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## Quarterly Technical Summary

## General Research

*1 of 2*  
15 May 1968

Prepared under Electronic Systems Division Contract AF 19(628)-5167 by

# Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



*AD0670832*

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General Research

15 May 1968

Issued 13 June 1968

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**Lincoln Laboratory**

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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AD 670 832

GENERAL RESEARCH

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Massachusetts Institute of Technology  
Lexington, Massachusetts

15 May 1968

## INTRODUCTION

This Quarterly Technical Summary covers the period from 1 February through 30 April 1968. 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.

Accepted for the Air Force  
Franklin C. Hudson  
Chief, Lincoln Laboratory Office

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# DATA SYSTEMS DIVISION 2

## INTRODUCTION

This section of the report reviews progress during the period 1 February through 30 April 1968 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 February through 15 May 1968

### PUBLISHED REPORTS

#### Journal Articles\*

JA No.			
2983	An Analog Comparator as a Pseudo-Light Pen for Computer Displays	K. H. Konkle	IEEE Trans. Computers <u>C-17</u> , 54 (1968)
3103	Theory of Magnetization Ripple in Ferromagnetic Films	K. J. Harte	J. Appl. Phys. <u>39</u> , 1503 (1968)
3166	Recent Developments in Lorentz Electron Microscopy	M. S. Cohen	IEEE Trans. Magnetics <u>MAG-4</u> , 48 (1968)
3177	Biography of the Third ICMF	D. O. Smith	IEEE Trans. Magnetics <u>MAG-4</u> , 3 (1968)
MS No.			
1947	High Resolution Lorentz Microscopy	M. S. Cohen	J. Appl. Phys. <u>39</u> , 1149 (1968)
1948	Excitation of Uniaxial-Anisotropy Relaxation Processes in Magnetic Films by a Rotating Magnetic Anneal	K. J. Harte D. O. Smith R. M. Anderson R. C. Johnston	J. Appl. Phys. <u>39</u> , 749 (1968)
1949	New Methods of Magneto-Optical Signal Modulation and Detection (abstract only)	D. O. Smith	J. Appl. Phys. <u>39</u> , 570 (1968)

\* \* \* \* \*

### UNPUBLISHED REPORTS

#### Journal Articles

JA No.			
3190	Surface Potential of a Free Electron Metal in the RPA	R. W. Davies	Accepted by Surface Sci.
3238	Magnetic Devices	J. I. Raffel	Accepted as Chapter 19 of <u>Handbook of Thin Film Technology</u> (McGraw-Hill, New York)

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\* Reprints available.

Meeting Speeches\*

MS No.			
2144	Large-Area, High-Density Precision Etched Wiring	E. A. Guditz T. O. Herndon W. J. Landoch G. P. Gagnon	Electronics Components Conference, Washington, D.C., 8 - 10 May 1968
2145	A Progress Report on Large Capacity Magnetic Film Memory Development	J. I. Raffel A. H. Anderson T. S. Crowther T. O. Herndon C. E. Woodward	Spring Joint Computer Conference, Atlantic City, New Jersey, 30 April - 2 May 1968
2181	Photon and Electron Beam Accessed Magnetic Film Memory System	D. O. Smith	Industrial Liaison Symposium on Electronic Materials and Devices Research, M.I.T., 13 February 1968
2185	Demagnetizing Fields of Planar Magnetic Film Structures with One Infinite Dimension	R. Berger	} Intermag Conference, Washington, D.C., 3 - 5 April 1968
2186	Specifications and Yields of Composite Magnetic Films for a High-Density Memory	T. S. Crowther	
2301	Micromagnetics in Two Dimensions	K. J. Harte	Seminar, Case-Western Reserve University, 30 April 1968
2303	Methods of Improving the Signal-to-Noise Ratio of Photon and Electron Beam Accessed Magnetic-Film Memory Systems	D. O. Smith	Seminar, Yale University, 16 April 1968

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

## DIGITAL COMPUTERS GROUP 23

### I. CIRCUIT AND NEW MACHINE DEVELOPMENT

#### A. Microprocessor

An integrated circuit version of the microprocessor IC-LX-1 will be constructed. It will be used to check out the detailed logic design before the LSI version of the microprocessor LX-1 is built, and will provide experience in programming this type of machine. In the IC-LX-1, the read-only control memory will be replaced with a 256-word integrated circuit flip-flop memory in order to allow the microprogram to be modified easily during experimentation. The IC-LX-1 will be connected to one of the processor ports on the TX-2 memory bus so that it can have access to TX-2 memory and in-out equipment.

#### B. Microprocessor Engineering

The processor will be constructed with MECL II current-steering integrated circuits mounted on four-layer printed circuit cards; two of the layers are used for signals, one for ground, and one for the supply voltage (-5.2 volts). The cards, which plug into 44-pin connectors, are  $4\frac{1}{4} \times 5$  inches in size and contain a maximum of 36 integrated circuit packages. Back panel wiring will consist of twisted pair and 50-ohm miniature solid coaxial cable. Four card types are required: register card, unary (shifter) card, binary (adder) card, and select (decoding) card. The layout of these cards has almost been completed.

#### C. Semiconductor Processing

Approximately 800 good 3-bit parity arrays have been produced, demonstrating that the two-layer metal system is usable technology with high-speed 0.1 mil device geometry. Several wafers of 9-bit parity arrays and  $1 \times 1$  combinational multiplier arrays are ready for testing. These two devices employ three-layer metal systems which are needed for large complex arrays.

Initial chip bonding tests, which require simultaneous formation of twelve bonds to a 3-bit parity array chip, have been successful. Complete wafer chip versions of the 9-bit parity array, each containing four 3-bit chips, are expected to be available very soon.

#### D. Circuits

Methods for improving heat removal and for reducing power dissipation in the basic gate LSI chip for the microprocessor have been studied. A modified basic gate has been proposed which will operate with a lower power supply voltage. This circuit is being evaluated on the bench and with the CIRCUS circuit simulation program.

A writeable control memory for the microprocessor is being designed using 16-bit integrated circuit memory cell array elements.

## E. Testing

The TIC (Testing Integrated Circuits) Terminal has been installed. It is operational for testing logical performance of devices and, with appropriate analog inputs and outputs, is used to do device testing as well. Both the electronics and the programming are in the formative stage for this application. So far, DC  $\beta$  (current gain) measurements have been made for transistors. Five to ten seconds are required for 200 data points to be measured and recorded. The terminal has also been used to control the servo system used to measure voltage ratios required for  $r_b^1$  and  $C_e$  calculations and has produced satisfactory curves of these quantities as a function of current. Further tests are being set up so that transistor parameters required for the CIRCUS model can be readily obtained.

## II. MAGNETIC FILM ENGINEERING

### A. Large Capacity Memory

#### 1. LCM Stack

The one-million-bit stack was reassembled after modification of the group circuits and operated with a full set of digit cards. About 100 bits with inadequate signal-to-noise ratio were found in a test of the entire memory. These bits have been eliminated by substituting spare word and digit lines. The bad locations were due to unbalanced coupling of digit line to word lines; some of this coupling was definitely attributable to digit line defects. Transients due to the word group selection voltage and the digit current pulse will limit cycle time to about  $1.2 \mu\text{sec}$ . Drive-current-margin testing is in progress.

#### 2. Noise in LCM Sense Amplifiers

The random noise magnitude distribution in several LCM sense amplifiers was measured by a sampling technique and found to agree with the theoretical normal distribution over eight decades. Assuming that this result may be extrapolated to even rarer events, the mean time between failures caused by random noise in the LCM sense amplifiers will be on the order of years for the lowest signal locations in the stack.

#### 3. LCM Digit Conductors

Efforts to improve the edge straightness of scribed and etched conductors have led to the use of plated metals as resists instead of photosensitive organic resists. In addition, scribing is done deeply so that a substantial thickness of the copper layer is removed in a form of micro-machining. Electroplated solder, lead, and gold and electroless tin have been successfully used as resists. After scribing, the remaining copper is removed with an etchant which has little or no effect upon the resist metal.

Proper lubrication of the work and the diamond tool has been found to be very important to good scribing. Best results have been obtained when using a commercial hand cream as lubricant.

Control of depth of the scribed groove is obtained through use of an adjustable (height) shoe mounted behind the diamond scribing tool. The tool is heavily loaded (approximately 50 grams) to eliminate tool bounce and undulation.

## Division 2

### 4. Digit Line Edge Definition

Improvements in the edge definition of photoetched digit lines have resulted from changes in processing techniques used with negative-working KPR. The quality of photoresist images exposed with collimated light is improved by reducing the master-to-subject spacing. Lines exposed through scribed and etched chromium masters have better edges than those exposed through Kodak scribecoat. Also, cleaner etched lines are produced by brush-etching to completion and then applying a final, short-duration spray etch.

Initial tests, utilizing positive-working photoresists, have resulted in photoetched lines having edge definition superior to that usually obtained with negative-working resists.

## B. New Film Techniques

### 1. Word Line Flux Closure

Experiments with cobalt and cobalt-nickel baths indicate the possibility of making better films over some desired ranges of properties by electroless deposition than those made by evaporation. It has been demonstrated that these films also can provide edge closure, which cannot be done with evaporated films. It has also been demonstrated that high coercivity in the upper film of sandwich structures has been due to copper roughness, not diffusion, and that high evaporation rates at low substrate temperatures can produce fairly smooth substrates.

### 2. Pinholes

One of the most significant remaining problems for word lines narrower than 2.0 mils is the number of pinholes. It has been observed that the number of pinholes increases by an order of magnitude for each factor of two reduction in diameter.

### 3. Fine Line Scribing

Metallic resists are being used for scribing and etching very narrow conductors. Electroplated lead is being used as a scribeable resist on magnetic alloys as well as on copper. Approximately 0.5-mil-wide conductors on 1.0-mil centers have been produced in 40,000-Å-thick copper over 1000-Å-thick permalloy.

## III. SYSTEM PROGRAMMING

### A. Applications Programming

#### 1. Integrated Circuit Mask Layout

The first set of circuits made from masks completely designed using the computer graphical layout program is being fabricated. A 3-input ECL gate was designed on the computer, and its masks were made and sent to Philco for fabrication. Working circuits should be on hand soon. The design time on the computer was less than 2 hours, and the precision pattern plotting took about 30 minutes.

A written pattern generating system has been created. A host LEAP program was written which defines a number of useful procedures for listing the rectangles to be plotted. A user augments this host program with a written description of a specific pattern he desires. The fact

that this description is really a program segment gives the user very powerful tools for making repetitive patterns and sets of coordinated patterns. The patterns can be viewed on the scope and, if correct, tapes for the precision pattern generator can be punched.

