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Quarterly Technical Summary

General Research

15 November 1966

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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

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INTRODUCTION

This Quarterly Technical Summary covers the period from 1 August through 31 October 1966. 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

CONTENTS

DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 August through 31 October 1966 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1966

PUBLISHED REPORTS

Technical Report

TR No.				DDC No.
405	On-Line Graphical Specification of Computer Procedures	W.R. Sutherland	23 May 1966	DDC 639734

* * * * *

UNPUBLISHED REPORTS

Meeting Speeches*

MS No.			
1678	The Lincoln Reckoner: An Operation-Oriented On-Line Facility with Distributed Control	A.N. Stowe R.A. Wiesen D.B. Yntema	Fall Joint Computer Conference, San Francisco, 8-10 November 1966
1741	Response Selection in Keeping Track of Several Things at Once	D.B. Yntema G.M. Schulman†	Symposium on Attention and Performance, Driebergen, Netherlands, 20 August 1966
1743	The Use of Birefringent Media to Improve the Efficiency of Longitudinal Magneto-Optical Mode Conversion in Thin Magnetic Films	D.O. Smith K.J. Harte	Optical Society of America, San Francisco, 17-21 October 1966

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

† Author not at Lincoln Laboratory.

DIGITAL COMPUTERS
GROUP 23

I. COMPUTER SYSTEMS

A. TX-2

The new Memory Bus Switch (MBS) is now in operation with the TX-2 computer. The switch allows up to four processor modules to select simultaneously any combination of four of the eight memory modules. Although the current memory capacity of TX-2 is only 100,000 words, the MBS was designed to handle a total memory capacity of over one million words. This will allow the large capacity memory to be added to the system relatively easily. Since original shakedown, the operation of the switch (which contains over 15,000 transistors) has been very satisfactory. At present, the TX-2 computer uses two of the processor module spigots in order to obtain overlap of instructions and operands. SPAT* is now being modified so that it can be time-shared by four instead of two processor modules.

B. Low-Speed Input

During this quarter, the Low-Speed Data Channel and the Data Terminal were finished. The Low-Speed Data Terminal is a new input/output (I/O) sequence (sequence 57) for the TX-2 computer. This sequence will handle a large number of concurrently operating low-speed I/O devices in a random, interleaved fashion. Automatic selection of the highest priority unit is provided. The Data Terminal is the first I/O unit to be connected to the above data channel. It provides the hardware necessary for automatically placing or answering calls on the Western Union Broadband Switching Exchange and then sending data in an ASCII-compatible, asynchronous format at 1200 bits/sec. This equipment will be used in the computer network experiments with System Development Corporation.

C. Displays

A new CRT display sequence for the TX-2 computer has been designed and is under construction. Included in the system are a conic waveform generator, character generator, and the ability to multiplex a maximum of ten display stations. The waveform generator is based on the homogeneous coordinate system which allows easy program manipulation of display patterns. The generator uses multiplying digital-to-analog decoders in a hybrid configuration to generate the horizontal and vertical deflection signals for the CRT's. A commercial symbol generator will provide the alphanumeric symbols.

The digital control for this new display is designed to allow easy addition of new features, such as storage-type displays, input tablets or three-dimensional wands. It also makes use of feedback signals from individual CRT deflection systems to initiate the next operation. Thus, fast- and slow-deflection CRT displays can be mixed without compromising their individual capabilities.

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* General Research Quarterly Technical Summary Report, Lincoln Laboratory, M.I.T. (15 August 1966), DDC 639570.

D. Selectric (Golf Ball) Typewriter

Specifications for an IBM Selectric input/output writer were written, and a machine was ordered after several vendors of modified Selectrics had been visited or called in to demonstrate their equipment. A "golf ball" which contains the 88 Lincoln Writer characters has been ordered from a vendor specializing in custom elements.

E. Power System

The TX-2 power system has been reorganized and rewired to take advantage of the elimination of the old 65K memory power supplies and to accommodate the MBS. Provision was made for power to the IBM units and the Xerographic printer on power-off days so that maintenance may be carried out with no loss of computer time. The AC timing chain and interlock system has been greatly simplified, distribution of AC has been centralized, and AC wiring in the computer room ceiling has been confined to conduits. Records and wire markings are being updated.

II. MAGNETIC FILM ENGINEERING

A. Fine-Line Etching

The methods for etching pressure connection patterns, summarized in the last report, have worked equally well for making 15-inch-long "digit" patterns with 6.5-mil-wide conductors on 10-mil centers. By projecting collimated light through the scribed master at slight angles (±2.5°) from the normal with the master spaced about 0.205 inch from the photosensitive surface, it is possible to "undercut" and reduce the adverse effect of dust particles or other contamination. A 50-percent increase in total exposure time is required. With this improved exposure technique, digit-line sets have been made which contain no "opens" or nicks in line edges which exceed 20 percent of line width.

B. Large Capacity Memory

Word Noise:– An extensive analysis was made of word noise in the prototype memory stack. Noise associated with wrinkling of the insulating sheet between word and digit lines was eliminated by using a coating of Kodak Thin Film Resist as insulation on the word piece. Production of a set of essentially perfect digit lines (no edge blemish as large as 0.001 inch) offers hope for elimination of all noise inductively coupled from word-to-digit line by edge irregularities. A residual component of word noise with amplitude as large as 50 percent of signal amplitude is a consequence of imperfect sense-system, common-mode rejection; common-mode filter techniques already used in test setups should substantially reduce this.

Random Noise:– Signal amplitude is low enough to make sense-amplifier random noise a serious problem in the LCM. With a magnetically good word piece, the measured ratio of peak signal to rms random noise is about 20:1, but consideration of variation in signal amplitude and input-transistor noise makes a reasonable worst-case estimate 12:1. Effective signal amplitude is reduced by word noise and by deviation of decision-circuit threshold from zero, and noise can be enhanced by as much as $\sqrt{2}$ by a synchronous clamp used to eliminate amplifier baseline shift. If all degrading effects are present simultaneously, the minimum tolerable signal-to-noise ratio

of 7:1 is barely achievable. Signal doubling by a magnetic keeper or a conducting ground plane would eliminate the problem. An investigation of the random-noise problem is continuing.

C. Large Capacity Memory Stack

The design of a stack structure for 26 substrates, instead of the present 10, has been completed. This was essentially a scaling-up of the existing stack. The fabrication of a new pressure connector using spring-loaded pins has been completed and is being carefully compared with the old etched connector to determine which best fulfills the requirements.

Interest in use of a ground plane immediately beneath the permalloy for signal enhancement and noise reduction has led to the investigation of surface smoothness, insulating layers between the ground plane and the magnetic material, and intralayer adhesion. Present work is with a 0.0005-inch-thick vacuum evaporated layer of copper on polished glass substrates, with sputtered glass and a commercial high-temperature varnish being investigated as possible insulating layers. Sputtered glass has initially exhibited poor adhesion to the copper ground plane, while the varnish has a tendency to bubble during permalloy deposition, causing pinholes. Work is continuing in this area.

D. Large Capacity Memory Testing

A number of improvements have been made on the LCM tester, including automatic operation of the indexing mechanism. A digit-disturb test of one substrate (100,000 bits) takes about one hour. A substrate must be tested a second time at a 5-mil displacement in order to detect small irregularities. Setup and error investigation may take one or two additional hours for each substrate.

E. Content Addressed Memory

Film manufacture has been moderately well regulated, so that most of the films from good runs are acceptable. Intermittently recurrent is a strange effect in which the very thin chromium layer (about 20 Å) used to adhere the copper shorting layer to the glass and permalloy strongly affects the magnetic properties of films that are evaporated through masks. Several techniques for handling this problem are available.

Efforts are now directed toward building a small test memory to evaluate the circuit problems.

F. Saturable Shielding

Testing of samples of memory configurations employing 5-mil-square shields has confirmed that (1) SiO is an effective exchange-breaking layer, (2) alignment to within ±0.5 mil can be maintained easily between each successive etching operation, (3) the induced voltage from the shield occurs early enough to be distinguished from the induced voltage from the storage film during reading. However, the nonuniform saturation of the shield degrades the sharpness of the switching threshold more than its shielding improves sharpness. Shield geometries with more uniform saturation properties will be tested.

G. Uniaxial Stress Relief in Etched Lines

It has been observed that when positive magnetostrictive films coated with 4 μ of copper are etched into 2-mil lines, the wall coercive force H_c goes up. Conversely, in negative magnetostrictive films, H_c goes down when etched into lines; if, however, the copper is selectively etched away, H_c returns to nearly its initial value.* This suggests that, initially, isotropic tensile stress is partially relieved in a direction perpendicular to the line edges.

Experiments have been performed to predict the controllability of stress relief as a practical means for raising H_c in etched lines. Measurements have shown that the isotropic stress in 4-μ copper varies little from run to run and averages $1.7 \pm 0.3 \times 10^9$ dynes/cm.† This stress, however, is independent of copper thickness in the range of 1 to 8 μ. Less predictable is the strain sensitivity of H_c for a given composition film. Typically, H_c changes only about one-fifth as much as H_k for the same strain. In an experiment in which line width was varied, it was observed that a larger increase in H_c due to stress relief occurred for narrow lines as predicted by theory.†

III. SYSTEM PROGRAMMING AND APPLICATIONS

A. MK5

MK5 is the assembly language programming system for the TX-2 time-sharing system, APEX. Recent work has concentrated on the implementation of several major facilities, including character files, a text input mode, and FLOW-MAP.

(1) A character file enables a user to expand a symbolic program (directive) into a string of characters which are then placed into a file. This character file may then be used in a manner analogous to paper tape for the merging of symbolic programs.

(2) The text input mode accepts any string of characters as text; the string is then assembled into the required number of registers of code with the characters packed in APEX typewriter output form.

(3) FLOW-MAP is a significant major addition to the MK5 debugging repertoire. It is an on-line graphical debugging system which supplies a user with a dynamic picture of the control flow of his program.

The FLOW-MAP system collects "from-to" pairs of jumps in a program and produces a display showing the flow of the program. Branch points, branches, and linear sections of instructions are represented by nodes, parabolic arcs, and vertical lines, respectively, on the scope. In addition, the symbolic addresses of the nodes and the order of their generation are displayed. In this way, the user receives an instantaneous, global view of his program's actions; he can see what code he is flexing, where his subroutine calls and returns are, strange places he may be jumping to, etc. The user may partition his program by designating the areas to be flow-mapped so that only the specified areas are flow-mapped in detail; the remaining areas are treated as black boxes with no detail shown. FLOW-MAP is fully integrated with the other debugging facilities of MK5. In particular, the use of FLOW-MAP in conjunction with meta-bit trapping provides an especially powerful debugging aid, since a user may thereby specify the (trapping) conditions under which a flow-map is to be produced.

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*R. J. Spain, J. Appl. Phys. 37, 2572 (1966).

†P. S. Theocaris and K. Dafermos, "The Elastic Strip Under Mixed Boundary Conditions," ASME, J. Appl. Mech. 31, 714 (1964).

B. Associative Processing

A user-oriented system having both numerical and associative processing capabilities has been designed and is being implemented on the TX-2 computer. A high-level programming language for the expression of complicated associative retrieval requests is being embedded in an ALGOL system. A scheme, based on hash-coding techniques, for the internal representation of a large store of relations between items of information has been implemented and debugged. A procedure for processing complicated associative retrieval requests, using this representation of a relational information store, is being implemented. The system has been designed to operate in the TX-2 time-sharing system under the control of VITAL.

C. Languages

VITAL has been completed according to current specifications and is presently being used in Junior, the Associative Language, and Coral II.

Junior has been modified to produce faster run time operation and to include more sophisticated checks for loop counting when operating on matrices of different sizes.

D. Diagnostics

Programming is virtually completed for diagnostics for SNAT, SPAT, SKM, SKX, and sequences 40, 41, and 42. All have been completely debugged or are in the last stages of debugging. Documentation for all tests is near completion and should be available shortly.

