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# Quarterly Technical Summary

## General Research

15 November 1967

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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

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# INTRODUCTION

This Quarterly Technical Summary covers the period from 1 August through 31 October 1967. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

# CONTENTS

# DATA SYSTEMS
# DIVISION 2

## INTRODUCTION

This section of the report reviews progress during the period 1 August through 31 October 1967 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

# DIVISION 2 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1967

## PUBLISHED REPORTS

### Journal Articles*

| JA No. | | | |
|---|---|---|---|
| 2818 | Improved Method of Optimizing Longitudinal Magneto-Optical Transmission-Scattering in Thin Magnetic Films | D. O. Smith<br>K. J. Harte | Optica Acta 14, 351 (1967) |
| 2986 | Comment on "Content-Addressed Memory Using Magneto- or Electro-Optical Interrogation" | D. O. Smith<br>K. J. Harte | IEEE Trans. Electron. Computers EC-16, 372 (1967) |
| 3028 | New Variational Approach in the Transport Theory of the Coupled Electron-Phonon System | R. W. Davies | Phys. Rev. 162, 621 (1967) |
| 3047 | Magnetic Films and Optics in Computer Memories | D. O. Smith | IEEE Trans. Magnetics MAG-3, 433 (1967) |

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## UNPUBLISHED REPORTS

### Journal Articles

| JA No. | | | |
|---|---|---|---|
| 2960 | Modern Techniques in Signal Processing | T. G. Stockham<br>B. Gold†<br>C. M. Rader†<br>A. V. Oppenheim† | Accepted by McGraw-Hill (M.I.T. Course, September 1967) |
| 3039 | Wave Optical Aspects of Lorentz Microscopy | M. S. Cohen | Accepted by J. Appl. Phys. |
| 3103 | Theory of Magnetization Ripple in Ferromagnetic Films | K. J. Harte | Accepted by J. Appl. Phys. |

* Reprints available.

† Division 6.

| JA No. | | | |
|---|---|---|---|
| MS-1947 | High Resolution Lorentz Microscopy | M. S. Cohen | Accepted by J. Appl. Phys. |
| MS-1948 | Excitation of Uniaxial-Anisotropy Relaxation Processes in Magnetic Films by a Rotating Magnetic Anneal | K. J. Harte<br>D. O. Smith<br>R. M. Anderson<br>R. C. Johnston | Accepted by J. Appl. Phys. |

Meeting Speeches*

| MS No. | | | |
|---|---|---|---|
| 1884B | Wave Optical Aspects of Lorentz Microscopy | M. S. Cohen | Third International Colloquium on Magnetic Films, Boston, Massachusetts, 18 – 20 September 1967 |
| 1947 | High Resolution Lorentz Microscopy | M. S. Cohen | International Congress on Magnetism, Boston, Massachusetts, 10 – 16 September 1967 |
| 1948 | Excitation of Uniaxial-Anisotropy Relaxation Processes in Magnetic Films by a Rotating Magnetic Anneal | K. J. Harte<br>D. O. Smith<br>R. M. Anderson<br>R. C. Johnston | |
| 1949 | New Methods of Magneto-Optical Signal Modulation and Detection | D. O. Smith | |
| 2051 | The Application of Generalized Linearity to Automatic Gain Control | T. G. Stockham | Conference on Speech Communication and Processing, M.I.T., 6 – 8 November 1967 |
| 2091 | A Microprogrammed Display Processor | G. D. Hornbuckle | IEEE Workshop, Lake Arrowhead, California, 25 – 27 August 1967 |
| 2135 | The Status of On-Line Circuit Design | H. B. Lee | NEREM, Boston, Massachusetts, 1 – 3 November 1967 |

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

# DIGITAL COMPUTERS
# GROUP 23

## I. COMPUTER SYSTEMS

### A. Networking

The PDP 338 has been installed in Washington and is being used as a remote console on a more or less routine basis. The few remaining software bugs will be shaken out as the system is used.

The synchronous data set (2,000 baud) originally scheduled for this link is complete and will be checked out. After its operation is satisfactory, the remote console operation will be shifted to this hardware.

### B. Typewriter and Input Keyboard

Fabrication of the TX-2 end of the Keyboard/Selectric logic has been completed, and check-out is near completion. Construction of the associated remote terminal is under way. The keyboard has been delivered by IBM, and the required mechanical modifications are being made. A new platen-rotator has been designed for the Selectric typewriter, and the prototype has been tested satisfactorily. The new one is cheaper and simpler than the present one and uses only standard purchased components.

### C. Display Printer

A display printer that uses heat-developed photosensitive paper has been ordered. The unit contains a CRT, optical system, and a rear-projection display screen as well as the printing unit. Indications are that we can slave the device to our present display system and fill the gap between Polaroid film display records and the curve-drawing capability of the Xerox printer.

## II. MAGNETIC FILM ENGINEERING

### A. Large Capacity Memory (LCM)

#### 1. LCM Substrate Testing

Of thirty substrates received for final inspection and testing, fourteen were accepted. Two were subsequently damaged, leaving the required ten for the one million bit memory plus two spares. On these fourteen the number of bad word lines requiring substitution of spare lines ranged from two to eight. The rejected substrates had at least one group with more than two bad lines, all due to physical defects such as pinholes in the evaporated layers or scratches in the glass surface. We are attempting to increase mechanization of the testing process and trying to reject bad substrates as early as possible in the processing.

#### 2. Stack for TX-2

All components are fabricated and tested, and final complete assembly of the memory is proceeding.

3. Extended LCM Stack

A substitute system for the plated-button word line connections has been designed and is being mocked up. It employs springloaded contacts attached directly to the selection diodes, an arrangement which simplifies assembly and provides improved contact reliability.

## B. Pattern Scribing

1. Experimental Scribing

Difficulties encountered in scribing narrow lines (less than 0.5 mil wide) in photo resist have resulted in modification of the procedure to one of ruling rather than scribing. Scribing removes resist by shaving it off, whereas ruling deforms and displaces material producing a path which conforms to the shape of the tool. In the ruling mode the diamond tool is operated backwards to the way it was intended to travel. Excellent rulings of even 0.1 mil wide lines have been produced by this method and wide variations of tool operating parameters can be tolerated. Tool loading is greater by a factor of 10 which virtually eliminates tool skipping. One disadvantage, at present, to this ruling method is that ruling must be done while the resist coat is fresh (less than 2 days old) or else the thin layer of resist remaining in the bottom of the ruled groove cannot be undercut and etching is inhibited.

2. Resist Application

For the ruling of narrow conductor spaces it is important that resist coatings be very flat. A new method for applying resist shows promise of producing these uniformly thin coatings possibly even on very large substrates. The substrate, instead of being pulled out of a vessel containing resist as is presently done, is immersed in resist and the vessel drained from the bottom. The resist coating is applied to the substrate as the resist drains from the vessel. Vacuum is applied to the vessel drain port, and the evaporating vapors are removed at a controlled rate. The resist dries uniformly, top to bottom, producing a resist layer of uniform thickness.

## C. New Film Techniques

1. Narrow Closed Flux Film Structure

In an effort to reduce the drive currents needed for thin-film memories, a three-layer film composed of a permalloy film, a copper conductor, and a second permalloy film was fabricated. When the film was etched into 1-mil lines and driven by the central conductor, the flux closure provided by the top magnetic film reduced the shape anisotropy field from 40 oe (when both films were driven externally) to a few oersteds. Work is continuing on still narrower lines, down to 0.1 mil.

2. Automatic Visual Testing of Word Lines

Tests have shown that it is feasible to perform some of the time-consuming visual inspection of word lines by means of a photocell mounted on the optical comparator presently being used for inspection. Nicks, bumps, and pinholes of significant size for memory purposes are clearly detectable.

3. Ground Plane Substrates for Magnetic Films

By choosing an appropriate thickness of evaporated copper for the ground plane, the advantage of signal enhancement can be realized without the associated disadvantage of increased digit current.* The principle is to make the time constant of the decaying image film of the order of the word rise time but short compared to the word pulse length. This time constant increases linearly with ground plane thickness and is 15 nsec for a 4-μ thick copper plane insulated from the magnetic film by 3 μ of Pyre-ML varnish. The signal using a 30-nsec rise time word current is 1.6 times that of an identical film without ground plane.

## III. SYSTEM PROGRAMMING

### A. Applications Programming

1. Mask Layout

The development of an integrated circuit mask layout program has progressed through another iteration. The program reported last quarter has been modified to utilize more exact geometries of the circuit components. In addition, a realistic set of spacing rules is now available when manipulating components on the scope surface. This new version is presently being tested and improved.

The same basic techniques used in the mask layout programs have been applied to printed circuit cards. A program under development allows a user to place and connect components on either side of a circuit card. During the next quarter we are planning some photography and etching experiments to complete the chain from graphic console design to etched card. The printed circuit card effort was undertaken first as a preliminary to the similar but more demanding problem of LSI circuit upper level metalization layout and design.

2. Constraints

Constraint-solving techniques have been utilized to produce two graphics simulation systems: one for mechanical linkages, the other for resistive networks.

The resistive network system was constructed by interfacing a constraint program with the circuit-drawing system. The interface consists of routines for generating a constraint structure from the geometry of the network and for permitting input-output of numerical values.

The two distinct areas of application were chosen in order to illustrate the versatility of the techniques being developed.

### B. Languages

1. VITAL

The VITAL I system has been extensively used without major modification this past quarter. The language systems created with VITAL I and presently in use are the PDP 8 assembler, the LEAP compiler, and a new compiler for the TIC language.

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*E. W. Pugh, V. T. Shanan, and W. T. Siegle, IBM Jour. of Res. and Dev. 11, 169 (1967).

The VITAL II system is partially designed and also partially programmed. This new system involves major changes in philosophy from the first VITAL. VITAL I has a sharp distinction between the syntactic and semantic portions of a compiler as evidenced by the two languages (FPL and FSL) used to define a compiler. The new VITAL will soften this split by providing a single language with pattern matching operations for syntactic parsing and table and stack operations for recording information during a compilation. Code generation will be initially provided by calls on generators rather than by the code bracket feature of VITAL I.

The base language for the new VITAL is defined, its compiler created using the present VITAL, and an experimental version of the run-time interpreter and routines has been written in LEAP.

2. LEAP

The LEAP compiler has been used for applications programming this past quarter as well as for programming the new VITAL interpreter. In addition to minor modifications, major changes in the base language have been made. The meaning of the structure has been changed and dynamic allocation of storage improved. Further additions to the associative features have been made. Named associative triples can be manipulated and named sets and matrix and set expressions can be passed as procedure parameters. A LEAP data structure can be saved from session to session and also exchanged between suitable programs.

## C. Debugging

Several new and improved debugging facilities have been made available through Mk 5:

(1) Changes were made to the APEX trapping executive to enable it to collect rapidly and efficiently the from-to address information about jumps and skips in user programs. This has greatly speeded up (in some cases by two orders of magnitude) tracing and flow-mapping in Mk 5.

(2) A related facility is a spy debugging mode for running programs. In this mode, all jumps and skips are monitored and collected in a circular buffer. Thus, when and if a problem develops, the recent history of the program is available. Average programs run about four to five times slower when operated in this mode; this is far better than could be achieved by running programs interpretively.

(3) Mk 5 now enables one to place metabit breakpoints on any files, not just the files which it produces or which are in the interrupted map, as was true in the past.

As an experiment, a rudimentary trapping debugger was produced which is completely separate from Mk 5. The debugger consists of two virtually independent programs:

(1) The debugger-selector enables one to select trapping modes and to place (or remove) metabit breakpoints on arbitrary registers of files. It is noteworthy that it accepts commands for these actions in a manner which is "coherent" with the conventions of the Lincoln Reckoner.