A 256-bit fusible read-only memory chip was designed and its masks made with this written pattern-making method. Samples are now in fabrication at Philco.

## 2. Waveform Processing

Since the new display generator was installed on TX-2, the image output programs had to be redesigned and special changes made to the equipment. The results are improved continuous tone digital photographic output at increased speed. Typical 8-bit images consisting of  $340 \times 340$  picture elements can be output in approximately 15 seconds onto Polaroid or standard negative films. A variety of emulsion nonlinearities can be compensated with this technique.

Simultaneous dynamic range reduction and sharpness enhancement processing was applied to x-ray images. Photographic gammas as high as 16 were applied to the sharpened components with the result that obscure detail in soft tissue was rendered readily visible. Explorations concerning x-ray processing are continuing.

Preliminary efforts to cancel the optical illusion known as Mach-bands by means of inverse multiplicative filtering produced weak positive results on the basis of two trials.

A study of the periodograms of digital images and their logarithms was performed. The objectives were to determine an appropriate whitening filter for typical images and to clarify questions concerning the preponderance of low-frequency energy in these waveforms.

A paper presenting a discussion of multiplicative homomorphic filtering as applied to audio volume compression and image processing was submitted to the IEEE Proceedings. This paper is a joint effort of members of Group 23 and Group 62 and describes a variety of applications and theories concerning homomorphic filtering as well as those topics mentioned above.

## B. Languages

Several major improvements were made in the Mark 5 assembler system:

- (1) A new binary translating routine provides vastly improved operating speeds and greater user control.
- (2) An optional answerback operating mode produces a response whenever the contents of the input buffer have been completely processed.
- (3) A new facility provides a concordance of all APEX calls in a particular program.
- (4) The running and debugging of programs which expect parameters was simplified and made compatible with the standard command translator.

## C. Debugging

A facility for doing hardware trapping of APEX calls has been developed. To achieve this kind of trapping, the TRAP-executive sets and clears metabits of the APEX "call table." This is the first use of trapping in the APEX-executive itself.

#### IV. COMPUTER SYSTEMS

##### A. TX-2 Memory System

The reorganization of the TX-2 memory system has essentially been completed. Two new 16,384 word core memory modules were added to the system, raising the total core memory capacity to 139,264 words. Another 25,600 words will be added when the LCM is installed. The minimum memory cycle time for these new memories is  $1.2\mu\text{sec}$  and for the other memories  $2.0\mu\text{sec}$ . The typical instruction execution time is now approximately  $5\mu\text{sec}$ ; however, this will be reduced to less than  $2.5\mu\text{sec}$  when the memory work is complete. Design is now under way on the control which will allow the IC-LX-1 to use the LCM memory, through the TX-2 memory bus switch, at a peak word rate of 5 Mc. A memory parity alarm trapping mechanism which permits APEX to correct failures in the memory used by the address translation hardware (SPAT) has been implemented.

##### B. Display

The load on the TX-2 Sequence 64 display has been increasing steadily under both time-sharing and single user operation. With five display consoles available in the time-shared mode, more users are depending on the display. In addition, circuit layout places a severe requirement on the speed of the display generator. In order to improve the performance, a variable rate clock has been added to the display system so that the basic operating rate of the conic generator can be varied to suit the application. For applications where precision is not important, the conic generator can operate at a 5-Mc rate; for more precise work the clock rate can be reduced to  $1/60$  of maximum. This rate change is under program control.

The speed of the display can also be improved by using the CRT deflection signal to determine if the CRT beam has reached final position. At present, a fixed amount of time is used to insure that the beam has reached final position before the intensification gate is turned on. This time is set for worst case, maximum deflection. A circuit has been designed to enable the deflection signal to control the time until intensification and thus minimize the waiting time.

##### C. Hard Copy Output

A prototype copier which provides any user with a copy of his scope display has been installed and has proven to be extremely useful in projects where display flicker is a problem, such as printed circuit board and integrated circuit layout. Picture quality is surprisingly good, and the manufacturer indicates that improved paper is now available.

##### D. Typewriter

The golf-ball typewriter is on-line and is being used to type out APEX system messages. No hardware trouble has been experienced to date.

## COMPUTER COMPONENTS GROUP 24

### I. MAGNETIC FILMS

#### A. Anisotropy Spectrum of Magnetic Films

##### 1. Experimental Results

In an attempt to correlate atomic defect structure with magnetic effects, a search was made for electrical resistance anisotropy which might accompany the magnetic anisotropy. The basic idea of the experiment is to measure resistance during the time the film undergoes a hard axis anneal. Of course a large and instantaneous anisotropy due to magnetoresistance will be observed, but the desired effects will occur with a time corresponding to the magnetic annealing effects. In order to avoid isotropic resistance fluctuations due to thermal drift, a compensated circuit was used. The experimental sensitivity was such that an anisotropy in resistance of 1 part in  $10^6$  could have been observed. For anneals at 25°, 150°, and 250°C no effect was found. This result puts a strong constraint on models of magnetic film anisotropy. For example, directed divacancies have been suggested as contributing to  $H_K$ .<sup>1,2</sup> However, the upper bound on the resistance anisotropy of  $10^{-6}$  implies that the magnetic interaction must be very strong, ruling out dipole-dipole magnetostatic coupling.

##### 2. Theory

Considerable progress has been made in constructing models for observed anisotropy processes. Two models are proposed in which interaction between single and divacancies during surface or volume diffusion between oriented grain boundaries results in an effective diffusion constant  $D_{\text{eff}} \approx 24 n_1 D_2 \exp(E_b/kT)$ , where  $n_1$  = concentration of single vacancies and  $D_2$  and  $E_b$  are the diffusion constant and binding energy, respectively, for divacancies. Both the surface and volume models are characterized by a spectrum of modes, but only the first few of these are resolvable. In a steady-state rotating anneal, the surface modes combine to produce a single, broadened Debye-type peak; in contrast, the first two volume modes can produce distinct peaks. For the first surface mode and second volume mode the effective relaxation times are of the order of  $\tau_{\text{eff}} \approx (R/\pi)^2 1/D_{\text{eff}}$ , where  $R$  is the grain size. Using known values of  $E_b$  and  $D_2$  for Ni, reasonable agreement with experiment can be obtained.

#### B. Lorentz Microscopy

##### 1. Domain Wall Theory

The quantum mechanical theory of Lorentz microscopy has been applied to a one-dimensional domain wall in a Group 24 study.<sup>3</sup> Although an exact expression for the wall shape as a function of electron intensity could not be found, an approximation has been developed which gives the classical result in zeroth order plus higher-order quantum mechanical corrections. The first-order correction has been calculated, but enormous labor would be required to calculate the second-order and higher corrections. However, the classical approximation should suffice over a wide range of experimental situations.

## Division 2

### 2. Optical Processing of Lorentz Micrographs

Several Lorentz microscope plates have been sent to Dr. J. Berger of the Roswell Park Memorial Institute in Buffalo, New York, to be evaluated on his optical diffraction camera to determine if the contrast and ripple structure are good enough to yield quantitative data. If so, a similar system will be built by us.

## II. PEBA MEMORY SYSTEM

### A. Theoretical

#### 1. Electron Beam Read Out

A photon and electron beam addressable (PEBA) magnetic-film memory has been proposed in which writing is accomplished by electron beam and reading uses both the photon and electron beam.<sup>4,5</sup> Therefore it is particularly pertinent to ask if reading can be accomplished with an electron beam only, with a consequent simplification of the system. Calculations have been carried out for four methods of operation of the electron microscope: (a) transmission, (b) reflection, (c) mirror, and (d) impact; reading is to be accomplished by detecting the deviation of the trajectory of the electron beam caused by the magnetization of the bit.

Under the assumptions that reading requires a signal-to-noise ratio of 10 and is to be accomplished in  $1\mu\text{sec}$  for  $1\text{-}\mu\text{-diameter}$  bits, it is found that electron beam reading cannot be accomplished. This result arises for two reasons, namely: (a) low brightness of currently available electron guns (particularly serious in mirror microscopy) and (b) small magnitude of the beam deviation caused by the magnetization of the bit (particularly serious in reflection microscopy).

#### 2. Dielectric-Film Enhancement

Calculations of mode-conversion for lossless magnetic films using dielectric-film optical cavities have been started. Structures which appear to be practical have been found for conversion to first-order in the gyro-electric constant.

### B. Experimental

Several experiments have been started but no significant results have yet been obtained. These experiments include: (1) fabrication of REIG film and single crystals; (2) spectroscopy of REIG in order to find suitable optical transitions for use in PEBA memory; (3) study of the frequency response of electron beam heating.

## III. ELECTRON TRANSPORT

### A. Theory of Hot Electron Transport

Most of the existing calculations of the rate of hot electron damping in metals involve an attempt to estimate the mean free path for electron-electron scattering. While such estimates provide some insight into the problem, it is clear that in actual hot electron devices there is a real transport problem to be solved. To answer questions concerning, for example, the angular distribution of hot electrons, one must solve an appropriate transport equation. We are presently attempting to consider such questions using a Boltzmann equation approach. The kernel of our

transport equation involves the imaginary part of the base metal dielectric constant, and thus the long-range nature of the coulomb interaction causes no real difficulty in the analysis.

### B. Triode Fabrication

New masks and substrate holders have been designed for the Varian mask changer to permit fabrication of tunnel triodes having single crystal collectors. Alignment problems and other mechanical difficulties with the mask changer are being solved before experiments can proceed with new collectors and composite base devices.

### C. Low Temperature Growth of Oxide Films on Metals

A theoretical treatment of a low-temperature model for oxide film formation on metal surfaces has been carried out in which electron transport from the metal to the oxide surface occurs by resonant tunneling through the oxide to a band of surface states existing at the free surface of the oxide. Calculation shows that this model exhibits certain general characteristics that have not been found in previous models<sup>6, 7</sup> for low temperature oxidation, namely:

- (1) In the early stages of growth, the magnitude of the surface potential increases monotonically with oxide thickness and tends to approach the Mott potential  $\phi_m$  in the limit of large oxide thickness.
- (2) As a result of the variation in the oxide surface potential during the early growth stage, an inverse logarithmic growth law of the form  $(L + L_0)^{-1} = A - B \ln(t + t_0)$  is predicted, rather than the simpler form  $L^{-1} = a - b \ln t$  that obtains from the Cabrera-Mott theory.

