipment PDP-5 appears to have certain advantages over a brute-force logic approach, particularly if we anticipate a switch to Selectrics in the future.

3. Central Processor and Memories

The core storage capacity of TX-2 will be increased, initially, by 32,000 words; installation of the remaining 16,000 words will be postponed until sometime later this fall. Delivery of the UNIVAC Fastrand file memory is now scheduled for July. Since the symbolic page-addressing system (SPAT) and other major additions to the TX-2 main frame will also be completed by late summer, the checkout of the new executive and translator programs can begin about that time.

The buffered, block transfer mode which is being added to the input-output control will use a 16-register version of the transistor flip-flop memory being used in SPAT. This will give more flexibility in the design of this system as well as reduce its size, complexity, and cost.

B. Arithmetic Element Test Unit

The AETU is now completed and is operating. Circuits transmit 1.7-volt, 2-nsec rise signals through 50-ohm terminated cables. Each cable can drive four loads and each circuit drives two cables, providing a fan-out of 8. The circuits use commercially available transistors connected in unsaturated differential amplifier fashion. Differential level amplifiers and gated-mixing pulse amplifiers each have 3-way AND and 4-way OR inputs and operate with a delay of 5 nsec. Flip-flops with 3-way AND and 3-way OR gates in each of the set, clear, and complement inputs switch state in 7 nsec.

GROUP 23

Although the machine performs multiplication by adding the multiplicand each time the appropriate multiplier bit is a ONE, and doing a single carry and right shift (it does not use any sophisticated look-ahead techniques), it requires only 250 nsec to multiply two 8-bit numbers; for long words it would require approximately 25 nsec per bit.

It should be noted that the circuits are designed to drive coaxial cables with very little reflection and, within the limitations of cable delays, these techniques could be applied directly to the design of a very large machine.

II. CIRCUIT DEVELOPMENT

A. Transistor Flip-Flop Memory

The transistor flip-flop memories to be used in SPAT and the Memory Snatch System (Sec. I) will be built in 16-word, 20-bit subassemblies, each consisting of a word driver, etched-wiring card, and 5 memory plane cards. Each memory card will contain 64 flip-flops arranged in a 16-word, 4-bit array along with the associated sense and digit amplifiers. The flip-flops are simple, direct-coupled transistor flip-flops with 2 diodes for coupling to the sense-digit lines. The word driver card will have address decoding and the word-selection line drivers. Four of these 16-word, 20-bit modules will be interconnected to provide a 64-word memory which will be mounted in a standard $19 \times 8\frac{3}{4}$ -inch card mounting rack. A 16-word, 4-bit memory plane card and the word driver circuits have been built and checked out. Access time will be approximately 50 nsec. Sixteen hundred of the flip-flop subassemblies and the memory plane cards are being constructed now. The system will be completed during the next quarter.

B. Integrated Circuit Evaluation

Performance characteristics of various digital integrated circuits are being studied in order to select types most suitable for use on a large scale. Small quantities of standard diode-transistor logic (DTL) gates, purchased from Westinghouse and Signetics, have been tested with emphasis on determining propagation delay, waveforms, and thresholds. Similar tests have been made on direct-coupled transistor logic (DCTL) gates purchased from Raytheon. Tests are also planned for DCTL gates manufactured by Fairchild and General Micro-electronics, emitter-coupled transistor logic (ECTL) gates manufactured by Motorola, and the emitter-coupled Series 53 gates built by Texas Instruments.

In connection with the transfer characteristics (output-vs-input voltage curves) of the integrated circuits being tested, a study of the general problem of the dispersion that can be tolerated in these curves has been made. A simple and useful criterion for finding the maximum permissible dispersion, or for finding out if a given dispersion can be tolerated, has been determined.

C. UHF Switching Transistors

1. Germanium Planar Switch

Successful germanium planar switching transistors have been developed at Texas Instruments, with Lincoln Laboratory support. While the initial devices are not as fast as the best

3-stripe mesa units we received previously, it is anticipated that the performance of these new units will soon surpass the best of mesa construction. Success in this area represents an important breakthrough in germanium technology, which should make possible the full utilization of the high-frequency capabilities of germanium and allow germanium switching transistors to again outstrip silicon devices in the VHF area.