(2) The debugger-analyzer provides an analysis of a program break through a suitable message on the typewriter.

Although this debugger is at present too rudimentary for general use, it has been useful for indicating techniques and problems which are inherent in this approach to debugging.

## D. Waveform Processing

The picture processing project, which involves the nonlinear processing of photographic images, has made substantial progress during this quarter. The project has four basic phases:

(1) Fundamental digital photography
(2) Simultaneous contrast enhancement and dynamic range reduction
(3) Bandwidth reduction
(4) Psychophysical experimentation.

The results are summarized by phase.

### 1. Phase A

A scanning algorithm was programmed to permit a new standard of storing scanned pictures. This was necessary to allow the retention of low illumination information contained by 12-bit linearly quantized samples. The need for such a large number of quantum levels is imposed by the fact that images are intended for dynamic range compression during which even the most poorly illuminated areas are substantially brightened. Memory constraints dictate that picture samples be limited to 9 bits for final storage; however, the use of 9-bit linear quantization caused noise to become visible after compression. Under the new standard the logarithm of the 12-bit samples is stored and rounded to 9 bits.

Original pictures are $4 \times 5$ negatives printed on low contrast paper next to a calibrated grayscale. The original tone range of the negative can be reclaimed by the computer by referencing the grayscale.

The curve drawing display was programmed to serve as an output scanner. The size of all scanned pictures is $340 \times 340$ samples. Each picture line is scanned using a fixed beam current and a variable velocity of scan to achieve intensity modulation. Each picture line is interlaced three times when the visibility of scan lines is to be minimized. Scan time is about 30 seconds per image.

Polaroid type 42 film and type 46-L transparencies are used throughout. The nonlinear density-exposure characteristics of these photographic materials are digitally compensated at display time. A grayscale accuracy of 10 percent or better is maintained throughout the useable range of each material. Output photographs give an impression of unusually high quality.

### 2. Phase B

A flexible program for applying multiplicative filtering to images was completed and many pictures have been processed using it. The facility allows independent and precise contrast control of large area and small area brightness variations. By employing reduced large area contrast and normal small area contrast it is possible to reduce the overall dynamic range of an image so that it can be rendered using materials or equipment of limited range without severe distortion. By employing increased small area contrast coupled with decreased large area contrast, the visibility of details can be enhanced without increasing the dynamic range of an image.

These results are achieved by subjecting images to linear spatial filtering while they are in the logged state. The frequency responses used are somewhat nominal in character, a broad class of characteristics producing similar results to an uncritical observer. The effect of small differences upon the critical observer is being studied.

3. Phase C

The well-known image bandwidth compression method employing "artificial highs" was evaluated as applied to the logarithm of images. Advantages that were hypothesized on the basis of the insensitivity of the high frequencies of a logged image to variations in scene brightness are being studied. Initial results are extremely promising. Bandwidth reduction factors that are usually achieved using these methods remain available. At the same time large errors in low brightness areas are avoided.

4. Phase D

An hypothesis that part of the human vision mechanism can be modeled usefully as a multiplicative image processor, is being studied. Attempts to nullify a set of well-known visual illusions by means of a single multiplicative filter are being planned.

## IV. CIRCUIT AND NEW MACHINE DEVELOPMENT

### A. Microsystems

The effort on the parity systems has been centered on the problems of obtaining more consistent yields of basic wafers and eliminating interconnection difficulties in the second and third level metal. Sufficient progress has been made in understanding the difficulties and wafer processing will be restarted. The basic cell will be used to generate 3-, 9-, and 27-bit parity systems and combinational multipliers.

All masks have been fabricated for the associative memory array and processing will start shortly on a single cell which will be used for performance studies.

### B. Integrated Circuit Testing

A compiler has been implemented on the TX-2 (using VITAL) for a language called TIC (for Testing Integrated Circuits). The goal is to provide a remote circuit testing facility. A TX-2 program written in TIC will generate test patterns for excitation of circuits under test. The circuit response may be read and interpreted in the TX-2. When the test is complete, a different test pattern can be generated or human intervention can be requested.

The features of TIC which make it particularly useful for circuit testing are (1) concise statements for manipulating individual bits which represent boolean test variables, (2) the ability to manipulate sets of boolean variables with ordinary, machine language like operations of add, subtract, complement, shift etc., and (3) simple input/output statements for the typewriter.

# COMPUTER COMPONENTS
# GROUP 24

## I. MAGNETIC FILMS

### A. Anisotropy Spectrum of Magnetic Films

#### 1. Experiment

Rotating magnetic annealing studies of Permalloy films have been extended to 250°C. Three more processes have been observed, with relaxation times corresponding closely to those of processes 3 and 5 of Ref. 1 and process II of Ref. 2. However, as was the case for the low-temperature peak reported in the previous Quarterly Technical Summary,[3] the magnitudes of these processes are only about 10 percent of the magnitudes measured by hard-axis annealing in Refs. 1 and 2. A possible explanation is that most of the anisotropy measured in the hard-axis annealing studies came from unstable surface-diffusion processes with a broad distribution of relaxation times.

Modifications of the experimental apparatus are in progress to allow measurement in a rotating field having a period ten times longer than at present.

#### 2. Theory

Some progress has been made toward identifying the atomic anisotropy processes responsible for the measured spectrum. Simple ordered-defect models predict activation energies Q which are too large by at least 0.4 eV and frequency factors $\nu_o$ which are too large by a factor of $\sim 10^{12}$. (Measured values are $Q \sim 0.3$ eV and $\nu_o \sim 10\,\mathrm{sec}^{-1}$.) However, a model in which vacancies and divacancies diffuse to grain boundaries oriented parallel to the magnetization predicts $Q \sim 0.4$ eV and $\nu_o \sim 100\,\mathrm{sec}^{-1}$ (for nickel with 500-Å grains) and an anisotropy magnitude which is not far from the measured values.

### B. Lorentz Microscopy

According to the wave-optic theory of Lorentz microscopy,[4] a magnetic film presents a phase object to the electron beam. Therefore the standard modes of light microscopy for observing a phase object may be used in principle for observation of magnetic structure, namely: A, defocussing; B, Foucault; C, Zernike phase contrast; and D, interference microscopy. Modes A and B are the customary modes of Lorentz microscopy while C and D have heretofore not been experimentally realized. Recently mode C was attained by putting a suitable phase plate in the back focal plane of the objective lens, while operating the illuminating system under the conditions of high coherence. Under these conditions faint images of domain walls were observed.

### C. Theory of Magnetization Ripple

By combining the wave optical theory of Lorentz microscopy with a micromagnetic theory of ripple,[5] the apparent ripple wavelength $\lambda$ has been calculated. In contrast to the classical

result,[6] $\lambda$ depends on the defocussing distance Z and electron wavelength $\lambda_{el}$. For very small Z, the classical limit is reached in which $\lambda$ is proportional to the crystallite size. For very large Z, $\lambda$ is nearly proportional to the exchange wavelength. For intermediate defocussing distances, however, $\lambda \simeq 1.66 \sqrt{\pi Z \lambda_{el}}$, independent of all magnetic parameters! Experiments are under way to test these predictions.

## II. MAGNETO-OPTICS

### A. Photon and Electron Beam Accessed (PEBA) Magnetic-Film Memory

Further study of the PEBA magnetic-film memory proposed in the last Quarterly Technical Summary[3] is in progress. The principal problem is to reduce the background light from unselected bits. The previously proposed solution using an interferometer will not work since the background from the selected bit must be retained. A solution based on diffraction effects from small bits is presently under consideration. Briefly, the specular background from all bits is removed by placing a stop at the focal point of the first viewing lens, while diffracted magneto-optical signal and in-phase background are supplied from the selected bit and a thermally activated region directly under the selected bit (e.g., a $VO_2$ film which has a semi-conductor to metal transition at 65°C).

Experimental work has been started to demonstrate writing with an electron beam and reading with combined electron and photon beams.

## III. ELECTRON TRANSPORT

### A. Mean Free Path of Hot Electrons

Measurement of the mean free path of hot electrons in Al have been made by a method previously described.[3] A mean free path of 150Å ± 20Å has been obtained. This method may be a very useful new tool for hot electron studies since it should be possible to apply it to metals other than aluminum by utilizing the composite base technique[7] of having a second metal layer in the base of a triode.

### B. Collection Efficiency in Metal-Insulator Triodes

Extrapolation of the above mean free path data to zero base thickness yields a saturated transport coefficient $\alpha \sim 5 \times 10^{-3}$. Of the numerous reasons which can be postulated for this low $\alpha$, a number have been eliminated experimentally. For example: a short collector-oxide mean free path has been ruled out by experiments which show that all of the collected electrons "see" the collector side of the collector barrier; the above measurement of the mean free path in Al rules out base mean free path effects; failure of the emitter to inject hot electrons has also been ruled out as described below. At present it is postulated that the conduction bands in the collector oxide which are responsible for the barrier heights and $\alpha$ which have been observed are so narrow that injection and collection are inefficient due to high effective mass in these bands. Experiments to test this possiblity are in progress.

### C. Emitter Injection

It is interesting to note that the one-electron model of the metal-insulator triode yields some results which are in fairly good agreement with experiment. An example of this agreement

can be found by making use of the small signal relation between the transconductance $g_m$, the internal current gain $\alpha'$, and the short circuit input resistance $r_i$, which is valid for any two-terminal-pair device, namely:

$$g_m = \alpha' r_i^{-1}$$

Both $\alpha'$ and $r_i$ can be measured experimentally while $g_m$ is quite easy to calculate theoretically from the one-electron model of the device. With the exception of a multiplying factor, both the theoretical and the experimental curves for $g_m$ vs $V_{eb}$ agree quite well.

One interesting conclusion which can be drawn from this result concerns the conjecture that the low experimental value of $\alpha$ for these devices, $\sim 10^{-2}$ as compared to the theoretical value $\alpha \approx 0.5$, is due to failure of the emitter to inject hot electrons into the base metal. This is to say that 98 percent of the electrons enter the base from the emitter by a mechanism other than tunneling. In this case, however, $r_i$ would be dominated by this other mechanism and the theoretical and experimental curves for $g_m$ vs $V_{eb}$ would not agree, since it is implicit in the calculation of the theoretical expression for $g_m$ that $r_i$ is the short circuit tunneling resistance of the device. Thus the cause of the failure of the experimental devices to exhibit $\alpha$ of the order of unity must be looked for elsewhere than in the emitter injection mechanism. At the present time this appears to be the collector barrier layer.

## REFERENCES


1. D.O. Smith, G.P. Weiss, and K.J. Harte, J. Appl. Phys. 37, 1464 (1966).
2. G. Kneer and W. Zinn, Proceedings of the International Symposium on Basic Problems in Thin Film Physics, Clausthal-Göttingen, 1965, p. 537.
3. General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 August 1967) p. 11, DDC 658834.
4. M.S. Cohen, "Wave Optical Aspects of Lorentz Microscopy," to be published in J. Appl. Phys.
5. K.J. Harte, "Spin-Wave Effects in the Magnetization Reversal of a Thin Ferromagnetic Film," TR 364, Lincoln Laboratory, M.I.T. (27 August 1964), DDC 610068.
6. General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 May 1965), p. 12, DDC 619676.
7. General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 February 1967), DDC 650401.

# PSYCHOLOGY
# GROUP 25

## I. MAN-MACHINE INTERACTION ON THE IBM 360 MODEL 67

### A. Editor System

Work on the Editor System is proceeding satisfactorily, and a first test version of an actual working Character Stream Editor should be on the CP-CMS System on the Model 67 within about six weeks.