E. Earth Display

The Earth Display program has been completed with a few bugs still remaining in the arithmetic routines. Suggestions have been made for some fairly minor improvements in the display and these will be implemented as soon as the current system is completely operational. Documentation of the system will commence shortly.

F. Waveform Processing

Maintaining satisfactory resolution over a wide dynamic range is a serious problem when acquiring data which are to be subsequently converted to digital form. For some applications, sufficient signal-to-noise ratios cannot be obtained. Dynamic range is often reduced by means of a soft limiter such as is provided by the square root or logarithm function. However, the data resulting are usually of such wide bandwidth that adequate transmission and/or storage media are unavailable.

A nonlinear circuit has been developed which avoids both of these drawbacks for the class of waveforms with rapid instantaneous variations and relatively slow amplitude variations. The process involved by this circuit is of such a nature that it can easily be inverted to re-form the original waveform. This inversion process can be performed digitally after analog-to-digital conversion has taken place or by means of an inversion circuit. A suitable inversion circuit has also been developed which is almost identical to the circuit mentioned above except for changes to a subcircuit consisting of three ordinary passive elements. Both circuits have been

tested using audio signals – specifically, speech and music. Signals involving dynamic ranges as large as 50 db were reduced to a dynamic range of 25 db, passed through audio channels (each with a sharp cutoff at 15 kHz), and subsequently restored to their original dynamic range. The total error committed by this three-stage process was sufficiently small to prevent subjective differentiation of the processed and unprocessed signals.

Larger or smaller dynamic range reduction ratios are continuously obtainable over a theoretically infinite range. Practical considerations require that ratios be chosen in the range from 0 (no reduction) to about 5 (50 db becomes 10 db) depending on the gain stability of the transmission and/or storage media.

As a by-product of this circuit development, a signal level meter with a 100-db range on a single scale has been devised.

COMPUTER COMPONENTS
GROUP 24

I. MAGNETIC FILMS

A. Theory of Magnetization Ripple

A theory has been developed which relates the hard-axis fallback angle[1] α_{90} to film parameters. For fine-scale dispersion, where the scale of inhomogeneity $R \ll 1\,\mu$ (e.g., crystalline anisotropy), we find $\alpha_{90} \propto K^2 R^2 H_k^{-1}$ in agreement with Hoffmann,[2] where K = mean local anisotropy energy. For coarse dispersion ($R \gg 1\,\mu$), we obtain the result $\alpha_{90} \propto K^{6/5}(R/d)^{1/5} H_k^{-1}$, where d is the film thickness.

B. Theory of High-Speed Switching

In previous work of spin-wave locking of the high-speed switching mode,[3] it was assumed that the spin-wave relaxation time is long compared to the uniform rotation switching time. The opposite case in which the spin-wave relaxation time is much shorter than the switching time yields surprisingly similar results. Whereas in the slow-relaxation model, the initial spin-wave state is dynamically locked, in the fast-relaxation model, quasi-static locking occurs through local instabilities induced by the nonlinear longitudinal magnetostatic field.[4] In both models, the uniform mode is then locked by the transverse magnetostatic field of the spin waves.

The main result of the theory is to predict the threshold pulsed field H_t for uniform rotation, which is experimentally always higher than predicted by single-domain theory. For small hard-axis bias field, the slow-relaxation model leads to $H_t \propto \alpha_{90}^{3/2}$, while in the fast-relaxation model, $H_t \propto \alpha_{90}$. Experimental results of Telesnin, et al.,[5] appear to verify the latter law. For somewhat larger bias, the slow-relaxation model gives the result $H_t - H_{sd} \propto \alpha_{90}$, while the fast-relaxation model predicts $H_t - H_{sd} \propto \alpha_{90}^{2/3}$, where H_{sd} is the single-domain theory threshold (the astroid).

C. Kerr Chamber for High-Temperature Domain Studies

A magnetic viscosity effect has previously been found in NiFeCu films;[6] i.e., under a constant field, uniform slow domain wall motion has been observed by Lorentz microscopy. The velocity varied exponentially with applied field.

It would be desirable to measure the velocity at various temperatures in order to find an activation energy which could be related to the magnetic parameters of the film. For this purpose, a Kerr effect apparatus has been built which allows films to be heated to ~400°C in a vacuum of about 10^{-5} torr. Tests indicate a loss in contrast between domains at the higher temperatures because of nonuniform warping of the glass substrates; however, enough contrast remains to permit measurements over a wide range of temperatures.

D. Anisotropy Spectrum of Magnetic Films

Improvements in the electronics associated with the rotating anneal method of measuring the anisotropy spectrum of magnetic films have included: (1) the design of a correction circuit

to sense and correct drift in the phase-sensitive detector during the film annealing time; (2) the improvement of signal-to-noise ratio by a factor of three by (a) canceling the 500-Hz pickup, and (b) matching to a higher amplifier input impedance; (3) the addition of a bucking circuit to cancel an unwanted quadrature component of the 500-Hz drive field.

II. OPTICS

A. Magneto-Optics

The role of birefringent media in maximizing the longitudinal magneto-optical mode conversion in magnetic and dielectric film structures has been re-evaluated. It was found that the use of such media does not, in principle, improve the conversivity, although there may be practical reasons for their use. The best conversivity is found to occur in transmission using a thin magnetic film, for which, in principle, the conversivity can approach unity. In practice, it is estimated that the improvement over reflection from a magnetic substrate might be as much as a factor of ~2000.

B. Thermo-Optics

A writing beam of ~2 μ has been demonstrated with an optical system providing ~3 cm of free working distance. Reading will be attempted with the reflection Kerr effect, with the magnetic film on the back of a prism operating just beyond the angle for total internal reflection.

C. Optical Amplifier

In order to obtain the highest possible resolution of a magneto-optically read memory and simultaneously allow single-bit selection, it is proposed to associate an optical amplifier with each memory bit. Amplification would be by stimulated emission and pumping by the same high-resolution beam used for thermal writing. Work has been started to develop the required optically active thin film.

III. ELECTRON TRANSPORT

A. Triode Measurements

A bridge technique has proved successful in measuring the small signal AC resistance parameters of tunnel triodes. It has been discovered that the reverse transfer resistance r_r is not negligible compared to the forward transfer resistance r_f for thin base devices. Therefore, an important parameter to measure is the internal current transfer, which involves $r_f - r_r$, not the short-circuit current transfer, which involves only r_f. Triodes which were previously believed to have very high (50-percent) hot-electron transfer are now believed to have been nearly passive devices. Nevertheless, the bridge has proved to be a very useful new tool in studying the onset of hot-electron collection, and the current transfer ratio has been found to be as high as a few percent under favorable conditions.

B. Control of Aluminum Oxidation

Improved control and seleetivity of tunneling-oxide thicknesses produeed by unbiased plasma oxidation of aluminum have been achieved using oxygen pressure as a parameter. With oxidation time, plasma eurrent density, and substrate temperature constant, oxygen pressures from 30 to 175 μ yield tunneling-oxide barriers whose resistivities at 1.5 volts are 10^4 ohm-cm at 175 μ inereasing to 10^{10} ohm-cm at 30 μ.

REFERENCES

1. T. S. Crowther, "Teehniques for Measuring the Angular Dispersion of the Easy Axis of Magnetie Films," Group Report 51-2, Lineoln Laboratory, M. I. T. (30 March 1960), DDC 255697, H-289.
2. H. Hoffmann, Phys. Stat. Sol. 5, 187 (1964).
3. K. J. Harte, "Spin-Wave Effects in the Magnetization Reversal of a Thin Ferromagnetie Film," Teehnical Report 364, Lineoln Laboratory, M. I. T. (27 August 1964), DDC 610068.
4. K. J. Harte, J. Appl. Phys. 37, 1295 (1966), DDC 640536.
5. R. V. Telesnin, et al., Phys. Stat. Sol. 14, 371 (1966).
6. M. S. Cohen, J. Appl. Phys., to be published.

PSYCHOLOGY
GROUP 25

I. ON-LINE USE OF THE TX-2 COMPUTER

A. APEX

APEX, the executive system that time-shares the TX-2 computer, continues to operate routinely and without serious troubles. With the exception of a small but important improvement in the user-switching algorithm, there has been little change in the basic system during the past quarter. Work has been concentrated on the design of improved input-output programs, including programs for communication with other computers.

The computer now has a low-speed data channel which will be used for communication with remote consoles and with other computers. The first phase of the software required to use this hardware with the APEX time-sharing system is now being checked out. APEX has been changed to allow two new consoles, and the basic routines for sending and receiving streams of characters are ready. The first remote connection will be with the FSQ-32 computer at the System Development Corporation in Santa Monica, California.

Considerable progress has been made on other input-output facilities. Satisfactory routines are now available for operating the photoelectric paper-tape reader, the Xerographic printer, and the analog-to-digital input equipment. The coding of routines for the magnetic tape units is nearly complete, and work should soon begin on a program to provide a digital-to-analog output during time sharing. The paper-tape punch will then be the only major input-output device that APEX will not be able to handle during time sharing: routines for the punch are still lacking and are not currently scheduled.

B. Lincoln Reckoner

The Lincoln Reckoner is a time-shared service that is based on the APEX system and intended for on-line use by a scientist or engineer who wants to explore a set of data or a theoretical computation.

In the past, the most important gap in the Reckoner has been the absence of a convenient means by which the user – or a programming assistant – could create a new primitive routine when the routines in the public library were not convenient for his problem. A small procedure-oriented language called Junior is now available for this purpose. It makes use of the VITAL compiler-compiler* and produces routines that, with one remaining minor exception, can be used exactly like the routines in the public library.

The only other change has been the addition of a few new routines to the library – especially a routine to produce rough graphs on the Xerox printer.

An initial version of a Reference Manual has been distributed. It is in loose-leaf form to facilitate additions and changes, and is intended for the non-programmer who wants exact

* See the Group 23 section of this Quarterly Technical Summary.

information about some detail of the Reckoner's operation. Detailed descriptions of all the computation routines are included, but descriptions of some of the others, especially the input-output routines, are still missing and will be added gradually.

II. ON-LINE USE OF THE IBM 360/67

A. General System Editor

A contract has been let for programming work on a general-purpose editing facility for the IBM 360 Model 67 time-sharing system that the Laboratory is acquiring. It is expected that this editor will be a primary means for inputting and modifying records and programs of all kinds. It is expected that some substantial capabilities will be available when the time-sharing system becomes operational at the Laboratory, and that a full range of services will be available early next fall. The work is being coordinated with IBM and with the institutions whose Model 67 systems will be operational shortly after the Laboratory system.

B. Using the System to Initiate Its Users

Work has been started on a curriculum for initiating users to on-line computing: operation of the console, use of editing facilities, and introduction to Fortran IV. It is hoped that, with the help of the editor mentioned above, on-line instruction in these areas can be made available to new users of the time-shared System 360 soon after it is introduced to the Laboratory. In the meantime, an "instructor" and a "student" linked by teletype will be used to explore an appropriate curriculum.

C. Facility Similar to the Present Reckoner

Experience with the present Reckoner (see Sec. I-B) has shown that the basic design is sound and that a similar facility would be of great practical value to scientists and engineers throughout the Laboratory. Because TX-2 is an experimental computer, the present Reckoner is not available for wide use. A contract has therefore been let to design for the IBM 360/67 a similar service that can be made available throughout the Laboratory sometime in the spring. The initial facility will be rather primitive in two areas, editing and data retrieval. However, the design will be such that it can be expanded to allow the user to call on a more powerful editor (see Sec. II-A) and a more sophisticated system for storage and retrieval.

III. HUMAN INFORMATION PROCESSING

A. Stimulus – Response Conflict

When a subject is asked to name the color in which a word is printed, the task is rendered difficult if the word happens to be the name of a different color. An experiment has just been completed to determine the extent to which such interference is related to a particular attribute such as color, and also to determine if a readout by verbal response produces more interference than a nonverbal readout by button pressing. Analysis of results will be completed in the coming quarter; however, it appears that both effects are present.

B. Word-Association Latency as a Function of Response Entropy

Analysis of choice-reaction studies done elsewhere suggested that response latency was directly related to the response uncertainty calculated from the distribution of errors. An experiment was performed, therefore, in which the effect of response uncertainty on latency could be investigated over a wide range of uncertainty.