2. Microcircuits

Preliminary device evaluation is being performed on various representative microcircuit types. It is anticipated that full utilization of UHF switching transistors will require application of microcircuit packaging and interconnection techniques.

III. MAGNETIC FILM ENGINEERING

A. High-Density Memory Development

The demagnetizing field measured in Co-Ni-Fe ($H_c \approx 10$ oe) is greater, by a factor of three, than that measured in Ni-Fe ($H_c \approx 2$ oe) crossed-line films of the same geometry. This cannot be accounted for by the absence of a closely spaced adjacent digit line, as first postulated, nor is it caused by saturated adjacent areas along the digit strip. It is hoped that Bitter patterns and the Kerr effect will provide some insight into the cause of this difference.

Work on a 2×2 assembly of substrates (each 5×1.6 inches) has concentrated on experiments with word noise and construction of versatile test equipment. Signal-to-noise ratio at signal time with 2×8 -mil, coupled 1000-\AA films is quite good using instrumentation drivers and sense amplifiers.

A test fixture for substrates 1.6×10 inches is being designed. This will accommodate as much as five crossed substrates in each direction for a total of approximately 800,000 bits. A series-switch scheme is being developed for this system in order to drive the 30- to 60-ohm word lines and reduce power dissipation. Also, the rotating drum for holding and moving 16 substrates (up to 30 inches long) and the shutter mechanism for the large vacuum system are completed and will be installed shortly. We are using crystal-deposition monitors in this system to improve thickness control of the copper and Permalloy layers.

Results of attempts to reduce pinholes in evaporated films by improved substrate cleaning and handling have been encouraging. Several test films have been prepared which show marked reduction in pinholes, but variation in film thickness makes it difficult to assess the effectiveness of the cleaning procedure.

A study is being made of the requirements for scribing or ruling 0.002-inch wide lines on 0.004-inch centers with diamond ruling tools. Initial attempts were made to rule patterns in a layer of silver chemically deposited on a coordinatograph layout table with the tool held and indexed by the traveling head of the machine. Modifications are being made to the apparatus to provide more accurate line-to-line indexing, variable line lengths, and automatic propulsion of the scribing tool.

GROUP 23

B. Page Address Memory

Each of the four 256-word modules of the 1024-word memory was tested separately in FX-1. Forty pretested arrays were needed to obtain 32 with acceptable margins. Under worst-case testing, all but 40 of the 13,312 bits had digit current margins of at least ± 25 percent. When the 40 bits are included, the margins are ± 6 percent. In non-worst-case operation, margins are wider.

The complete stack has been assembled and is undergoing final checkout. Care was taken in stack construction to eliminate film-to-drive line spacing variations, which cause local stressing of film areas. The word and digit noise is low enough to give adequate margins in page address memory (PAM) operation and will provide a four-to-one signal-to-noise ratio and a 300-nsec cycle time. The entire system will be checked for all margins in FX-1 prior to installation in TX-2.

C. Content-Addressed Memory

A number of studies* have indicated the potential utility of parallel search, content-addressed memories as peripheral computer devices. Quite significant improvements are to be expected in such diverse activities as information retrieval, list processing, and sorting by using content-addressed (rather than location-addressed) memory. However, most published hardware realizations use cryogenic elements, and these developments appear still some distance in the future.

Among the requirements for content-addressed memory elements are nondestructive readout, unipolar output, and high signal-to-non-signal ratio. Investigations on the magnetoresistive effect, or change in electrical resistance with applied magnetic field,[†] suggest that memory elements might be developed using this effect for nondestructive readout from thin Permalloy films of the type used in normal location-addressed memories. Work is now proceeding to define the film parameters and modes of operation which would be most useful in a content-addressed memory.

* G. Estrin and R. Fuller, "Algorithms for Content Addressed Memories," Proc. Pacific Computer Conference (1963), p. 118.

† J. I. Raffel, "Magnetic Films - New Possibilities - New Problems," Switching Theory in Space Technology, H. Aiken and W. F. Main, Eds. (Stanford University Press, Stanford, 1963), p. 254.