At present all the basic routines have been designed, written and checked out except for the following. The programming for accessing files and file directories is nearly finished and testing will begin shortly. An internal "procedure runner" is being built for building procedures that handle requests for the user Editors. This facility will include the ability to set up and handle separate Profiles for the users and individual Editors. The handling of procedure formats at the user level (e.g., stacking requests on one line) has been designed, and programming will begin soon. The basic routine for string matching has been blocked out and will be designed shortly; this routine is used directly by the "locate" and "find" requests, and implicitly by several others.

All the subroutine calls made by the many parts of the Editor System are in general compatible with Fortran techniques, on the grounds that most user programs are, at least for now, dominated by Fortran.

### B. Implementation of a Reckoner on the IBM 360 Model 67

Most of the routines have been written for the implementation of a Reckoner facility as outlined in the previous Quarterly Technical Summary.* The routines are being tested, debugged, and linked together using the time-shared facilities currently on the Laboratory IBM 360 Model 67. Work has progressed to the point of a demonstration of some directory and other Mediator services.

### C. Specifications for Remote Terminals

As part of the work for a SHARE subcommittee, a set of specifications has been drafted for typewriter-like terminals that are to be used remote from computers. Questions are covered that range from physical characteristics, e.g., sharp corners, and the ease of changing paper; and mechanical functions, e.g., half-line feed for superscripts and subscripts; to the communications logic, e.g., interrupts by the computer and by the user. The full set of specifications is ambitious by today's practice, but well within the range of technological feasibility. We have tried to distinguish between levels of requirements as, for example, features that are requirements for all classes of users, options that are requirements only for certain classes of users, or desirable features that are not firm requirements for any class of users.

* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 August 1967), DDC 658834.

Before publication, the draft will be widely circulated to organizations such as computer users and even terminal manufacturers.

## II. MAN-MACHINE INTERACTION ON THE TX-2 COMPUTER

### A. Speech Recognition

Work continues on revising the speech recognition programs to operate in the time-sharing environment. Substantial parts of the recognition system are now operating. A new interactive display routine has been written which makes the results of the phoneme segmentation program available at the console in a graphical form. Values of selected measurements and portions of the spectral data may be simultaneously displayed under light-pen and knob control. The display program is working, but it has not yet been widely used since the data available in the time-sharing environment are still very limited: access to our large body of digitally recorded speech awaits the availability of magnetic tape routines in APEX. The new speech input hardware, which makes the analyzer output of the Lincoln Vocoder available to users of the APEX System, is now working and the programs to use it are being debugged.

### B. APEX

The past quarter has again been one of little external change to the APEX time-sharing system. A number of minor features have been added for the convenience of users, and others have been added to simplify system maintenance. Internal reorganization has continued at a moderate rate: parts of the system have been considerably simplified, with a consequent reduction in overhead and improvement in adaptability. The system still lacks routines for handling magnetic tapes. These and new routines for handling the new TX-2 display generators are under development.

### C. Coherent Programming

The coherent library of public programs now includes about 130 entries, i.e., programs and alternate entrances to programs. Since the library seemed to be in a period of comparative stability, an effort was made to prune out entries that had been superseded, combine programs that have similar functions, and straighten out some of the programs that were left in a confusing state in the rush to get them running. A new guide to that part of the library which is called the Lincoln Reckoner has been prepared. The Reckoner is a set of public programs that belong to the coherent library and are designed for use by non-programmers who need to do calculations on-line.

Consideration has been given to the feasibility of using the LEAP compiler* to compile public programs that operate on arrays of numbers according to the conventions of the coherent library. It appears that adding the necessary features to the compiler will probably be economical, and the work has been undertaken.

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* See page 9 of reference footnoted on page 14.

## III. HUMAN INFORMATION PROCESSING

### A. Associative Structure in Memory

An index of the subjective organization of verbal items in successive attempts at free recall has been devised and is being studied. Let the number of words intervening between two given words in a recall attempt be defined as an ordinal measure of their separation in memory storage; then the index of organization is the correlation between the separations of pairs of words on one attempt and their separations on the next attempt. One advantage of this index is that it can be applied to the data from a single subject.

Some experiments in free-recall learning have been conducted which at the present stage of the data analysis seem to indicate the utility of the above measure. In these experiments the amount of time the subject was allowed to study the lists and the amount of explicit rehearsal required from the subject were parametrically varied, and seemed to change the value of the index of subjective organization in the way that would be expected. These experiments and the described index are part of a continuing investigation into cognitive and mnemonic structure in human behavior.

### B. Judgment Aspects of Sensory Recognition

A further analysis was made of data on a simulated signal-detection task in which numbers were used as "stimuli."* The results show that if the "noise level" is varied, the subject moves his criterion to track the changes. However, other effects were observed that seem to be related to the fact that numbers were used as stimuli. An experiment on an actual psychophysical task, judgment of the numerosity of dots in a random field, is planned. It is expected that less complex, more valid results will be obtained.

* See footnote on page 14.

# COMPUTER SYSTEMS
# GROUP 28

## I. COMPUTER CENTER DEVELOPMENT

Multiple remote access under the CP/67 – CMS time-sharing system has become established as a normal mode of operation for many programmers throughout the Laboratory. During the quarter ten more terminals have been installed and 35 user accounts are now established. Besides the two daily 2-hour sessions, there have been several extended sessions which not only demonstrate the increasing demand for more time, but also the improving reliability of the system over long periods.

A batch monitor and preprocessor are nearly ready for regular use under CP/67. With these two powerful tools it will be possible to take a collection of jobs and run them without change either on Operating System/360 or the batch monitor multiprogrammed to operate concurrently with other users under CP/67. This means that although CP/CMS will be running for longer periods of time to satisfy user demands, it need not delay the regular flow of OS/360 work. One reservation is that the CP/67 monitor has only G-level Fortran while Lincoln's OS/360 system has both the G-level and the larger H-level. Although the syntactical differences between the two are few, it does present a limitation for some Fortran-H users. Because of the large overlay structure of Fortran-H, it would require a considerable effort to put it under CP/CMS. Hence it is unlikely that it will be done in the near future. On the other hand, there is a big investment in Fortran-H under OS/360 that would require varying degrees of difficulty to convert to Fortran-G. Notwithstanding this stumbling block, the implementation of the batch monitor under CP/CMS is a significant milestone in our time-sharing development activities.

A considerable amount of effort has been expended in preparation for the installation of various pieces of equipment during the coming quarter. This involves both the physical installation planning and the systems programming. The devices which will have the greatest impact in both of these areas are the 2314 Direct Access Storage Facility and the 2365 Core Memory. The former will increase total disk storage capacity by a factor of 8 and transfer rates by a factor of 2. The latter will increase main memory size by one third.

Work is all but finished on a Lincoln-designed and built status board. It is located over the configuration console and within easy sight of both 360/67 operating consoles to show the Off/On status of every device by means of red and green lights. These lights are located on plastic scale models which in turn are mounted on the vertical display board according to the floor plan of the computer center. The lights are connected to the power lines of the device they represent and give a centrally located summary of all equipment along with the configuration switch settings located directly below. Because each model is to scale, the display board also serves as a handy guide for tours, physical planning and training.

## II. LISTAR (Lincoln Information Storage and Associative Retrieval System)

Over the past quarter several new programs have been implemented and tested for the LISTAR system. These include the basic searching program, routines for reading and writing to and from disk storage and a number of routines to perform special functions within the system, e.g., creating a push-down list of system parameters. Programs currently being coded will add new entries to existing files and give the user the means for adding entries from the keyboard.

# RADIO PHYSICS
# DIVISION 3

## INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 August through 31 October 1967. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary Report and the Quarterly Letter Report to ARPA.

S. H. Dodd
Head, Division 3

M. A. Herlin
Associate Head

# DIVISION 3 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1967

## PUBLISHED REPORTS

### Technical Note

| TN No. | | | | DDC and Hayden Nos. |
|---|---|---|---|---|
| 1967-2 | Three Fortran Programs That Perform the Cooley-Tukey Fourier Transform | N.M. Brenner | 28 July 1967 | DDC 657019<br>H-856 |

### Journal Article*

| JA No. | | | |
|---|---|---|---|
| 2884 | Midlatitude F-Region Densities and Temperatures at Sunspot Minimum | J.V. Evans | Planet. Space Sci. 15, 1387 (1967) |

* * *

## UNPUBLISHED REPORTS

### Journal Articles

| JA No. | | | |
|---|---|---|---|
| 3116 | Aperture Synthesis in Radar Astronomy and Some Applications to Lunar and Planetary Studies | T. Hagfors<br>B. Nanni<br>K. Stone | Accepted by Radio Sci. |
| 3141 | A Radar Study of the Lunar Crater Tycho at 3.8 and 70 cm Wavelength | G.H. Pettengill<br>T.W. Thompson† | Accepted by Icarus |

### Meeting Speeches‡

| MS No. | | | |
|---|---|---|---|
| 2008 | Radiometric Mapping of the Region of the Orion Nebula | M.L. Meeks | International Astronomical Union, Prague, Czechoslovakia, 22 – 31 August 1967 |
| 2045 | 3.8 cm Radar Observations of the Surface and Atmosphere of Venus and Mars | G.H. Pettengill | |

* Reprints available.

† Author not at Lincoln Laboratory.

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

| MS No. | | | |
|---|---|---|---|
| 2050 | 8 GHz Emission Links from the Orion Nebula | M.A. Gordon | NEREM, Boston, Massachusetts, 1 – 3 November 1967 |
| 2080 | Measurements of the Afternoon Radio Aurora at 1295 MHz | W.G. Abel<br>R.E. Newell* | Fall URSI Meeting, University of Michigan, 17 – 19 October 1967 |
| 2118 | Graphical Display of Radio Astronomical Data | M.L. Meeks | SWAP-13 Conference of Organization of Control Data Computer Users, Boston, Massachusetts, 23 – 25 October 1967 |

* Author not at Lincoln Laboratory.

# SURVEILLANCE TECHNIQUES
# GROUP 31

Group 31 is responsible for the operation, maintenance and research program of the Millstone and Haystack experimental radio/radar installations at Lincoln Laboratory's Millstone Hill Field Station.

The radars at the Millstone site are used in ionospheric research, in the development of space tracking techniques, in meteorological research pertaining to space communications and in propagation studies important to anti-ballistic missile system development. In otherwise idle time, the steerable 84-foot antenna is used as a radio telescope.

Radar technology developments centered at Haystack have resulted in the world's most sensitive X-band radar which has been used in extensive studies of the orbits and surface characteristics of the moon, Venus, Mercury and Mars. An X-band radar interferometer established between Haystack and the Westford Communications Terminal has mapped some of the more important radar features on the surface of Venus. This same experiment has established that there are at times atmospheric limitations on the use of long base line multistatic high definition radars at X-band.

A program of readjustment (rerigging) of the Haystack antenna surface is nearly complete. To date, optical measurements indicate a surface accuracy sufficient to support use of the antenna at wavelengths less than 8 mm.

## I. ENGINEERING

### A. Millstone Radar Facility

A new analog celestial coordinate converter was delivered to Millstone by the Control Systems Group. It is capable of keeping the Millstone antenna pointed to any selected spot on the celestial sphere with an accuracy of about ±1 arcmin during calibration and other observations of radio sources.

The environmental control installations have been completed within the radiometer equipment enclosure at the prime focus of the 84-foot reflector. Work has been resumed at low level on construction and installation of advanced solid-state receiver components for the L-band tracking radar system. In addition, remote control of L-band receiver front ends has been provided, eliminating the requirement for frequent trips to the antenna pedestal.