Sixty subjects were given a word-association task, using the Kent-Rosanoff list as stimulus words. The subjects were instructed to respond orally with the first word that came to mind as soon as possible after presentation of the stimulus word. The latency of this first response was found to have a strong positive correlation with the entropy of the distribution of associations in the Minnesota norms for this task. Thus, contrary to what might perhaps be expected, a subject responds more slowly when he has a wide choice of associations.

COMPUTER SYSTEMS
GROUP 28

I. COMPUTER CENTER DEVELOPMENT

With the exception of the drum, which will be installed within a few weeks, all major components of the IBM System 360/67 have been delivered and are in operation. As part of a continuing program by IBM, every device in the system is undergoing a series of engineering changes and improvements. This effort parallels programming systems debugging and improvement and represents a response to field experience. In the few days since some of the changes have been made, there has been a noticeable improvement in or elimination of trouble spots.

The 360/40 System has rounded out its supporting role with the installation of a paper-tape reader/punch and a second card reader/punch. In addition to its primary activity, the 360/40 is also building up a repertoire of tasks operating under the supervisor but aimed at various external devices. These include the IBM 2741 (typewriter) terminals, the IBM 2260 (CRT) terminals, telemetry data collection lines interfaced through an IBM 2702, and connection with a remote Univac 1219 computer.

Although there are still a few programs not yet converted from the 7094, there appears to be some workable solution to every known programming problem. The area of greatest continuing difficulty is that of reading "had" tape, particularly tapes which have been written on other systems. Work on a new IBM-supplied version of Operating System/360 is already under way. As with the hardware improvements, this new version should correct and improve system performance.

Notwithstanding the hardware and software problems, or possibly because of them, the number of jobs handled by the 360/67's has almost doubled over the number formerly handled by the 7094. In the past month, there has been a very noticeable increase in the number of long production jobs submitted, so that both processors are kept busy twenty-four hours a day, five days a week and usually well into the weekends. It is difficult to imagine how this volume would have been handled on the 7094.

II. LISTAR SYSTEM

A Lincoln Laboratory report* describes an on-line data storage and retrieval system operating under the M.I.T. Compatible Time Sharing System (CTSS). The system is being redesigned to run on the Laboratory's IBM 360/67 computer under the Time Sharing System (TSS). Changes in design reflect the differences in the increased hardware and software capability of the IBM 360/67 over the IBM 7094. The system will be referred to by the mnemonic LISTAR, designating the Lincoln Information Storage and Associative Retrieval System.

LISTAR will give users at a console, or a user program, the ability to define, search, modify, and cross-associate files of information to suit the user's particular interests and needs. During the past quarter, the LISTAR file structure and its interfacing with the data management facilities of TSS have been defined. During the coming quarter, the program requirements will be defined and implementation begun.

* J. F. Nolan and A. W. Armenti, "An Experimental On-Line Data Storage and Retrieval System," Technical Report 377, Lincoln Laboratory, M.I.T. (3 February 1965), DDC 615658.

RADIO PHYSICS
DIVISION 3

INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 August through 31 October 1966. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary Report and the Quarterly Letter Report to ARPA.

S. H. Dodd
Head, Division 3

M. A. Herlin
Associate Head

DIVISION 3 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1966

PUBLISHED REPORTS

Journal Articles*

JA No.			
2721	Note on the Effect of Shadowing on the Backscattering of Waves from a Random Rough Surface	R.A. Brockelman T. Hagfors	IEEE Trans. Antennas Propag. AP-14, 621 (1966)
2765	Study of Radio Echoes from the Moon at 23 Centimeters Wavelength	J.V. Evans T. Hagfors	J. Geophys. Res. 71, 4871 (1966)
2836	Stokes Parameters for 1665-Megacycles-per-Second Emission from OH near Source W3	M.L. Meeks J.A. Ball J.C. Carter R.P. Ingalls	Science 153, 978 (1966)

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2797	Radar Observations of Venus at 3.8 cm Wavelength	J.V. Evans R.P. Ingalis L.P. Rainville R.R. Silva	Accepted by Astron. J.
2840	Radar Observations of Venus at 23 cm in 1965-1966	J.V. Evans R.A. Brockelman E.N. Dupont L.B. Hanson W.A. Reid	Accepted by Astron. J.
2867	Comments on Paper by A.K. Fung and R.K. Moore, "The Correlation Function in Kirchhoff's Method of Solution of Scattering of Waves from Statistically Rough Surfaces"	T. Hagfors	Accepted by J. Geophys. Res.
MS-1484	Radar Signatures of the Planets	J.V. Evans	Accepted for Planetology and Space Mission Planning, Annals of New York Academy of Sciences

* Reprints available.

Meeting Speeches*

MS No.			
1354A	Radar Studies of the Moon	J. V. Evans T. Hagfors	COSPAR 9th Plenary Meeting and 7th International Space Science Symposium, Vienna, Austria, 10-19 May 1966
1680	Recent Radar Results on the Rotation and Surface Features of the Inner Planets	G. H. Pettengill	Colloquium, Goddard Space Flight Center, Greenbelt, Maryland, 27 May 1966
1688	Time Variations in Quasar Flux at 3.75 cm and 2 cm Wavelengths	M. L. Meeks	International School of Physics, Varenna, Italy, 20 July 1966
1713	The Temperature of Neutral and Charged Particles in the Ionosphere and Magnetosphere	J. V. Evans	Inter-Union Symposium on Solar-Terrestrial Physics, Belgrade, Yugoslavia, 29 August – 2 September 1966
1729	Some Recent Lunar Radar Observations and Their Interpretation	T. Hagfors	NEREM, Boston, 2-4 November 1966

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

SURVEILLANCE TECHNIQUES
GROUP 31

Group 31 operates the Millstone Hill Field Station which includes the Millstone radar facility and the Haystack research facility. Research programs in satellite observation techniques and in ionospheric and auroral studies are conducted at Millstone. Programs in radio and radar astronomy are conducted at both Millstone and Haystack. At present, the radar astronomy program is centered largely around the new Haystack 500-kw Planetary Radar System, the completion of which is of primary interest this period. An increasing share of the radio astronomy program in the 10- to 70-cm region is being undertaken at Millstone, while at Haystack, emphasis is being placed upon observations at shorter wavelengths at which the capabilities of the 120-ft precision reflector are unique. A coordinated propagation studies program in connection with the Laboratory's Space Communications Program has been planned, with the objective of understanding the effect of precipitation upon the signal path between a satellite and ground station at X-band frequencies and above. Both Millstone and Haystack facilities, as well as the West Ford communications site, will be utilized in this work.

I. OPERATION, MAINTENANCE, AND IMPROVEMENTS

A. Millstone Radar

1. L-Band Radar System

The antenna system was arranged for radiometric operations from 4 to 29 August. During September and October, radar operations included satellite tracking, ionospheric backscatter measurements, and lunar studies. As part of the propagation studies program, implementation and testing began for a 10-μsec RF pulse capability intended for observations of precipitation echoes.

A scanning surveillance radar was specified and ordered as government furnished equipment for installation at the Station. It will provide a means of alerting Millstone and Haystack to meteorological conditions favorable for the Space Communications propagation studies, and will also provide data for directing these sensors to areas of greatest interest.

A 3-channel nitrogen-cooled parametric amplifier provided by Group 46 was installed in the L-band receiving system. This has greatly improved the stability and reliability of the system.

An adjustable coherent signal generator, at 1295 MHz, to be used for phasing and amplitude calibrations, has been built and tested. Installation of this equipment, to be completed by mid-November, will permit more accurate signal level calibrations by the SDS-9300 computer.

2. Ionospheric Backscatter System

Data gathering operations for this period included six 24-hour periods with the UHF system and three 12-hour periods with the L-band system.

The UHF receiving system has been improved by replacing the vacuum tube second-stage amplifier and mixer with a solid state 440-MHz amplifier and a Hewlett-Packard mixer. A

minor modification to the operating console, together with the use of the 9300 computer since 9 June, has increased the speed of data taking and reduced the number of human errors.

The installation of the new L-band parametric amplifiers mentioned in Sec. 1-A-1 has also improved the L-band backscatter data.

3. Radiometric Systems

Observations of radio recombination lines of hydrogen near 400 and 1300 MHz were attempted at Millstone. The UHF effort was unsuccessful because of intense interference. Since a survey at Haystack showed that the 1303-MHz hydrogen-line frequency was clear of interference, it was decided to conduct a search for this line at Millstone. The radar receiving system was modified for easy changeover from radar to a radiometric configuration, and radiometric observations in the 23-cm region began late in October.

Work was begun on the implementation of a new interferomcter for radiometric studies using the 84-ft Millstone antenna and the 60-ft antenna at the Harvard University Agassiz Site in Harvard, Massachusetts. The initial use of this long (8.3-mile) baseline system will be to obtain improved angular resolution of OH sources observed previously with the 2000-ft Millstone/Haystack interferometer.

4. Data Processing and Computer Systems

The CG-24 computer was dismantled and removed from the site after all the necessary computer functions had been transferred to the SDS-9300 computer. The punched paper-tape block reader previously used with the CG-24 computer to direct the antenna has been connected directly between the interface equipment and the digital antenna director. A system of eight 10-bit analog-to-digital signal quantizers, each having a conversion rate of 10 μsec, has also been interfaced between the radar and the SDS-9300 computer.

A Scientific Data Systems Model CFE-1 correlation filter was installed in the SDS-9300 computer system, but is not yet operational.

B. Haystack Research Facility

1. Antenna System

During August, an access net was installed by North American Aviation, Inc., on the back of the 120-ft reflector. This net provides a safe means for performing maintenance work and surface panel adjustments. Following the installation of the access net, the dish surface was surveyed for a number of different temperature conditions. Appreciable differences in surface distortion and focal length were observed between daytime and nighttime conditions. Study of these and earlier data indicated that thermal lag in the 60-ft-diameter splice plate to which the inner and outer panel sections are secured is a principal cause of this effect. It was also discovered during the course of these measurements that the inner and outer sections conform to slightly different paraboloids. The difference is not great enough to appreciably affect antenna performance at X-band, but will cause significant degradation at shorter wavelengths.

The splice plate was blackened to reduce its thermal time constant, resulting in a substantial reduction in observed day-to-night surface distortions. Plans have also been made for

rerigging the dish to bring the inner and outer sections into conformity with each other and to reduce the overall surface error.

2. Data Processing and Computer Systems

Several subsystems were completed for use in the lunar mapping work and in the range measurements required for the 4th test of the General Theory of Relativity.

The radar sequencer used to time the radar transmit-reeeive eycle and other system funetions was placed in operation.

The receiver Doppler frequency steering system has been upgraded. The second local oscillator at 100 MHz may be controlled by the Univac 490 computer to tune the recciver during radar operation. In this arrangement, a frequency synthesizer is eontrolled in 0.1-Hz steps at a 20-pps rate from ephemeris information either fed through the computer from preeomputed tape or computed direetly by the Univac 490 pointing program. A "Doppler-offset range rate" generator has also been added to provide a nominal 4-MHz cloek signal offset in frequency to provide a time base that traeks a moving target in range. This signal is used by the radar synehronizer to develop analog-to-digital eonversion sampling pulses.

The CDC 3200 eomputer was replaced during this quarter with a CDC 3300. The radar reeeiver had already been interfaeed to the CDC 3200, and minor differences between the two eomputers necessitated some modifieation of the interface.

3. Operations

From 4 August until the week of 5 September, the antenna aecess installations and surface measurements mentioned in Sec. I-B-1 were carried out. Radiometric operations began with re-evaluations of the gain and pointing accuracy of the antenna during the first half of September. Apparently, the aeeess installations have not appreeiably affected the antenna. Other radiometrie operations ineluded measurements at X-band of thermal emissions from the moon and from the terrestrial atmosphere, as well as obscrvations of anomalous OH emissions from a number of diserete sourees as detailed below.