COMPUTER COMPONENTS

GROUP 24

I. ELECTRON TRANSPORT

A. Transistor Behavior at High Current Densities

Present theory indicates that high-frequency transistors ($f_T \sim 50$ kMcps) can be obtained by reducing the physical dimensions of the active portion of the transistor and operating at higher current densities. Attempts to fabricate such devices have led to the discovery of effects at high current density that limit the performance to frequencies $\lesssim 5$ kMcps. These effects are being investigated by extrapolating the solutions of the general transistor equations for charge conservation, charge transport, and electric field to high current density. Results so far indicate that with increasing current density: the neutral base layer region widens by spreading into the collector region with a consequent reduction of the frequency response; the output impedance falls and the input impedance rises thus reducing the over-all power gain.

B. Contact Potential

In order to clarify the source of nonreproducibility of gold-aluminum contact potentials reported in the previous quarterly progress report, measurements were made on gold-gold contact potentials – with only one of the gold electrodes exposed to dry oxygen. The experiment consisted of: (1) evaporating a fresh surface of gold on both electrodes and measuring the contact potential; (2) exposing both electrodes to oxygen, evaporating fresh gold on only one of the electrodes, and remeasuring the contact potential. The fresh-gold vs fresh-gold potential was within a few millivolts of being zero after proper outgassing of the vacuum system and evaporation sources. The fresh-gold vs exposed-gold potential was not significantly different from this after a one-hour exposure to dry oxygen at 5×10^{-5} torr, but the potential changed about 160 mv after a 24-hour exposure at 100 torr. The fact that the work function of gold did not change in the short-term, low-pressure exposure is encouraging. It shows the feasibility of using gold as a reference electrode (at least under the low-pressure, short-term exposure conditions), and it is in agreement with Trapnell* who found that gold does not chemisorb dry oxygen within an experimental accuracy of 0.02 monolayer. Therefore, it is thought that the main problem in measuring gold-aluminum potentials is to obtain, for aluminum, a suitable contamination-free evaporation source which can be used enough times before burning out to establish reproducibility. This is a difficult problem since aluminum either reacts or alloys with most refractory metals and ceramic oxides. Electron-beam heating of an aluminum pellet resting on a water-cooled copper block will be tried.

C. Metal-Insulator Triode Fabrication

Tunneling barrier studies are now being performed in ion-pumped ultra-high-vacuum (UHV) systems. It is encouraging to note that reproducibility is far superior to previous work using oil

* B. M. W. Trapnell, Proc. Roy. Soc. (London) 218A, 566 (1953).

diffusion pump (DP) systems. In the UHV system, aluminum films do not form tunneling barriers when exposed to dry oxygen below 200°C; however, oxygen saturated with water vapor ($\sim 17,000$ ppm H_2O) reacts reproducibly at room-temperature to form tunneling barriers. By fitting the experimental I-V curves to the tunneling theory, the barrier height and thickness are found to be 3.0 volts and 12 \AA , respectively. Breakdown occurs at 1.6 volts giving a breakdown field strength of 1.3×10^7 volts/cm. For comparison, aluminum-aluminum oxide diodes made in DP systems typically have barrier heights ~ 1 volt, thickness $\sim 30 \text{ \AA}$, and breakdown field strengths $\sim 4 \times 10^6$ volts/cm. The stability of the UHV diodes is very much greater than the DP diodes, with very little electrical change noted for UHV devices aged at room atmosphere. Attempts are now being made to find, with the UHV system, a way to make reproducible low barriers (~ 1 volt) which could serve as the collector barrier in a triode structure.

II. MAGNETIC FILMS

A. Magnetic Fine Structure and High-Speed Switching

The theory of the magnetic fine structure has been extended in two directions.