Installation of additions to the transmitting and microwave complex of the UHF zenith-looking ionospheric radar, designed to permit transmission of pulse pairs in alternating polarizations, has continued at a modest level, including the installation of most of the second UHF waveguide run from the transmitter area to the zenith antenna and the installation of a diode phase shifter in the drive line to one of the final klystron amplifiers. The so-called "two-pulse" system which will result from these modifications will provide a radar which can yield simultaneously good height resolution and good definition of the doppler spectrum of backscatter echoes from the E region.

Late deliveries of matched filter banks have slowed down the completion of the all-range spectrum analysis system which will utilize in real time data from the ionospherie radar operating in the long-pulse mode. The associated computer program has been written and is under test.

A speeial arrangement of the L-band system was set up to calibrate the weather radar using satellites of known cross section. The radar transmitted two pulses, one 2 msec long and one 10 μsec, separated by 300 μsee. The long pulse echo was used by the traeking radar as usual while the 10 μsec echo was quantized and sent to the computer. The data sampling window, computer interrupts and receiver calibration noise pulse were all slaved to the range tracking gate so that the short pulse echo always came within the sampling window, and the computer timing was correct.

### B. Haystack Research Facility

The surface readjustment procedure (rerigging) for improving the Haystack antenna began on 25 September 1967. To minimize thermal distortions, all measurements and adjustments were made at night from 9:00 p.m. to 5:00 a.m. Preadjustment data yielded an rms deviation of 0.037 inch corrected to 45 degrees elevation angle under nighttime conditions – in close agreement with results obtained in 1966.

Great care was used in beginning the actual adjustments until it was established that control of the surface was quite in aceord with eomputer predietions. The most time-consuming operation was the collection and reduction of measurement data necessary to evaluate progress.

After six weeks of work, the rms deviation was reduced to 0.017 inch. The antenna will be returned to operation on the scheduled date, 10 November 1967.

The Planetary Radar receiving maser was operated by filling the dewar (which was defective) with liquid helium every four hours, through the end of the radar operating period on 13 September. Consistent 60°K system temperatures were achieved with maser No. 1 for the planetary ranging and Hayford interferometer experiments. Radiometric observations were not scheduled because of the helium expense and manning problem occasioned by the short dewar hold time.

A rebuilt dewar (No. 3) was tested on the ground and then installed with maser No. 1 in the Planetary Radar box while it was off the antenna during rerigging. This replacement dewar seems to be able to support 18-hour operation periods on the basis of limited testing. A series of receiver system temperature measurements and noise tube injection calibrations has begun.

The waveguide arrangement in the Planetary Radar receiving system is being modified to reduce system losses in the radiometer configuration and to give greater flexibility in the operation of calibration equipment.

From 1 August to 15 September, the transmitter supported planetary operations at power levels of 300 to 350 kw. The two klystrons presently in use, Serial No. 1 and Serial No. 7, have logged 518 RF hours and 107 RF hours, respectively. Since 15 September, the PR box has been located at Test Dock No. 1 and no RF operations have been possible because of radome painting, rerigging and radiometer operations. This free period has permitted a number of modifications that will ease transmitter operation, improve reliability and help in evaluating system performance.

A central monitoring console from which the Test Director can assess system status before and during operations is presently about 75 percent installed. Its use will reduce substantially the operating manpower requirement.

A new mass storage system for the Haystack computer has been installed, based upon four so-called "disk-pack" drives and a mass storage controller. It will replace the older disk file, providing 4 percent more capacity, a higher transfer rate and a lower rental rate. An associated software system is under test.

A program has been written for the Haystack computer which replaces the IBM 7094 program that previously has generated all of the master ephemeris tapes for the Haystack pointing system. As in the case of the earlier program, the basic data required came from the U.S. Naval Observatory.

## II. SPACE SURVEILLANCE

### A. Computer-Aided Tracking

The real-time tracking and orbit-fitting group of Millstone computer programs called the MHESPOD system uses current observations and an iterated differential correction process to update a predicted satellite ephemeris in real time. Actual satellite observations show that this program can provide computer steering of the antenna to better than 1 milliradian accuracy after the program has gone through only two iterations (30 sec real time).

This level of performance has been possible for data from weak, fluctuating returns as well as for high-quality data. The evidence suggests that both the amount and accuracy of tracking data can be enhanced in the case of the weak targets by using computer steering of the radar, applying monopulse boresight angle errors as corrections to the pedestal position data in deriving true target azimuth and elevation.

Another feature of the program permits the establishment of an initial state vector from a modest run of initial observations. If the ephemeris resulting from this is frequently updated as new observations are obtained, the technique can successfully generate smooth real-time steering commands to another sensor having significantly smaller beamwidth than the Millstone tracker.

In response to requests, documentation concerning the real-time (MHESPOD) and the non-real-time (NRTPOD) precision orbit programs now in use at Millstone have been forwarded to the Project AMOS observatory in Hawaii and to the Space Defense Center, Colorado Springs.

### B. Tracking Support

An increasing portion of Millstone's tracking time is devoted to support of the MITRE-Millstone radar interferometer development, in view of MITRE's increased assistance in site operations.

Several tracks on calibration spheres were made for accurate calibration of the Millstone narrow-pulse weather radar configuration which was operated through the summer in support of the Laboratory's Space Communications program.

A number of tracks on selected objects were made to explore atmospheric propagation errors in tracking at lower elevation angles. This sort of information is valuable in studying certain anti-ballistic missile configurations.

## III. LUNAR STUDIES

No further data were taken in support of NASA Contract NSR 22-009-106 during the past quarter, but a final report was issued covering those aspects of the earlier measurements dealing with the statistical properties of the lunar surface. All the data taken in connection with the high resolution 3.8-cm mapping studies have been reduced and maps prepared. The contract terminates 31 December 1967.

## IV. PLANETARY STUDIES

### A. Echo Delay Observations

Precision measurements of echo delay and doppler frequency shift at Haystack (3.8 cm) for the planets Mercury and Venus were made during August and up to 14 September when the Planetary Radar Box was removed from the antenna prior to the start of the rerigging sequence. Measurements at Millstone (23 cm) were made of Venus over the period 21 August to 19 October in order to compare with those at Haystack as well as to fill partially the interval during which Haystack was out of service for surface upgrading.

### B. Interferometric* Radar Studies of Venus at 3.8 cm

Interferometric radar observations of Venus at 3.8 cm wavelength were carried out from mid-August to mid-September around inferior conjunction. These involved both straight and coded CW transmissions at about 250 kw from Haystack and the echoes were received and coherently recorded simultaneously at the Haystack and Westford Communications Terminal antennas. Partial reduction of these observations has yielded success in isolating radar reflecting features on the planetary surface. A resolution of $1 \times 3$ arcsec was achieved† across and along the doppler axis, respectively. As a byproduct of this experiment, considerable data have been obtained concerning the cross section of Venus as a function of time. It was also established that phase coherence between the sites was markedly disturbed on days when meteorological conditions were poor. A means was devised in the processing, however, for using the echo from the leading edge of the planet as a reference, so that the phase difference data could be recovered, yielding relative positions of planetary features.

These experiments required the development of a bistatic ephemeris computer program and several data processing routines associated with the two basic modes of operation. Software to permit display of the data on planetary coordinates is being developed.

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* With the so-called Hayford (Haystack-Westford) radar interferometer.

† Roughly equivalent to what could be achieved optically from earth, were not the planet obscured by clouds.

## V. ATMOSPHERIC STUDIES

### A. Thomson Scatter

Observations at UHF and L-band have continued at Millstone at their current rate of two 24-hour and one 12-hour run per month, respectively. A technical report covering the 1964 observations has been prepared.

Beyond observations, the major effort this period has been on system improvements as described earlier.

### B. Auroral Studies

Additional spectral analyses of Millstone data were made to test the two-stream instability theory of Farley as an explanation of radio auroral echoes. It is found that the spectral pattern of auroral echoes from either side of the magnetic meridian is skewed in a manner similar to that of echoes from an equatorial electrojet. This skewness is explained by Farley, in a recent extension of the theory, in terms of secondary waves produced by the ion-acoustic waves in the electrojet.

## VI. RADIOMETRIC TECHNIQUES

### A. Instrumentation

An uncooled parametric amplifier covering the OH lines (1612 to 1720 MHz) has been installed in the new environmental enclosure at the prime focus of the 84-foot Millstone reflector, and the aperture efficiency of the antenna in this configuration (Cassegrainian subreflector removed and clamped at the apex of the paraboloid) has been measured as 42 percent. Observations of the OH spectral lines can now be made with the low-noise system at Millstone.

At Haystack a new tunnel-diode amplifier covering the 15- to 16-GHz band was installed in the Radiometer Box. This modification reduced the system temperature of the continuum radiometer system from 2500°K to 900°K, giving almost a three-fold increase in sensitivity. Also the new 35-GHz radiometric system was installed and operated on the Haystack antenna. This system consists of two superheterodyne receivers, each with a 30-MHz bandwidth, which are alternately switched between the antenna and load. In this way one receiver is always on the antenna. The system temperature at 35 GHz is 3000°K!

### B. Haystack Gain and Pattern Measurements

Just prior to the rerigging operation, measurements were made to document the gain and antenna patterns at 8, 15.5, and 35 GHz. Similar measurements will be made after the rerigging. Antenna patterns were obtained by using the radiometric mapping program to observe cosmic radio sources of very small angular size. These measurements disclosed sidelobes that were down from the main beam by 18 db at 8 GHz and 13 db at 15.5 GHz. The 35-GHz performance was measured with a pattern transmitter 26 miles away on Pack Monadnock mountain. (The subreflector was adjusted to focus the antenna on the transmitter.) This measurement, together with a scan across the limb of the sun, disclosed a jumble of sidelobes extending out 0.2° from the beam axis. The surface tolerance before rerigging was thus proved inadequate to support operations at 35 GHz.

### C. Radio Astronomy

The Radiometer Box was installed on the Haystack antenna for five days of around-the-clock observations. No radiometric observations were made with the maser receiver in the Planetary Radar Box because of previously-mentioned heat leaks in the liquid-helium dewar.

The new 15.5-GHz radiometer was used to make high-resolution maps in the region of thermal radio sources W3, W75, and the Orion Nebula. Haystack was also used to search for short-period variations in OH emission from W3. No significant variations were found with characteristic times of the order of hours. The sources known to show variations in periods of the order of days were measured in a continuing program of observations.

Data taken in previous long-baseline interferometer experiments – involving Haystack and antennas in Green Bank, West Virginia and Hat Creek, California – were reduced on the CDC 3300 computer. These data reductions for the first time reveal the structure of the bright OH emission points. In W3, some features show elongated structure with the long axes roughly parallel to the galactic plane. The length of one feature is 0.050 arcsec and the width 0.005 arcsec. Other features are totally unresolved at 0.005 arcsec.

### D. Calibration Equipment for ALTAIR (Project PRESS)

Radio astronomical methods are to be employed in the measurement and calibration of the new ALTAIR antenna. Since Group 31 has had extensive experience in both the scientific and engineering aspects of this problem, the Group is consulting with the PRESS site personnel in developing measuring procedures. The Group is also helping to specify and construct radiometric equipment for this task.

## VII. SPACE COMMUNICATIONS – PROPAGATION STUDIES

Scheduling demands precluded making weather observations after 15 August 1967. Analysis of the data taken with the Millstone Radar and with the Haystack radiometers during the summer has verified the validity of employing radar backscatter measurements of precipitation to predict the effects of hydrometeors on microwave propagation circuits. Using a pencil-beamed weather radar, data can be obtained on elevated paths typical of earth-satellite links.