The growth laws predicted by the different models are quite similar, so that experimental attempts to distinguish between the models by measuring oxide growth as a function of time would be difficult. The time dependent behavior of the surface potential  $V_s$  during oxidation, however, is remarkably sensitive to the specific model of the oxidation process. Thus an experimental determination of  $V_s$  as a function of time should allow discrimination between the models.

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7. N. Cabrera and N. F. Mott, Rept. Progr. Phys. 12, 163 (1949).

## PSYCHOLOGY GROUP 25

### I. HUMAN FACTORS IN ON-LINE COMPUTATION

A long-term program of experiments on human factors in on-line computation has been undertaken.

This program has been part of the Group's tentative plans for some time; one of the reasons for constructing the Lincoln Reckoner, and the APEX time-sharing system on which it rests, was to provide the TX-2 computer with a framework for these experiments. It was assumed that the behavior of a scientist or engineer working on-line would change radically if he were given a computer facility that allowed him to spend more time thinking about his problem than about the mechanics of communicating with the machine. Since the factors that loom large in such a system were likely to be obscured by other problems if the system were less convenient, it did not seem wise to begin experimentation until a facility at least as convenient as the present Reckoner was available.

The first variable to be considered is the speed with which the machine responds — a variable that probably has a large effect on the user, and certainly has a large effect on the cost of an on-line computer service. Programs are being written that will delay outputs from TX-2 in such a way as to simulate the behavior of an extremely fast machine shared among a great many users. These programs will also record the commands the subject uses and the time of the carriage return that ends each command. A preliminary version of these programs has been used in the first series of experimental sessions.

On the principle that it is well for experimenters to try the subjects' task themselves, the four psychologists who have planned the experiments have been serving as their own subjects. And on the principle that it is well to begin cautiously, the first task was very simple. The subject was given a CRT display of a pair of curved lines that remained a constant distance from each other — just like a railroad track — and he was to adjust a third line so that it fell between them. Each adjustment consisted of adding to the third line a Gaussian, bell-shaped curve with a width, height, and center-point specified by the subject; and after each adjustment the machine responded by showing him all three curves, so that he might judge what further adjustment was necessary. In the condition of longest delay, the machine responded after about 100 sec; in the condition of shortest delay, after about 1 sec.

As might be expected, the results showed that with long delays, the time required to perform the task is approximately proportional to the delay, but with short delays, changing the delay has little effect. Also, the results from different subjects were related in a very consistent way throughout the range of delays. Whatever the ultimate value of these data may be, their primary significance at the moment is that consistent, orderly results can be obtained in this kind of experiment.

A second experiment is being done with a task that has more of the character of solving a problem.

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

### A. Editor System

All the modules of the Editor have been checked out, and they are being used in conjunction with the Editor's procedure mechanism to write and combine the procedures that make up the visible Editors. As had been planned, initially there will be three visible Editors: (1) The Character Stream Editor treats every file as a string of characters and provides the user with unlimited access to every bit in the file. Characters may be handled as typewriter terminal characters or as hexadecimal pairs. (2) The Fortran Editor will handle Fortran files in all the usual ways, and will provide several powerful new services, including macros, literal labels, and some legality checking during editing. (3) The Script Editor will handle general alphanumeric files in a way that emphasizes their textural nature. Its purpose is to prepare documents of all kinds for outputting. It is a descendant of the TYPSET command of CTSS and the SCRIPT EDIT command of CMS.

It is hoped that all three Editors will be available for use in July.

### B. Mediator and Reckoner

The activity during this quarter has been confined largely to testing the Mediator and further design work on both the Mediator, which is the on-line operating system, and the Reckoner, which is the matrix arithmetic library that operates within the Mediator.

The shakedown tests of the Mediator have been carried out with a few text manipulation programs written for this purpose. The results reveal that the current implementation is basically sound; only a few programming bugs and a few minor design errors were found. It has been decided to extend the utility of the Mediator by providing automatic core or disc swapping. This will allow the user of a facility like the Reckoner to operate from a larger base of programs and data. The need for this improvement was anticipated in the original design; the decision to implement the full capability in this area now was a result of discussions with potential Reckoner and Mediator users in the ballistic missile data analysis group. Plans have also been drawn up to apply the Editor System, which was developed separately, to the problems of text and matrix editing in the Reckoner.

A display driver, identical to the ARDS-II design of Project MAC, and a high resolution, direct view storage tube that has recently been put on the market have been delivered and proven operational. Plans have been made to link the display to the 360/67 computer by a 1200 baud (or higher) telephone data line, and to provide supporting software to display text and to plot graphs for Reckoner users. The quality of the display is very high, and the cost is low enough so that it could be duplicated at a number of the typewriter terminals that will be used by Reckoner users.

## III. MAN-MACHINE INTERACTION ON TX-2

### A. APEX

The addition of two 16,000 word modules of core memory to TX-2 had the anticipated effect on the performance of the time-sharing system. The new memory added about 50 percent to the amount of memory available for user programs. Some large programs which had been runnable only when the user load was light can now be run under almost all conditions. Also, the increased

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supply of memory reduced the probability of having to swap user programs out to secondary memory, and thus increased the probability that some user program would be in main memory and runnable at any given time; the scheduling algorithm can now switch between users at a more rapid rate, and response time has therefore improved.

All these improvements can be lost quickly if users' programs expand to fill the large memory. In order to use the increased memory to better advantage, major changes are being made in the APEX algorithms for memory-allocation and time-sharing. The memory-allocation algorithm is being changed to make better use of knowledge about what memory pages are actually being used by active programs, and to limit the number of pages that will be allocated to a single user at any one time. The time-sharing algorithm is being changed to allow the user to freeze small programs in main memory and to give them fast, short-burst scheduling, even though a larger, slower program is being run for the same user. The first version of these modified algorithms should be operational during the coming quarter.

### **B. Speech Recognition**

Work has continued on the reworking of the recognition programs for operation in the time-sharing environment. The limited word-recognizer is now working and is being shaken down on a new group of test words. Programming is beginning on some new routines to aid in the large data-collection and evaluation tasks involved in the learning phase of the recognition process. The necessary programs should be available about the time that the required magnetic tape facilities become available in the time-sharing system.

### **C. Coherent Programming**

Further development of the concept of coherent programming has been slowed down by the effort required to begin the human factors experiments described in Sec. I. However, work continues on providing the programmer with a more convenient way to compile programs that will come up to the requirements set for programs in the public library.

## COMPUTER SYSTEMS GROUP 28

### I. COMPUTER CENTER DEVELOPMENT

Work is now in progress in the computer room to increase the capacity of the inadequate air handling facilities and change the air conditioning equipment over to an externally supplied chilled water system. Temporary cooling units have been installed to carry the heat load while existing duct work is removed and replaced by larger capacity runs. Concurrently a fire detection and fire protection system is being installed. This consists of replacing the present ceiling with a system of suspended fireproof tiles, locating heat and smoke detectors throughout the room, and installing a delayed action sprinkler system. All of this work is being scheduled and carried out in a manner that produces the least possible interference with normal 24-hour computer operations.

Among the continuing improvements made to the CP/CMS conversational time-sharing system during the quarter was that of changing the disk storage format to take full advantage of the new IBM 2314 disks installed during the previous quarter. The result is 40 percent increase in assigned storage space for each user at the same time that the total number of user accounts has been increased to sixty. Efforts directed toward performance improvement have included experiments with different hardware configurations to determine the effect of various components on the whole system.

One of the interesting new applications being implemented on the time-sharing system is a unified file of information on employees replacing a number of existing files of different formats with frequently duplicated data. By simply updating this one file such diverse entities as the telephone directory, security records, and the internal mailing list are all made current. Having demonstrated the potential, there is virtually no limit to the number of additional programs which might be written to operate on this same data base.

The single task sequential batch monitor, IBM's Operating System/360, continues to handle the bulk of the Laboratory's production computing load. Work is in progress to implement version fourteen of OS/360. One of the expected benefits of this new version, in addition to the correction of old troubles, is a greater compatibility between the two Fortran compilers, G and H. This is significant because the Laboratory's time-sharing system only provides the G version while many production jobs are written in Fortran H and are therefore limited to OS/360 batch operation. It is unlikely that there will be 100 percent compatibility because of minor discrepancies between the two compilers, but the new version should make it easier for all users to convert to Fortran G and thus afford themselves a choice of systems. Typically, this would allow them the advantages of time-sharing for debugging during the working day and then doing the production runs under OS/360 at night.

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

Over the past quarter, programs to conduct a general file search of a file extending over many blocks and programs to input data entries from the terminal were designed and coded. These are being checked and tested.



# RADIO PHYSICS DIVISION 3

## INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 February through 30 April 1968. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary 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 February through 15 May 1968

## PUBLISHED REPORTS

### Technical Reports

TR No.				<u>DDC Nos.</u>
430	Millstone Hill Thomson Scatter Results for 1964	J. V. Evans	15 November 1967	DDC 668436
441	Spectral Line Interferometry and Interferometer Noise Analysis	A. E. E. Rogers	16 January 1968	DDC 666038
444	A Radar Interferometer Study of Venus at 3.8 cm	A. E. E. Rogers	14 February 1968	DDC*

### Journal Articles<sup>†</sup>

JA No.			
3046A	Night Sky Photometry of [OI] $\lambda$ 5577 and $\lambda$ 6300 Inside the Southern Auroral Zone	M. A. Gordon	Planet. Space Sci. <u>16</u> , 297 (1968)
3153	Variations in the Radar Cross Section of Venus	J. V. Evans	Astron. J. <u>73</u> , 125 (1968)

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## UNPUBLISHED REPORTS

### Journal Articles

JA No.			
3138	On the Sunrise Behavior of the F-Layer at Midlatitudes	J. V. Evans	Accepted by J. Geophys. Res.
3183	Radar Astronomy	G. H. Pettengill	Accepted as Chapter 33 in <u>Radar Handbook</u> (McGraw-Hill, New York)
3198	Absorption of Radar Signals by the Atmosphere of Venus	J. V. Evans R. P. Ingalls	Accepted by J. Atmos. Sci.

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\* Not yet assigned.

<sup>†</sup> Reprints available.