- (1) The "chessboard" model of a polycrystalline film has been replaced by a more realistic model in which the crystallites have random sizes and shapes. The basic results of the theory are unchanged; however, using this improved model we have been able to show that coupling of the fine structure components (through random anisotropy forces) may be neglected. This has been a key assumption of the theory, unproven until now.
- (2) Calculation of nonlinear damping of the uniform-switching mode by the fine structure has been extended to anisotropic films with arbitrary bias and pulse fields. For the usual arrangement in high-speed switching experiments of a hard-axis bias field H_{\perp} and an easy-axis pulse-switching field H_S , it is found that the transition from noncoherent to coherent rotation occurs at a pulse field H_{sc} which is in excess of the rotational threshold field and roughly proportional to the square of the angular magnetization dispersion. This is in contrast to the cube law found for isotropic films and has not yet been experimentally verified. However, the dependence of H_{sc} on H_{\perp} has been measured and found to be in good agreement with the theory.

B. Ternary Alloys

In continuation of the study of Ni-Fe-Cr alloys,^{*} work is progressing on the preparation of a vacuum system which will permit simultaneous evaporation of NiFe and a third metal from two separate sources. It is planned to monitor the NiFe evaporation rate by monitoring the melt temperature, while the third metal evaporation rate will be monitored by reading an ion gauge through which the metal vapor passes directly.

C. Ferromagnetic Circles

As the size of a ferromagnetic particle is reduced it becomes energetically favorable for the particle to become a single magnetic domain.[†] The size of such particles is in the micron

* M. S. Cohen, J. Appl. Phys. **35**, 834 (1964).

† C. Kittel, Revs. Modern Phys. **21**, 541 (1949).

range, and the predicted magnetic-domain behavior has not previously been clearly observed experimentally. A special technique for the production of circles of NiFe film about 100 \AA thick and less than 10 microns in diameter has been developed recently. Lorentz microscopy of such samples clearly reveals some of the predicted magnetic configurations.

D. Magneto-optics

The conditions under which an efficient high-frequency light modulator or switch can be fabricated using the magneto-optical properties of ferromagnetic metal films have been further clarified theoretically. One essential requirement is that the magnetic permeability μ be gyrotropic (skew-symmetric tensor) at optical frequencies, there is some evidence that such is the case.* However, sufficient doubt still exists on this point, therefore, an experimental program has been undertaken to obtain more conclusive evidence. At the same time, one of the vacuum systems used to fabricate magnetic films is being adapted to permit the evaporation of the multilayer dielectric films required for the fabrication of a light switch.

III. ADVANCED CIRCUITS

A. Sense Amplifier for the High-Density Memory

A blocking oscillator circuit using a transformer, two diodes, and a transistor was found to have a triggering sensitivity of $300 \mu\text{v}$. Noise measurements showed $12\text{-}\mu\text{v}$ rms (referred to input), so that a setting of 8σ or $100 \mu\text{v}$ would give a probability of 10^{-16} , or one false trigger per year from 10^3 circuits operating 10^6 cps. The required $300\text{-}\mu\text{v}$ setting results from a need to prevent self-triggering upon completion of recovery.

Other circuits, similar in concept but having no transformer, were also tried. A two-transistor version of the blocking oscillator had $200\text{-}\mu\text{v}$ sensitivity but retained the poor polarity discrimination and poor common-mode rejection properties of the original.

B. Improved Sense Amplifier for the FX-1 Memory

A strobed multivibrator circuit which triggers one way or the other, depending on the input polarity, gave a sensitivity of 1 mv , with poor stability, but good common-mode rejection. Incorporation of this circuit concept into the last stage of the FX-1 film-memory sense amplifier is under way.

* W. Breuer and J. Jaumann, *Z. Physik* 173, 117 (1963); K. H. Clemens and J. Jaumann, *Z. Physik* 173, 135 (1963).

PSYCHOLOGY

GROUP 25

I. AUTOMATIC PROCEDURE EXECUTOR

Work has continued on the design of APEX, the executive part of a general system to share the TX-2 computer among several on-line users. The other major parts of the system are the working programs, i.e., a translator that will accept statements in various users' languages and an expandable set of topical routines that will perform the actual computations and manipulations.

