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Quarterly Technical Summary

General Research

15 February 1967

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

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

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Quarterly Technical Summary

General Research

15 February 1967

Issued 22 March 1967

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

INTRODUCTION

This Quarterly Technical Summary covers the period from 1 November 1966 through 31 January 1967. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

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

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DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 November 1966 through 31 January 1967 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 November 1966 through 15 February 1967

PUBLISHED REPORTS

Technical Notes

TN No.				DDC and Hayden Nos.
1967-1	Planar Representations of Complex Graphs	R.M. Baecker	6 February 1967	DDC* H-
1967-4	Magnetic Film Memory Evaporation System	C.G. Ryan	6 January 1967	DDC* H-
1967-12	VITAL Compiler-Compiler System Reference Manual	L.F. Mondshein	8 February 1967	DDC* H-

Journal Articles†

JA No.			
2781	Work Function Changes Due to the Chemisorption of Water and Oxygen on Aluminum	E.E. Huber, Jr. C.T. Kirk, Jr.	Surface Sci. 5, 447 (1966)

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2763	Oblique Incidence Magnetic Anisotropy in Co-Deposited Alloy Films	M.S. Cohen	Accepted by J. Appl. Phys.
2790	Finite Temperature Theory for the Attenuation of Quasi-Particle Excitations in Real Metals	R.W. Davies	Accepted by J. Phys. Chem. Solids
2818	Improved Method of Optimizing Longitudinal Magneto-Optical Transmission-Scattering in Thin Magnetic Films	D.O. Smith K.J. Harte	Accepted by Optica Acta

* Not yet assigned.

† Reprints available.

Meeting Speeches*

MS No.			
1686	Insight: A Graphical Debugging System	T.G. Stockham W. Kantrowitz	Fall Joint Computer Conference, San Francisco, 7 – 9 November 1966
1708	Optics and Thin Magnetic Films in Computer Memories	D.O. Smith	NEREM, Boston, 2 – 4 November 1966
1764	Parallel Oblique Incidence Anisotropy in NiFe Films	M.S. Cohen T.S. Crowther	12th Annual Conference on Magnetism and Magnetic Materials, Washington, D.C., 15 – 18 November 1966
1777	Spin-Wave Locking of the Uniform-Rotational Switching Mode in Magnetic Thin Films	K.J. Harte	
1852	VITAL – The TX-2 Compiler-Compiler System	W.R. Sutherland J.E. Curry†	Association for Computing Machinery, Cambridge, Massachusetts, 26 January 1967
1872	The TX-2 Network Project	J.W. Forgie	IEEE, Santa Monica, California, 19 January 1967

* 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. Memory Bus Switch

The first large capacity film memory will be installed in TX-2 as part of one of the eight memory modules on the memory bus switch. The design of the interface logic is nearly complete and it should be possible to operate the memory with a 1.6-μsec cycle time. Suitable connections to the memory are also being provided so future use can be made of the long-word characteristic of the memory.

B. Encoded Interrupt Sequence (55)

A new input/output (I/O) sequence, the Encoded Interrupt Sequence (55), has been designed and is now being constructed to replace the present Light Pen Sequence. It will handle efficiently a large number of interrupt devices (32 initially) such as light pens, analog comparators, the RAND tablet, the WAND, and others.

It consists of an interrupt buffer register, an interrupt mask register, an interrupt synchronizing register, a priority net, an encoder, and control logic. The encoder provides TX-2 with the number of the highest priority unmasked interrupt. The mask register is under program control. Reading the number of the highest priority interrupt cleans it and allows the next highest priority interrupt to be encoded.

C. Displays

The conic display generator based on homogeneous matrix mathematics and built with multiplying digital to analog decoders has been tested off-line and with TX-2. Operation appears satisfactory and it will be placed on-line this quarter.

D. 3D Light Pointer

A light pointer which provides 3D position information has been developed as an inexpensive alternative to the ultrasonic WAND. It uses a pair of photocells with shadowing baffles in each corner of the active volume to measure the angular position of the plane through the light source and the baffle edges.

Cells in three corners are sufficient to determine the position of the source. Preliminary results have been encouraging although background noise from ambient light is still a problem. Unlike the ultrasonic WAND this device is not degraded when used as a 2D input near a writing surface.

II. MAGNETIC FILM ENGINEERING

A. Large Capacity Memory (LCM) Digit Circuits

A new four-channel digit card has been constructed and is under test. Circuits differ substantially from those used earlier. The sense amplifier has higher gain and better signal-to-random-noise ratio to be compatible with low signal amplitude.

B. Film Testing

Large Capacity Memory Tests:– During this quarter 28 LCM substrates were tested, some exhaustively, both electrically and visually. Several alloys and a range of magnetic characteristics were included in order to determine the limits on characteristics for memory use. Of those substrates with nominally good characteristics, none have been acceptable for memory use. Several had regions of low coercive force. This has been found to be due, in part, to temperature variation during deposition, and is being corrected. Most substrates had more bad lines than can be replaced with spares but through improved procedures and better early inspection this number is decreasing. Poor electrical performance of a bit is nearly always attributable to large-scale magnetic characteristics or physical defects in the line. Some defects do not affect the magnetic properties but do cause excessive word noise. Visual inspection is necessary to find these defects.

Ferrite Keeper Experiments:– A signal increase of about 20 percent has been obtained by lowering the reluctance around the digit line with a plastic ferrite material. The required digit current decreased slightly. Larger signal increases could be obtained by decreasing the digit line thickness of 2.6 mils. However, due to asymmetries in spacing or nonuniformitics in the ferrite material, the increase in word noise was excessive.

Ground Plane Experiments:– Investigations of the use of insulated ground planes as substrates for permalloy for signal enhancement has shown that pinholes in the insulator are the major problem. The sources of these are presumed to be dust, poor adhesion or high stress. Various types of dielectric and multiple depositions are being tried as possible solutions to this problem.

C. Fine-Line Scribing

A scribing test apparatus has been constructed to evaluate emulsions and scribing parameters. The scribing tool is held stationary while the substrate moves beneath it permitting observation of the cutting action with a microscope. Parameters studied include tool tilt, pitch and skew angles, tool pressure, and tool driving force and speed. By far the most significant variable is the angle of tool pitch, or the angle of the cutting face relative to the work. The range of usable tool force vs tool pitch angle has been measured and a deviation of $\pm 1\frac{1}{2}$ percent tool pitch from optimum is all that can be tolerated. The second most significant parameter is angle of skew of the tool or the relation between the tool cutting edge and the direction of tool travel. Best results are obtained when these are mutually perpendicular.

D. Extended Large Capacity Memory Stack

An extended LCM stack which will accommodate 26 substrates is being built. The new diode array-pressure connector evaluation has not shown this approach to be clearly superior to the existing connector.

E. Content-Addressed Memory

The potentialities of the magnetoresistive element in a content-addressed memory were reviewed. The feasible memory size is limited because the element itself requires word organization and only a modest word size at best is permitted by the signal and impedance levels. The high current levels required for operation and small signal levels demand large numbers of amplifiers. Although the need for a small, fast, content-addressed memory continues, the rapid development of low-cost integrated circuits indicates our device would not be competitive. Hence this project has been terminated.

III. SYSTEM PROGRAMMING AND APPLICATIONS

A. Display Executive

The revised display executive system reported on last quarter has been incorporated as the standard. Most of this quarter has been devoted to the interrupt system and to modifications required by the network. Preliminary work on changes to the display executive required by the new scope hardware has been done.

B. Mk 5

Several new facilities were incorporated into Mk 5, the time-sharing assembly language programming system of the TX-2 computer. A new concordance facility produces a list of the symbolic identifiers within a program, each identifier accompanied by a list of all the places of its occurrence in the source program. A partial binning (or patching) capability was incorporated into Mk 5 for local changes to a program. It is now possible to change the source language and bin the new code lines into the binary file simultaneously without having to re-bin the entire program. The display parts of Mk 5 were modified to run under the new display scope executive. The changes included major modifications to the display routines in FLOW-MAP and a complete revision of EDIT.