JA No.			
3214	Indirect Experimental Evidence for the Existence of Hall and Pedersen Currents in the Auroral E-Region	R. E. Newell* W. G. Abel	Accepted by Nature
3243	Fourth Test of General Relativity: Preliminary Results	I. I. Shapiro† G. H. Pettengill M. E. Ash† M. L. Stone W. B. Smith† R. P. Ingalls R. A. Brockelman	Accepted by Phys. Rev. Letters
3245	The Case for the Radar Radius of Venus	M. E. Ash† D. B. Campbell* R. B. Dyce* R. P. Ingalls R. Jurgens* G. H. Pettengill I. I. Shapiro† M. A. Slade* W. B. Smith† T. W. Thompson	Accepted by Science
3250	The Temperature of Neutral and Charged Particles in the Ionosphere and Magnetosphere	J. V. Evans	Accepted by Revs. Geophys.
3259	The Structure of the OH Source in W3	J. M. Moran* B. F. Burke* A. H. Barrett* A. E. E. Rogers J. C. Carter J. A. Ball D. D. Cudaback*	Accepted by Astrophys. J. Letters

Meeting Speeches‡

MS No.			
2217	Conjugate Point Heating of the F-Layer Observed at Millstone	J. V. Evans	} URSI, Washington, D.C., 9 - 12 April 1968
2218	The Sunrise Behavior of the F-Layer at Midlatitudes	J. V. Evans	
2243	High-Resolution Mapping of Lunar Radar Echoes at 3.8 cm	G. H. Pettengill	
2250	Doppler Spectrum of Auroral Echoes at 1295 MHz	R. E. Newell* W. G. Abel	

\* Author not at Lincoln Laboratory.

† Division 6.

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

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MS No.

2253	Absorption of Microwaves by the Atmosphere of Venus	R. P. Ingalls J. V. Evans R. A. Brockelman	} URSI, Washington, D.C., 9 - 12 April 1968
2255	Radar Interferometer Observations of Venus at 3.8 cm	T. Hagfors G. H. Pettengill A. E. E. Rogers	
2253A	Absorption of Microwaves by the Atmosphere of Venus	R. P. Ingalls J. V. Evans R. A. Brockelman	2nd Arizona Conference on Planetary Atmospheres, Tucson, 13 March 1968
2311	Imaging Radio Sources with a Digital Computer	M. L. Meeks	Colloquium, National Radio Astronomy Observatory, Charlottesville, Virginia, 25 April 1968.

## SURVEILLANCE TECHNIQUES

### GROUP 31

#### I. SUMMARY

Group 31 operates and maintains the Lincoln Laboratory radio/radar facilities located at Millstone and Haystack Hills. At Millstone, work has continued in improving the accuracy and experimental flexibility of the radar system, and in making observations of tropospheric, ionospheric and auroral phenomena. An understanding of these phenomena appears relevant to many areas of current interest to the U.S., ranging from civil air transport to the anti-ballistic-missile program.

In the area of astronomical research, a successful verification of the additional signal retardation predicted by the General Theory of Relativity (the so-called "Fourth Test") has been reported. Interest in the applications of interferometry, both short-baseline (coherent reference maintained by direct communication) and long-baseline (coherent reference obtained by independent highly stable oscillators), continues in the investigation of radio source sizes and relative locations.

#### II. SPACE SURVEILLANCE TECHNIQUES

##### A. Precision Tracking Improvement at L-Band

In order to obtain the most precise measurement of angular position that the received echo signal-to-noise ratio permits in a monopulse radar system, it is necessary to supply corrections to the indicated mechanical position of the antenna based on the electrically measured displacement of the target within the antenna beam. These digital corrections, derived from the error signals supplied to the servo tracking loop, are now available for use in Millstone's real-time differential-correction program for updating observed satellite orbits.

A relatively simple calibration technique for this correction has been devised which does not require long-term stability or slow-moving targets (such as those needed when making conventional "drift-scan" calibrations). A sinusoidal signal having a period that is long compared with natural system resonances, but short compared with system drift times, is injected into the servo loop while locked on the target. This procedure superimposes sinusoidal oscillations on the antenna motion which are directly related to the known applied voltage. By searching the shaft-encoder output for this frequency component, a direct calibration is available for the errors observed at other frequencies (presumably related to servo tracking inaccuracies). A number of successful trials of this method have been made, and further efforts are being devoted to automating the process as a part of the normal calibration.

##### B. Radar Studies of the Aurora

A search for radio aurora was made for 13 days during this period, using the Millstone L-band radar system. Radar echoes were present long enough to make completely successful quantitative measurements on 5 days with partial success on 5 other days. Data were recorded

## Division 3

at pulse lengths between 10 and 500  $\mu$ sec using several modes of antenna scanning. A partial analysis of the data show that the maximum echo strength is greater by a factor of at least 5 than that observed with the same radar in 1965, near the minimum of the sunspot cycle. There is also evidence that the average echoing region is now somewhat thicker and higher than in 1965.

### III. LUNAR AND PLANETARY RADAR STUDIES

#### A. Lunar Studies

Final reports of the radar investigations of the moon under NASA Contract NSR 22-009-106 have been prepared. Current effort is being devoted to planning and instrumenting for the dual-polarization mapping work at 3.8-cm wavelength, to be carried out under a new NASA Contract NAS 9-7830 for partial support.

#### B. Planetary Studies

Difficulties in obtaining new Varian Type-VA 949-AM X-band klystrons have limited transmitter operation during this quarter largely to single-tube operation, at a power level of only about 150 kW. At this level it was impossible to obtain echoes from Venus, because of the great distance to this planet during this quarter. Measurements of Mercury were possible in February and March, but the increasing distance ruled out even these during April, as superior conjunction was approached.

A report has been released on the experimental verification (to within an accuracy of about 20 percent of the effect) of the retardation predicted by the General Theory of Relativity for electromagnetic signals propagating in the strong solar gravitational field. Thus four different ways in which Einstein's theory differs from Newton's in its predicted effects have now been experimentally verified.

### IV. THOMSON SCATTER STUDIES

Two graduate students from the University of Illinois, Lynn Carpenter and Ralph Cicerone, began work during this reporting period. The routine ionospheric observations at 440 and 1295 MHz have been continued and in addition, two new types of observation have begun.

Using the newly acquired AIL parametric amplifiers, it has been possible to search for the plasma lines with greater sensitivity than before. The lines have been detected over the frequency range 4 to 9 MHz. The lower cut-off ( $\leq 4$  MHz) has been explored but the upper, theoretically-predicted cut-off near 9 MHz has not yet been examined because the plasma frequency (electron density) in the ionosphere has at no time been sufficiently high. These data are being reduced by Cicerone, who has also undertaken measurements to compare the intensity of the up-shifted and downshifted lines at a given frequency (and thereby the equality of the approaching and receding photo-electron fluxes at a given height).

Carpenter has been attempting to observe vertical drifts in the F region by measuring small displacements of the average spectra from the radar frequency. The present spectrum analyzer is ill-suited to this task because of the characteristics of the filters employed. Nevertheless, by transposing the signal spectra (by switching the local oscillator alternately above and below the signal frequency) systematic shifts have been detected that appear to be caused by vertical drifts of the plasma.

Work is proceeding on the development of a new spectral analyzing system: RETIAS (REal Time Analyzing System), which will end the need for analog data recording and later digitization. Delays in delivery of the new filters have slowed down this work. However, the system is now complete and working, though the dynamic range requires improvement. New software to handle RETIAS outputs has been written and checked out. A data analysis program has been specified and is being written.

Analysis of the 1965 results is nearing completion. These data will be examined largely with a view to determining differences in the behavior during magnetically quiet and disturbed conditions. Spectrum analysis of the 1966 and 1967 data must be repeated to remove the effects of leakage of a spurious signal that developed in the tape recorder playback system and was previously unrecognized.

## V. RADIOMETRY

### A. Instrumentation

The radiometric instrumentation remained relatively static during this quarter. No major improvements were made in the hardware. However, the Millstone-Haystack interferometer system (termed MILSTAK) has become very much easier to operate with the installation of remote monitoring on the Millstone antenna. An antenna operator is no longer required in the Millstone control room during MILSTAK observations. This has greatly reduced the manpower demands and the scheduling problems for operating the MILSTAK system.

### B. Radio Astronomy

The observations of OH emission have continued with the Millstone antenna participating in a long-baseline-interferometer experiment from April 5 through 8. The 140-ft Green Bank and the 84-ft Onsala (Sweden) antennas formed the distant terminals. Data from previous observations with Onsala were reduced during this quarter and all of the OH emission points at 1665 MHz in source W3 were finally resolved. The angular size of these points appears to be about 0.004 second of arc. The cluster of bright emission points comprises a region about 2 seconds of arc in diameter.

Harvard graduate students used the maser system in the Planetary Radar Box in searching for a new OH line at 7832 MHz. This line corresponds to a lambda-type doublet in the state  $\Pi_{1/2}$ ,  $J = 3/2$ . The source in W3 was observed for about 10 hours but no detection corresponding to an upper temperature limit of 0.1°K was made.

On April 17 the moon occulted the center of our (Milky Way) galaxy. The event was observed with the OH spectral-line system to determine the structure of the interstellar clouds of OH that absorb emission from the galactic center. The MILSTAK system was also used to study the structure of similar clouds in the direction of the bright radio source Cassiopeia "A."

The Haystack antenna continued to be used at wavelengths of 3.7 and 2 cm to monitor several time-varying extra-galactic sources. A dramatic increase in the 2-cm flux from 3C120 was observed. This increase occurred in an interval of a few weeks and rivaled the increase in flux from quasar 3C273 which was observed about 18 months ago at 2-cm wavelength.

## VI. SPACE COMMUNICATIONS AND METEOROLOGY

### A. Effects of Rain

Interest continues in radar observation of rain at L- and X-bands, primarily from the point of view of space communication. During this quarter, however, almost no rain occurred during the test periods available. Data reduction based on observations from previous quarters is continuing, with excellent agreement indicated between calculations based on radiometric observation at X-band (Haystack) and near-simultaneous radar observations at L-band (Millstone).

### B. Clear Air Turbulence

Clear air turbulent backscattering observations were continued using the Millstone L-band radar. Fourteen sets of measurements were made during the present quarter. In each of the sets of measurements, turbulent scattering from the tropopause was detected. In six of the measurements, four of which were made in March, thin turbulent layers above the tropopause were detected.

The properties of the thin elevated turbulent scattering layers were further investigated in a bistatic scattering experiment. An X-band CW transmitter was located at the NASA facility in Wallops Island, Virginia, and the Westford Communications terminal was used as the receiver. The experiment consisted of illuminating the scattering layer with a relatively wide-beam antenna ( $1.5^\circ$ ) and scanning the illuminated volume with a narrower-beam antenna ( $0.15^\circ$ ). From the distribution of scattered energy received while scanning, the height of the layer and the product of its thickness and turbulent intensity were obtained.