Operations with the new Planetary Radar System were started during the week of 17 Oetober and continued throughout the month.

C. Station Time and Frequency Standards

The hydrogen-maser frequency-standard installation at Haystack was completed. Station frequency standards at both Haystaek and Millstone are phase-locked to the hydrogen maser. At present, all cloeks normally involved in Station operations are driven from frequency sources which are phase-locked to the maser; all system frequencies are so derived also. The short-term phase instability of this system has been found to be less than 20° peak-to-peak at 8 GHz. This arrangement is appropriately baeked up by two rubidium vapor standards driving indepenent clocks.

D. Planetary Radar Development

Integration and initial operation of the Haystack X-band Planetary Radar System were achieved in this reporting period. The transmitter is operated succcssfully at a power output

level of 250 kw. Breakdown in certain areas of the microwave system, as well as a limitation in the performance of one of the two klystron amplifier tubes, has delayed realization of the 500-kw design objective. These problems derive from manufacturing deficiencies and are not fundamental; it is expected that the full-power capability will be realized very soon. The X-band traveling-wave maser has operated with a high degree of reliability, permitting overall system temperatures between 40° and 60°K in clear weather. Digital control and timing equipment developed to support high-accuracy planetary ranging operations has also been performing well. The real-time range-Doppler processing program using the CDC 3300 to perform range-code-compression and spectral analysis was successfully demonstrated in test operations on the planet Mercury.

II. SPACE SURVEILLANCE

A. Orbit Upgrading Programs

An intensive effort was made at Millstone to fit the precision orbit determination program (MHESPOD) into its planned real-time environment. Considerable recoding was necessary to adapt the program to the SDS-9300 computer with its radar interface. (The original version of the program was "tested" only with card input on the IBM 7094.)

Numerous programming difficulties have been encountered, mainly because of errors in coding, but some were traced to malfunctioning real-time subroutines. A revised "system tape" from SDS is expected to resolve some of these difficulties.

The real-time data smoothing program (DAP) has been run on a routine basis during regular tracking exercises, and useful satellite data have been forwarded to Space Track almost weekly. The shorter version of DAP contained in MHESPOD has not yet been run successfully in actual operations. However, the errors responsible appear to have been corrected, and good results have now been obtained with simulated radar data.

The preparatory routine PREMOD was also brought into operation. (Starting from an initial set of mean elements, PREMOD provides acquisition data and the basic orbit and core ephemeris which MHESPOD is to correct during an operation.)

B. Tracking Support

Although the Millstone antenna system was available for tracking operations during only September and October, an unusually heavy schedule of satellite tracking was undertaken. Some 100 hours were devoted to MITRE/Millstone interferometer operation, largely as a result of an Air Force request to cooperate in a classified project. Satellite tracking in support of SPADATS and of Lincoln Laboratory programs, including MHESPOD tests, accounted for 90 hours.

III. LUNAR STUDIES

Radar observations at 23 cm continued at Millstone, while at Haystack, further radiometric observations were made at 3.7 cm. The third quarterly progress report* in the partially NASA-supported lunar studies program has been issued, and the fourth such report was prepared for a 15 November publication date.

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*Quarterly Progress Report No. 3, Radar Studies of the Moon, Lincoln Laboratory, M.I.T. (15 August 1966).

A. Millstone Observations

The results of the work to determine the mean depolarizing properties of the lunar surface at 23 cm have been prepared for publication. New observations at 23 cm have been made to provide input data for the unambiguous mapping experiment* for which computer programs are being revised and debugged.

B. Haystack Radar Observations†

No observations have been made during the quarter, but work has continued on the analysis of data obtained previously. In particular, the effort has been centered on an improvement in the ephemeris calculations and on developing satisfactory displays of the data. A few impressive preliminary maps of an area around the crater Plinius have been developed.

C. Haystack Radiometer Observations†

High-resolution observations of the phase variation of the thermal emission from the moon at 3.7 cm have continued. Considerable new data have been taken, and improvements in the computer programs for reduction and presentation of the data have been made. A few runs have been analyzed successfully and displayed as contour plots – others have not produced satisfactory data, possibly because of slight thermal instabilities in the antenna gain. Data covering approximately half of one lunation have been collected.

IV. SHAPIRO TEST OF GENERAL RELATIVITY

During the current reporting period, the various elements which make up the precision planetary ranging system for Haystack were fitted together. Attempts to observe the planet Mercury were begun on 19 October and, after encountering and clearing up some small system problems, resulted in success on 25 October. The system noise temperature finally achieved was about 55°K at an elevation of 45° in clear weather. The design objective was 75°K. The transmitter output was limited to about 200 kw on that operation, and is presently limited to 250 kw, 3 db below the design objective.

Despite the limitation in system performance imposed by the low transmitter output, it was calculated that should Venus exhibit a cross section (say, 2 percent of the geometric cross section) in the upper range of the distribution of values obtained during the summer's CW observations, it would be detectable after a day's operation. Summing of the results obtained over several days can yield a useful result even in the face of a nominal 1-percent value for the fractional cross section. Operations on Venus were begun on 27 October, but by 31 October only two full days of operation had been possible. As of that date, no definite echoes from Venus could be reported.

The retardation in the echo delay introduced, according to the General Theory of Relativity, by the solar gravitational potential near superior conjunction, whose measurement forms the

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* Quarterly Progress Report No. 3, Radar Studies of the Moon, Lincoln Laboratory, M.I.T. (15 August 1966), Sec. III.

† For details, see Quarterly Progress Report No. 4, Radar Studies of the Moon, Lincoln Laboratory, M.I.T. (15 November 1966).

basis for the Shapiro test, continues to be significant in the case of Venus well into December 1966. Intensive efforts to detect Venus will thus continue. A superior conjunction of Mercury occurs in January 1967, and a further, although less favorable, opportunity for applying this test will arise then.

V. ATMOSPHERIC STUDIES

A. Ionosphere

Analysis of the backlog of incoherent backscatter data continues, emphasizing work on early 1965 data. In an effort to increase the speed of analysis, preliminary work was begun on developing a non-real-time computer program for obtaining the power spectrum of the scatter signal. (A bank of Doppler filters is presently used.)

B. Auroral Studies

Analysis of the range distribution of auroral echoes was completed, and a computer program was written to obtain a model of the distribution expected for several assumed thicknesses of the layer in which auroras originate. Spectral analysis of a small portion of the 1965 data was also completed.

VI. RADIOMETRIC OBSERVATIONS

Radio astronomy observations during this quarter are summarized in the following paragraphs.

A. System Evaluation and Calibration

Following installation of the access net on the Haystack antenna, the gain and pointing of the antenna were rechecked on bright radio sources previously used in this work. Variation in antenna gain as a function of thermal conditions was also investigated.

B. Radiometric Mapping

Observations at 2 cm (beamwidth, 2') were made to provide high-resolution continuum maps of regions of OH emission, including the galactic center and sources with catalogue numbers W3, W49, W51, W75, and NGC6334.

C. Spectral-Line Observations

The OH emission from NGC6334 was observed at monthly intervals in order to investigate time variations. The polarization properties of OH emission were measured for the catalogue sources listed in the preceding paragraph. The Millstone antenna and the Haystack spectral-line hardware were used together for observations of a hydrogen recombination line at 1303 MHz in the Orion nebula.

D. Continuum Radiometer Observations

The 8- and 15-GHz radiometers at Haystack were used for a continuing program of observations of the time-variable quasars, the moon, and various weather phenomena in the atmosphere.

RADAR
DIVISION 4

INTRODUCTION

This section summarizes the General Research activities of Division 4 during the period 1 August through 31 October 1966. The major portion of Division 4's activities is devoted to Radar Discrimination Technology, PRESS, BMRS, and Space Communications, which are described in separate reports. The General Research activities in Division 4 are carried out by Group 46, which is engaged in work on Haystack instrumentation, millimeter radar, and microwave component development.

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head

DIVISION 4 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1966

PUBLISHED REPORTS

Journal Articles*

JA No.			
2758	RF Generated Shock Waves	R.M. Weigand	Proc. IEEE (Correspondence) 54, 1485 (1966)
2773	Aural Pulse Compression by Bats and Humans	J.J.G. McCue	J. Acoust. Soc. Am. 40, 545 (1966)

* Reprints available.

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 requirements arising from radar projects. Contributions are made to the General Research Program through the support of Haystack Hill, operation of a high-power microwave laboratory, development of low-noise receiver techniques, participation in a millimeter-wavelength program, and studies of very-high-gain antennas and antenna feeds.

II. HAYSTACK MICROWAVE COMPONENTS – PLANETARY RADAR BOX

Construction and final assembly of the Planetary Radar (PR) Box and its components were essentially completed during this reporting period. On 7 October 1966, a 250-kW output was first achieved for a sustained period. Body interception problems in one of the klystrons and waveguide arcing problems traceable to poor fabrication techniques have led to a decision not to try to increase the transmitter power until after the period of the superior conjunction of Venus.

A. High-Power Multimode Feed and Circular Polarizer

Prior to installation of the high-power feed and circular polarizer in the PR Box, the components were tested at low power with a circularly polarized source to verify the feed patterns and match. The illumination taper is 13.8 ± 0.3 dB over a ±1-percent band at 7.84 GHz. The feed beam efficiency is defined as the fraction of the total power radiated by the feed which illuminates the subreflector. Within the 2-percent band, the feed efficiency is 90 ± 1 percent; within a ±4-percent band, the feed efficiency is greater than 75 percent. The VSWR of the feed is 1.08 at 7.84 GHz and 1.11 over a ±1-percent band at 7.84 GHz. The maximum response of the feed to cross-polarized signals is 23 to 24 dB below the normal pattern peak in this 2-percent band. The VSWR is less than 1.2 within a ±5-percent band at 7.84 GHz. A report on the feed will appear as a journal article.

The feed-horn assembly was installed and checked in the system during the early part of the reporting period. During operation, arcs developed in the mode generator as a result of faulty electroforming. The arcing was eliminated by filling some voids with soft solder. Since the spare assembly exhibits similar problems, another electroforming or fabrication approach is under investigation.

Losses in the mylar radome led to the development of a hole by RF heating. The mylar was replaced by polyethylene, with good results achieved to date.

B. Crystal Power Monitors

Crystal power monitors were installed during the early part of the reporting period. These units have proved to be excellent fault detectors, both from the viewpoint of fast system protection and diagnosis.

Extra fixed pads were installed in some units to compensate for a higher sensitivity of the crystals than that anticipated when the coupler values were established.

C. Transmitter

The final calibration of the monitoring system was completed upon installation of the feed horn and power monitors. System use has shown that the monitor bridge for indication of the klystron balance is quite satisfactory.

Arcs in waveguide components were temporarily eliminated after tracing the cause to faulty fabrication of brazed assemblies. Replacement items are under procurement.

D. Arc Location

A possible means of locating the position of an RF breakdown in a waveguide by other than a visual determination is under investigation. The method involves a measurement of the interval between the occurrence of the arc and the time the accompanying sound wave reaches a microphone located at some point in the waveguide system. The scheme shows promise for use in the PR Box.

E. Auxiliary Receiver Line

In its original form, the receiver waveguide was configured for minimum loss in the main receiver line to permit operation of the PR Box as either a sensitive CW planetary radar or as a high-performance radiometer. During this reporting period, it was decided to add a short-pulse mode of operation to the PR Box for proposed lunar mapping without compromising the use of the PR Box as either a planetary radar or as a radiometer. Short-pulse capability was implemented by the addition of an auxiliary receiver line. The auxiliary line contains a gas-tube attenuator and a ferrite switch for receiver protection during short-pulse operation. The losses in the auxiliary receiver line are somewhat greater than those in the main receiver line. However, such losses can be readily tolerated in the short-pulse mode of operation.

F. Maser

The traveling-wave maser system has been installed in the PR Box and operated successfully. The system noise temperature was measured at 60°K by means of liquid nitrogen and room temperature loads.