To exploit the page address memory (PAM) that is to be installed in TX-2 (see the Digital Computers section of this report), a fundamental change has been made in the way in which computation and manipulation is to be controlled. In the earlier plan, APEX included an executor that could be requested to run a sequence of routines. The executor was to transfer control to each routine, taking control again after the routine had ended. In the present plan, control resides in the working programs and APEX is limited to two functions: it referees among users, deciding whose program is to run next and how long it may run; and it complies with service requests made by the working programs, e.g., requests for input or output and requests that files of data be put in certain locations. Each console has, in effect, a copy of an elementary program that accepts basic commands from the user's keyboard. All of the work performed for that user (with the exception of input and output) is done by working programs that run as subroutines of the elementary program, or as subroutines of these subroutines, and so on, to any depth. The system has therefore been redesigned to facilitate the calling of subroutines and, in particular, to make it efficient for one routine to use another as a subroutine even though both were compiled to occupy the same addresses in memory. In the new plan APEX has four major parts:

A Secretary which handles input-output transfers and interrupts.

A Maestro which regulates time and in a sense controls APEX. It allots time to the users and inspects the traps and alarms.

A Csar (core storage allocation routine) which does the bookkeeping needed in sharing time, space, and programs. It stores the information that must be recorded when a working program is interrupted to descend to a subroutine or to move aside so that another user may run. It sets relocation and boundary registers and moves files to new apparent locations by changing the PAM.

A Mover which transfers information from and to the auxiliary drum-memory. It does the bookkeeping involved in allocating and maintaining files on the drum.

Some of the in-out routines to be included in the secretary are being written in cooperation with Group 23. Design of the maestro and the csar is nearly complete, design of the mover has just begun, and specification of the form of the calls to APEX from the working programs is in progress.

II. HUMAN INFORMATION PROCESSES

A further experiment has been performed on the immediate recall of digits spoken very rapidly by the TX-2 computer. Lists of six digits were presented at speeds ranging from

3 to 10 digits per second. In one condition all six digits were sounded in the usual manner; in the other condition the first three digits were spoken in the usual manner and the other three were passed through a 1.25 kcps high-pass filter so that they seemed to be spoken in a distant, tinny voice. At all speeds, recall was superior in the condition in which voice quality changed in the middle of the list. Even at these very high speeds – those at which rehearsal during the presentation of the list seems impossible – the digits are apparently stored in memory with "tags" indicating the quality of the voice in which they are spoken.

A more general form of the decision model for choice behavior in the unidimensional triad situation is under investigation. Since evaluation of such models requires extremely precise control of the stimulus display, a new experiment using patterns of dots rather than patches of light has been carried out. Results thus far indicate a close fit of the model to the data.

New data have been collected on the ability of human observers to detect statistically defined bar patterns. In these experiments the computer-generated patterns differed with respect to bar width, bar length, and degree of constraint in the placement of the dot elements comprising the display. The displays, on film strip, were viewed under two conditions: large (6°) visual angle and small (1°) visual angle. For all patterns, except those with the narrowest bars, the smaller displays yielded lower detection thresholds than the larger. The bar patterns whose elements were subject to little constraint in their placement were harder to detect than those whose elements were constrained, and thresholds rose as the bars in the displays were decreased in either width or length. These results replicate and amplify findings reported earlier by Green, et al.*

* B. F. Green, Jr., A. K. Wolf, and B. W. White, *Am. J. Psychol.* 72, 503 (1959).

CONTROL RESEARCH

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I. HYBRID COMPUTATION

The program of development and application of on-line hybrid computers has three interacting areas of activity: the development of computational facilities, the development of special programs, and the development of analytical models for research. The following specific tasks describe the current work.

Interconnection:- The interconnection of the Lincoln Laboratory digital computer (LINC) and the Applied Dynamics electric analog computer is complete, and a number of programs have been tried in order to study on-line techniques for solving two-point boundary value problems. Special features now implemented in this system are: displays for three-dimensional problems, parameter knobs for manual adjustment, and programmed parameter adjustments. A set of floating point routines has been written for the LINC to simplify arithmetic computations.

Description:- A report is being prepared which describes the program outlined in the previous quarterly progress report. The report will include a much more complete description of the first digital differential analyzer (DDA) and a more complete introduction to programming the present and proposed hybrid facilities.