It is expected that in the future one of Mk 5's roles will be to serve as a test vehicle for experimentation and the evaluation of various debugging facilities. Light pen pointing capabilities for FLOW-MAP and data-reference traces are among features that suggest themselves as natural extensions of the current debugging repertoire. Some exploratory design and coding for the new facilities has begun.

C. Languages

A reference manual for VITAL, the TX-2 compiler-compiler system has been completed.

Improvements were made on VITAL's character input program. Modifications were incorporated that will permit this program to be used as a general-purpose character processor for future projects.

Experience with VITAL has uncovered a number of desirable modifications which were incorporated this quarter. In addition, facilities for formatted input/output have been added to the system. Work on a variety of language implementations has continued, most notably on a new version of CORAL. This new language, an extension of a basic ALGOL, has had relational, homogeneous matrix and display operations added. These extensions make use of the routines developed as earlier parts of the programming effort and are part of the facilities planned for graphics applications.

D. Network

The 338 remote display computer was received from DEC this quarter. The software checkout is proceeding and, when complete, tests will be conducted with the TX-2 computer.

The network link between the TX-2 and the AN/FSQ 32 at SDC has been exercised with mixed success. Significant demonstrations are planned for the next quarter.

IV. TRANSISTOR AND CIRCUIT DEVELOPMENT

A. Switching Transistors

The present limit in the state of the art of switching transistors is represented by the SX-4 transistor, which employs 0.005-mil emitter and base stripes, and was developed for us under subcontract by Philco-Ford. Measurements of f_t made at Lincoln Laboratory have shown peaks of 7 GHz at 8 ma and 6 volts. The units are reproducible.

B. Microcircuits

The SX-4 geometry referred to above is being employed in a monolithic current-mode gate. It is anticipated that the delay per stage of this device should be well under 1 nanosec.

C. Microsystems

Several SMX-5 three-bit parity systems have been successfully fabricated in single array form. The necessary techniques for production of 9-bit and 27-bit arrays have been demonstrated. Special test gear has been fabricated to determine which devices are operable. This is a considerable problem in the 27-bit system which contains 754 components.

D. Machine-Aided Design

The SMX-4 current mode gate which employs 0.1-mil geometry has been set up to run on the NET-1 circuit analysis computer program. So far a simplified version of the circuit has been run on the computer and the transient response output calculation is reasonable. A more sophisticated version of the circuit, which includes strays, and measured values for different transistors, is being processed for analysis by NET-1. When this operates satisfactorily, it will be possible to calculate the effects of designed parameter changes on transient response.

E. In-House Mask Design

Preliminary mask designs for a monolithic associative memory array have been made. After several iterations it is anticipated that these will be run through the Philco 0.1-mil laboratory process.

COMPUTER COMPONENTS
GROUP 24

I. MAGNETIC FILMS

A. Anisotropy Spectrum of Magnetic Films

Measurements of easy-axis lag angle vs frequency of rotating anneal between 0.4 and 200 mHz in a nonmagnetostrictive permalloy film at 144°C have revealed one pronounced peak, two "shoulders," and a broad background. As expected, when the temperature was lowered to 115°C, the peak and shoulders were shifted down in frequency; the background did not appear to change. Until the experiment is repeated at a few more temperatures, it is impossible to tell if these results are consistent with earlier perpendicular annealing experiments.[1]

A difficulty was encountered in measuring the lag angle: It was found that the remanent domain configuration near holes and possibly near film edges depended on the magnitude and direction of the preceding annealing field, and was therefore different for rotating and parallel anneals. This is being eliminated by means of a high field spike to saturate the film between annealing and measuring.

B. Wave Optics of Lorentz Microscopy

Wohlleben[2] has pointed out that the mechanism of Lorentz microscopy should be interpreted on the basis of wave optics rather than geometric optics. Calculations of the expected intensity distributions of samples containing domain walls and magnetization ripple patterns were made using this viewpoint. Of the various possible high resolution electron-optical arrangements, there are a few that look promising for a detailed study of the magnetization distribution in the ripple and domain patterns. A full report of this work will be ready shortly.

II. OPTICS

A. Magneto-Optical Enhancement Theory

It has been shown theoretically that in transmission the longitudinal magneto-optical conversivity for a thin magnetic film can approach unity by the use of dielectric layers.[3,4] However, practical limitations appear to be severe. The problem does not lie in obtaining good conversion efficiency within the film structure, but rather in coupling the converted mode to the outside world. This suggests that a structure should be designed for which the converted mode is dissipated within the magnetic film, with a resulting modulation of the incident mode. Calculations are in progress and preliminary results are encouraging.

B. Magneto-Optical Interrogation with Phase Modulated Light

A principal problem in magneto-optical read-out arises from the background light. Fluctuations in this background from bit to bit can be expected to be much greater than the magneto-optical difference between ones and zeros. Treves[5] has described a dc differential measurement

using a beam splitter and two analyzers which is quite successful in eliminating spatial fluctuations in the background light. Several difficultics remain, namely: (1) to assure that the beam is not depolarized after reflection, it is only possible to focus in onc dimension; (2) laser noise, which is present up to ~1 MHz, is not eliminated; (3) non-magnetic surface imperfections which rotatc the plane of polarization, remain as a noise source.

The above difficulties can be overcome as follows: (1) usc incident light with nearly cqual components parallcl and perpendicular to the plane of polarization; (2) do not use an analyzcr; (3) phase modulate one of the incident components; (4) detcct oncs and zeros by noting the phase (0 or 180°) of the output relativc to the modulation. The advantages of this schcme are: (1) fully focussed light can bc used; (2) laser noise can be eliminated by filtering if the modulation is above 1 MHz, say 100 MHz; (3) non-magnetic polarization changes should not contribute to thc output signal. Initial experiments using the above scheme have bcen very encouraging.

C. Thermo-Optics

By means of the read-out method described above, a bit ~2 μ in diameter has been dctected by means of a focussed laser beam. In this initial experimcnt, modulation was obtained by switching the cntire film; optical phasc modulation is yet to be demonstrated for such a small bit. If successful, phase-modulation read-out will greatly simplify the dctection and study of thermal writing.

The Curie point, T_c, of Ni-Cu alloy films has been studied using the magnetoresistance effect. The objective is to lower T_c in order to make thermal writing easier. The lowest T_c for which the films could still be measured was ~150°C. Other alloys will be studied.

III. ELECTRON TRANSPORT

A. Saturation of α in a Metal-Insulator Triode

It has proved possible to fabricate and measure hot-electron collection in a triode having a composite base consisting of a layer of gold adjacent to the emitter and a layer of aluminum adjacent to the collector. With this structure it has been possiblc to obtain higher emitter-base breakdown voltages than with previous devices and thereby it was verificd that a true saturation effect in the transport coefficient, α, exists as a function of emitter base bias. The measurcd value of this saturated α is $\sim 10^{-3}$. The collisionless or ballistic α of a metal insulator triodc structure has been calculated. The calculations show that the ballistic α rises rapidly from zero as the applied voltage between the emitter and base V_{eb} exceeds the insulating collector barrier height φ_c and approaches unity when V_{eb} cxceeds φ_c by about 0.3 volt. This calculated bchavior of thc ballistic α is very similar to the measurcd α except that thc cxperimental values approach a saturation value $\sim 10^{-3}$ rather than unity. The reason for the low value of the saturation α is being investigated both experimentally and theoretically.