To permit operation of the PR Box for an extended period, an Air Products and Chemicals, Inc., closed-cycle helium refrigerator is being modified to accept two traveling-wave masers with superconducting magnets. This modification includes a temperature controller that will maintain the temperature to ±0.01°K. The stringent requirement on temperature regulation is needed, since a change in the maser temperature of 0.1°K results in a change in the maser gain of 1 dB.

An estimated seven to eight hours will be required to cool the masers and magnets from ambient temperature to 4.2°K with liquid nitrogen precooling. Once cooled to helium temperatures, the masers should be continuously operational for 2500 hours. At the end of this period, the compressors should be subjected to the specified maintenance procedure. It is expected that this system will be operational in the early spring of 1967.

G. Parametric Amplifier Subsystem

For experiments in which the sensitivity of the maser is not required, a low-noise parametric amplifier of the type designed for direct immersion in a cryogenic bath will be employed. A parametric-amplifier monitor and control chassis and a regulated pump source have been fabricated for use with the parametric amplifier.

III. SOLID-STATE AMPLIFIERS

A. X-Band Parametric Amplifiers

Two low-noise, X-band parametric amplifiers of the type described in the preceding quarterly report have been successfully cascaded to give a 30-dB gain and about a 100-MHz bandwidth with no degradation in noise temperature. These amplifiers have been operated with improved varactor diodes received from Sylvania Electric Products, Inc., and found to have noise temperatures of about 95°K. This is an improvement of about 15°K over results achieved with conventional varactors.

The computer program for the design of parametric amplifiers has been debugged and used to design a new X-band parametric amplifier. Some prototype amplifiers will be fabricated on the basis of this design.

A second computer program has been completed that predicts the gain-vs-frequency performance of computer-designed parametric amplifiers. Further work on computer-designed parametric amplifiers is under way to permit designs with rectangular as well as circular idler cavities.

B. Diode Measurements

A new technique for the measurement of the impedance of packaged or unpackaged varactor diodes is under analytical and experimental investigation. This technique employs multi-resonant waveguide cavities and promises to extend the evaluation of diode impedance to much higher frequencies than were previously possible.

C. Unpackaged Varactor Diodes

An investigation has begun of the possibility of acquiring unpackaged varactor diodes in order to study their mounting problems and to measure their characteristics at frequencies from 1 to 100 GHz. This program was initiated because a further reduction in the noise temperature of uncooled parametric amplifiers will require the use of varactor diodes of much higher quality than those presently available and the employment of higher idler frequencies.

IV. DUAL-POLARIZED FEEDS FOR THE MILLSTONE 85-FOOT REFLECTOR

Two dual-polarized feeds have been obtained from TRG, Inc., and evaluated. One feed operates over a ±3.6-percent band at 3.3 GHz; the other operates over a ±4-percent band at 5.0 GHz. The waveguide horns are square with dual-mode transducers, each having two coaxial terminals. These horns are used at the focal-point of the large reflector which has an f/D ratio of 0.3. The feeds have essentially identical behavior with patterns of equal principal plane beamwidths and an illumination taper of 13 ± 1 dB. The VSWR of the feed, measured at the coaxial input terminals in the through and side arms, is equal to or less than 1.30, and over most of the band, it is less than 1.20. The isolation between side and through arms is better than 48 dB.

V. CASSEGRAIN SUBREFLECTOR SUPPORT STRUCTURES

Experimental work was completed on this investigation after a prolonged interruption. The results are given in a Technical Report.*

VI. CAMROC

A set of computer programs has been written to permit ealeulation of the effeetiveness of distortion compensation techniques for reflectors. These programs are easily modified to simulate either near- or far-field Cassegrain optics and are being used to investigate near-field axial defoeusing characteristics. Computer studies and experimental tests are being earried out. These may also have an important bearing on the gain problems being experieneed at Haystack at L-band frequencies.

* F. I. Sheftman, "Experimental Study of Subreflector Support Structures in a Cassegrainian Antenna," Technical Report 416, Lincoln Laboratory, M.I.T. (23 September 1966).

ENGINEERING
DIVISION 7

INTRODUCTION

Two projects of the General Research Program received major attention from the Engineering Division during the quarterly period ending 31 October 1966. These were Haystack and CAMROC.

At Haystack Hill, final integration of mechanical details is being completed at the Planetary Radar Box in preparation for the 4th test of the General Theory of Relativity. In addition, work is proceeding on plans for rerigging the 120-ft-diameter reflector surface to make it more accurate, for reducing the amount of metal blockage in front of the reflector, and for correcting a troublesome problem in the hydraulic drive motor system.

The CAMROC design studies, being reported for the first time, concern the design and construction of an advanced radar and radio telescope research facility which may be erected in New England. It has been determined that there would be definite cost advantages to a Cassegrain paraboloidal antenna protected by a radome.

J. F. Hutzenlaub
Head, Division 7

MECHANICAL ENGINEERING
GROUP 71

I. HAYSTACK

A. Planetary Radar Box

1. Microwave Integration

The Planetary Radar (PR) Box, to be used during the 4th test of the General Theory of Relativity, was first tested on the inside test dock using two VA-849 tubes. Later, two VA-949 tubes were installed, using the special handling equipment secured for this purpose. With the horn and arithmetic waveguide network in place, it was discovered that the mylar radome over the horn failed because of excessive radiation heating. Thus the radome was replaced with one made of polyethylene, which has a lower loss tangent.

Some minor arcing problems were encountered with the waveguide runs because of oxides and/or excess solder. This problem reinforces the principle that extreme care must be taken in the manufacture and handling of waveguide components used at these power levels.

2. Air Conditioning

The five fan-coil units were tested and balanced to give an operating air temperature of 70° to 75°F in the PR Box. Because of a delay in the fabrication of the chiller building, one 7.5-ton chiller was relocated inside the radome area for winter operation.

A $\frac{1}{2}$-hp booster pump was installed in the antenna tower to help circulate the chilled water to the antenna box position. A partial collapsing of a portion of the $1\frac{1}{2}$-inch-diameter chilled-water return line at the elevation wrap area may require changing to a reinforced hose.

3. Maser

The first maser has been installed in the PR Box. This unit operates in a batch liquid gas dewar using 18 liters of nitrogen and 10 liters of helium. Because of space limitations within the box, a fixed liquid helium transfer tube has been incorporated into the dewar. The second and third masers, being fabricated at Microwave Electronics Corporation, have been delayed by improper impurity concentration in the ruby material. Current estimate is for delivery of the second maser early in November and the third maser before 1 December.

A spectrograph head is being fabricated to enable operation of the second maser with a batch liquid gas dewar which is currently available. The third maser will be incorporated together with the second maser into a closed cycle refrigerator which is being modified by Air Products and Chemicals, Inc. The delay in the delivery of the masers has advanced the completion date of the refrigerator to 15 December.

4. Weight Balance

By means of the Bytrex unit in the Box Facilities Building, the PR Box was weighed at 7950 pounds and was balanced using 900 pounds of lead. The box was positioned on the alignment

fixture to check the four hard-point mounting positions and, after temporarily removing the balance lead and certain other equipment for hoisting, was positioned on the antenna on 10 October.

B. Blockage Reduction

In an effort to reduce the blockage of radar signals in the Haystack antenna, tests are being conducted to determine if some of the aluminum rods which brace the quadripod support legs for the secondary reflector can be replaced by fiberglass rods. A creep-temperature test fixture for the two 40-ft-long fiberglass tension members (FTM) has been built and installed on the control room roof at the site. Actual loading of the two FTM rods will take place at the next appropriate break in the Haystack operations. The mechanical design effort in support of the actual installation has been postponed until preliminary data on relative electromagnetic blockage are available from the tests. If the tests and final design show that the fiberglass tension members will adequately brace the quadripod support of the secondary reflector, it is planned to install these members in place of the present $\frac{1}{2}$-inch-diameter aluminum rods during the surface rerigging operation next spring.

II. LASER RADAR

The second Nike-Ajax pedestal has been received and installed on Tower 3 at the Millstone facility. Delivery of a 5-inch-diameter by 5-mm-thick germanium optical disk has been delayed because of fabrication difficulties.

III. MILLIMETER LUNAR RADAR

Design for installation of the elevation and azimuth shaft-angle encoders has been completed. Orders have been placed with vendors for parts fabrication.

In conjunction with the encoder installation, the azimuth cable wrap will be extensively modified. Azimuth limit-stops, both electrical and hydropneumatic, will be installed.

IV. STRUCTURAL RESEARCH

The work normally reported in this section was particularly applicable to the CAMROC effort during the quarter, and is therefore included in the following CAMROC report.

V. CAMROC

A. Introduction

The Cambridge Radio Observatory Committee (CAMROC) is comprised of a group of scientists from Harvard University, Massachusetts Institute of Technology, Lincoln Laboratory,* and the Smithsonian Astrophysical Observatory. The Committee is studying the design, construction, and operation of an advanced radar and radio telescope research facility which may be located somewhere in New England. To accomplish the scientific objectives envisioned by the Committee for this research center, a fully steerable antenna in the size range of 300 to

* Lincoln Laboratory, by authorization of the Air Force, provides technical support to the CAMROC project which is sponsored cooperatively by the National Science Foundation, Harvard University, and Massachusetts Institute of Technology.

500 ft in diameter and capable of operation at frequencies up to 6 GHz will be required. A nominal diameter of 400 ft was adopted to identify the antenna and serve as a basis for design studies and cost analysis.

Lincoln Laboratory participation in the CAMROC program at this time is primarily concerned with the design and evaluation of existing and new antenna configurations, with and without a radome, that may be considered for the proposed research facility. A design study program is now under way which draws technical support from various institutions and organizations to assist Lincoln personnel in their efforts to achieve the study objectives of this program. These objectives are to:

(1) Prepare quantitative studies (cost-vs-size curves) for structures capable of operating at a given minimum wavelength.

(2) Perform sufficient structural-mechanical analyses of these proposed antenna configurations to determine structural behavior and ability to achieve the required surface accuracy.

(3) Make comparative studies of prospective antenna configurations, with and without a radome, based on both electromagnetic and structural performance capability, usable observation time, and estimated costs.

B. Engineering Design Studies

Design studies have been made by Lincoln Laboratory together with a balanced group of consulting engineers, research and development institutions, and industrial organizations. The design team is made up of the CAMROC organization plus Ammann & Whitney (consulting engineers, New York), Paul Weidlinger Associates (consulting engineers, New York), Simpson, Gumpertz & Heger, Inc. (consulting engineers, Cambridge, Massachusetts), and the Rohr Corporation (Chula Vista, California). In addition, North American Aviation, Inc. (Columbus, Ohio) and Goodyear Aerospace Corporation (Akron, Ohio) have studied certain problem areas on their own and presented the results to CAMROC.

The broad scope of these studies was initially defined in a report to the National Science Foundation entitled "Engineering Design Objectives for a Large Radio Telescope." In essence, this report suggested a study of six antenna configurations with and without radomes. Very early in the study, it was apparent that of the six configurations, there were really only two basic types. These were the moving paraboloid (prime focus, Cassegrain, and open Cassegrain paraboloids) and the fixed paraboloid (horn, CORT, and clam-shell reflectors) systems. Thus it was decided to restrict the studies to the Cassegrain paraboloid and CORT antenna systems with and without a radome.

A number of studies have been undertaken to identify pertinent features of each of these basic configurations. A brief outline of each study follows.

1. Cost Study of an Environmental and Non-Environmental Large-Diameter Radio Telescope (Rohr Corporation)

The purpose of this study was to determine dollar costs and cost ratios for an antenna system with and without a radome. Two antenna sizes (210 ft and 328 ft) were studied in order to use as much previously published information as possible. The results of this study show that, even with a nonoptimized antenna-radome system, there are significant cost reductions to be

realized by using a radome. At a diameter of 210 ft, the antenna-radome system would cost approximately three-fourths that of an antenna system without a radome. At a diameter of 328 ft, there are strong indications that the cost ratio will favor the radome-protected system even more, but these numbers are not as firm, since they are based on a study and not on actual costs as in the case of the 210-ft-diameter antenna. As a result of this work, the remaining studies will be restricted to an antenna system utilizing a radome.