Design:- The design of the first DDA is continuing. Specifications have been prepared and ordering of parts has begun. The machine will have an 83-bit word length, a 2.5- μ sec cycle time for each of the 256 integrators, a 14-inch display oscilloscope, and will connect to the LINC through a 36-bit buffer. The length of the y-Register (y is the integrand) is 24 bits.

A simulation program, to operate on the IBM 7094, is being prepared in order to test the operation of all the logic in the DDA. Test programs will be written and run as they would be on the actual DDA.

Programming:- Methods of programming the DDA have been investigated by modeling the DDA by a computer program. These programs have been operated on-line on M.I.T.'s time-shared computer to test methods of mapping and scaling problems and the effect of these methods on computational accuracy. For example, the accuracy in generating trigonometric and Bessel functions has been tried. As a start, a general approach to problem mapping and scaling is being developed on a compiler for automatic problem insertion to the DDA.

Investigation:- A study of possible future machine configurations also has been started. This will examine methods for storing, methods for adding, techniques for interconnecting, and modes of controlling which will indicate good systems for selected classes of problems. The study is also considering the possible application of a large thin-film memory for a future DDA.

The study of signal design problems using state variable, differential-equation models and Pontryagin's Maximum Principle* is continuing. Various approaches are promising for on-line

* F. C. Schweppe, "Optimization of Signals," Group Report 1964-4, Lincoln Laboratory, M.I.T. (16 January 1964), H-557.

solution on the hybrid computer. Analytical results are presently being documented for amplitude and frequency modulations for a radar tracking an accelerating target. Investigations have begun on more general signal design problems which require computer solutions.

State variable techniques have also resulted in a new data-processing algorithm for detecting and decoding Gaussian signals such as those occurring in multipath communication systems or in radar returns from fluctuating targets. The new algorithm is expressed in terms of differential equations which can be directly implemented for real-time computation with bounded memory requirements.

Earlier results* of nonlinear regression problems typical of space vehicle trajectory estimation are being extended. The basic algorithm is a system of differential equations with a bounded memory requirement. Tradeoffs between accuracy and system complexity are being delineated.

II. DATA FILE, STORAGE, RETRIEVAL AND EDITING

During this reporting period work has been done on the design of a general-purpose data storage and retrieval system. The system is intended to allow computer users to construct, interrogate, and edit large files of information on-line.

The system has the following features:

- (a) The system tells the user what information it needs to set up files or to determine requested operations on files, informs the user of input errors, provides him with information about the files, and gives him a list of the choices available for input operations.
- (b) The files that can be constructed by the user can vary in length and content.
- (c) All formats are set up by the system. The user refers to the file contents, e.g., data values, by name only. The user therefore does not need to know about the specific structure of the files.
- (d) The user can redefine or modify files on-line using ordinary English commands and calling the files, or parts of files, by name.
- (e) The user can create many files, differing in length and content, and establish relationships between files and parts of files. This allows the user to organize the same set of data under a number of category headings or data from a number of different files under a single category heading. This multiple association of data sets is carried out by use of link structures; duplicate storage of data is not necessary.

Conventional data storage and retrieval systems are designed for special applications to operate upon files of fixed format with a fixed set of user queries. To gain versatility of operation, more recent systems internally store selected information on the files' formats and thereby provide response to a broader class of user queries. The system under design allows the user, in effect, to modify these master files on-line. This permits changes to both the file contents and the data retrieval operations. Changes to the master files result from defining new files, modifying or deleting old file definitions, defining new cross-associations of existing files, etc. The user will be able to request from the system special formats for magnetic tape records of data thus allowing automatic translation of the data into and from the

*I. A. Gardner, Jr., "A Recursive Estimation Procedure for Certain Nonlinear Regression Problems - Scalar Single Parameter Case," IEEE Symposium on Adaptive Statistical Inference, Chicago, October 1963, to be published in Proc. IEEE.

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system's files. These features allow multiple users to edit and select data from common files for special uscs.

Preliminary design of the file conventions and system operations has been completed and a model system is being programmed. The programming for the model is being done in the Project MAC compatible time sharing system (CTSS). A number of programs for setting up the system files and defining new files have been written and checked out.