B. Transport Theory of the Coupled Electron-Phonon System

The conventional theory of electron transport in solids is usually developed in terms of a kinetic or Boltzmann equation. Exact analytic solutions of the Boltzmann equation are generally not possible when the dominant collision mechanism involves inelastic processes, as in the case

of electron-phonon interactions. A very powerful approximation method for obtaining transport coefficients from the Boltzmann equation in such cases is based on a certain variational principle. A discussion of this principle may be found in standard solid-state texts.[6,7]

We have recently considered the electrical response of the normal coupled electron-phonon system from a rather new point of view. If this problem is analyzed using graphical, finite temperature perturbation theory, it is found that a transport equation emerges as the integral equation for certain vertex functions. However, even in the simplest non-trivial approximation (the "ladder" approximation), an exact solution of the relevant transport equation seems out of the question. It is then natural to inquire whether there exists a variational principle which might provide the basis for a useful approximation method.

We have been able to obtain such a variational principle, valid for the general case of response to an electric field of arbitrary wavelength and frequency. While the general variational appears to be rather difficult to apply, the theory may be reformulated, in the long-wavelength limit, to give a more tractable variational theorem. The basic trick for obtaining this reformulation is to make full use of the generalized Ward identity for charge conservation. Employing a simple application of the resulting variational principle, we have obtained an expression for the long-wavelength conductivity of the system. Upon approximating the conductivity formula, we may obtain the standard Boltzmann equation results in the dc limit. Details will be presented in a future paper.

REFERENCES

1. D. O. Smith, G. P. Weiss, and K. J. Harte, J. Appl. Phys. 37, 1464 (1966).
2. D. Wohlleben, Physics Letters 22, 564 (1966).
3. D. O. Smith, Optica Acta 13, 121 (1966).
4. D. O. Smith and K. J. Harte, Optica Acta, to be published.
5. D. Treves, J. Appl. Phys., to be published.
6. J. M. Ziman, Electrons and Phonons (Oxford University Press, London, 1960).
7. A. H. Wilson, The Theory of Metals (Cambridge University Press, London, 1958).

PSYCHOLOGY
GROUP 25

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

A. APEX

The APEX time-sharing system, which has absorbed a large fraction of the Group's effort for more than two years, has reached a turning point: the effort devoted to it declined abruptly during the past quarter, and the people who were chiefly responsible for creating it have been attempting to document their work before turning to other projects.

A large program like APEX is of course never finished entirely. While there have been no major changes in the central parts of the system during the past quarter, some minor changes have been made to match the growing capabilities of peripheral equipment, and the response of the system to certain kinds of overloads and errors has been improved. A number of bugs have been detected and eliminated, and reliability has improved significantly. A start has been made on the development of programs that will help in maintaining the system and in gathering the statistical information needed to evaluate performance and to adjust the parameters of the scheduling algorithm.

The executive routines needed for digital-to-analog conversion during time-sharing have been delayed, but work on them continues. The magnetic-tape routines, which have been postponed repeatedly because the delivery of a different tape-drive seemed imminent, have been postponed again for the same reason.

B. Lincoln Reckoner

The Lincoln Reckoner is in part an attempt to design a computational service for scientists and engineers to use on-line. The guiding principle has been that the design must develop by successive approximations: only by observing the use of a moderately convenient service can one judge what is truly important in making it more convenient.

The Reckoner, like APEX, has now reached a turning point. The system that was originally envisioned is complete and has now been used enough so that the next step is clear. As was expected, the most pressing requirement is in the area of better notation, but the need proved to be unexpectedly specific: the user should be able to use algebraic notation to perform element-by-element operations on arrays that have the same dimensions.

This relatively simple change will apparently have a large effect on the behavior of the sort of Lincoln users who are attracted to the system. Judgments about the importance of other major changes will therefore be postponed until the effects of this change have been observed.

During the last quarter the operations that display arrays of data on the CRT or on the Xerox Printer have been generalized so that they will display processes, i.e., "console programs." Routines have been written for six simple mathematical operations that users seem to want frequently.

C. Coherent Programming

An effort is being made to help programmers adopt a policy called coherent programming,* whose purposes are:

(1) To allow programmers who provide user-oriented services to build on each other's work more easily.

(2) To aid the on-line user, who may not be a programmer, in switching back and forth between packages of services provided by different programmers. Thus the user is not trapped in the package of services he started with; he can call upon other packages, written by other programmers, as the problem develops.

The concept of coherent programming is still rather novel. As it has developed here it has two aspects – coherence in operations and results, and coherence in calling. For a set of programs to be coherent in their operations and results, each program must declare its results in the directory of the APEX system. Enough descriptive information must be filed with the results to assure that if a second program in the set is directed to operate on the results of the first, the second program can determine whether these results are legal inputs for it, and how they are to be processed.

An example of coherence of this type is the relation between the Lincoln Reckoner and PATS1,† which is a language that has been developed in Group 62 and used primarily in the simulation of vocoders. PATS1 assembles programs that are coherent with the programs which constitute the Reckoner. When the user wants a complicated input signal – say, a piece-wise polynomial – he can specify it by means of Reckoner programs, then apply to it a program that simulates some particular vocoder, and then use Reckoner programs to do a Fourier analysis of the results, compare them with results from other vocoders, and so on. Thus the creators of PATS1 were not required to provide the user with a number of services that are available from the Reckoner.

Coherence in calling is more difficult to achieve. In its full form, it requires that programs call each other in a standard fashion that will allow a user to pass parameters through one user-oriented language into another, without special arrangement between the authors of the two languages. A standard format that covers a restricted range of languages is already used in more than 80 programs. The development of a more general technique is requiring much discussion among TX-2 programmers.

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

A. An Editor and a Facility Similar to the TX-2 Reckoner

Work continues on the design of a General System Editor, on a facility similar to the present Lincoln Reckoner, and on a common interface between them and the Time Sharing System. Much of the present effort is devoted to understanding the characteristics of the Time Sharing System that must be taken into account in elaborating a more detailed design.

---

* J. C. R. Licklider, "Languages for Specialization and Application of Prepared Procedures," in Second Congress on the Information System Sciences, J. Spiegel and D. E. Walker, Eds. (Spartan, Washington, 1965).

† C. M. Rader, "Speech Compression Simulation Compiler" (Abstract), J. Acoust. Soc. Am. 37, 1199 (June 1965).

B. Using the Computer to Instruct Its Users

The first draft of a manual for instruction of new users in on-line Fortran has been completed. The manual is keyed to exercises which the neophyte will be able to perform on the system, and is organized so that the user is introduced first to the things he first encounters upon sitting down to a console: logging in, output requests, and simple editing. The first draft is being evaluated with the help of two teletypes, one for the student, and one for an instructor who plays the part of the computer. Later a random-access slide projector will be used to send error messages to the student, thus providing feedback at a rate commensurate with his reading speed and relieving the instructor of a large typing burden.

III. HUMAN INFORMATION PROCESSING

A. Stimulus-Response Conflict

Analysis has been completed on the color-naming experiment described in the previous Quarterly Technical Summary.* Results indicate that interference is more pronounced when the read-out is verbal than when it is accomplished by a non-verbal means such as button pressing. The degree of interference is also related to the nature of the attribute to be read out. If the attribute is color, interference is great when the stimulus is a color word and minimal when the stimulus is a nonsense syllable. If the attribute is position, however, the semantic proximity of the stimulus word has relatively little effect on the ease of reading out the attribute.

B. Stereoscopic Depth in Computer Generated Random Dot Patterns

A series of film loops has been constructed, designed to study visual contour formation and stereoscopic depth perception. It has been demonstrated with one of these loops that stereo depth can be achieved even when the right- and left-eye views are separated by one frame in movie presentation. This is accomplished by dimming the display coming to the leading eye – a variant on the classic Pulfrich phenomenon. Other loops are designed to determine the conditions under which Michotte's "amodal completion" effect occurs.

* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 November 1966), DDC 645776.