The bistatic scattering measurements were made on eight of the days that the backscattering measurements were made. Because of the distance to the scattering layer (170 n.mi) the radar could not provide surveillance over the region of the layer used for the bistatic measurements. From radar measurements of layer intensity at other elevations from Millstone and from comparisons of radiosonde data taken at Bedford and near the common volume of the bistatic experiment, the horizontal homogeneity of the layer could be established. On days when the scattering was caused by a single layer and the layer was horizontally homogeneous, the bistatic scattering data were consistent with the radar data and a thin turbulent scattering layer model.

# RADAR DIVISION 4

## INTRODUCTION

The General Research activities of Division 4, which are carried out in Group 46, are summarized for the period 1 February through 30 April 1968. The major activities of the Division are in the RDT, PRESS, and BMRS programs, which are reported on separately.

J. Freedman  
Head, Division 4  
H. G. Weiss  
Associate Head

## DIVISION 4 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1968

### UNPUBLISHED REPORTS

#### Journal Articles

JA No.			
3136	A High-Power Waveguide Tuner	C. E. Muehe	Accepted by IEEE Trans. Microwave Theory Tech.
3215	High-Power, Microwave Power-Combiner Using a Series-Parallel Array of Diodes	W. J. Getsinger	Accepted by Proc. IEEE
3233	The Feasibility of Locating Waveguide Arcs by Sound Ranging	A. A. L. Browne	Accepted by IEEE Trans. Microwave Theory Tech.

## 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. DIODE-USING DEVICES

#### A. Diode Measurements

The 30-inch-diameter, radial-line cavity, designed to measure the equivalent circuit element values of packaged diodes, has been made operative over the frequency range from 6 to 26 GHz. Performance is qualitatively as expected, but with a greater random variation in measured impedance than is desirable. Measurements are being made to locate and evaluate the sources of error.

#### B. Power Combiners

Design work is continuing on a high-power varactor doubler using a diode array imposed on an equi-phase surface of a radial transmission line. The doubler is expected to use 35 diodes and deliver about 150 W CW at 2.0 GHz. It will be driven by another high-power varactor doubler. The driving doubler will use 15 diodes in series-parallel connection, forming an array which will be connected in series with a coaxial-line center-conductor. The latter doubler will deliver about 200 W CW at 1.0 GHz.

New diplexers and tuners have been designed for these high-power doublers, and auxiliary coaxial-line components are on order.

Each series-connected column of diodes for use in the doublers will be made as a single, integral unit by a commercial diode-manufacturer to specifications established by Lincoln Laboratory.

#### C. Low-Noise Balanced-Diode Mixers

The low-noise mixer designed for use at 3 GHz is almost completed in the waveguide configuration. Performance testing of the individual components is being undertaken at the present time. In addition, a coaxial version of the reversing switch mixer has been designed for use at 3 GHz, and its fabrication will begin shortly. The performance is expected to be at least as good as that of the waveguide version.

## Division 4

A new diode test mount is being made in order to facilitate measurement of the package capacitance  $C_p$ , spreading resistance  $R_s$ , and junction capacitance  $C_j$ , of the high-quality Schottky Barrier diodes which are required for use in the low-noise mixers.

Studies have been initiated in two areas in connection with the mixer program:

- (1) The feasibility of dielectric resonators as elements for low-loss band-pass or band-reject filters at higher frequencies, i.e., X-band and above.
- (2) The theoretical and practical aspects of microstrip circuitry for use in low-noise mixers.

### D. Gain Compression in Parametric Amplifiers

Further measurements have been made of the output saturation characteristics of one of the computer-designed X-band parametric amplifiers described previously. The variation in the output power level with small-signal gain for 0.5 dB of gain compression agrees closely with that predicted by the theory derived for an abrupt-junction varactor if it is assumed that the pump circuit has a loss of about 1 dB in addition to the loss associated with the varactor series resistance. This assumption would not appear to be unreasonable.

## III. MILLIMETER-WAVELENGTH PROGRAM

The 35-GHz radar described in the preceding Quarterly Technical Summary has been in operation for about 3 months. The power supply and protective circuits for the transmitter have required a large amount of debugging, but about 8 nights of observations have been made with circular polarization transmitted and the opposite circular polarization received. The data lack self-consistency. At least some of the causes of error have been identified and eliminated. Present indications are that the return from the limb is between 5 and 10 dB less than the return from the subradar region, and that the crater Tycho has a reflectivity larger than that of other features on which the beam impinges at the same angle of incidence. Difficulties with the signal-processing system make these findings tentative. However, the known difficulties have been eliminated, and the signal processing is believed now to be reliable.

The receiver bandwidth of 170 Hz is adequate to cover the Doppler spread in any region within the 3-dB beamwidth of the antenna. However, the Doppler removal program which keeps the return centered in the receiver pass-band compensates accurately only at the subradar region, and must be accomplished by cut and try for other regions. Guard channels centered just above and below the center frequency of the receiver allow this to be accomplished. An automatic Doppler compensation scheme is being incorporated which samples the echo for a few milliseconds and adjusts the Doppler compensation to the correct value.

Up to this point, only measurements of radar echoes in the principal polarization have been made. A receiver for simultaneously receiving the two orthogonal returns is being installed.

## ENGINEERING DIVISION 7

### INTRODUCTION

The Engineering Division has supported the General Research program of the Laboratory principally by its work at Millstone Hill, by its modifications to the data processing facilities at Building J, and by its further development of specific circuits in the Hybrid Integrated Circuit Facility. At Millstone Hill, modified shaft encoders were installed on the existing laser radar while design decisions were reached concerning an integrated pointing system for both the existing and the new CO<sub>2</sub> laser radars. Rather extensive air conditioning and fire protection modifications are being made at Building J because of the great increase in computing capacity there. And the new Integrated Circuit Facility is now actively producing circuits for specific applications even while building modifications are going on.

J. F. Hutzenlaub  
Head, Division 7

# DIVISION 7 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1968

## PUBLISHED REPORTS

### Technical Report

TR No.				<u>DDC and Hayden Nos.</u>
442	Time Optimal Control for a Class of Common Random Disturbances	N. P. Smith	2 February 1968	DDC 667521

### Technical Note

TN No.				
1968-7	Haystack Antenna Reflector Surface Improvement Program	D. G. Stuart	29 January 1968	DDC 667518 H-878

## MECHANICAL ENGINEERING GROUP 71

### I. SOLID STATE RESEARCH

Analysis of the quality and structure of solids can be made rapidly by means of spectroscopy. For this purpose, an existing Laboratory spectrograph was modified in order to increase the resolution of the light spectrum and to improve the versatility of the apparatus to meet experimental requirements. The modifications included: a new housing for photomultiplier and infrared tubes to increase the spectrum band, new mounts for the light projector, vacuum sealed mirror housings, a dewar support for the magnetometer section, and special tools to facilitate alignment of the system.

### II. LASER RADAR AT MILLSTONE HILL

#### A. Encoder Installation on the Nike Mount

Modifications to permit the installation of a new azimuth encoder for the laser radar on the Nike mount at Millstone Hill have been completed. The slip-ring assembly was removed and a new mounting bracket was made to hold the encoder, as well as a new drive coupling. These were installed, and the unit is now ready for wiring.

The elevation axis encoder installation will not require any major modifications. This encoder will be realigned and new locating pins installed.

#### B. CO<sub>2</sub> Laser

Three separate pedestals are being designed for this application. The ground-level unit located inside the base of the old concrete gun mount will hold a fixed mirror. Its pedestal will be positioned and leveled manually, after which the mirror will be adjusted in elevation. A similar pedestal will hold another fixed mirror on the top of the tower, at the tower rim. The third pedestal will also be mounted on the top rim of the tower diametrically opposite the second. This pedestal will hold the tracking mirror and will be servo-controlled on both axes. An existing camera mount is being modified for this purpose by installing new servo-motors and encoders on both axes.

Layout of the equipment in the building has been completed. The two beam expanders in the system are being designed and will be released for manufacture shortly. Supports for the granite tables supporting the expanders have been designed.

## COMPONENT DESIGN AND DEVELOPMENT GROUP 73

### INTEGRATED CIRCUIT FACILITY

Development of the principal sections within the Integrated Circuit Facility has continued during this period, and although the competence and rate of development of these areas vary, many tasks have been undertaken and completed.

About twenty-five tasks are currently in progress. Some involve circuit or subsystem fabrication; others are related to special high performance development systems. Still others involve device or component fabrication which is frequently based on high resolution line patterns.

A few areas of the Facility are lagging in their development because of the lack of space or inappropriate environmental conditions, and this frequently reduces the amount of work that can be undertaken and increases the length of time required to complete the work. Dielectric insulating films of relatively large area, for instance, have become very important to the success of several programs, but the extremely low yield due to the environment has added considerably to the processing time.

Emphasis has been placed on improving as rapidly as possible the areas of the Integrated Circuit Facility that are not limited in space or by environmental conditions but do affect the fabrication turn-around time. In this regard the layout area now has the ability to process all layout artwork by computer methods. In many cases, particularly the high resolution line layouts, the computer technique in combination with a high resolution plotter is the only method that will lead to high quality, low cost masks. Complex multimask layouts for subsystems can also be made by computer techniques, but improvements in the transfer of information from the engineering drawing to the computer will be necessary before the total artwork time can be optimized. Continued manual layout effort is of course required for the initial engineering drawing, and although many layouts require only a rough sketch prior to the automatic artwork step, it will be highly desirable to develop or acquire automatic routing and placement programs.

In order to improve the present fabrication limitations, particularly the problems related to packaging, heat transfer and wire bonding uncertainties, a beam lead substrate has been developed. Several materials have been used for the substrate and the present effort employs alumina and silicon. Windows or apertures are provided in the substrate for the monolithic chips, and beam leads from the substrate are fashioned to overhang the apertures and register with the monolithic chip pads. The chips are inserted into the substrate windows from the bottom side of the substrate, and attachment of the beam leads to the chip pads is accomplished by thermocompression bonding. The substrate serves not only as a holder for the chips but as an interconnection medium, and results in a rugged planar-type substrate that with some protective coating can be used without the usual flat pack container.

Additional effort will be required to establish the reliability of the system and to develop convenient interfacing of the substrate to printed circuit boards.

## PHYSICAL PLANT ENGINEERING GROUP 75

### BUILDING J MODIFICATIONS

Because of the continual demand for increased computer time, it has become necessary to take steps to augment the present computer facilities. In order to undertake this program, additional floor space is required, and the environmental control equipment necessary to meet the temperature and humidity criteria of the computer system is being updated. Schedules have been arranged to accommodate the environmental and fire protection modifications in a first phase.