2. Antenna Configuration Study (Ammann & Whitney)

The purpose of this study is to obtain preliminary design information on both the CORT and Cassegrain systems. This includes a concept of the overall system, a preliminary design, and a cost estimate. The CORT antenna consists of a paraboloid fixed in elevation with a rotating 45° plane for the elevation transit. The paraboloid and plane both rotate in azimuth. The radome costs which are being used throughout the CAMROC studies come from a previous Lincoln-sponsored study by Ammann & Whitney. This study has progressed to the point where it is evident that the CORT system, even after taking into consideration its RF advantages, will cost considerably more than the Cassegrain system. As a result of this cost difference, it has been decided to restrict further studies to a Cassegrain paraboloid antenna within a radome.

Ammann & Whitney has started the second phase of this study program which will involve a more detailed investigation of various Cassegrain concepts. The following configurations will be studied:

(a) Single layer reticulated shell with compensation.
(b) Double layer reticulated shell with compensation.
(c) Space truss with compensation of a few critical members.
(d) Deep space truss (no compensation).
(e) Drum type construction.

No results are available from this phase of the study.

3. Antenna Compensation and Configuration Study (Paul Weidlinger Associates)

The purpose of this study is to evaluate the feasibility and degree of control possible with various open-loop surface control devices and to pursue, in some detail, various antenna configurations. It has been shown that both force and displacement types of control devices are feasible and that the degree of control is dependent only on the number and inherent accuracy of the devices used. The second phase of the study is in progress and deals with the investigation of a vertical truss antenna supported on a yoke-type pedestal similar, in some respects, to the Haystack and Jodrell Bank Mark II antennas. Configuration studies are now being made, with no definitive results available at present. This effort will provide a concept for the overall system, a preliminary design, and a cost estimate.

4. Antenna Configuration Study (Simpson, Gumpertz & Heger)

A previous study by Simpson, Gumpertz & Heger under Lincoln sponsorship has shown that the 210-ft-diameter C.S.I.R.O., Parkes, Australia, antenna exhibits good deflection

characteristics which can be accurately predicted. It was decided to perform an optimization study on this type of reflector with a diameter of 400 ft. It appears that the resulting antenna would meet the CAMROC deflection requirements with a reasonably low weight. It has been found that a significant redistribution of member properties is required to accomplish this result. Both the spiral purlins and the circumferential rings would have to be strengthened with respect to the radial ribs. This work, which is nearing completion, will produce a realistic optimized design with firm figures on weight and cost.

5. Antenna Configuration Study (Rohr Corporation)

As an extension of the original Rohr cost study, this work concerns an optimized version of the 210-ft-diameter antenna expanded to 400 ft. The original cost study showed that the present structural geometry was not necessarily optimized when enclosed within a radome. The present study will, therefore, expand the size to 400 ft and optimize the geometry and member sizes taking full advantage of the radome. As with the other configuration studies, we will obtain a concept for the overall system, a preliminary design, and a cost estimate. No results are available at present.

6. Antenna Configuration Study (North American Aviation, Inc.)

As part of an in-house engineering effort, North American has re-examined its Haystack concept at a diameter of 400 ft and has prepared a report for CAMROC. This report describes how the original concept has been modified to optimize it for the larger diameter. North American did produce a preliminary design and a weight estimate, but no cost estimate. From this brief study, it would appear that the weight of this new configuration is quite high and, therefore, expensive. However, final evaluation will not be made until the other configuration studies have been completed.

7. Buoyant Antenna Configuration Study (Goodyear Aerospace Corporation)

At the suggestion of CAMROC, Goodyear is undertaking an in-house study of the cost advantages of a large buoyant Cassegrain antenna system. With only gravity acting on the structure, they hope to reduce the weight of the structure through the use of helium-filled cells. This reduction in weight (balancing the weight of the reflector by the uplift of the helium) would minimize surface distortion and at the same time reduce the total weight of material required. The object of this study is to evaluate the cost of sustaining the buoyant system versus the savings in initial system costs. This study has just started, and therefore there is no progress to report.

8. Antenna Drive System Study (Rohr Corporation)

An extremely accurate drive system is required for the CAMROC antenna. Most previous drive systems have been designed for high horsepower motors, fast tracking response, and extreme drive stiffness because of the wind environment. Taking full advantage of the radome will allow a design with low horsepower, reasonable response, and low stiffness while maintaining the required pointing accuracy. This suggests the possibility of utilizing some rather novel

antenna drive systems such as a timing chain drive and a friction drive.

Following this study, a comparison can be made between these and the more conventional electric and hydraulic drives, after which the best system will be chosen. This study is in a very early phase and no results are available.

9. Preliminary Conclusions

Significant progress has been made thus far in the CAMROC antenna studies. It has been found that there are definite cost advantages to a Cassegrain paraboloidal antenna protected by a radome. As a result, seven organizations are studying this configuration in depth. In addition, a study is under way to determine which type of drive system best meets the CAMROC requirements. It is planned that, upon the completion of these studies, a particular concept will be chosen for the CAMROC system, and a complete preliminary design will be prepared.

C. Hammerhead Design Study

The Hammerhead concept is a configuration specifically tailored for operation within a radome and which is completely unsuitable for use in an exposed environment. The size of the system is awesome when it is considered that the enclosed volume of its 550-ft radome could house most of the Yankee Stadium.

A study of the Hammerhead concept for the CAMROC 400-ft antenna was undertaken at Lincoln Laboratory by Groups 71 and 75. The purpose of the study was to provide a basis for comparison with the other concepts under consideration, stimulate new ideas and their application to other concepts, encourage outside design firms to maintain their study effort at a high level, and possibly, but not primarily, to provide a concept for design by an outside firm.

The concept is named for the hammerhead crane, common in construction work, which has a T-shape with a long horizontal boom on a slender tower. In this antenna concept, the horizontal boom is used for an axle about which rotate parallel vertical trusses supporting the reflector surface. Since the vertical trusses are each individually counterweighted, the "axle" (or hammerhead truss) does not bend when the reflector changes elevation angle. Loads on the vertical trusses do change as the elevation angle varies and the resulting deflections are compensated by two jacks on each truss. The jacks literally pull or push the truss back to its original parabolic shape.

Use of this simple compensation technique allows the supporting structure to be highly stressed and less massive than conventional antennas, with a resulting economy of weight and cost. Thus it adds a new curve, with both a lower exponent and base, to the usual cost-vs-size graphs for large antennas.

One particular advantage of this concept is its potential use in the construction of the radome; a crane can be mounted on rails on top of the hammerhead truss, which then can be rotated in azimuth to locate the crane over the work.

Optimization of the structure was made possible by several hundred small computer runs of less than two minutes each. Components of the structure (vertical trusses, torque tube, hammerhead truss, and turret) were designed, checked for deflection and stress at different elevation angles of the dish, and revised with a relatively small engineering effort. Upon

achievement of an optimized design, the inertia and weight of the structure, together with its natural frequency and rms deflection, were calculated by an auxiliary computer program.

Results of the work to date indicate that a 400-ft antenna is not only feasible, but will be less expensive than originally anticipated. Weight of the structure is approximately one-half the original concept, and drive horsepower requirements are measured in the tens instead of hundreds.

Preliminary mechanical designs for the hydrostatic bearings and drive systems on both axes of rotation indicate that the design loads and fabrication techniques are within the present state of the art.

D. CAMROC Structural Research

1. Structural Analysis

a. Stresses

The structural analysis of the proposed CAMROC radome is being performed at Lincoln Laboratory and involves modifying and extending several existing computer programs, developing new ones where required, and linking the separate elements into a complete design process. The finished program to be called STAR (Structural Analysis of Radomes) will require that a batch of vertex points and beam members corresponding to one-sixth of an icosahedral triangle (one-twentieth of the spherical radome area) be read into the program.

The first section of the program will then develop all the vertex points and beam members for the complete radome structure. By utilizing a Fourier fit to the measured wind tunnel pressure-distribution data, the program will determine the forces acting at each vertex point and the intensity of the triangular load distribution acting along the length of each beam. This information will be automatically transferred to cards, part of which will be used as input data to the STAIR program. By means of STAIR, the axial load acting on each member in the frame will be computed. The remaining information on the transverse loads will be coupled with the STAIR results to ascertain the maximum stresses in each beam member in the space frame. This process will be repeated until the minimum acceptable beam dimensions for every member in the frame are developed. The procedure will be used with different geometries and the optical blockage of each final structure computed. The frame which yields the minimum optical blockage is regarded as the most efficient.

b. General Instability

Analytical and experimental efforts to determine the buckling capacity of a space-frame radome structure are in process under CAMROC sponsorship at M.I.T. (Aeroelastic and Structures Research Laboratory and Structural Models Laboratory) and at Simpson, Gumpertz & Heger.

A 14-ft-diameter random geometry radome cap section has been designed and is now being fabricated. After assembly, it will be tested by imposing equal radial loads over most of the vertex points until a buckling failure is precipitated. Restraints will prevent excessive deformation of the structure and allow the test to be repeated. Information compiled in this fashion will be used to develop a buckling theory for space-frame structures.

Plastic scale model sections of the hexagonal frame element which appears extensively in most radome geometries are being tested to provide information for the larger frame model tests and also to assist in the analytical formulation.

The formulation of the governing equations has been completed and a computer program selected for the buckling analyses. Modifications to the computer program have been initiated.

2. Environment

A preliminary investigation of wind storms in the northeast United States has been performed by the Air Force Cambridge Research Laboratories. A map of the wind speeds for which there is a 1 percent risk that these will be exceeded in a 25-year period has been completed and is being evaluated.

3. Site Survey (Metcalf & Eddy)

It is obvious that an installation of the magnitude of CAMROC will require a considerable land area. As a result, a preliminary study was initiated with the firm of Metcalf & Eddy (consulting engineers, Boston, Massachusetts) to prepare a Site Criteria Report. This has been completed and presents a logical plan for the selection of the optimum site for CAMROC. The next step will be to initiate the preliminary investigation phase utilizing the maps and forms presented in the report.

4. Membrane Study

North American Aviation is currently evaluating the electrical and mechanical properties of various membrane materials for use in the space-frame radome.

PHYSICAL PLANT ENGINEERING
GROUP 75

I. HAYSTACK HILL

A. Capacitor Room Cooling

An extension of the existing ductwork is being designed to maintain a correct operating temperature in the capacitor room where the cooling load has been increased from approximately 20 to 50 kw.

B. Filtration Improvement for Main Air Conditioning System

Filters of higher efficiency are to be installed in the main air conditioning system in order to meet the environmental requirements of the CDC 3200 computer.

C. Control Room Pressurization

Minor modifications will be required in the supply and return air ducts serving the control room area in order to raise the pressure above atmospheric. This will reduce the infiltration of dust to the computer area. The system is now being designed.

II. MILLSTONE HILL

A. Safety Net

A safety net has been designed for the Nike-Ajax/Laser tower at Millstone Hill, Westford, Massachusetts. The net is supported by a series of angle brackets projecting from the sides of the circular tower, thus giving personnel protection around the circumference of the tower. Nylon webbing is being used in the net because of its inherent resistance to the elements and its elastic properties.

B. Air Conditioning for Switchgear Room

A three-ton packaged air conditioning unit with controls, ductwork, and accessories is being designed to maintain a correct temperature for the electronic equipment installed in the switchgear room.

CONTROL SYSTEMS
GROUP 76

Effort in this quarter has been primarily concerned with antenna work and control system development for Haystack.

I. ANTENNA DRIVE

As a result of recent azimuth hydraulic motor failures, an effort has been undertaken to provide design information for elimination of the malfunction. Motor failures in both axes were quite common prior to March 1965. At that time, changes were made in the hydraulic system to deal with the problem. No elevation motors have failed since, but in this period, five azimuth motors have failed. Failure has always been in one to three of the eight cam follower rollers of the hydraulic motor. Both instrumentation and experimental hydraulic changes aimed at providing more information on the problem and means for its solution are being effected. The hydraulic time constants involved are extremely fast and full-scale antenna investigative tests risk actual motor failure.