COMPUTER SYSTEMS
GROUP 28

I. COMPUTER CENTER DEVELOPMENT

The activity of the past quarter may be characterized as that of transition from the upheaval of installation to the less dramatic task of implementation and improvement. Although the major components of the 360/67 System are all operational, many of the special features have either not been installed or not well exercised. The partitioning capability of the system has been invaluable in maintaining a nearly normal work flow during this period.

Operating System/360 (OS/360), which now carries the Laboratory's computing load, has also progressed beyond the difficult period of initial installation. Not only has programmer performance improved through greater familiarity, but the system itself has been significantly improved through widespread use and the addition of new features. As an example, the current version of OS/360 is the first one to make use of memory protection. This prevents the user's program from accidentally destroying the system itself and requiring a time consuming re-initialization procedure. This one feature alone has probably saved an hour or more of operational time every day.

The first elements of Time Sharing System/360 (TSS/360) are now being run at the Laboratory under STRATO. The latter is a complete system capable of assembling and executing program modules, as well as a scaffold on which time sharing system modules may be exercised and debugged. One of the first goals of this activity was to shake down those features of the 360/67 not used by OS/360, such as the relocation hardware. This goal has been realized and attention is now being directed toward the debugging and integration of more and more system modules as they are completed by IBM. Various special features required by the Laboratory are also being implemented in TSS/360.

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

Over the past quarter, the LISTAR working group has been testing a new list processing language called *1 which will serve as a convenient tool for constructing and operating on the complex list structures which make up the system. The language was written by Jay Early of Carnegie Institute of Technology to run on the IBM 360. It is based on the language L^6 written for the IBM 7094 by K. C. Knowlton of the Bell Telephone Laboratories. A substantial part of the coding for LISTAR will be written in *1 when it is fully checked out.

The group is also preparing a detailed external specification for console and task program calls to the system. These will be designed to permit convenient access to system functions, both by non-programmers using the system from a console, and programmers writing in Fortran or machine language.

RADIO PHYSICS
DIVISION 3

INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 November 1966 through 31 January 1967. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary Report and the Quarterly Letter Report to ARPA.

S. H. Dodd
Head, Division 3

M. A. Herlin
Associate Head

DIVISION 3 REPORTS ON GENERAL RESEARCH

15 November 1966 through 15 February 1967

PUBLISHED REPORTS

Journal Articles*

JA No.			
2797	Radar Observations of Venus at 3.8-cm Wavelength	J. V. Evans R. P. Ingalls L. P. Rainville R. R. Silva	Astron. J. 71, 902 (1966)
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	Astron. J. 71, 897 (1966)

* * * * *

UNPUBLISHED REPORTS

Meeting Speeches†

MS No.			
1778	Electron Temperature and Ion Composition in the F1 Region	J. V. Evans	Fall URSI Meeting, Palo Alto, California, 7 – 9 December 1966
1779	Midlatitude F Region Densities and Temperatures at Sunspot Minimum	J. V. Evans	
1803	Observations of the 94 α Hydrogen Line in Four Galactic HII Regions	M. A. Gordon M. L. Meeks	
1840	OH Radical in Radio Astronomy	M. L. Meeks	Colloquium, Clark University, Worcester, Massachusetts, 20 December 1966

* Reprints available.

† 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. Radio astronomy and lunar studies programs are conducted at both Millstone and Haystack. Presently all planetary radar studies are being conducted with the Haystack Planetary Radar System. Most of the radio astronomy programs in the 10- to 20-cm region are now conducted at Millstone thus complementing the Haystack facility which is best used for observations at shorter wavelengths at which the capabilities of the 120-foot precision reflector are unique. The maser receiver in the Planetary Radar System can now be used as an X-band radiometer thus providing better continuity for programs in both radio and radar astronomy. Propagation studies in connection with the Lincoln Space Communications program, presently conducted radiometrically at Haystack, have been extended to include the Millstone L-band System as a "weather radar." Also, an S-band radar for weather surveillance use in the propagation studies is being installed in one end of the Millstone warehouse.

I. OPERATION, MAINTENANCE AND IMPROVEMENTS

A. Millstone

1. L-Band Radar System

During this quarter the Millstone radar was used for satellite tracking, ionospheric backscatter measurements and lunar observations. Satellite tracking activities included orbit data gathering for the Space Defense Center and for testing of Millstone precision-orbit determination (ESPOD-type) computer programs. MITRE/Millstone interferometer tracking also continued. Satellite tracking was conducted on approximately a one-day-per-week schedule and the MITRE observations one evening per week for periods of 4 to 5 hours.

S-band patterns of the 84-foot antenna were taken using a focal-point feed horn provided by Group 46. The purpose of the measurement was to evaluate the dish for possible radiometric and other passive uses at the upper end of this band. The results were close to those predicted for a dish of this size and indicate good performance at frequencies as high as 3 GHz.

2. Weather Surveillance Radar

An FPS-18 scanning radar has been procured as government furnished equipment and is being installed in the laboratory area at the Millstone warehouse. This radar will be adapted to weather surveillance in connection with propagation studies to be conducted jointly with Division 6 during the coming spring and summer.

3. Ionospheric Backscatter System

The UHF and L-band systems were used in experiments designed to elucidate the effects of ground clutter on vertical-incidence backscatter studies of the E region. If clutter presents no insurmountable obstacle, it is planned to modify the UHF zenith-looking system to operate in a so-called "2-pulse mode" which would afford good height resolution, good spectral resolution and high sensitivity for gathering data leading to electron density profiles, thermal properties and chemical constituency of the E region from 100 to 200 km.

4. Radiometric Systems

The Millstone antenna and radar receiving system were joined to the spectral line processing equipment at Haystack via the intersite coupling system to permit observations of the 171 α hydrogen recombination line at 1304 MHz. Modifications included bypassing sections of the radar waveguide system to reduce losses, and installing a new uncooled parametric amplifier. Calibration, data processing and antenna pointing are remotely controlled from the U-490 computer at Haystack.

The initial spectral-line interferometer system using the 60-ft Agassiz Station antenna of Harvard University and the Millstone 84-ft antenna was constructed with a one-way microwave link. The system utilizes much of the equipment of the Haystack-Millstone interferometer (which remains operable). Its principal purpose is for the study of the structure of galactic OH emission sources. The baseline is 45,000 ft long at a bearing of 22.5° from north giving it a minimum fringe spacing of 3 seconds of arc.

5. Data Processing and SDS-9300 Computer

The Scientific Data Systems correlation filter model CFE-1 which was installed in the SDS-9300 computer system last period became operational and was accepted this period. Other SDS peripheral equipment received this month were a 300-card-per-minute punch, a fourth data subchannel II and a RAD (Rapid Access Drum). Installation of the RAD has not been completed. The SDS-9300 system was rearranged for more efficient utilization of space created by the removal last period of the CG-24 computer.

B. Haystack Research Facility

1. Transmitter

The Planetary Radar (PR) Box transmitter was operated extensively during this quarter for planetary ranging and lunar mapping experiments. The planetary experiments used CW transmission at 7840 MHz with phase-reversal modulation and, with two klystrons, operated typically at 350 kw. A 10-μsec pulse capability for lunar operations was achieved using a line pulse modulator in place of the switch stacks in the Beam Control Unit. Unfortunately, two of the three VA 949AM klystrons existing on-site failed during the period and consequently operations during the period of Mercury superior conjunction were accomplished at reduced power using a substandard spare.

Three new klystrons were assembled at the Varian Associates plant but all failed during tests at the factory. Two of the failures were attributed to lack of effective fault protection

equipment on the power supply. One of these klystrons achieved a power output of 260 kw before failure in the test stand.

A number of DC and RF arc problems were cleared up so that a maximum transmitter power output of 390 kw was achieved. Breakdown of the electroformed fin loaded, mode launching section of the feed horn is now the limiting factor in achieving higher power output. Alternate means of assembling this component are being investigated.