Plans and specifications have recently been completed for the first phase of the extensive renovations to Building J. Three direct-expansion air conditioning units totaling about 85 tons of refrigeration will be replaced by two 60-ton chilled water fan coil units. Chilled water will be furnished by means of a recently connected branch from the main chilled water line that links L. G. Hanscom Field and Lincoln Laboratory. Valves were installed to enable the use of chilled water from either the Hanscom Field or the Lincoln Laboratory chilled water plants, thus providing chilled water backup in the event of mechanical failure at either chiller plant.

An appraisal of the facilities housing the computer was made during the recent study, indicating that a high degree of fire hazard existed. To meet the requirements for this type of occupancy, it will be necessary to remove all exposed combustible material. Thus a new non-combustible ceiling and acoustical wall panels will be installed.

Since the roof deck is constructed of wood, complete conformance was not possible or practical. For this reason, an automatic sprinkler system will be installed with heads above the ceiling to protect the roof structure, and below the ceiling for general area protection. To provide a higher degree of insurance against lost time due to fire, fire detectors will be installed above the ceiling, in the room, under the raised floor, and in the return air ducts. These detectors are sensitive to heat and the products of combustion.

At the present time, the first phase is 20 percent complete, and is anticipated to be completed by mid-July 1968. The second phase of this project will include a 6000-square-foot addition to the existing building.

## CONTROL SYSTEMS GROUP 76

### I. HAYSTACK

Technical Note TN-1968-7,\* containing detailed information on the measurement and computation techniques employed in rerigging the Haystack reflector, was completed. It was previously indicated† that the rerigging was completely successful in that the rms error from the best fit paraboloid, initially 0.037 inch, was reduced to 0.017 inch.

Further studies of the Haystack antenna power drives were conducted. Test results indicate that the existing servo motors may be unsuited for high inertia loads, even if all possible precautions are taken in maintaining positive back pressure on the motors. The search continues for a suitable motor with positive piston control which is mechanically and functionally interchangeable with the existing motor.

### II. MILLSTONE OPTICAL TRACKER COMPLEX

A decision on the details of an integrated pointing system for the two tracking instruments was reached. The laser radar, an elevation-traverse or X-Y mount, and the cold tracker, a modified Nike-Ajax azimuth-elevation mount, will be linked through a general purpose digital computer. Slaving of each mount to the other, to the Haystack or Millstone Radar, or to a celestial program will be provided through the computer. Range and range rate operations and calculations necessary for decimal angle displays also will be performed by the computer. Group 76 will furnish servo systems and control consoles for each mount, plus the logic circuitry required to exchange input-output information between the computer and each mount and between the computer and the Haystack-Millstone complex.

Logic design and printed circuit card layout for the command logic subsystem were completed, and the new control console for the Nike mount was delivered to the site. Installation of the console and necessary modifications to the mount servos and interconnection wiring are under way. Components were ordered for the new laser radar servos. Expressions for the several required angle transformations were derived for use by the computer programmer.

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\* D. G. Stuart, "Haystack Antenna Reflector Surface Improvement Program," TN 1968-7, Lincoln Laboratory, M.I.T. (29 January 1968), DDC 667518.

† General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 February 1968), DDC 666712.

# SOLID STATE DIVISION 8

## INTRODUCTION

This section summarizes the work of Division 8 from 1 February through 30 April 1968. 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 February through 15 May 1968

## PUBLISHED REPORTS

### Journal Articles\*

JA No.			
3104	Shallow Donor Levels of InSb in a Magnetic Field	D. M. Larsen	J. Phys. Chem. Solids <u>29</u> , 271 (1968)
3108	Magnetic Properties of $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_3$ Near Its Curie Temperature	N. Menyuk P. M. Raccach K. Dwight	Phys. Rev. <u>166</u> , 510 (1968)
3119	Tellurium Vapor Pressure and Optical Density at 370-615°C	R. F. Brebrick	J. Phys. Chem. <u>72</u> , 1032 (1968)
3137	Metallurgical and Electronic Properties of $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ , $\text{Pb}_{1-x}\text{Sn}_x\text{Se}$ , and Other IV-VI Alloys	A. J. Strauss	Trans. Met. Soc. AIME <u>242</u> , 354 (1968)
3140	Crystal Growth, Annealing, and Diffusion of Lead-Tin Chalcogenides	A. R. Calawa T. C. Harman M. C. Finn P. Youtz	Trans. Met. Soc. AIME <u>242</u> , 374 (1968)
3150	Spin-Wave Resonance	R. Weber	IEEE Trans. Magnetics <u>MAG-4</u> , 28 (1968)
3154	Magnetic Ordering and the Electronic Properties of the Heavy Rare-Earth Metals	R. E. Watson <sup>†</sup> A. J. Freeman <sup>†</sup> J. O. Dimmock	Phys. Rev. <u>167</u> , 497 (1968)
3161	Growth of Single Crystals of ZnTe and $\text{ZnTe}_{1-x}\text{Se}_x$ by Temperature Gradient Solution Zoning	J. M. Steininger R. E. England	Trans. Met. Soc. AIME <u>242</u> , 444 (1968)
3176	Dependence of Critical Properties on Dimensionality of Spins	H. E. Stanley	Phys. Rev. Letters <u>20</u> , 589 (1968)
3185	Self-Trapping in Media with Saturation of the Nonlinear Index	T. K. Gustafson <sup>†</sup> P. L. Kelley R. Y. Chiao <sup>†</sup> R. G. Brewer <sup>†</sup>	Appl. Phys. Letters <u>12</u> , 165 (1968)

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\* Reprints available.

<sup>†</sup> Author not at Lincoln Laboratory.

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JA No.

3187	Isotope Effect in Superconducting Rhenium	E. Maxwell* M. Strongin* T. B. Reed	Phys. Rev. <u>166</u> , 457 (1968)
3191	Continuous Operation of a Long-Lived CO <sub>2</sub> Laser Tube	R. J. Carhone	IEEE J. Quant. Electron. <u>QE-4</u> , 102 (1968)
3196	Comments on "Standing Spin-Wave Resonance in 'Flash-Evaporated' Permalloy Films"	P. E. Tannenwald R. Weber	Phys. Rev. Letters <u>20</u> , 918 (1968)
3213	Time Dependence in the Thermal Blooming of Laser Beams	R. L. Carman P. L. Kelley	Appl. Phys. Letters <u>12</u> , 241 (1968)
3230	Linear- $\vec{k}$ Valence Band Splitting in InSb	C. R. Pidgeon* S. H. Groves	Phys. Rev. Letters <u>20</u> , 1003 (1968)
3237	Observation of Interband Transitions in Arsenic	M. Maltz* M. S. Dresselhaus	Phys. Rev. Letters <u>20</u> , 919 (1968)

MS No.

1857	An Effective Hamiltonian for the Optical Properties of Silicon and Germanium	G. F. Dresselhaus M. S. Dresselhaus	Intl. J. Quant. Chem. <u>1S</u> , 595 (1967)
1859B	The Virial Theorem for a System of Interacting Particles Under External Forces and Constraints	P. N. Argyres	Intl. J. Quant. Chem. <u>1S</u> , 699 (1967)
1943	Analysis of Distant-Neighbor Interactions in Cubic Spinels	K. Dwight N. Menyuk	J. Appl. Phys. <u>39</u> , 660 (1968)
1945	Nuclear Magnetic Resonance and Magnetization Studies of CdCr <sub>2</sub> Se <sub>4</sub>	G. H. Stauss* M. Rubinstein* J. Feinleib K. Dwight N. Menyuk A. Wold*	J. Appl. Phys. <u>39</u> , 667 (1968)
1954	Localized vs Collective Descriptions of Magnetic Electrons	J. B. Goodenough	J. Appl. Phys. <u>39</u> , 403 (1968)
1955	Magnetic Properties of SrRuO <sub>3</sub> and CaRuO <sub>3</sub>	J. M. Longo P. M. Raccach J. B. Goodenough	J. Appl. Phys. <u>39</u> , 1327 (1968)
1956	A Localized-Electron to Collective-Electron Transition in the System (La, Sr) CoO <sub>3</sub>	P. M. Raccach J. B. Goodenough	J. Appl. Phys. <u>39</u> , 1209 (1968)
1958	Resistivity and Magnetic Order in Ti <sub>2</sub> O <sub>3</sub>	L. L. Van Zandt J. M. Honig J. B. Goodenough	J. Appl. Phys. <u>39</u> , 594 (1968)

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\* Author not at Lincoln Laboratory.

MS No.			
1959	Band Structure of Nickel and Low-Energy Optical Transitions	J. Hanus J. Feinleib W. J. Scouler	J. Appl. Phys. <u>39</u> , 1272 (1968)
1961	Observation of Ferri- and Anti-ferromagnetic Resonance in Insulating Magnetic Spiral Structures	J. J. Stickler H. J. Zeiger	J. Appl. Phys. <u>39</u> , 1021 (1968)

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## UNPUBLISHED REPORTS

Journal Articles

JA No.			
3186	Light Scattering from Single-Particle Electron Excitations in Semiconductors	A. Mooradian	Accepted by Phys. Rev. Letters
3192	Spin-Orbit-Coupling Effects in Transition-Metal Compounds	J. B. Goodenough	Accepted by Phys. Rev.
3206	Partial Pressure of Se <sub>2</sub> (g) in Selenium Vapor	R. F. Brebrick	Accepted by J. Chem. Phys.
3218	Band Model for Transition-Metal Chalcogenides Having Layer Structures with Occupied Trigonal-Bipyramidal Sites	J. B. Goodenough	Accepted by Materials Res. Bull.
3219	The Tuning of PbSe Lasers by Hydrostatic Pressure from 8 to 22 Microns	J. M. Besson* A. R. Calawa W. Paul*	Accepted by Phys. Rev.
3220	Type Conversion and p-n Junctions in n-CdTe Produced by Ion Implantation	J. P. Donnelly A. G. Foyt E. D. Hinkley W. T. Lindley J. O. Dimmock	Accepted by Appl. Phys. Letters
3223	Upper and Lower Bounds for the Intermediate Coupling Polaron Ground State Energy	D. M. Larsen	Accepted by Phys. Rev.
3225	Tri-Arc Furnace for Czochralski Growth with a Cold Crucible	T. B. Reed E. R. Pollard	Accepted by J. Cryst. Growth
3239	Copper-Doped Germanium Detectors	T. M. Quist	Accepted by Proc. IEEE

\* Author not at Lincoln Laboratory.

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JA No.