II. HYDRAULICS LABORATORY

A. Antenna Servo Control Valve

Instrumentation of the spool assembly has been completed. The complete servo valve assembly is ready for test and awaits hydraulic stand availability.

B. Motor Torque Test Table

Modification for integration of a rate drive has been completed, and checkout for proper operation is in process.

C. Inertia Rig

This rig has been located next to the hydraulic test bench and has been hydraulically connected to it. The rig awaits availability of a spare hydraulic motor for completion of cleanout flow cycling and pressurized leak testing.

D. Hydraulic Test Stand

Test of the oil-cooling system has shown it to be unable to hold oil temperature within the approximate ±5°F band required for the expected stand load and flow test ranges. On-site layout and implementation of an improved pneumatic cooling control system have been undertaken. Control components are on order for the new layout. All components of the electronic reheat control system still have not been received. The major units of the electronic controller have been received and interwired, and open-loop bench checkout has been started. This controller and the pneumatic controller contain proportional, derivative, and reset functions.

III. MAIN ANTENNA CONTROL CONSOLE

Work is continuing on electrical diagrams, and organization of a brief operator's manual, which also describes the system, has been undertaken.

IV. REFLECTOR MEASUREMENT AND RERIGGING

A. Rerigging Facilities

The rerigging study program is complete except for final reports from outside contractors. During this period, a system was installed to provide access to the rear reflector surface adjustments. A front access catwalk system was similarly completed. A new instrument stanchion was installed and has resulted in very stable operating conditions for the instrument.

B. Painting

Thermal deflections in the reflector were reduced to about 30 percent of their former value by painting the splice plate flat black.

C. Computer Studies

Computer studies of measurement data indicate that a surface tolerance of 0.020- to 0.030-inch rms should be attainable by modest rerigging of the center 60-ft-diameter of the reflector.

D. Photographic Data System

The photographic data collection system mount has been delivered to the site. Acceptance tests at the vendor plant showed the mount to have ±0.6-sec runout in the zenith-look position and ±1.0-sec runout in horizon-look attitude.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 August through 31 October 1966. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1966

PUBLISHED REPORTS

Journal Articles*

JA No.			
2620	A Volumetric Determination of Arsenic and Antimony in Mixed Manganese Arsenide, Antimonide and Phosphide Compounds	E. R. Whipple D. H. Ridgley	Anal. Chim. Acta 35, 499 (1966), DDC 641009
2719	Partial Pressures of $Te_2(g)$ in Equilibrium with $Ge_{1/2-\delta}Te_{1/2+\delta}(c)$ from Optical Density Data	R. F. Brebrick	J. Phys. Chem. Solids 27, 1495 (1966)
2723	Single Crystal Growth and Electrical Transport Properties of Intermediates in the Spinel System $CO_{1+\delta}V_{2-\delta}O_4$	D. B. Rogers A. Ferretti W. Kunnmann†	J. Phys. Chem. Solids 27, 1445 (1966)
2725A	Thermodynamic Aspects of the Temperature-Pressure Phase Diagram of InTe	M. D. Banus P. M. Robinson†	J. Appl. Phys. 37, 3771 (1966)
2727	Photoelectron Statistics Produced by a Laser Operating Below and Above the Threshold of Oscillation	C. Freed H. A. Haus†	IEEE J. Quant. Electron QE-2, 190 (1966)
2739	Oscillatory Faraday Rotation of the Indirect Transition in Germanium at 1.7°K	J. Halpern	J. Phys. Chem. Solids 27, 1505 (1966)
2740	Phonon Generation, Propagation, and Attenuation at 70 GHz	J. B. Thaxter P. E. Tannenwald	IEEE Trans. Sonics and Ultrasonics SU-13, 61 (1966)
2768	Anomaly in the X-Ray Scattering of ZnSe	P. M. Raccah R. J. Arnott A. Wold†	Phys. Rev. 148, 904 (1966)
2774	Generalization of the Ruderman-Kittel-Kasuya-Yosida Interaction for Nonspherical Fermi Surfaces	L. M. Roth† H. J. Zeiger T. A. Kaplan	Phys. Rev. 149, 519 (1966)
2824	Incoherent Source Optical Pumping of Visible and Infrared Semiconductor Lasers	R. J. Phelan, Jr.	Proc. IEEE (Correspondence) 54, 1119 (1966), DDC 642196

* Reprints available.

† Author not at Lincoln Laboratory.

Division 8

JA No.			
2827	Efficient Ultraviolet Laser Emission in Electron-Beam-Excited ZnS	C. E. Hurwitz	Appl. Phys. Letters 9, 116 (1966)
2832	First Order Raman Effect in III-V Compounds	A. Mooradian G. B. Wright	Solid State Commun. 4, 431 (1966)
2847	Maser Model for Interstellar OH Microwave Emission	M. M. Litvak A. L. McWhorter M. L. Meeks H. J. Zeiger	Phys. Rev. Letters 17, 821 (1966)
2852	High Pressure Synthesis of Arsenopyrite-Type Ternary Compounds	M. D. Banus M. C. Lavine	Materials Res. Bull. 1, 3 (1966)
2853	Possibility of a Phase Transition for the Two-Dimensional Heisenberg Model	H. E. Stanley T. A. Kaplan	Phys. Rev. Letters 17, 913 (1966)
2869	Infrared Magnetoelectroreflectance in Ge, GaSb, and InSb	S. H. Groves C. R. Pidgeon* J. Feinleib	Phys. Rev. Letters 17, 643 (1966)
2894	Bulk GaAs Negative Conductance Amplifiers	A. L. McWhorter A. G. Foyt	Appl. Phys. Letters 9, 300 (1966)
2897	Photovoltaic Effect in $Pb_xSn_{1-x}Te$ Diodes	I. Melngailis A. R. Calawa	Appl. Phys. Letters 9, 304 (1966)
MS-1719	Maser Emission at 18 cm from Interstellar OH	M. M. Litvak A. L. McWhorter M. L. Meeks H. J. Zeiger	NEREM Record 8, 188 (1966)

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
2652	Electron Recombination in Laser-Produced Hydrogen Plasma	M. M. Litvak D. F. Edwards	Accepted by J. Appl. Phys.
2796	Experimental Atomic Form-Factors in MgO	P. M. Raccah R. J. Arnott	Accepted by Phys. Rev.
2805	Spin Waves in Paramagnetic Fermi Gases	L. L. Van Zandt	Accepted by Phys. Rev.

* Author not at Lincoln Laboratory.

JA No.			
2837	Low Temperature Crystallographic and Magnetic Study of $LaCoO_3$	N. Menjuk K. Dwight P. M. Raccah	Accepted by J. Phys. Chem. Solids
2857	Unusual Crystal-Field Energy Levels and Efficient Laser Properties of YVO_4:Nd	J. R. O'Connor	Accepted by Appl. Phys. Letters
2872	A First-Order Localized Electron ⇌ Collective-Electron Transition	P. M. Raccah J. B. Goodenough	Accepted by Phys. Rev.
2875	The Virial Theorem for the Homogeneous Electron Gas	P. N. Argyres	Accepted by Phys. Rev.
2878	Low Temperature Absolute Reflection Measurements of Small Samples	J. Feinleib B. Feldman	Accepted by Rev. Sci. Instr.
2879	Electro-Optic Effect in Trigonal Selenium at 10.6 μm	M. C. Teich T. A. Kaplan	Accepted by IEEE J. Quant. Electron.
2886	Stimulated Brillouin and Raman Scattering in Quartz at 2.1-293°K	P. E. Tannenwald J. B. Thaxter	Accepted by Science
2887	Spark Source Mass Spectroscopy	E. B. Owens	Accepted by Appl. Spectroscopy
2889	Stimulated Four-Photon Interaction and Its Influence on Stimulated Rayleigh-Wing Scattering	R. Y. Chiao* P. L. Kelley E. Garmire*	Accepted by Phys. Rev. Letters
2900	Quantum Kinetic Equations for Electrons in Random Impurities	P. N. Argyres E. S. Kirkpatrick	Accepted by Ann. Phys.
2903	Excitation Spectra of Group III Impurities in Germanium Under Uniaxial Stress	D. H. Dickey J. O. Dimmock	Accepted by J. Phys. Chem. Solids
2912	Optimum Heterodyne Detection at 10.6 μm in Photoconductive Ge:Cu	M. C. Teich R. J. Keyes R. H. Kingston	Accepted by Appl. Phys. Letters
MS No.			
1629A	Narrow Band Electrons in Transition-Metal Oxides	J. B. Goodenough	Accepted by Czech. J. Phys.
1657	Single Crystal Growth and Electrical Transport Properties of the Spinel MgV_2O_4	A. Ferretti D. B. Rogers	Accepted by J. Phys. Chem. Solids

* Author not at Lincoln Laboratory.

Division 8

MS No.

1702	Optical and Laser Properties of Nd^{+3}- and Eu^{+3}-Doped YVO_4	J. R. O'Connor	Accepted by Trans. Met. Soc. AIME
1771	Characterization of d Electrons in Solids hy Structure	J. B. Goodenough	Accepted by Materials Res. Bull.

Meeting Speeches*

MS No.

1608	Oscillatory Magnetoabsorption of the Direct Transition in the Layer Compound GaSe at 1.5°K	J. Halpern	International Conference on the Physics of Semiconductors, Kyoto, Japan, 8-13 September 1966
1609	Polaron Induced Anomalies in InSb	D. M. Larsen E. J. Johnson	
1610	Sulfur Donors in Silicon: Infrared Transitions and the Effects of Calibrated Uniaxial Stress	W. E. Krag W. H. Kleiner H. J. Zeiger S. Fischler	
1611	Magneto-Piezo-Optical Experiments in Semiconductors	J. G. Mavroides M. S. Dresselhaus R. L. Aggerwal† G. F. Dresselhaus	
1612	Electron-Phonon Interaction in n-InSb at 9 GHz	K. W. Nill A. L. McWhorter	
1629A	Narrow Band Electrons in Transition-Metal Oxides	J. B. Goodenough	International Conference on Magnetic Oxides, Liblice, Czechoslovakia, 3-7 October 1966
1630	The Luminescence in a Magnetic Field of Excitons with a Screened Coulomb Potential	G. B. Wright	International Conference on Luminescence, Budapest, Hungary, 23-30 August 1966
1635	Injection Luminescence and Laser Action in Semiconductors	R. H. Rediker	
1681	Role of Spark Source Mass Spectroscopy	E. B. Owens	American Chemical Society, New York, 11-16 Septemher 1966
1702	Optical and Laser Properties of Nd^{+3}- and Eu^{+3}-Doped YVO_4	J. R. O'Connor	Metallurgical Society of AIME Conference, Boston, 29-31 August 1966
1770	Recent Developments in Solid State Microwave Oscillators	A. L. McWhorter	

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

† Author not at Lincoln Laboratory.