A new signal simulator was placed in operation and was used to demonstrate the excellent phase stability performance of the overall Haystack system as described in Sec. I-C.

2. Receiver

The liquid helium cooled maser was used extensively for planetary and lunar radar experiments at 7840 MHz. System temperatures of 60°K were typically achieved for the CW radar experiments at elevation angles above 30°. The maser has been continuously cooled to at least liquid nitrogen temperature since 13 September 1966 with no down time for repairs.

In addition, the PR Box receiving system was used for both continuum and X-band spectral line radiometry. The variable stalo frequency control system developed originally for the Radar/Communications (R/C) Box was installed to observe spectral lines near 7795 MHz.

Two maser structures designed for use in a closed-cycle refrigerator have been delivered and are being integrated in the system.

3. Data Processing

This quarter saw the extensive use of a number of subsystems which were placed in operation during the previous quarter. The radar sequencer was used to time the radar cycling of both the 5th Test ranging experiments and lunar mapping experiments. The CDC 3300 computer interface was also used for these same experiments. Both of these subsystems have operated with excellent reliability.

4. Antenna System

A total of 389 hours of actual observing time was logged on the antenna this period. There was no down time other than for routine maintenance. Minor improvements to provide better operation of the system included modification of hydraulic back biasing (larger orifices and pipes) to prevent motor starvation at high speeds, modification of the scan rate generator to provide variable aided or slewing modes and installation of an observation port through the antenna deck to facilitate box hoisting operations.

A new camera and optics mount for use in surveying the dish surface was received from Boller and Chivens.

An investigation of the feasibility of changing the prime drive system from hydraulic drive to electric motor drive was initiated.

5. Operations

a. Planetary Radar

Ranging operations on Venus and Mercury were conducted regularly during the period. Lunar radar operations were resumed following the installation of a new pulse modulator.

b. Radiometer

Provision for X-band radiometry in the PR Box has made it possible to carry out a program of continuum and spectral line observations when the radar is not in use.

For these observations the receiver in the PR Box is connected to the radiometer data processing system and a separate phase-locked local oscillator is used to tune the maser. The maser front end provides a much better signal-to-noise ratio than the 8 GHz tunnel diode radiometer in the Radiometer Box (R-Box).

Most continuum observations with the maser radiometer have been made near the radar frequency of 7840 MHz and all spectral-line work has been in the 7793 to 7796 MHz band.

C. Station Time and Frequency System

The hydrogen maser phase-lock system which had operated continuously since last September failed on 17 January because of reduced power output from the maser.

The low power output was the result of reduced output from four vacuum tubes used in the RF excitation system, and low pressure in the hydrogen supply flask. Although low power output prevented its direct use in the phase-lock system, the hydrogen maser continued to function as the Station primary frequency standard. A secondary standard, referenced daily to the maser, was used to drive the system until the troubles were corrected.

The phase stability of the Haystack system was measured at 7750 MHz. The system frequency synthesizers and the new X-band signal simulator were driven from a common frequency source. The simulator signal was phase-detected in the Haystack radar receiver. Measurements of phase instability were obtained by photographing CRO displays of lissajous figures generated by the resulting quadrature video signal voltages. The results of these measurements show the peak-to-peak phase instability varies from about 15° in 0.1 sec to not more than 30° in 60 sec.

An automatic frequency error sensing system has been constructed which detects both momentary transients and actual failures. Alarms for the system will include bright lights on the control consoles at Millstone and Haystack and at the guards' desks.

II. SPACE SURVEILLANCE

A. Orbit Upgrading (MHESPOD)*

A prime function of MHESPOD is to provide, before a pass, an acquisition ephemeris based upon the best available orbit, and then to update the ephemeris in near-real-time from radar data during a pass, so that an improved ephemeris is immediately available for antenna steering in the event of target loss during the pass. During the latter half of November 1966, MHESPOD was successfully run for the first time in its intended real-time environment. Detailed checkout is still under way, and computer-aided tracking using the automatically updated ephemeris remains to be implemented.

In testing the above capability, the approach is to acquire and track a satellite through an entire pass, to use the earlier portion of the data to update the ephemeris for the later part of the pass, and then to compare the updated ephemeris with the actual radar data for the later part

*Millstone Hill (real-time version of) Electronic Systems Precision Orbit Determination Program.

of the pass. Analysis of test data obtained so far shows that MHESPOD updating offers significant improvement over the ephemeris predicted from SPADATS mean elements alone. However, the program in its present form suffers from inadequate editing which allows the acceptance of bad data. One consequence of this effect has been to increase the number of iterations of the differential correction procedure needed for satisfactory convergence.

Results obtained in a January test with PAGEOS, a large spherical satellite, offer a preliminary standard of comparison for measuring the success of planned modifications to the program. In this test, live observations differed from predictions based upon SPADATS mean elements by about 300 km in range (out of 500) and as much as 3° in angle. These residuals were reduced by a factor of ten after one MHESPOD iteration and were generally well below 3 km in range and 0.1° in angle after three iterations.

Two factors contributed to more rapid convergence and a closer fit to the data than had been seen in previous test cases: (1) smoothed data of uniformly small variance were obtained because of the large non-scintillating target; (2) the data interval was deliberately centered on the approximate point of zero Doppler.*

The following modifications are planned: (1) real-time data editing based upon the variance and the number of "hits" associated with each smoothed data point (DAP) to supplement the present linear-consistence test, (2) data spacing to provide the option of spacing the DAP points over a longer segment of an orbit rather than concentrating the same number of points in a short segment (a maximum of 60 DAP points can be processed within the present timing restrictions for an up-date), and (3) the addition of real-time displays to provide more adequate operator control of the program.

B. Tracking Support

Satellite tracking this period in support of the MITRE-Millstone interferometer amounted to 70 hours. This was exactly equaled by tracking in support of SPADATS and MHESPOD tests.

III. LUNAR STUDIES

A number of new 3.8-cm radar observations of the moon have been made at Haystack. The lunar radar observations at 23 cm have continued on a limited scale. No further radiometer observations have been made at Haystack due to lack of a linearly polarized feed system. The fourth quarterly progress report† to NASA was issued on 15 November 1966.

A. Millstone Observations

A report on studies of the mean depolarizing properties of the lunar surface was prepared and has been accepted for publication in Radio Science. Two new sets of observations were made during the quarter to provide input data for the unambiguous mapping technique described in the third quarterly progress report.‡ The analysis programs now work and low-resolution maps of

* On the same pass, an equal number of observations with equally small variance were subsequently obtained with Doppler having constant sign. Slower convergence was quite evident, along with a generally poorer fit to the data. Previous experiments of this sort show similar indications.

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

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

both the "depolarized" and the "expected" circularly polarized returns have been made. Adequate data appear to be available for a detailed study of the depolarization of circularly polarized waves over the whole disk of the moon. However, considerable analytic work remains to be done to extract all the available information from these data.

B. Haystack Radar Delay-Doppler Lunar Mapping

Lunar mapping observations at X-band have been resumed at Haystack using the gridded Varian type 949 klystrons in the new, high-power planetary radar. A number of other modifications in the configurations of the system, chiefly in the use of the CDC 3300 and the U-490 computers at Haystack, have greatly improved the convenience and accuracy of taking the data as compared to the previous observations last summer. About 50 percent of the lunar regions of immediate interest to NASA have now been mapped, although not all the data taken have yet been reduced.

IV. PLANETARY RADAR OBSERVATIONS

During this period the planetary effort has been devoted exclusively to attempts to obtain precise radar measurements of Venus and Mercury echo delays and Doppler shifts using the X-band Haystack facility. Emphasis was placed particularly on measurements during the periods surrounding superior conjunction – 9 November 1966 for Venus and 18 January 1967 for Mercury – when the relativistic retardation predicted by I. Shapiro would be most evident. A number of results have been obtained which are currently being analyzed in Group 63. All measurements used an effective pulse width of 60 μsec and took advantage of correlation processing techniques to yield the greatest accuracy possible.