# RADAR
# DIVISION 4

## INTRODUCTION

The General Research activities in the Radar Division for the period 1 August through 31 October 1967 include work in three areas: (1) the development of improved microwave components, (2) the use of solid-state elements in microwave systems, (3) millimeter wave radar technique studies. Principal activities of the Radar Division are described in reports on RDT, PRESS and BMRS.

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head

# DIVISION 4 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1967

## UNPUBLISHED REPORTS

### Journal Article

| JA No. | | | |
|---|---|---|---|
| 3020 | Mounted Diode Equivalent Circuits | W.J. Getsinger | Accepted by IEEE Trans. Microwave Theory Tech. |

### Meeting Speech*

| MS No. | | | |
|---|---|---|---|
| 2077 | A Multi-Diode Power-Combiner | W.J. Getsinger | NEREM, Boston, Massachusetts, 1-3 November 1967 |

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

# MICROWAVE COMPONENTS
# GROUP 46

## I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave needs of the Laboratory. Contributions are made to the General Research Program through the support of the Haystack Microwave System, operation of a high-power microwave laboratory, study of the problems of solid-state diode-using devices and techniques for computer design of these devices, studies of very-high-gain antennas and antenna feeds, and participation in a millimeter-wavelength program.

## II. HAYSTACK MICROWAVE COMPONENTS

### A. Planetary Radar (PR) Box

A gas-tube pulsed attenuator for use as a maser protector has been described previously. It was reported earlier that the attenuator was limited to a peak power input of approximately 20 watts because of sharply rising leakage power. A modification of this device, in which a resonant section with a Q of 15 is used at the input of the attenuator, has been tested. The peak leakage power is less than −60 dBm for a peak input power of 3 kW. The insertion loss is less than 0.1 dB, and the average power handling capability is in excess of 300 W.

### B. Model Study of an L-Band Feed

Experimental work on the 1/20 scale model of the Haystack antenna indicates that high aperture efficiency at wavelengths as long as 21 cm cannot be obtained with the present three-reflector system. Model work with various sizes and curvatures of subreflectors and feed dishes showed that the efficiency of the antenna aperture could be increased to slightly over 50 percent at the expense of an increase of perhaps 50 percent in the sizes of the subreflector and the primary feed dish. In addition, the Clavin feed would have to be replaced by a simple focal-point feed, and the curvature of the subreflector would have to be changed.

Since the above approach would not be feasible, some horn feeds were tried with the scaled version of the existing Haystack subreflector. A horn with an aperture of $1.9\lambda \times 2.5\lambda$, and located 35 feet from the vertex of the main dish, produced an aperture efficiency of slightly over 55 percent and acceptable radiation patterns. To obtain this performance, the subreflector had to be defocused by $1.66\lambda$ away from the main dish. Somewhat lower gain was obtained with a horn having an aperture of $2.5\lambda \times 4.5\lambda$ and located 30 feet from the vertex of the main dish. With the larger horn, the defocusing of the subreflector was about $0.8\lambda$ away from the main dish.

The results of the model study are now being evaluated, and a more detailed report will be presented at a later date.

## III. SOLID-STATE COMPONENTS

### A. Diode Measurements

The thirty-inch diameter, radial transmission-line cavity, which will be used to measure the impedance of packaged varactor diodes at frequencies from 6 to 40 GHz, is now under construction and should be completed soon.

Mandrels have been fabricated for diode test fixtures which will be used for the measurement of varactor diode cutoff frequencies at 35, 45, 55, 70 and 100 GHz. Equipment has also been received for the direct mounting of semiconductor chips in waveguide sections.

### B. Power Combiners

The 18-diode power combiner, which was employed as a doubler from 500 to 1000 MHz, has been rebuilt as a 12-diode power combiner because of the accidental loss of several diodes during experiments. The high power diplexer has been completed and successfully tested.

It was anticipated that the 12-diode power combiner would deliver about 90 watts at 1000 GHz for an input of 160 watts at 500 GHz, with maximum output power determined by thermal overloading of the diodes' junctions. During tests, the power combiner delivered a maximum of 50 watts at 1000 GHz with a 90-watt input at 500 GHz, with the maximum output power limited by a nonlinear switching action. The cause of the switching action is not known, but is the subject of investigation at this time.

### C. Study Programs

Study programs have been initiated in two areas: gain-saturation and intermodulation distortion in parametric amplifiers, and analysis of balanced-diode, low-noise mixers. The purpose of these studies is to enhance Group 46's capabilities in these areas of increasing technical importance. It is expected that the studies will lead to useful publications and improved components for low-noise receivers.

## IV. MILLIMETER-WAVELENGTH PROGRAM

As the demand for frequency allocations continues, it seems inevitable that millimeter waves must take on an important role in the radio spectrum; frequencies corresponding to wavelengths between 1.0 cm and 1.0 mm constitute a band about nine times as wide as the whole of the presently exploited part of the spectrum. At these wavelengths, attenuation in the atmosphere is important, but there are bands in which the attenuation is moderate, and there are uses for the parts of the spectrum in which the atmosphere severely limits the range at which a signal can be detected.

Recent work on millimeter waves at the Laboratory has been reported quarterly in connection with Contract NSR 22-009-106 with the National Aeronautics and Space Administration. The object of the work has been to measure some electromagnetic properties of the moon's outermost region, using a wavelength of 8.6 mm, corresponding to a frequency of 35 GHz. From its inception date in 1965 when available CW power at 35 GHz was limited to a few tens of watts, the project has counted on having a one-kilowatt transmitter with a stability of about 1 Hz. Realizing this goal has been the project's major accomplishment up to this time. The radar is still under

construction, but the transmitter, receiver, signal-processor, and antenna have been completed. Only the control system remains to be finished before the radar can be put into operation with circular polarization. Under design is a new RF head that will permit reception of both circular polarizations in two separate channels; a dual-channel IF rack and accompanying signal-processing units are finished.

The 1-kw transmitter consists of three principal sections: a stable 5-MHz oscillator, a multiplier, and a power amplifier. All three are now available from commercial firms as a result of the millimeter radar project. The 35-GHz amplifier is the Varian Associates 928A; its major parameters are: an input power of 5 to 6 mW, an output power of 1.0 to 1.2 kW and an efficiency >10 percent. Though developed for a radar, it is potentially useful for communication systems.

# ENGINEERING
# DIVISION 7

## INTRODUCTION

Engineering support of the Laboratory's General Research program usually consists of the design and fabrication of mechanical and electromechanical improvements to the large facilities at Haystack and Millstone Hills, and the design of devices for solid state research. This has also been true in this quarterly period from 1 August to 31 October 1967. At Haystack, while the 120-foot reflector is being rerigged for greater contour accuracy, thus permitting operation at higher frequencies, the entire radome is being refurbished. At Millstone, while screening is being supplied at the feed horn and support spars of the 220-foot zenith antenna to reduce ground clutter, the newly installed coordinate converter is being aligned to minimize pointing errors.

An important new development has been the establishment of a facility for producing hybrid integrated circuits. Its goals are to provide prototype integrated circuits to the Laboratory's system designers, and to undertake research in the development of new devices and techniques.

J. F. Hutzenlaub
Head, Division 7

# DIVISION 7 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1967

## PUBLISHED REPORT

### Technical Note

| TN No. | | | | DDC and Hayden Nos. |
|---|---|---|---|---|
| 1967-27 | Micropower Error-Correcting Redundant Circuit Design | R. E. McMahon<br>N. B. Childs | 23 August 1967 | DDC 659750<br>H-859 |

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## UNPUBLISHED REPORTS

### Meeting Speeches*

| MS No. | | | |
|---|---|---|---|
| 1802A | Maser Dewar for System Operation | A. M. Rich<br>W. Peterson† | Cryogenic Engineering Conference, Palo Alto, California, 21 – 23 August 1967 |
| 2076 | Metal Space Frame Radome Design | R. D'Amato | International Symposium on Structures Techniques for Large Radio and Radar Telescope Systems, M.I.T., 18 – 20 October 1967 |

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

† Author not at Lincoln Laboratory.

# MECHANICAL ENGINEERING
# GROUP 71

## I. HAYSTACK MASER

For the past six months the number one maser has been operating on a 4-hour liquid helium fill-time eyele. This has been due primarily to a thermal short whieh existed between the helium and nitrogen dewars. When the PR box was taken down from the antenna in September, the maser and dewar were removed, disassembled and inspeeted. It seems that the thermal short was eaused by the eompression of the balsa spaeers and supports between the nitrogen and helium dewars. This has been eorrected by ehanging to a spider support which has three spokes that hold the bottom of the helium can above the bottom of the nitrogen dewar. This revised dewar has been designated number two; it is antieipated that it will be a working unit early in November.

The number one maser has been installed in the number three dewar whieh previously had a eold helium leak that was repaired by tinning the heli are welded seams. The resulting hold time for a single fill of helium is now 19-1/2 hours. This was eheeked in the Laboratory prior to installation in the PR box.

Dewar number four, purchased from Cathy Enterprises, supplier of the original equipment, was received. It was found to be defeetive and was returned for repair. Component parts for still another dewar are on hand. However, sinee the helium can was fabrieated by the same company whieh made the number three dewar, it was felt that the heli are welded joints should be tinned prior to assembly.

The elosed eycle refrigerator was operated with the third maser installed early in September. Although the refrigerator attained a temperature of 4.2 °K, the maser did not. A study is being initiated to determine the best way to improve the heat transmission from the maser to the eold station.

## II. MILLSTONE 220-FOOT ZENITH ANTENNA

A 14-foot diameter by 6-foot high eonieal sereen has been installed around the feed horn to reduee ground elutter on the two-pulse UHF system. Also, a 4-foot wide nylon spaee net has been mounted on the inside of the three spars whieh support the feed horn to absorb ground elutter due to spar refleetions. Preliminary data indicates an improvement, and further data evaluation is being made.

Installation of a WR-2100 waveguide reeeive-line from the antenna to the transmitter building is continuing.

## III. SOLID STATE

Axial tensile stresses have caused struetural failures in the carbide liner of the hydrostatic high pressure cell in the horizontal plane. To correet this fault, a clamping press that provides a vertieal elamping foree has been designed.

The clamping press is a hand-pump operated unit of 300 tons capacity which actuates the piston of the liquid cell. The vertical clamping force is provided by the housing of the clamping press and the 1000-ton Clifton main press.

One unit is in operation and a second unit is on order.

## IV. LUNAR RADAR

A preliminary survey has been made to determine the feasibility of converting this 28-foot antenna at the Laboratory to a Cassegrainian configuration. The proposal is for a 2.8-foot diameter hyperbolic secondary reflector. A preliminary analysis indicates that a tripod support structure consisting of three 5-inch diameter, 1/8-inch wall aluminum tubes would be required to maintain the position of the secondary reflector within ±0.040 inch in a 25-mph wind. The tripod support structure would attach to the ring frame at the outer edge of the main antenna. Allowance for axial and tilt adjustments of the secondary reflector would be inherent in the design of the support system. It was concluded from the survey that no unusual problems would be inherent in this conversion.

A new azimuth bearing has been received and will be held until performance of the antenna indicates the need for a replacement.

## V. CAMROC

Design optimization studies of this proposed 440-foot diameter radio telescope are continuing with the latest results detailed in a Lincoln Laboratory interim status report entitled, "CAMROC Hammerhead Antenna Concept."