3240	Long Wavelength Infrared Pb <sub>1-x</sub> Sn <sub>x</sub> Te Diode Lasers	J. F. Butler T. C. Harman	Accepted by Appl. Phys. Letters
3249	Effect of Pressure on the Structure and Magnetic Properties of RbNiF <sub>3</sub>	J. A. Kafalas J. M. Longo	Accepted by Materials Res. Bull.
3260	Band Antiferromagnetism and the New Perovskite CaCrO <sub>3</sub>	J. B. Goodenough J. M. Longo J. A. Kafalas	Accepted by Materials Res. Bull.
MS-2282	Interpolation Methods for Phonon Spectra in Crystals	G. F. Dresselhaus M. S. Dresselhaus	Accepted by Intl. J. Quant. Electron.

Meeting Speeches\*

MS No.

1719F	Interstellar OH Maser Emission	M. M. Litvak	Seminar, M.I.T., 10 May 1968
1882D	Raman Scattering from Elementary Excitations	A. Mooradian	Seminar, M.I.T., 5 April 1968
1882E	Raman Scattering from Plasmons and Phonons	G. B. Wright	Seminar, Southern Illinois University, 26 February 1968
2141B	Zero Gap Semiconductors	S. H. Groves	Seminar, Lowell Technological Institute, 3 April 1968
2161	Spark Source Mass Spectroscopy, Recent Developments and Present Capabilities	E. B. Owens	American Chemical Society, San Francisco, 1 April 1968
2165	Polymorphism in Ag <sub>2</sub> Te at High Pressures and Temperatures	M. D. Banus M. C. Finn	} Electrochemical Society, Boston, 5 - 9 May 1968
2176	Metallic Inclusions and Low Angle Grain Boundaries in Pb <sub>1-x</sub> Sn <sub>x</sub> Te Crystals	J. F. Butler T. C. Harman	
2179	Si-Te System: Partial Pressures and Thermodynamic Properties from Optical Density of the Vapor Phase	R. F. Brebrick	
2166	Electronic Raman Scattering from Impurities in Semiconductors	G. B. Wright A. Mooradian	} American Physical Society, Berkeley, California, 18 - 21 March 1968
2174	The Two Phonon Infrared and Raman Spectrum of CdTe	A. Mooradian G. B. Wright	

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

MS No.			
2183A	Interband Magnetoreflexion of Gray Tin	S. H. Groves C. R. Pidgeon* A. W. Ewald* R. J. Wagner*	} American Physical Society, Berkeley, California, 18 - 21 March 1968
2184	Exciton Structure in the Magneto-absorption Spectrum of Germanium	E. J. Johnson	
2188A	Electroreflection Study of Inversion Asymmetry and Warping Induced Interband Magneto-Optical Transitions in InSb	C. R. Pidgeon* S. H. Groves	
2189	Microwave Acoustic Amplification and Noise Emission from n-InSb	K. W. Nill	
2191	Type Conversion and p-n Junctions in n-CdTe Produced by Ion Implantation	J. P. Donnelly A. G. Foyt E. D. Hinkley W. T. Lindley J. O. Dimmock	
2193	Optical Transmission of $Cd_{1-x}Mg_xTe$ Alloys	A. J. Strauss	
2197	Photoluminescence Due to Oxygen in $ZnTe_{1-x}Se_x$ and $Zn_{1-x}Cd_xTe$ Alloys	G. W. Iseler A. J. Strauss	
2198	Determination of Experimental Form Factors on an Absolute Scale from Relative X-Ray Intensities	P. M. Raccach	
2202	Electronic Energy Bands in Cu and Ni	G. F. Dresselhaus J. Hanus	
2203	Electronic Energy Bands and Optical Properties of Cu and Ni	J. Hanus G. F. Dresselhaus	
2204	Plasma Waves and Fermi Liquid Effects in Alkali Metals	D. C. Hamilton A. L. McWhorter	
2205	Effect of Orbital Overlap on Charge Densities in Crystals	T. A. Kaplan J. Hanus W. H. Kleiner P. M. Raccach H. E. Stanley	
2206	Effect of Orbital Overlap on Momentum Distributions in Crystals	W. H. Kleiner J. Hanus T. A. Kaplan H. E. Stanley	

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\* Author not at Lincoln Laboratory.

Division 8

MS No.

2207	Relation Between Ising, Heisenberg, and Spherical Models: Critical Properties of Isotropically Interacting Classical Spins of Arbitrary Dimensionality	H. E. Stanley	} American Physical Society, Berkeley, California, 18 – 21 March 1968
2208	Some Properties of LCAO Bloch Functions	H. E. Stanley J. Hanus T. A. Kaplan W. H. Kleiner	
2210	Finite Temperature Single-Determinant Theory	T. A. Kaplan	
2211	Optical Properties of Ni-Cu Alloys at 300 and 77°K from .2-11 eV	W. J. Scouler J. Feinleib J. Hanus	
2261	Band Approach to the Transition Metal Oxides	J. Feinleib	
2264A	The d-Electrons in Thiospinels	J. B. Goodenough	
2190	Like-Atom Cluster Formation and Elastic Memory in TiNi	J. B. Goodenough	International Conference on Metal-Nonmetal Transition, San Francisco, 14 – 16 March 1968
2212	The Present Position of Solids Mass Spectroscopy in Trace Analysis	E. B. Owens	American Chemical Society, Bayside, New York, 5 April 1968
2251	Homogeneity Range of Bi <sub>2</sub> Te <sub>3</sub> from Optical Density of the Vapor	R. F. Brebrick	} American Physical Society, Washington, D.C., 22 – 25 April 1968
2252	Magnetic Properties of MnAs Under Pressure	N. Menyuk J. A. Kafalas K. Dwight J. B. Goodenough	
2264	Band Structure and Magnetic Interactions in Transition-Metal Chalcogenide Spinels	J. B. Goodenough	
2266	Raman Scattering from Plasmons in Semiconductors	A. L. McWhorter	AIIME Annual Meeting, New York, 25 – 29 February 1968
			American Physical Society, Boston, 26 – 28 February 1968

MS No.			
2267	Growth, Properties and Band Structure of $Pb_{1-x}Sn_xTe$ and $Pb_{1-y}Sn_ySe$	T. C. Harman	Conference on Semimetals and Narrow Gap Semiconductors, University of Durham, England, 2 - 4 April 1968
2277	Electronic Structure of Transition Metals	J. Hanus	Colloquium, Brandeis University, 5 March 1968
2278	CO <sub>2</sub> Laser Radar	R. H. Kingston	Seminar, United Aircraft, East Hartford, Connecticut, 7 March 1968
2281	Uses of an Ultra High Power Glass Laser for Basic Research	R. L. Carman	Seminar, Naval Research Laboratory, Washington, D. C., 19 March 1968
2282	Fourier Expansions for the Electronic Energy Bands in Solids	G. F. Dresselhaus	Seminar, University of Illinois, 22 March 1968
2284	Crystal Growth Research at the M. I. T. Lincoln Laboratory	T. B. Reed	Seminar, Texas Instruments, Incorporated, Attleboro, Massachusetts, 21 March 1968
2285	Recent Results in the Statistical Mechanics of Magnetism	H. E. Stanley	Seminar, University of California, 22 March 1968
2293	Thermal Blooming - Theory and Experiment	R. L. Carman	Seminar, M. I. T., 29 March 1968
2296	Hydrodynamic Modes and Propagation of Intense Light Beams in Liquids and Gases	P. L. Kelley	Seminar, Harvard University, 10 April 1968
2299	Exact Solution for a Linear Chain of Isotropically Interacting Classical Spins of Arbitrary Dimensionality	H. E. Stanley	19th Statistical Mechanics Meeting, Yeshiva University, New York, 10 April 1968
2302	Raman Scattering from Plasmons, Phonons, and Impurities in Semiconductors	G. B. Wright	Seminar, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, 25 April 1968
2305	Fermi Liquid Effects on Plasma Wave Propagation in Metals	A. L. McWhorter	Seminar, M. I. T., 12 April 1968
2324	Polarons in Indium Antimonide	D. M. Larsen	Seminar, Northeastern University, 7 May 1968



## SOLID STATE DIVISION 8

### I. SOLID STATE DEVICE RESEARCH

Photovoltaic detectors with long-wavelength cutoffs up to  $20\ \mu$  at  $77^\circ\text{K}$  and up to  $30\ \mu$  at  $12^\circ\text{K}$  have been produced from annealed Bridgman-grown and vapor-grown  $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$  crystals in the  $0 < x < 0.25$  composition range. Responsivities as high as  $190\ \text{V/W}$ , detectivities of nearly  $10^{10}\ \text{cm}^2/\text{W sec}^{1/2}$ , and external quantum efficiencies up to 37 percent have been obtained at wavelengths up to  $12\ \mu$  in diodes operated at  $77^\circ\text{K}$ . Detectivities at  $12^\circ\text{K}$  were generally about an order of magnitude higher than at  $77^\circ\text{K}$ .

Photoconductivity at wavelengths up to  $15\ \mu$  has been observed at  $77^\circ\text{K}$  in Bridgman-grown and subsequently annealed crystals of  $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$  which had carrier concentrations as low as  $2 \times 10^{15}\ \text{cm}^{-3}$  and  $77^\circ\text{K}$  mobilities of about  $3 \times 10^4\ \text{cm}^2/\text{V sec}$ . Detectivity values between  $10^8$  and  $10^9\ \text{cm}^2/\text{W sec}^{1/2}$  at  $77^\circ\text{K}$  and  $10^{10}\ \text{cm}^2/\text{W sec}^{1/2}$  at  $4.2^\circ\text{K}$  were measured. Photoconductive lifetimes of about  $10^{-8}$  and  $10^{-6}\ \text{sec}$  were obtained at the two respective temperatures.

Diode lasers with low thresholds and emission wavelengths up to  $28.1\ \mu$  have been fabricated from vapor grown single crystals of  $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$  containing Bi as the dominant donor impurity. For  $x \geq 0.2$ ,  $77^\circ\text{K}$  threshold current densities were less than  $1500\ \text{A cm}^{-2}$ . With pulse bias, a peak power output of  $0.1\ \text{W}$  and an external quantum efficiency  $\eta_x$  of 0.08 were observed in a  $\text{Pb}_{0.8}\text{Sn}_{0.2}\text{Te}$  diode at  $12^\circ\text{K}$ , and a peak power of  $0.03\ \text{W}$  with  $\eta_x = 0.01$ , was measured at  $77^\circ\text{K}$ . With CW operation at  $12^\circ\text{K}$ ,  $5 \times 10^{-3}\ \text{W}$  with  $\eta_x = 0.03$  was obtained.