V. ATMOSPHERIC STUDIES

A. Ionospheric Studies

Data-taking operations during this quarter included three 12-hour runs with the L-band radar, as well as five 24-hour runs and one 36-hour run with the UHF Zenith-pointing radar. The 36-hour run was scheduled to include a period in which several ionospheric rocket probes, sponsored by the University of Michigan, were launched from Cape Kennedy. Copies of the backscatter data are being prepared for transmittal to Professor Nagy at the University.

In an effort to reduce the amount of time required for the reduction and analysis of the incoherent backscatter data, two computer programs have been written and are being debugged. The purpose of the first program is to provide an improved method of obtaining the power spectrum of the backscattered signal, while the other is intended to produce a composite profile of echo intensity vs height from the profile data obtained at pulse lengths of 100, 500 and 1000 μsec.

In the analysis of the data backlog, most of the work has been completed on data taken during the first quarter of 1965.

B. Auroral Studies

After considerable modification, the auroral model program written during the last quarter was run successfully to obtain the expected shape of the auroral echo as a function of layer thickness. Much of the 1965 auroral data has now been reanalyzed in terms of this model.

VI. RADIOMETRIC STUDIES

The modified Millstone radar receiving system was used to observe the 171 α recombination line (1304 MHz) of atomic hydrogen in the Orion nebula. The velocity shift of this line relative to the local standard of rest agrees with the velocity shift of the 94 α line (7793 MHz) previously observed in Orion from Haystack. The two lines differed in half-intensity widths relative to their center frequencies. The larger relative width of the 171 α line may be the first operational evidence of Stark effects in the Orion nebula. The relative intensities of the two lines are such that, at least in the wavelength region from 4 to 23 cm, the nebula is in thermal equilibrium and has a temperature of 6000 to 7000°K. This temperature is significantly lower than the temperature derived from optical observations. Disagreement between radio and optical measurements could be due to structure within the nebula; the optical observers may see an emission component different from that seen by radio observers.

The Millstone-Agassiz interferometer was used to study the OH emission region near the radio source W3. It was already known to be less than 20 seconds of arc in diameter from observations with the Haystack-Millstone interferometer. Fringe amplitudes were easily visible on one-minute integration periods and upper limits on the sizes of the principal spectral features were placed at 2 seconds of arc. The velocity features were also found to be separated spatially by up to 2 seconds of arc. Since long-term instrumental phase stability was not achievable with the present version of the interferometer, only the relative positions could be determined.

The first successful operations with the maser X-band radiometer receiver in the planetary radar system (PR Box) took place on 8 November 1966. Antenna gain and pointing checks were performed, showing gain to agree with that measured with the old R/C Box, and pointing to be unchanged from measurements with the R-Box. Observations of time-varying discrete radio sources, mapping of regions in the galactic plane, and an investigation of gain fluctuations due to the radome continued throughout the quarter. Some time was spent observing thermal emission from the atmosphere in support of propagation studies of interest to the Space Communications program.

On 23 January, using the maser radiometer in the PR Box, we detected the 94 α recombination line (7796 MHz) of atomic helium and re-observed the 94 α line of atomic hydrogen in emission in the Orion nebula (M-42). The ratio of line intensities of He to H is approximately 0.14 – the same ratio as the optically determined cosmic abundances. The Doppler shifts of both lines are the same. The hydrogen profile was generally symmetrical, whereas the helium profile appears highly asymmetrical.

A set of computer programs has been written to produce contour maps of radio brightness from raw antenna data. The computer used is a CDC 3300 with an auxiliary storage disk file. Output maps are displayed on a DD-280 cathode ray tube.

The computer removes noise from the data, averages together data at the same coordinates and draws the contours of equal brightness. A human operator (normally the astronomer who took the data) acts as "quality control." He examines intermediate outputs displayed on the CRT and, if necessary, modifies the computer's choice of parameters by entering instructions at the console typewriter.

Maps of over half a dozen regions of the radio sky have been successfully produced by this method.

RADAR
DIVISION 4

INTRODUCTION

This section summarizes the General Research activities of Division 4 during the period 1 November 1966 through 31 January 1967. The major portion of Division 4's activities is devoted to Radar Discrimination Technology, PRESS, BMRS, Space Communications, and Radar Studies of the Moon, 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 and microwave component development.

J. Freedman
Head, Division 4

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Associate Head

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, studies of very-high-gain antennas and antenna feeds, and participation in a millimeter-wavelength program. The latter is reported separately under Radar Studies of the Moon.

II. HAYSTACK MICROWAVE COMPONENTS

A. Planetary Radar Box

During the month of November, the Planetary Radar (PR) Box was successfully operated at a power level of 400 kW. Problems with one of the klystrons have prevented any increase in power above this level. A complete set of spare components for the waveguide system is being procured, with an improved standard of fabrication. All major components are on hand, and are undergoing calibration except for special radiometer switches.

High-power RF testing of new arc detector bends and high-power circulators has been completed. The arc detector bends were tested at a power level of 400 kW and the circulators at a level of 180 kW.

An evaluation was made of the losses in the receiver line from the feed horn to the maser. The total was less than 0.3 dB including losses in switches, couplers, power dividers and waveguide runs. The system noise temperature of 60°K correlates well with the receiver temperature of approximately 18°K and the antenna-radome temperature of 20°K.

Experience gained in making the loss measurements has shown that for small values of attenuation at a fixed frequency, a technique* which employs bolometers and a ratio transformer is less subject to errors from drift and is perhaps easier to use than the conventional dual-channel system. Certainly the use of a single tuned amplifier as a null indicator for balancing the bolometer outputs has the advantage of not requiring identical and linear tuned amplifiers at the modulation frequency.

B. Model Study of an L-Band Feed

The measured gain of the Haystack antenna at L-band has turned out to be unexpectedly low. No satisfactory explanation of this result is currently available. One possible cause of the

* C. J. Finnie, D. Schuster and T. Y. Otoshi, "AC Ratio Transformer Technique for Precision Insertion Loss Measurements," Technical Report 32-690, Jet Propulsion Laboratory, California Institute of Technology (30 November 1964); D. White, "AC Ratio Transformer Insertion Test Set," Space Programs Summary 32-27, Vol. IV, Jet Propulsion Laboratory, California Institute of Technology (30 June 1964), pp. 165-167.

difficulty may be the distance between the feed and the subreflector. The present separation is about 1/5 of the distance that would customarily be chosen in a conventional Cassegrain geometry. This constrains the feed to operation in the region intermediate between the far field and the near field.

Since the intermediate region is difficult to treat analytically, an experimental study involving a 1/20 scale model has been undertaken. The aim of this investigation is to find an efficient feed compatible with the existing Haystack geometry. A number of different feeds will be compared in compatible, as well as different, Cassegrain configurations. Most of the components for the model have been procured or fabricated. Assembling and testing of the model antenna should be possible in the near future.

C. Masers

The maser system that is in current use at the Haystack facility has been operating satisfactorily for over 800 hours. This system has been used for the Planetary Radar experiments, lunar mapping, and radiometry.

Two additional masers have been accepted and received. These units are being integrated into an Air Products Company helium refrigerator. The refrigerator has been modified to accept the two masers together with their superconducting magnets. In addition, a temperature control unit has been developed to maintain the temperature at the 4.2°K flange to within ±0.001°K. During the next quarter, all tests should be completed on the maser-refrigerator package. This package will then be integrated into the existing PR Box and should be operable during the spring.