In this newest design the principal departures from the original Hammerhead concept, which was outlined in the Cambridge Radio Observatory Committee report "A Large Radio-Radar Telescope CAMROC Design Concept" dated 15 January 1967, are:

1. A reduction of panel weight from 0.5 psf to 0.3 psf.
2. The antenna sky coverage in elevation will be from 2-1/2° to 82-1/2° above the horizon.
3. The eight hydrostatic elevation bearing assemblies (approximately 52 feet in diameter) which were designed external to the Hammerhead truss are now located on axis. Design studies are being made for hydrostatic and rolling element bearings varying in diameter from 2 to 6 feet.
4. The distance from the primary reflector vertex to the elevation axis has been reduced from 42 to 21 feet.
5. A Gregorian secondary reflector with prime focus feed capability has replaced the Cassegrainian secondary reflector design.

# COMPONENT DESIGN AND DEVELOPMENT
# GROUP 73

## I. HYBRID INTEGRATED CIRCUIT FACILITY

The Hybrid Integrated Circuit Facility, established in the past six months, will provide prototype integrated circuit fabrication for the Laboratory circuit and system designers, and undertake research in the development of new devices and techniques.

The general work areas of the facility, either established or under development, include:

1. Circuit Evaluation and Testing
2. Computer-Aided Circuit Analysis
3. Thin Film Processing
4. Thick Film Processing
5. Semiconductor Processing
6. Bonding and Final Assembly
7. Packaging
8. Environmental Testing

### A. Circuit Evaluation and Testing

The circuit evaluation and testing section interfaces between the circuit or system designer and the materials processing area. Each circuit request (throughout this report the term circuit will be used to define simple circuits as well as complex subsystems) is reviewed in terms of the integrated circuit process characteristics and the circuit requirements to insure that the finished circuit will meet the originator's specifications. It is important to note that many of the limitations of the integrated circuit process frequently necessitate considerable redesign of the original circuit, but it is equally true that many inherent processing characteristics can be used to enhance the circuit performance or utility. This dialogue with the circuit designers offers an excellent opportunity to educate them in the techniques of integrated circuit design so that their future work will be based on a more intimate knowledge of integrated circuit processes.

This section also performs electrical measurements on the integrated circuit components for uniformity and reliability and tests all circuits after each significant processing step as well as prior to delivery.

### B. Computer-Aided Circuit Analysis

The computer-aided circuit analysis section is a vital part of the integrated circuit fabrication, particularly in reducing processing time and insuring that circuit optimization is achieved.

The initial work of this section has concentrated on the debugging and development of the CIRCUS circuit analysis program, and its application to circuits being fabricated by the Integrated Circuit Facility. A printer plotter program has been incorporated within the main program in

order to provide graphical outputs concurrent with initial program execution, thereby significantly increasing the usefulness of the over-all analysis program.

Experience is now being accumulated in the area of device modeling and a time-shared teletype terminal has been acquired, connecting with the Laboratory's 360/67 computer.

Efforts are also under way to incorporate the CIRCUS program into the time-sharing system in order to allow general use of the program quickly and effectively through the consoles distributed around the Laboratory.

Several approaches to computer aided layout problems involving printed circuit as well as integrated circuit layouts are currently being considered, and proposals in this area are being circulated.

### C. Thin Film Processing

Thin film and thick film processes are presently the primary techniques employed in circuit and subsystem fabrication. Both processes provide conductor, resistor, and capacitor implementation. Active devices and monolithic circuit chips are currently purchased commercially and interconnected by bonding techniques as part of the thin or thick film networks.

Thin film processing employs vacuum evaporation and sputtering to deposit resistors, conductors, and dielectric films. Tantalum, chromium, and nichrome films with sheet resistances up to 500 ohms per square and line widths down to 1 mil are used for resistors. Aluminum and composite films of chromium gold and titanium gold are used for conductors.

RF sputtering techniques are currently under development, particularly for the deposition of insulating films of glass, quartz, silicon nitride, and aluminum oxide. Dielectric films are used not only for capacitor fabrication, circuit encapsulation, and multilayer interconnection implementation, but for many new element and device designs. Anodization techniques are also being developed to use as a dielectric and as an impervious encapsulating film on tantalum resistors.

Considerable effort in the thin film section will be directed toward achieving smaller conductor and resistor sizes consistent with the limitations of the contamination in the area, and in achieving large area dielectric coatings that are free from pin holes.

### D. Thick Film Processing

The thick film process employs screening and firing of resistor and conductor pastes in the fabrication of resistor and capacitor networks. The use of both thin and thick film techniques does not represent duplication, since the different characteristics inherent in each process provide great flexibility in circuit implementation.

Resistor, conductor, and dielectric furnaces have been installed for thick film processing, and the evaluation of available thick film paste material is nearly complete.

Associated equipment such as prebaking ovens, screen printers, alignment fixtures, and mixing equipment is currently being used to fabricate preliminary prototype circuits.

A complete characterization of the thick film materials and the resulting circuit networks will be completed within the next few months.

### E. Semiconductor Processing

The semiconductor section is just now being staffed and will be concerned initially with improvements in bonding and final fabrication of the passive networks with device or circuit monolithic chips. The handling, testing, and fabrication of monolithic chips will be improved and the investigation of new fabrication methods using beam lead and face bonding will be undertaken. Work in silicon oxide for capacitor fabrication and the interconnection of large numbers of monolithic circuit chips will be initiated as early as possible.

### F. Packaging

Packaging of the integrated circuits is via the typical ceramic flat packs or TO-5 metal units. Essentially, it is desirable to achieve a hermetic seal that will protect the materials and reduce long-term degradation of component values. The limited availability of packages and the need to restrict package configurations to reduce testing and handling problems conflict seriously with the desire to achieve optimum packaging for the varied circuit configurations. The present work attempts to solve this problem by packaging subsystems rather than single circuits, but other approaches are under investigation that hopefully will eliminate much of the packaging dilemma.

### G. Environmental Testing

Environmental testing presently includes a 2-week thermal soak with power applied for all circuits. A portion of each circuit batch is subjected to a long-term life test at an elevated temperature. Hermeticity, centrifuge, and vibration tests are only partly implemented but should be complete within a few months.

### H. Further Developments

The over-all direction of the facility is influenced not only by the techniques and processes that are successfully developed, but primarily by the needs of the Laboratory circuit and system designers. In this respect it is interesting to note that in addition to the requests for fabrication of prototype circuits and subsystems, many designers familiar with the integrated circuit processes are actively interested in the development of new elements or devices peculiar to their own design problems. In many cases these are relatively simple elements requiring dielectric insulation or unique metallization that can be implemented with the facility. It is expected that this material processing work may become a significant portion of the work done in the Integrated Circuit Facility.

# PHYSICAL PLANT ENGINEERING
# GROUP 75

## I. HAYSTACK RADOME REFURBISHING

A complete refurbishing of the 150-foot diameter Haystack Hill radome is under way. This includes caulking all exposed seams, patching all visible craeks in the fiberglass panels, inspecting all hubcaps for possible water leakage, washing and brushing to remove chalking from existing paint, priming, and painting two coats.

This work is an effort to minimize water absorption by the fiberglass radome panels, minimize solar radiation effects on the antenna, minimize leakage through the radome onto critical equipment, and, in general, extend its usable life.

The silicone paint and primer selected have been specially formulated for the job and should provide a protective life expectancy of ten years or more. We are attempting to coat the radome with a minimum of two mils and a maximum of three mils of paint. Any less would seriously detract from the life expectancy and any more could begin to attenuate the antenna signals.

In eonjunction with the above, we plan to remove and replace one of the top fiberglass panels for testing in an effort to evaluate its durability after exposure to New England weather since 1961.

## II. SURVEY OF BASE LINES

Interconnecting base lines have been surveyed and calculated which join the intersections of the azimuth and elevation axes between the following antennas:

Millstone Hill and Haystack Hill
Haystack Hill and Westford
Millstone Hill and Aggasiz (Harvard)

The lines represent the true slope distance from point to point, the horizontal distance, the forward and back azimuths, and the elevation or depression angle from one site to the other.

The final toleranees for these measurements vary, but in general, they are as follows:

| | |
|---|---|
| Distances 4000 feet or less | 1/20,000 |
| Distances of 8 miles | 1/100,000 |
| Azimuth Angles | ±7 arc-sec |
| Elevation Angles | ±6 arc-sec |

# CONTROL SYSTEMS
# GROUP 76

## I. HAYSTACK

Rerigging of the 120-foot Haystack reflector to make possible operation at higher frequencies began in this quarter. As of 19 October, rms surface accuracy had been improved from 0.037 inch to 0.023 inch. It is expected that the rerigging operation will be completed by 10 November 1967.

A tentative decision was reached to replace the existing servo valves in the azimuth and elevation power drives with variable displacement pumps (A-ends). Advantages expected to derive from this change include improved resolution at very low (sidereal) rates, reduction of hydraulic pressure to the motors at zero speed, and complete isolation between the azimuth and elevation systems. This change, together with the planned improvements to the replenishing system, should provide reliable operation of the power drives at the originally designed rates and bandwidths.

## II. MILLSTONE RADAR

The analog celestial-to-terrestrial coordinate converter was installed at Millstone Radar. Measured rms errors are 1.7 minutes of arc in deflection and 1.3 minutes of arc in elevation. It is expected that further refinements of the alignment procedure will permit the design goal, 1.0 minute of arc per axis, to be attained.

## III. 8-MM RADAR

Installation of the Group 76 portion of a digital recording system for the 8-mm radar on the Building D roof was completed. This equipment accepts binary coded decimal inputs representing azimuth, elevation, output power, horizontally and vertically polarized signal strengths, time, date, and event number. In turn, this information is used to provide decimal outputs at intervals of 28 seconds from an IBM 526 card punch. Peripheral equipment includes binary-to-binary coded decimal converters for azimuth and elevation, a digital clock and an event counter. The system has been checked out and operated satisfactorily, to the extent possible in the absence of analog-to-digital encoding circuitry.

## IV. LASER TRACKERS

A proposal and cost estimate for a digital control system for the Millstone Hill laser complex were completed. This system would provide coordinate conversion between the Nike-Ajax azimuth-elevation and the Powertronics elevation-traverse mounts, permit slaving of either mount to the other, provide pointing information for orbital or stationary targets, and furnish decimal angle readout data for display.

Design of modifications to improve the performance and reliability of the Nike-Ajax tracker was completed. Improvements will include a new control console, simplified power and control switching, modification of the position servo, and replacement of vacuum tube circuitry with solid state circuitry wherever feasible.

# SOLID STATE
# DIVISION 8

## INTRODUCTION

This section summarizes the work of Division 8 from 1 August through 31 October 1967. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

# DIVISION 8 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1967

## PUBLISHED REPORTS

### Technical Report

| TR No. | | | | DDC and Hayden Nos. |
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| 435 | LCAO Secular Determinant Program | D. Esterling | 12 July 1967 | DDC 659749 |

### Journal Articles*

| JA No. | | | |
|---|---|---|---|
| 2805 | Spin Waves in Paramagnetic Fermi Gases | L.L. Van Zandt | Phys. Rev. 162, 399 (1967) |
| 2939 | Fourier Expansion for the Electronic Energy Bands in Silicon and Germanium | G.F. Dresselhaus<br>M.S. Dresselhaus | Phys. Rev. 160, 649 (1967) |
| 2964 | Temperature Dependence, Orientation Correlation, and Molecular Fields in Second-Harmonic Light Scattering from Liquids and Gases | D.L. Weinberg | J. Chem. Phys. 47, 1307 (1967) |
| 2973 | The Crystal Structure of Neodymium Monotellurooxide-$Nd_2O_2Te$ | P.M. Raccah<br>J.M. Longo<br>H.A. Eick† | Inorg. Chem. 6, 1471 (1967), DDC 658765 |
| 2977 | Interband Magnetoreflection and Band Structure of HgTe | S.H. Groves<br>R.N. Brown†<br>C.R. Pidgeon† | Phys. Rev. 161, 779 (1967) |
| 2989 | A Thermodynamic Investigation of the Compounds $In_3SbTe_2$, InSb and InTe | A.K. Jena†<br>M.B. Bever†<br>M.D. Banus | Trans. Met. Soc. AIME 239, 1232 (1967) |
| 2998 | Hall Coefficient and Transverse Magnetoresistance in HgTe at 4.2°K and 77°K | T.C. Harman<br>J.M. Honig<br>P.H. Trent | J. Phys. Chem. Solids 28, 1995 (1967) |
| 3025 | InSb-GaAsP Infrared to Visible Light Converter | R.J. Phelan, Jr. | Proc. IEEE (Correspondence) 55, 1501 (1967) |
| 3060 | Polarization and Intensity of Raman Scattering from Plasmons and Phonons in Gallium Arsenide | A. Mooradian<br>A.L. McWhorter | Phys. Rev. Letters 19, 849 (1967) |

* Reprints available.