Extrinsic far infrared photoconductivity has been observed at  $4.2^\circ\text{K}$  in high purity n-type epitaxial layers of GaAs grown on Cr-doped semi-insulating GaAs substrates. Responsivities as high as  $5 \times 10^3$  and  $4 \times 10^4\ \text{V/W}$  have been measured at  $195$  and  $337\ \mu$ , respectively. At  $902\ \mu$ , the responsivity dropped to  $9 \times 10^2\ \text{V/W}$ . Measurements of the noise in the detection system at  $300\ \text{Hz}$  in a  $1\text{-Hz}$  bandwidth yield an NEP of  $1.2 \times 10^{-11}\ \text{W}$  at  $195\ \mu$ ,  $1.4 \times 10^{-12}\ \text{W}$  at  $337\ \mu$ , and  $6 \times 10^{-11}\ \text{W}$  at  $902\ \mu$ . The time constant of the detector has been determined to be shorter than  $1\ \mu\text{sec}$  using a Ge avalanche modulator to chop the incident radiation. A time constant of about  $5\ \text{nsec}$  was measured using impact impurity ionization in the GaAs.

We have found that proton radiation damage can be used to convert both p- and n-type GaAs into high-resistivity material, and have used this technique to isolate p-n junctions on a diffused GaAs substrate and also to prevent edge breakdown in Au-GaAs Schottky barriers. This technique of creating high resistivity material should be useful for the fabrication of structures in which thin high-resistivity layers are required.

The photovoltaic response of InSb-MOS detectors to modulated  $3.9\text{-}\mu$  radiation from an InAs diode emitter has been measured at  $77^\circ\text{K}$  following irradiation with short wavelength light in the energy range between 1 and 5 eV. Effects are observed due to trapping and detrapping of electronic charge at oxide states and/or at oxide-InSb interface states; however, the precise model for this trapping has not yet been determined.

## II. OPTICAL TECHNIQUES AND DEVICES

The 100-W CO<sub>2</sub> laser amplifier has been operated in the sealed-off mode and yields an output of 88 W compared to 114 W using a flowing gas mixture. The output beam pattern is a close reproduction of the input TEM<sub>00</sub> mode.

The 1.5-meter stable CO<sub>2</sub> oscillator has been used to drive the above amplifier. An output power of 10 to 15 W is obtained, and the frequency stability should be comparable to that of previous smaller versions once the output window heating is eliminated by the use of lower-loss materials.

An attempt has been made to observe thermal blooming of a 10.6-μ CO<sub>2</sub> laser beam in an absorbing gas. Substantial blooming does occur, but difficulty has been encountered in making quantitative measurements due to the asymmetry caused by convection in our horizontal gas cell and to the lack of a good image detector at the 10-μ wavelength.

Optical heterodyning at 10.6 μm between a current-tunable, single-mode Pb<sub>0.88</sub>Sn<sub>0.12</sub>Te diode laser and a stable, single-frequency CO<sub>2</sub> gas laser has produced a controllable beat frequency in a Ge:Cu detector from under 50 to 1300 MHz. From these measurements, we have determined the cut-off frequency of a Ge:Cu detector considered for application in the laser radar system, and have obtained a direct indication of the linewidth of emission from the semiconductor p-n junction laser.

## III. MATERIALS RESEARCH

A theoretical analysis of the forced convection method of vapor crystal growth has shown that the growth velocity is proportional to the first power of the available concentration of condensing vapor and to the square root of the carrier gas velocity. These results are supported by experimental data reported previously on the growth of iodine and camphor crystals. The condition required for stability of the growth interface has been formulated in terms of a relationship between the temperatures at the interface, at the edge of the diffusion boundary layer adjacent to the interface, and at the solid source.

Optical transmission measurements have been made at room temperature on single crystals of Cd<sub>1-x</sub>Mg<sub>x</sub>Te alloys with 0 ≤ x ≤ 0.46. The energy gap evaluated from the data increases linearly with increasing x, from 1.50 eV for CdTe to 2.23 eV for x = 0.46.

Photoluminescence spectra due to oxygen in ZnTe<sub>1-x</sub>Se<sub>x</sub>, ZnTe<sub>1-x</sub>S<sub>x</sub>, and Zn<sub>1-x</sub>Cd<sub>x</sub>Te alloys have been measured at 4.2°K. As expected for the isoelectronic trap model of the oxygen center, the trapping energy decreases with increasing ZnSe and ZnS content, but is essentially independent of CdTe content.

The pressure-composition phase diagram for the Ba<sub>1-x</sub>Sr<sub>x</sub>RuO<sub>3</sub> system at 1000°C has been determined by x-ray diffraction measurements on powdered samples. Four different structures, with different proportions of cubic and hexagonal close packing, are observed. The addition of strontium and the application of pressure both favor structures with more cubic and less hexagonal close packing.

A method has been developed for evaluating absolute atomic form factors in solids by analysis of integrated intensity data obtained in x-ray diffraction measurements. Application of this method to data for nickel suggests a transfer of 0.3 electron from the outer levels (4s) to the first inner levels (3d), but this should be considered as a qualitative result.

#### IV. PHYSICS OF SOLIDS

The optical investigation of the band structure of nickel has now been extended to nickel-copper alloys. Reflection measurements, from 0.2 to 11 eV, in several alloys seem to indicate that below 4 eV the alloys behave according to a "localized states" or to a "minimum polarity" model.

A study of the effect of stress on the impurity spectrum of bismuth-doped silicon has now been completed. All measured relative intensities and transition energies as a function of stress are in agreement with predictions of a strain Hamiltonian derived from effective mass and deformation potential theory.

Two sets of interband transitions, analogous to those in HgTe, have now been observed in the magnetoreflexion of gray tin. One of the lowest energy transitions does not fit into the Landau level scheme; it is suggested that this line may arise from transitions between impurity states associated with the Landau levels.

Investigation of the "extra" transitions in the interband magnetoreflexion and magneto-electroreflexion of InSb, caused by the warping and linear- $\vec{k}$  splitting of the valence band, has been concluded. The warping obtained is in good agreement with the cyclotron resonance results of Bagguley, *et al.*; the linear- $\vec{k}$  splitting is one-third the value deduced from cyclotron resonance by Robinson, but is in agreement with the theoretical estimate of Kane.

A technique has been developed for determining the Debye temperature  $\Theta_D$  of crystals by means of thermal modulation of x-ray diffraction. This new method, which has been tested on NaCl, gives results in good agreement with other techniques, and, aside from holding promise of surpassing the accuracy of existing DC methods, has the additional advantage of yielding  $\Theta_D$  from measurements at a single temperature.

Substantial amplification, greater than 25 db/cm, of 9-GHz longitudinal ultrasonic waves has been obtained in n-InSb on application of a pulsed electric field. Theoretical calculations of this effect are in reasonable qualitative agreement with the experiment.

Measurements of the magnetic properties of the high-pressure (orthorhombic) phase of MnAs have been extended to 11 kbars. The variation with temperature of the magnetic moment has been studied as a function of magnetic field and throughout the pressure range.

A study of the properties of the one-dimensional, two-sublattice model of a spiral magnetic structure has been completed. For a range of parameters, a ferrimagnetic conical spiral structure is the ground state. The spin wave spectrum for this case has been investigated.

The well-known spherical model of a ferromagnet has been shown to be thermodynamically identical to a system of infinite-dimensional spins interacting through a Heisenberg Hamiltonian.

It is known that for the Ising model, the onset of magnetic order is characterized by the collapse of the eigenvalue spectrum of a certain linear operator. It has been demonstrated that the same mathematical phenomenon characterizes the onset of ordering in a set of  $\nu$ -dimensional spins interacting via a Heisenberg Hamiltonian.

A new form of temperature-dependent Hartree-Fock theory is being investigated, based on a variational principle for the free energy. The one-electron orbitals used to construct single determinant wave functions must satisfy an equation which is more general than the usual Hartree-Fock equations. This new formulation eliminates some of the paradoxical results of ordinary temperature-dependent Hartree-Fock theory.

## Division 8

Using high-resolution Brillouin scattering techniques, the velocity and attenuation of 28-GHz longitudinal phonons propagating along the x-axis of  $\alpha$ -quartz have been measured in the temperature range 300° to 600°K. Although the velocity variation with temperature agrees with the earlier ultrasonic measurements, the hypersonic attenuation agrees with theoretical extrapolations of ultrasonic data only in order of magnitude.

For the first time, light scattering has been observed from screened single-particle electron and also hole excitations. Scattering from electron excitations was found in GaAs, InP, AlSb and CdTe, and from hole excitations in p-type GaAs doped with cadmium, zinc and magnesium.

The study of thermal defocusing of a laser beam has now been extended to steady state (and approach to steady state) conditions. Competing conduction and convection processes have been investigated in a number of new experiments.

Methods of achieving single mode operation of a high-power pulsed ruby laser have been explored. In the best arrangement, a single transverse mode and less than six longitudinal modes are obtained.

<b>DOCUMENT CONTROL DATA - R&amp;D</b>		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY (Corporate author)  Lincoln Laboratory, M. I. T.	2a. REPORT SECURITY CLASSIFICATION Unclassified	
	2b. GROUP None	
3. REPORT TITLE  Quarterly Technical Summary on General Research		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Quarterly Technical Summary for 1 February through 30 April 1968		
5. AUTHOR(S) (Last name, first name, initial) Frick, Frederick C.      Dodd, Stephen H.      Freedman, Jerome      Hutzenlaub, John F. Nedzel, V. Alexander      Herlin, Melvin A.      Weiss, Herbert G.      McWhorter, Alan L. Tannenwald, Peter E.		
6. REPORT DATE 15 May 1968	7a. TOTAL NO. OF PAGES 56	7b. NO. OF REFS 8
8a. CONTRACT OR GRANT NO. AF 19(628)-5167 b. PROJECT NO. 649L c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) General Research QTS for 15 May 1968  9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ESD-TR-68-83	
10. AVAILABILITY/LIMITATION NOTICES  This document has been approved for public release and sale; its distribution is unlimited.		
11. SUPPLEMENTARY NOTES  None	12. SPONSORING MILITARY ACTIVITY  Air Force Systems Command, USAF	
13. ABSTRACT  This Quarterly Technical Summary covers the period from 1 February through 30 April 1968. 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.		
14. KEY WORDS  data systems                      control research                      microwave equipment digital computers                  radio physics                          mechanical and structural engineering computer components              space surveillance                      solid state physics psychology                              radar		