III. SOLID-STATE AMPLIFIERS

A. X-Band Parametric Amplifier

The low-noise, X-band parametric amplifier described in previous quarterly reports has been broadbanded by the addition of a shunt-tuned stub. Before broadbanding, the amplifier had a 3-dB bandwidth of 165 MHz at a 12-dB gain and an 8.0-GHz center frequency. Broadbanding increased the bandwidth to 400 MHz with a gain ripple of 0.4 dB for the same midband gain and center frequency.

Present work is directed toward measuring the noise temperature of the broadbanded parametric amplifier, and observing the effects of various adjustments of the amplifier and tuning stub. Following this, an additional stub will be added to further increase the bandwidth.

B. Diode Measurements

The new technique for the measurement of the impedance of packaged diodes has given encouraging results up to 18 GHz. Additional experimental work is under way to extend this range to 40 GHz.

The program to measure the quality factors of varactor diodes at frequencies as high as 100 GHz has been taking shape through discussions with developers of advanced varactor diodes, the consideration of measurement methods, and the investigation of equipment and techniques for mounting and making low-resistance contacts to diode chips.

ENGINEERING
DIVISION 7

INTRODUCTION

The two principal engineering efforts to be reported on under the General Research Program at the end of the year concern the improvement of facilities at Haystack and the evaluation of radio telescope studies for CAMROC. At Haystack, the microwave hardware and cooling systems for the Planetary Radar (PR) Box were upgraded, and work continued on improving the antenna drive system.

Five independent studies have been completed for an advanced radio and radar telescope for CAMROC under the auspices of the National Science Foundation, Harvard, and M.I.T. These are abstracted in this report.

J. F. Hutzenlaub
Head, Division 7

DIVISION 7 REPORTS ON GENERAL RESEARCH

15 November 1966 through 15 February 1967

UNPUBLISHED REPORT

Meeting Speech*

MS No.			
1754	The Haystack Antenna – Mechanical Concept, Design and Testing	W.R. Fanning	ASME 1966 Winter Annual Meeting, 30 November 1966. Also published in "Deep Space and Missile Tracking Antennas," ASME (1966)

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

MECHANICAL ENGINEERING
GROUP 71

I. HAYSTACK

A. Planetary Radar Box

1. Microwave Components

The Planetary Radar (PR) Box experienced two VA-949 klystron tube failures during the quarter. Thus the tube rack assembly, consisting of two VA-949 tubes, two magnets, and a beam control unit, and weighing 1800 pounds, had to be removed from the PR Box position in the antenna to the box facility building for tube removal and replacement. With the aid of special handling fixtures the entire operation, including electrical, water and waveguide connections, was accomplished in approximately 6 hours.

Several waveguide components were reworked or replaced because of contamination of their inside surfaces. It is still felt that this contamination is caused by fluxes used during the brazing operation. An ultrasonic cleaner is now being used to clean all components and electron beam welding is being tested as a replacement process for brazing.

Testing is continuing on the copper electroforming process to ascertain the correct procedure for producing good parts that are void-free and capable of temperature cycling without blistering, cracking, or warping.

2. Air Conditioning

The problem of partially collapsed chilled water lines from the 7.5-ton chiller to the box mount position was corrected by adding more water to the system, thus increasing the pump pressure from 40 to 70 pounds. Recirculation returned the lines to their original form without evidence of damage.

3. Distilled Water Cooling System

A report was received from the vendor stating that the failure of one of the turbine flow meters was caused by rust in the turbine wheel bearings. What appears to be rust has also become visible on the collectors of the VA-949 klystrons. Since this cooling system uses distilled water, and great care was taken in the selection of materials and the fabrication of the system to insure against contamination, the origin of this foreign material is obscure. Samples of the distilled water, taken from several locations, and of the filters are being tested in an attempt to determine the origin of this material.

4. Maser

The first maser installed in the PR Box has been in operation since last September without any major problems. The temperature of the maser during this time has never gone above 77 °K. Cooldown of the unit to 4.2 °K can be accomplished in $\frac{1}{2}$ hour. The second and third masers on

order from Microwave Electronics Corporation, Palo Alto, California, have been received at the Laboratory. These two units are identical and include a super-conducting magnet. It is contemplated that the second unit will be operated in a batch dewar to be used as a back-up for the unit now in operation at Haystack. The third maser is to be installed in the closed cycle refrigerator which is being modified by Air Products & Chemicals, Inc., Allentown, Pennsylvania. Integration of the maser and closed cycle refrigerator is anticipated for March 1967.

B. Blockage Reduction

In an effort to reduce aperture blockage in the Haystack antenna, evaluation of fiberglass tension members (FTM) as replacements for the present $\frac{1}{2}$-inch-diameter aluminum tension rod members of the quadripod support legs of the secondary reflector has been under way for 120 days. The creep-temperature test fixture for the two 40-foot-long FTM test samples has been loaded to 1000 pounds, and readings of changes in length, temperature, and load are being recorded on a weekly basis. Over this time period there has been no significant variation in the readings. The present test will continue into the coming quarter and then the load will be increased to 1500 pounds for an additional time period. At the present time the FTM material appears to be very stable under the design load and is expected to be a desirable substitute to effect reduced blockage. At the conclusion of the test program, fiberglass tension members can be installed during the Haystack reflector re-rigging program.

II. MILLSTONE TRACKER

Design studies and contractor inquiries have been made for the fabrication of an enclosure having a controlled environment to house the equipment on the apex platform located above the secondary reflector.

In the chosen design the present triangular platform will be expanded to a circular one 10 feet in diameter upon which will be mounted a spherical urethane-insulated fiberglass radome enclosing the equipment and the apex of the spar supports. Doors in the radome and in its platform will enable personnel to stand within the enclosure in order to make equipment adjustments.

The final enclosure will be air conditioned for a temperature differential of ±5 °F. Two 10,000 BTU/hr fan-coil units mounted inside the enclosure will be supplied with chilled water by a 3-ton unit mounted on the azimuth platform. Strip and tubular heating elements together with controls will be positioned inside the enclosure.

Installation is proposed for April 1967.

III. LUNAR RADAR

In order to improve the pointing capabilities of this radar, encoders are being installed on both the elevation and azimuth axes. The installation of the azimuth encoder required a complete redesign of the azimuth cable wrap and extensive modifications to the pedestal base, including the installation of a new hydraulic buffer and electrical limit stops.

All of the parts required for the installation of encoders on the azimuth and elevation axes of this pedestal have been delivered to the Laboratory. It is expected that the installation will be completed during January.

IV. CAMROC

A. Antenna Studies

The five engineering design studies (including the "Hammerhead" concept) of possible antenna configurations for CAMROC, which were described in the previous Quarterly Technical Summary,* have been completed and final reports submitted. These reports, which conclude Phase I of the CAMROC antenna studies, have been reviewed and incorporated into a progress report to the National Science Foundation. One notable feature of this report is a series of parametric cost curves which were developed from the cost relationships of these engineering design studies. Table I summarizes the principal features of the five configurations studied in Phase I.

An evaluation of the five concepts is currently under way with the object of selecting one or two of these designs for a Phase II study. The object of the Phase II study will be an in-depth preliminary design with cost estimates for the selected concept(s). At the conclusion of this work, which should require approximately 6 to 8 months, it is expected that preliminary drawings, cost estimates and firm recommendations for future effort will be submitted by CAMROC for review by the National Science Foundation.

B. Radome Studies

1. Structural

A preliminary structural analysis of the CAMROC radome was prepared for incorporation in the progress report to the National Science Foundation.

The analysis is based on an approximate method which had been developed previously for radome design. In the report the optical blockage of a series of structurally sufficient radome space frames is expressed as a function of the radome radius and the dimensions of the beams – length, width and depth – which constitute the frame.

The radome design parameters described in the report must, of course, be subjected to a more rigorous analysis when the computer programs now under development become operational.