† Author not at Lincoln Laboratory.

| JA No. | | | |
|---|---|---|---|
| 3070 | Tetrahedral-Site Copper in Chalcogenide Spinels | J.B. Goodenough | Solid State Commun. 5, 577 (1967) |
| 3080 | Current Runaway and Avalanche Effects in n-CdTe | M.R. Oliver<br>A.L. McWhorter<br>A.G. Foyt | Appl. Phys. Letters 11, 111 (1967) |
| 3085 | Observation of Exciton Fine Structure in the Interband Magnetoabsorption of InSb and Germanium | E.J. Johnson | Phys. Rev. Letters 19, 352 (1967) |
| 3087 | Inversion Asymmetry Effects on Oscillatory Magnetoresistance in HgSe | L.M. Roth*<br>S.H. Groves<br>P.W. Wyatt* | Phys. Rev. Letters 19, 576 (1967) |
| 3091 | Electroreflectance Study of Interband Magneto-Optical Transitions in InAs and InSb at 1.5°K | C.R. Pidgeon*<br>S.H. Groves<br>J. Feinleib | Solid State Commun. 5, 677 (1967) |
| 3126 | Electron-Hole Pair Effects on Landau Levels of InSb | D.M. Larsen | Phys. Rev. Letters 19, 1128 (1967) |

* * * * *

## UNPUBLISHED REPORTS

### Journal Articles

| JA No. | | | |
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| 3038 | Long-Term Operation of a Sealed $CO_2$ Laser | R.J. Carbone | Accepted by IEEE J. Quant. Electron. |
| 3044 | Optical Properties of the Metal $ReO_3$ from 0.1 to 22 eV | J. Feinleib<br>W.J. Scouler<br>A. Ferretti | Accepted by Phys. Rev. |
| 3049 | Characterization and Structure of $La_4Re_6O_{19}$: A New Metal Cluster Compound | J.M. Longo<br>A.W. Sleight* | Accepted by Inorg. Chem. |
| 3065 | Self-Steepening of Light Pulses | F. De Martini*<br>C.H. Townes*<br>T.K. Gustafson*<br>P.L. Kelley | Accepted by Phys. Rev. |
| 3078 | Infrared Heterodyne Detection | M.C. Teich | Accepted by Proc. IEEE |
| 3104 | Shallow Donors of InSb in a Magnetic Field | D.M. Larsen | Accepted by J. Phys. Chem. Solids |

* Author not at Lincoln Laboratory.

| JA No. | | | |
|---|---|---|---|
| 3107 | Mode Pulling in a Stimulated Raman Oscillator | P.E. Tannenwald | Accepted by J. Appl. Phys. |
| 3108 | Magnetic Properties of $La_{.5}Sr_{.5}CoO_3$ Near its Curie Temperature | N. Menyuk<br>P.M. Raccah<br>K. Dwight | Accepted by Phys. Rev. |
| 3110 | A New, Widely and Continuously Tunable, High Power Pulsed Laser Source | R.L. Carman<br>J. Hanus<br>D.L. Weinberg | Accepted by Appl. Phys. Letters |
| 3140 | Crystal Growth, Annealing and Diffusion of Lead-Tin Chalcogenides | A.R. Calawa<br>T.C. Harman<br>M.C. Finn<br>P. Youtz | Accepted by Trans. Met. Soc. AIME |
| 3161 | Growth of Single Crystals of ZnTe and $ZnTe_{1-x}Se_x$ by Temperature Gradient Solution Zoning | J.M. Steininger<br>R.E. England | Accepted by Trans. Met. Soc. AIME |
| MS-2072 | Metallurgical and Electronic Properties of $Pb_{1-x}Sn_xTe$, $Pb_{1-x}Sn_xSe$, and Other IV-VI Alloys | A.J. Strauss | Accepted by Trans. Met. Soc. AIME |

Meeting Speeches*

| MS No. | | | |
|---|---|---|---|
| 1742 | Analysis of Tellurides of Lead and Tin by Automatic Titrations | J.C. Cornwell<br>K.L. Cheng† | International Congress on Pure and Applied Chemistry, Prague, Czechoslovakia, 4 – 10 September 1967 |
| 1943 | Analysis of Distant-Neighbor Interactions in Cubic Spinels | K. Dwight<br>N. Menyuk | International Congress on Magnetism, Boston, Massachusetts, 10 – 16 September 1967 |
| 1945 | NMR and Magnetization Studies of $CdCr_2Se_4$ | G.H. Stauss†<br>M. Rubinstein†<br>J. Feinleib<br>K. Dwight<br>N. Menyuk<br>A. Wold† | |
| 1952 | Observation of Magnetoelastic Coupling by Spin Wave Resonance | R. Weber | |
| 1954 | Localized vs Collective Descriptions of Magnetic Electrons | J.B. Goodenough | |
| 1955 | Magnetic Properties of $SrRuO_3$ and $CaRuO_3$ | J.M. Longo<br>P.M. Raccah<br>J.B. Goodenough | |

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

† Author not at Lincoln Laboratory.

| MS No. | | | |
|---|---|---|---|
| 1956 | A Localized-Electron ⇄ Collective-Electron Transition in the System (La, Sr)$CoO_3$ | P. M. Raccah<br>J. B. Goodenough | International Congress on Magnetism, Boston, Massachusetts, 10 – 16 September 1967 |
| 1958 | Resistivity and Magnetic Order in $Ti_2O_3$ | L. L. VanZandt<br>J. M. Honig<br>J. B. Goodenough | |
| 1961 | Observation of Ferri- and Antiferromagnetic Resonance in Insulating Magnetic Spiral Structure | J. J. Stickler<br>H. J. Zeiger | |
| 1959 | Band Structure of Nickel and Low-Energy Optical Transitions | J. Hanus<br>J. Feinleib<br>W. J. Scouler | |
| 1952B | An Analysis of Magnetoelastic Coupling in Magnetic Films | R. Weber | Seminar, Tufts University, 22 September 1967 |
| 1976B | The Evolution of Intense Short Pulses in Nonlinear Optical Media | P. L. Kelley<br>F. De Martini*<br>C. H. Townes*<br>T. K. Gustafson* | Third USSR Symposium on Nonlinear Optics, Erevan, Armenia, U.S.S.R., 20 – 27 October 1967 |
| 2011 | Stabilization of Trapped Beams | T. K. Gustafson*<br>P. L. Kelley<br>R. Y. Chiao* | |
| 2012 | Stimulated Light-by-Light Scattering | R. Y. Chiao*<br>P. L. Kelley<br>R. L. Carman<br>E. Garmire* | |
| 2018 | Stimulated Raman Scattering in Quartz | P. E. Tannenwald | |
| 1976C | The Evolution of Intense Short Pulses in Nonlinear Optical Media | P. L. Kelley<br>F. De Martini*<br>C. H. Townes*<br>T. K. Gustafson* | Fall URSI Meeting, University of Michigan, 16 October 1967 |
| 1985 | Crystal Growth, Annealing and Diffusion of Lead-Tin Chalcogenides | A. R. Calawa<br>T. C. Harman<br>M. C. Finn<br>P. Youtz | AIME, New York, 28 – 30 August 1967 |
| 1993 | Growth of Single Crystals of ZnTe and $ZnTe_{1-x}Se_x$ by Temperature Gradient Solution Zoning | J. M. Steininger<br>R. E. England | Electronic Materials Conference, New York, 27 – 30 August 1967 |
| 2072 | Metallurgical and Electronic Properties of $Pb_{1-x}Sn_xTe$, $Pb_{1-x}Sn_xSe$, and Other IV-VI Alloys | A. J. Strauss | |

* Author not at Lincoln Laboratory.

| MS No. | | | |
|---|---|---|---|
| 1996 | High Power and Efficiency in CdS and CdSe Electron Beam Pumped Lasers | C.E. Hurwitz | International Conference on II-VI Semiconducting Compounds, Brown University, 6 – 8 September 1967 |
| 2009 | Homogeneity Range and Concentration-Pressure Isotherms of HgSe | R.F. Brebrick<br>A.J. Strauss | |
| 2013 | Inversion Asymmetry Splittings from Oscillatory Magnetoresistance in HgSe | S.H. Groves<br>L.M. Roth*<br>P.W. Wyatt* | |
| 2014 | Low Temperature Reflection and Electroreflection Study of Interband Magneto-Optical Transitions in HgTe | C.R. Pidgeon*<br>S.H. Groves | |
| 2075 | Band and Transport Parameters of Hg-Chalcogenides | T.C. Harman | |
| 2079 | Optical Absorption and Band Edge Parameters of Group II-VI Semiconductors | J.O. Dimmock | |
| 2024 | The Raman Spectrum of Trigonal, $\alpha$-Monoclinic and Amorphous Selenium | A. Mooradian<br>G.B. Wright | First International Symposium on Physics of Selenium and Tellurium, Montreal, Canada, 12 – 13 October 1967 |
| 2037 | Structure of $La_4Re_6O_{19}$: A New Metal Cluster Compound | A.W. Sleight*<br>J.M. Longo | American Crystallographic Association, Minneapolis, Minnesota, 20 – 25 August 1967 |
| 2049 | $Pb_{1-x}Sn_x$-Salt Infrared Diode Lasers | J.F. Butler | NEREM, Boston, Massachusetts, 1 – 3 November 1967 |
| 2071 | An Autotracking $CO_2$ Laser Radar | H.A. Bostick<br>A.H.M. Ross | |
| 2053 | Influence of a New Chemical Bond on the Perovskite vs Defect-Pyrochlore Structures | P.M. Raccah<br>J.M. Longo | Molecular Dynamics and Structure of Solids Conference, Gaithersburg, Maryland, 16 – 19 October 1967 |
| 2095 | Recent Research on Spin Density | H.E. Stanley | Spin and Charge Density Conference, Sagamore, New York, 5 – 8 September 1967 |
| 2096 | Spin Wave Resonance | R. Weber | International Colloquium on Magnetic Films, Boston, Massachusetts, 18 – 20 September 1967 |
| 2097 | Etching of Silicon Nitride Using Thin Deposited Layers of Silicon as an Etch Mask | W.T. Lindley | Electrochemical Society, Chicago, Illinois, 15 – 20 October 1967 |

* Author not at Lincoln Laboratory.