MS No.			
1715	Current Research Activities of the Solid State Physics Group at Lincoln Laboratory	G. B. Wright	Institute of Physics, Polish Academy of Sciences, Warsaw, 31 August 1966; Institute of Solid State Physics, Czechoslovak Academy of Sciences, Prague, 1 September 1966
1719A	Interstellar Maser Emission at 18 cm from OH Molecules	H. J. Zeiger	Optical and Infrared Laser Seminar, M. I. T., 28 October 1966
1719B	Interstellar OH Maser Emission	M. M. Litvak	Colloquium, Brandeis University, 8 November 1966
1726	Electron Beam Pumped Semiconductor Lasers	C. E. Hurwitz	NEREM, Boston, 2-4 November 1966
1772	Low-Energy-Gap Semiconducting Alloys for Infrared Emission and Detection	A. J. Strauss	Seminar, Texas Instruments, Inc., Dallas, Texas, 25 August 1966
1776	Coherent Infrared Radar	R. H. Kingston	IEEE Microwave Theory and Techniques and Electron Devices Joint Meeting, Boston, 18 October 1966
1784	Epitaxial GaAs Gunn Effect Oscillators	A. G. Foyt C. M. Wolfe	GaAs Symposium, University of Reading, England, 26-28 September 1966
1787	Spin Waves in Paramagnetic Fermi Gases	L. L. Van Zandt	Seminar, Ford Motor Scientific Research Laboratory, Dearborn, Michigan, 21 September 1966
1790	Retrograde Solubility in n-Type PbS	A. J. Strauss	Conference on Defects in Semiconductors, AIME, Chicago, Illinois, 31 October 1966
1806	Photovoltaic Effect in $Pb_xSn_{1-x}Te$ Diodes	I. Melngailis A. R. Calawa J. F. Butler T. C. Harman J. O. Dimmock	International Electron Devices Meeting, Washington, D. C., 26-28 October 1966
1813	Optimum Detection of CO_2 Laser Radiation by the Heterodyne Technique	M. C. Teich	Seminar, Cornell University, 11 November 1966

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Photovoltaic response has been observed in p-n junctions of $Pb_{1-x}Sn_xTe$ at wavelengths up to 11 μ at 77°K and 14 μ at 12°K. Noise measurements at 12°K give a noise equivalent power for a $Pb_{0.86}Sn_{0.14}Te$ diode of about 5×10^{-12} W sec$^{\frac{1}{2}}$ and a D^* of 8×10^9 cm/W sec$^{\frac{1}{2}}$ at 11 μ. The responsivity cutoff of a $Pb_{0.83}Sn_{0.17}Te$ diode, taken at 50 percent of the peak responsivity, is 14 μ at 12°K and 11 μ at 77°K. These results indicate that alloys in this series have considerable potential for infrared detection throughout the 8- to 14-μ atmospheric window and well beyond.

Infrared laser emission has been observed at 12° and 77°K from diodes of $Pb_{1-y}Sn_ySe$ and $Pb_{1-x}Sn_xTe$. A $Pb_{1-x}Sn_xSe$ diode with a nominal Sn composition of 5 percent produced laser emission at 12.4 μ at 12°K and at 10.2 μ at 77°K. Spontaneous emission from different $Pb_{1-x}Sn_xTe$ diodes at 12°K was observed at 9.4, 12.7, 13.5 and 13.7 μ. The third diode in this series also produced laser emission at 10.6 μ at 77°K.

The interface-alloy technique has been used to produce heterojunctions between GaAs and InSb. Despite the relatively large 14-percent lattice mismatch between the semiconductors, these heterojunctions are single-crystal, with an interdiffusion of the four elements of less than 2 μ. Photocurrent, current-voltage and capacitance-voltage measurements are explained by a model for the heterojunction band structure employing a linearly graded energy gap of the order of 60 Å long joining the GaAs to the InSb.

A 400-keV Van de Graaff positive ion accelerator has been used to implant phosphorus ions in germanium. Experimental evidence indicates that the implanted ions have produced n-type regions in bulk p-type material. Implantation for one hour with an incident phosphorus beam current of 0.4 μA resulted in a phosphorus concentration at the sample surface of the order of 1×10^{20} cm^{-3}, and an n-type region approximately 2 μ deep.

By taking the negative mobility as an adjustable parameter, good quantitative agreement has been obtained between the measured small-signal admittance parameters of GaAs negative conductance amplifiers and those calculated from the three-slope piecewise-linear model for velocity vs electric field. The same set of parameter values also provides both a reasonable fit to the measured current-voltage characteristics and a correct prediction of the frequency and threshold bias for oscillation.

Very pure epitaxial layers of GaAs have been grown on Cr-doped semi-insulating GaAs substrates. The best layers have electron concentrations in the high 10^{14} to low 10^{15} cm^{-3} range, both at room temperature and at 77°K. The electron mobilities for these layers are typically 8000 cm^2/V sec at room temperature, and increase at 77°K to values as high as 77,000 cm^2/V sec. Gunn effect oscillators made from similar films deposited on heavily doped substrates have yielded power conversion efficiencies as high as 9 percent from devices delivering a peak output power of 1.75 watts at 9.3 GHz. This represents a substantial improvement over previously reported results of other workers and demonstrates that Gunn oscillators with relatively high efficiencies can be fabricated using epitaxially grown GaAs.

II. OPTICAL TECHNIQUES AND DEVICES

Heterodyne sensitivity at 10.6 μm has been measured using a Cu-doped germanium photoconductor at liquid helium temperature. The measured minimum detectable power is within 10 dB of the theoretical limit, $h\nu B = 2 \times 10^{-20}$ W/Hz bandwidth. The signal frequency was 60 kHz and the noise bandwidth approximately 300 kHz.

A sealed-off CO_2 laser has been operated for approximately 100 hours without serious loss in output power. Although the gas fill was CO_2, N_2, and He, spectra of the visible spontaneous emission from the side of the tube indicate the presence of CO, CN, and N_2. The mechanism of formation of the additional constituents is being investigated to determine their relation to the operating life limitations of sealed-off systems.

III. MATERIALS RESEARCH

The crystal structure of Nd_2O_2Te has been determined by computer analysis of x-ray powder diffraction data. The atomic arrangement is derived from the K_2NiF_4 structure, in which the rare-earth atoms exhibit an unusual nine-fold coordination.

In order to determine the cause of the anomaly observed in the x-ray scattering of ZnSe, neutron diffraction measurements have been made on this compound at room temperature and liquid helium temperature. The results obtained so far are inconclusive because of difficulties in evaluating background intensity corrections.

The phase diagram of Ag_2Te at high pressure has been investigated by means of electrical resistivity and x-ray diffraction measurements. Evidence has been obtained for three high-pressure phases, two of which exist at room temperature.

Hysteresis of the first-order $B8_1 \rightleftarrows B31$ magnetic transition in MnAs has been studied by measuring the resistivity and magnetic susceptibility as functions of pressure and temperature. The experimental results, together with earlier data for $MnAs_{1-x}P_x$, show that the transition is due to a large exchange striction in the basal planes together with a volume-dependent Weiss molecular field and manganese atomic moment.

The retrograde solubility of Pb in PbS has been investigated by means of Hall coefficient measurements on n-type samples prepared by annealing and quenching single crystals containing excess Pb. The carrier concentration decreases with decreasing annealing temperature from 2.4×10^{19} cm^{-3} for 912°C to 1.3×10^{18} cm^{-3} for 350°C.

Measurements of the Hall coefficient vs temperature for S-doped GaSb have shown that the lowest donor level of sulfur lies about 0.075 eV below the lowest conduction band at atmospheric pressure. The pressure dependence of resistivity at room temperature shows that this donor level is associated primarily with the conduction-band minima at the (100) zone faces.

The magnetoresistance and Hall coefficient of high-purity and V-doped Ti_2O_3 single crystals have been measured at magnetic fields up to 218 kG. The high magnetoresistance of the high-purity samples at 4.2°K is inconsistent with a conventional one-band carrier transport mechanism The p-type conductivity and negative magnetoresistance of V-doped Ti_2O_3 suggest that part of the V is present in the quadrivalent state.

Efficient pulsed laser operation has been obtained in Nd-doped YVO_4 single crystals. The threshold is only about 1 joule. This low threshold is due to the reduced Stark splitting of

Nd^{+3} ions in YVO_4 and to substantial transfer of absorbed energy from the lattice to the Nd^{+3} ions.

A method employing PbTe and SnTe as standards has been developed for determining the presence of Pb and Sn in $Pb_{1-x}Sn_xTe$ alloys by electron microprobe analysis. The results are in good agreement with those obtained by wet chemical techniques.

IV. PHYSICS OF SOLIDS

The optical study of metals and semiconductors by means of sensitive differential techniques is continuing. One of these methods, the current pulse modulation technique, has been applied to the study of gold and nickel in the energy region from 2 to 10 eV; much well-defined structure not observed in the standard reflectivity has been found. This same modulation technique is also being used in InSb to study the magneto-oscillations associated with transitions across the direct energy band gap, and also from the spin-orbit split-off valence band to the $\vec{k} = 0$ conduction band.

Oscillations in the infrared magnetoreflectivity of arsenic have been observed for the first time. Two distinct sets of interband transitions, taking place at different points in the Brillouin zone, have been seen.

The optical study of the effects of calibrated uniaxial stress on infrared transitions in S-doped silicon continues. A value for the pure shear deformation potential of the conduction band, $E_2 = 7.9$ eV, is obtained from the behavior of the p-like transitions. The application of stress helps distinguish between possible symmetries of observed centers and aids in identification.

While studying polaron effects in InSb, a discontinuity in the functional dependence of the polaron cyclotron energy on magnetic field was observed near the LO phonon energy; this phenomenon had been predicted theoretically. In addition, absorption lines associated with donor states were found to exhibit polaron effects.

Experiments, in collaboration with Professor W. Paul's group at Harvard, to establish the band ordering in the mercury chalcogenides have now been extended to studies of the pressure dependence of the absorption edge. These new experiments suggest the same relative energy level orderings at $\vec{k} = 0$ for the Γ_6 and Γ_8 bands in HgSe and HgTe, which is inconsistent with the previous conclusion derived from the pressure dependence of the thermoelectric power. This contradiction appears to have been resolved by Hall measurements under pressure which, although incomplete, indicate that at least some of the HgSe samples were not extrinsic, thereby invalidating the thermoelectric power interpretation.

An analysis is being made of the beating effects observed by Whitsett in Shubnikov-de Haas measurements in n-type HgSe. Using the theoretical energy momentum expressions derived by Kane for zinc-blende materials with small energy gaps, an attempt is being made to construct the Fermi surface for this semiconductor.

The conductivity tensor in bismuth has been calculated, assuming an anisotropic effective mass for holes and the two-band model for the electrons. A detailed lineshape calculation for the magnetoreflection is now under way.

The electronic energy bands in silicon have been calculated by using the Fourier expansion technique in which the band parameters are determined from the experimental values for the

energy gaps and effective masses. This band structure has allowed the calculation of a frequency dependent dielectric constant which is in reasonably good agreement with experiment.

Calculations using high temperature expansion techniques for an ensemble of spins interacting with a Heisenberg exchange interaction are continuing. Thermodynamic functions, such as the spin correlation function and zero field susceptibility, are being treated for any range of exchange interaction and any lattice. Higher order coefficients of the high temperature series for the zero field susceptibility have been incorporated in the arguments for phase transitions in two-dimensional Heisenberg models.

The study, in the time-dependent Hartree-Fock approximation, of spin sound (or spin density waves) in unmagnetized or weakly magnetized Fermi gases has been concluded; the results will appear in the Physical Review. As a sequel to this work, the properties of ordinary density waves have been studied in the same approximation. In addition to the usual plasmon dispersion relation, another branch of the density oscillation spectrum is discussed.

In studying the influence of the electron-electron interaction on the transport properties of the conduction electrons in a metal, a model of an interacting electron gas driven by an external electromagnetic field and scattered by randomly distributed impurities has been considered; the electron-electron interaction is treated in the random phase approximation. So far, this theory has been applied to the special case of a homogeneous electron gas in the Born approximation.

For the case of a Landau quasi-particle distribution function in the presence of random impurities, the transport theory is incomplete, since it is only valid for $\omega = 0$ or $\omega\tau \ll 1$; for $\omega\tau \gg 1$, which is the case of experimental interest, the result is incorrect. The possibility of a new approach, valid for an arbitrary ω, is now being investigated.

Further results on stimulated scattering experiments in quartz at 2.1°K have lent additional support to the contention that the anomalous Brillouin shifts reported by Krivokhizha, et al., were misinterpreted and are actually due to intense Raman radiation which sets in at low temperatures. This phase of the experiment is now completed; results have been submitted to Science.

A study of the effect of orientational correlation and molecular fields in second-harmonic light scattering from liquids and gases, with application to temperature dependence and depolarization, has been concluded. The results are being prepared for publication.

Work on infrared Raman scattering in solids continues. Raman spectra have been observed in GaS, GaSe, and trigonal selenium.

The analysis of a maser model of interstellar OH microwave emission has been published in Physical Review Letters. Further calculations of self-consistent populations under directional UV pumping and the effect of microwave saturation on mode suppression are now being carried out.

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This Quarterly Technical Summary covers the period from 1 August through 31 October 1966. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

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