| MS No. | | | |
|---|---|---|---|
| 2100 | The Effect of Pressure on Some Compound Semiconductors and Defect-Structure Metallic Oxides | M.D. Banus | Naval Research Laboratory, Washington, D.C., 9 October 1967 |
| 2112 | Arc Techniques for Materials Preparation and Czochralski Crystal Growth | T.B. Reed | Conference on High Temperature Technology, Asilomar, California, 17 – 20 September 1967 |
| 2120 | Raman Scattering Studies Using Laser Sources | A. Mooradian | Seminar, National Bureau of Standards, Washington, D.C., 26 October 1967 |
| 2121 | Nonstoichiometry of Semiconducting Compounds | R.F. Brebrick | Materials Symposium, University of Missouri, 29 – 31 October 1967 |
| 2126 | Laser Scanned Imaging and Storage Device | R.J. Phelan, Jr. | International Electron Devices Meeting, Washington, D.C., 18 – 20 October 1967 |
| 2132 | A Phenomenological Theory for Dispersion Relations in Solids | G.F. Dresselhaus | Seminar, Harvard University, 25 October 1967 |
| 2149 | Infrared Detection and Imaging Using an InSb-MOS Structure | J.O. Dimmock | Seminar, Yale University, 7 November 1967 |
| 2152, 2152A | Raman Scattering from Plasmons and Phonons in Semiconductors | A.L. McWhorter | Seminar, Purdue University, 10 November 1967; Seminar, Harvard University, 15 November 1967 |

# SOLID STATE
# DIVISION 8

## I. SOLID STATE DEVICE RESEARCH

Photovoltaic detectors with high quantum efficiencies and high detectivities at 12°K have been fabricated from Bridgman-grown and subsequently annealed $Pb_{0.8}Sn_{0.2}Te$ crystals. The p-n junctions were prepared by diffusing approximately 15-μ deep n-type layers into p-type substrates with carrier concentrations ranging from 2 to $7 \times 10^{17}$ $cm^{-3}$. The cutoff wavelength of these detectors is 13 and 17 μ at 77°K and 12°K respectively. At 12°K the quantum efficiency is about 40 percent and the detectivity is between 2 and $4 \times 10^{10}$ cm/W $sec^{1/2}$. Since about half the incident radiation is reflected at the surface, the measured quantum efficiency corresponds to an internal collection efficiency of about 80 percent.

Measurements of the noise voltages of photovoltaic $Pb_{1-x}Sn_xTe$ and $Pb_{1-y}Sn_ySe$ detectors have shown that at frequencies in the 1-kHz range the noise is dominated by the Johnson noise of the incremental diode resistance at zero bias, which for state-of-the-art diodes operated at 77°K ranges from 1 to 10 ohms. To achieve background limited operation at 12 μ in a detector of unit quantum efficiency at 77°K, a resistance of 20 ohms is required for a 1 $mm^2$ diode. In the present diodes, the resistance at zero bias is determined by bulk leakage, possibly due to metallic inclusions in the crystal. Such metallic inclusions and low angle grain boundaries have been revealed in some Bridgman-grown crystals of $Pb_{1-x}Sn_xTe$ by electrolytic etching.

Infrared images in the 4- to 5-μ range have been detected using the radiation-sensitive characteristics of a uniform InSb metal-oxide-semiconductor structure. The infrared images are detected by rapidly scanning the device with 0.63-μ light from a CW He-Ne laser. The detection depends on the highly nonlinear photoresponse of the structure, whereby the presence of the 4- to 5-μ image affects the signal generated by the 0.63-μ light. In addition, optical information at 1 μ has been read in and stored for over 1 hour using this same InSb-MOS structure. The information can be nondestructively read out using 5-μ radiation and can be erased with 0.25-μ radiation. This operation depends on the difference between the effect of 1- and 0.25-μ radiation on the population of electron states in the oxide or at the semiconductor-oxide interface. The local population then affects the response of the device to the 5-μ radiation.

Several major equipment modifications have been made in the 400-keV Van de Graaff accelerator system used to implant heavy ions in semiconducting crystals. These modifications have been primarily in the vacuum system and in the ion source. Following these alterations, the modified system has operated reliably, delivering over 1 μA of $As^+$ ions at drift tube and sample chamber pressures of $10^{-6}$ torr or less.

This system has been used to implant p-type germanium samples with $As^+$ and $N^+$ ions. For the $As^+$ implants, doses ranged from $2 \times 10^{12}$ to $1.6 \times 10^{16}$ ions/$cm^2$, and the target temperature was varied between 20° and 500°C. The room temperature implants required post implantation annealing to over 400°C to produce conversion to n-type. However, most of the

implants performed with the germanium wafers elevated to temperatures in the 450° to 500°C range produced n-type conductivity immediately. To date, the results obtained with $N^+$ are inconclusive.

CdTe has been bombarded with 400 keV $N^+$ and $As^+$ ions which should be p-type dopants. To date, the $N^+$ implantation has given no indication of converting CdTe; however, the $As^+$ implants have shown some promising results. Materials problems, however, have hampered the reproducibility of these results. An annealing program has been initiated to achieve homogeneous starting material.

## II. OPTICAL TECHNIQUES AND DEVICES

Short term stability measurements have been made on improved versions of the $CO_2$-$N_2$-He lasers previously described. For an observation time of 0.1 sec, the frequency is stable to less than 400 Hz. An order of magnitude improvement is expected upon elimination of power ripple and coolant temperature variations.

A sealed-off $CO_2$ laser has been operated for over 1000 hours. Analysis of the gas content at this time indicates that the heated nickel cathode maintains the proper $CO_2$ concentration, thus circumventing the usual $CO_2$ loss observed to degrade performance in previous experiments.

A 9-meter long $CO_2$ amplifier is under construction. Preliminary tests of the first 3-meter section indicate that the final system should yield at least 100 W continuous output.

## III. MATERIALS RESEARCH

The eutectic phase diagram of the PbSe-SnSe pseudo-binary system has been determined by differential thermal analysis. At the eutectic temperature (870°C), the solubility of SnSe in PbSe (rocksalt structure) is 52 mole-percent, and the solubility of PbSe in SnSe (orthorhombic structure) is 24 mole-percent.

The results of magnetic susceptibility measurements have confirmed an earlier report that $SrRuO_3$ is ferromagnetic and that $CaRuO_3$ has antiferromagnetic interactions. These measurements show that $CaRuO_3$ has a Néel temperature of 110° ± 10°K and exhibits a small parasitic ferromagnetism below 77°K. Data on neutron diffraction and on magnetization at fields up to 125 kOe show that $SrRuO_3$ exhibits collective-electron magnetism and that both the spin-up and spin-down bands contain holes. The presence of holes in both bands presumably accounts for the fact that the interactions in this compound are ferromagnetic rather than antiferromagnetic.

The pressure coefficient of the Curie temperature, $dT_c/dP$, was found to be negative for the magnetic spinels $CdCr_2Se_4$, $CuCr_2Se_4$, and $CuCr_2S_4$. For $CdCr_2Se_4$, this indicates that a reduction in lattice size increases the antiferromagnetic direct superexchange interaction between B sites more rapidly than the ferromagnetic 90° superexchange interaction between these sites. It is probable that the same mechanism is primarily responsible for the negative pressure coefficients of the Cu spinels, but the band electrons in these compounds could also be contributing to the negative coefficient.

Theoretical relationships between various electronic phases, including ferromagnetic, antiferromagnetic, metamagnetic, and Pauli paramagnetic, have been summarized by constructing a qualitative electronic phase diagram. The diagram gives the boundaries between the phases

in terms of the parameters $n_d$, the number of electrons per relevant orbital, and the energy transfer integral b which appears in tight-binding collective-electron theory and in localized-electron superexchange theory.

## IV. PHYSICS OF SOLIDS

The mechanically integrated thin film package previously developed for electroreflectance studies, has now been adapted to electroabsorption. The new technique allows the simultaneous measurement of both these effects and a comparison by means of the Kramers-Kronig transforms.

Recently, it has been suggested that the plateau in the temperature variation of the conductivity of HgTe, which is observed in pure samples in the vicinity of 20° to 30°K, arises from an excitonic insulator to a semimetal transition. Our measurements indicate that this plateau can be attributed to a reasonable variation of carrier concentration and mobility with temperature.

A system for automatically recording and processing spectrometer data has been devised, built and placed into operation. The system has been applied to the study of the effects of a uniaxial stress on the impurity spectrum of phosphorous-doped silicon. The pure shear deformation potential, $E_2 = 7.9 \pm 0.2$ eV, measured here agrees with the value previously obtained in sulfur-doped silicon.

By use of the exciton theory, which has been confirmed previously by experiment, the motion of the Landau levels in the interband magnetoabsorption of InSb has been obtained. The conduction band Landau levels move as expected from the Bowers-Yafet theory whereas valence band levels do not, probably because the top of the valence band is not at $\vec{k} = 0$.

A variational trial function has been developed for the polaron problem which gives the exact ground state energy through order $\alpha^2$ at weak coupling and, with computer calculations, "variational" effective masses which are expected to be highly accurate for $\alpha \lesssim 4$.

The upper limit on the number of bound states of a particle in a semidefinite nonlocal potential has been derived by a generalization of a procedure used by Schwinger for a local potential. Applications for specific potential expressions have been worked out.

The magneto-elastic coupling of magnetic and elastic waves in magnetic metallic films has been studied directly for the first time by means of spin wave resonance in the vicinity of 60 GHz. By curve fitting in the crossover region, the magneto-elastic coupling constant, speed of transverse microwave phonons in the film, and phonon relaxation time were determined.

Microwave resonance results on $CoCr_2O_4$ as a function of temperature are being analyzed on the basis of a modification of the molecular field model of Dwight and Menyuk. The two resonances observed at temperatures above the spiral spin ordering temperature (31°K) are associated with a high frequency exchange mode and a low frequency uniform mode; the interpretation of the two-resonance modes below 31°K is awaiting the results of molecular field calculations which are presently under way.

A study of the effects of pressure, up to 5 kbars, on the magnetic properties of MnAs has been initiated. The phase diagram in the region between 70° and 320°K has been mapped out by measuring directly the magnetic moment as a function of pressure.

The Heisenberg model susceptibility has been expanded in terms of the Langevin parameter $u \equiv \mathfrak{L}(2J/kT)$ and a formal similarity with the S = 1/2 Ising model has been noted. The new expansion permits more reliable extrapolations for one, two and three dimensional lattices.

Critical properties have also been calculated in terms of high temperature expansions for the Vaks-Larkin model, which is essentially equivalent to a lattice of isotropically-interacting two-dimensional unit vectors (or classical spins). The properties which have been studied so far, namely $T_c$, $\gamma$, and $\alpha$, appear to be bounded on one side by those predicted from the one-dimensional Ising model, and on the other side by those of the three-dimensional Heisenberg model.

A study has been carried out of spontaneous and stimulated Raman emission from the lowest optical E-vibration in $\alpha$-quartz. The relaxation rate, as determined from the linewidth, is very high, ~20 to 100 times faster than the generation rate as measured by Stokes production. Furthermore, the phonon reabsorption rate as determined from anti-Stokes generation is comparable to pure phonon emission near the phase-matched angle. These factors make the observation of far infrared radiation during the stimulated Raman process difficult.

It has been found that when a mode-locked, Q-switched ruby laser is pumped hard enough to double pulse, the second pulse contains more regular and probably higher power spikes than the first. It is suggested that this is the cause of the high breakage rate of ruby rods in rotating prism Q-switched lasers in the double Brewster configuration.

An experimental investigation of thermal self-defocusing arising from the passage of a laser beam in an absorbing liquid cell has been initiated. The time dependence of the process is being studied quantitatively.

The possibility of maser emission from excited OH $\Lambda$-doublet states has been investigated. Trapped infrared resonance radiation, generated in the cascades following ultraviolet or chemical pumping to higher excited states, might invert the $\pi_{1/2}$ and anti-invert the $\pi_{5/2}$ $\Lambda$-doublets, resulting in observable signals if an early-type star were a fraction of a light year away from the OH.

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This Quarterly Technical Summary covers the period from 1 August through 31 October 1967. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

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