2. Development of Computer Programs

The development of various subsections of the STAR (STructural Analysis of Radomes) computer program is under way. The section which will be used to generate the radome geometry from an input of vertices and beam members corresponding to 1/60 of the radome surface area has been used successfully to define three uniform radome geometries for the proposed 550-foot-diameter radome.

Using the STAIR (STructural Analysis Interpretive Routine) computer program, a structural analysis of the axial loads on the radome caused by a 130-mph wind acting on a geometry having an average beam length of 55 feet has been completed. These results will be reported on at a later date.

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* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 November 1966).

TABLE I

RESULTS OF CAMROC ANTENNA CONFIGURATION STUDIES

Study	Reflector			Antenna Pedestal	Rotating Support System and Drives	Interface Reflector to Elevotian Axis	Antenna Diometer and Weight			
							Elevation		Azimuth	
	Configuration	Gravity Compensation Technique	Type of Ponels				Feet	Tons	Feet	Tans
Ammann & Whitney	Reticulated shell back-up structure with compensation. Aluminum Panels, steel back-up.	Computerized position-cantrolled jacks at corners af panels. Open loop cantral.	Isosceles triangular shope. Average 26 ft an 2 sides. Oriented an surface ta farm square pattern. Jacks at either 4 ar 8 panel carners.	Not considered in study.	Not considered in study.	Small dio beorings supporting shell and two axi-symmetric spine trusses.	400	770	400	965
ROHR	Radial rib truss and spar back-up structure. Optimizatian of 1/r for members by special shapes. All aluminum structure.	Undetermined at this time.	Rings af panels af trapezaidal shape. One stand-off stud at each panel carner.	Space frame yoke, tower mounted, elevation trunnians 130 ft apart. 65 ft radius elevation gear which is alsa used as caunter-weight.	Two 24-in.-dia anti-frictian bearings for elevatian axis. 40-ft-dia hydrostatic thrust bearing with anti-frictian bearing far radiol loads.	130-ft-dia main circular truss in back-up structure. Interconnecting trusses.	400	290	400	575
Simpsan, Gumpertz & Heger	Radial trusses with circumferential stabilizing members and spiral purlins to simulate a shell. All aluminum structure.	Nane Used	Rings af panels averaging 13 ft radiolly and 4 ft circumferentially. Each adjuster will support one paint on twa panels.	Not considered in study.	Nat cansidered in study.	50-ft- dia hub with elevotion interconnect at 43-ft dia. Steel weldment construction of truss.	300 400 500 Weights da nat include drives, counter-weight and secondary reflector.	198 448 893	Nat can-considered in study.	

TABLE I (Continued)

Study	Reflector			Antenna Pedestal	Rotating Support System and Drives	Interface Reflector to Elevation Axis	Antenna Diameter and Weight			
							Elevation		Azimuth	
	Configuration	Gravity Compensation Technique	Type of Panels				Feet	Tons	Feet	Tons
Paul Weidlinger	Vertical trusses and horizontal purlins with compensation. Aluminum panels, steel trusses.	Precalculated forces which are proportional to elevation angle and gravity vector. Open loop.	Rectangular panel singly curved, assembled in a rectangular coordinate orientation. Panels are 4 × 13 ft.	Space frame yoke extending from concrete cellular turret diagonally up to end of elevation axis. Intermediate towers from yoke to elevation axis which support series of elevation bearings and drive units.	8 anti-friction bearings approximately 2 to 3 ft in dia. Azimuth turret of concrete. Cellular design is supported on tower-mounted hydrostatic thrust bearing — 50-ft dia.	Integrated vertical truss and reflector surface at the 8 vertical truss stations.	300 400 500	413 580 810	300 400 500	633 1015 1680
Lincoln Laboratory	Vertical trusses and horizontal purlins with compensation. Aluminum panels, steel trusses.	Precalculated deformations which vary with elevation angle.	Rectangular panel singly curved, assembled in a rectangular coordinate orientation. Panels are 4 × 13 ft.	360-ft long doubly cantilevered horizontal truss which is integral with a turret. Truss assembly rotates on a bearing 40 ft in diameter atop a 150-ft high tower.	Series of 8 52-ft-dia hydrostatic support systems for elevation rotation designed to rotate about horizontal truss. 40-ft-dia hydrostatic thrust bearing for azimuth rotation.	Integrated vertical truss surface at the 8 vertical truss stations.	300 400 500	442 946 1603	300 400 500	680 1430 2469

3. Radome Buckling Model

The mandrel upon which the experimental 14-ft diameter space frame model will be mounted has been erected. Measurement and loading fixtures have been designed and are presently being fabricated. It is estimated that the model will be constructed, instrumented and readied for testing in from 10 to 12 weeks. This work is being performed by the Aeroelastic and Structures Research Laboratory at M.I.T.

CONTROL SYSTEMS
GROUP 76

I. HAYSTACK

A. Antenna Drive

1. Instrumentation and Analysis

Instrumentation has been completed for monitoring azimuth drive motor behavior; however, the recorder employed is bandwidth-limited with respect to proper observation of all hydraulic transients. The initial cause of motor roller failure is judged to be motor cavitation during cutoff of motor control oil by closure of the antenna blocking valve during operation at fast angular rates. A replenishing system exists for supplying oil to combat motor cavitation conditions. The replenishing system reaction time appears to be too slow to prevent the worst-case cavitation. Once cavitation has started, the exact sequence of failure is unknown. Certain failures could be avoided by motor modification in spite of cavitation if it were possible to verify the exact sequence. This would require special motor failure testing.

2. Preventive Measures

Secondary measures of reduced antenna slew speeds, higher replenishing system pressure, rearrangement of replenishing oil input points, and reduced blocking valve closure rates have been implemented to reduce the severity of cavitation. Investigation of component reaction time and motor failure analysis indicates that manufacturers of the components in question do not have information available nor are they interested in obtaining information to support solution of the problem; therefore, Laboratory-designed changes for producing an improved replenishing system are being considered.

B. Hydraulics Laboratory

1. Antenna Servo Control Valve

This valve has been plumbed into the hydraulic stand and inertia rig for testing. A high pressure pump has been installed for supplying the pilot stage. Strain gauge electronic equipment used for valve spool checkout has been found to be poorly temperature-compensated. Equipment of two other manufacturers is being tested for this application. Test levels are in the order of 1 to 5 micro-inches of elongation per inch of length.

2. Hydraulic Test Stand

Component delivery has not been completed for the stand oil-cooling and reheat control system. The reheat control system has been installed and connected in its own closed loop with a dummy load for checkout.

C. Main Antenna Control Console

Electrical diagrams have been completed. A preliminary instruction manual for this equipment is approximately 60 percent complete.

D. Reflector Surface Measurement

1. Measurement System Components

The azimuth spindle assembly for the camera data collection system has been tested. The spindle and bearing assembly shows total runouts of 0.65 and 0.15 seconds of arc, the two values occurring on alternate revolutions. A new, redesigned, theodolite leveling mount has been manufactured and acceptance tests made at the manufacturer's plant. The new mount makes re-leveling of the theodolite possible during a series of measurements without altering the instrument location.

2. Rigging Manual

The reflector rigging manual ordered under the contract with North American Aviation has been completed. This manual preserves for future use the experience and judgment gained by North American Aviation in the original construction of the reflector and incorporates the latest thinking up to the completion time of the manual.

II. NIKE-AJAX MOUNT

A second Nike-Ajax pedestal was interconnected with the existing Nike-Ajax control system at the Millstone facility. Modifications to data boxes and mount wiring were necessary to make this pedestal compatible with the improved pointing circuitry. Satisfactory operation in all control modes was demonstrated.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 November 1966 through 31 January 1967. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 November 1966 through 15 February 1967

PUBLISHED REPORTS

Journal Articles*

JA No.			
2652	Electron Recombination in Laser-Produced Hydrogen Plasma	M. M. Litvak D. F. Edwards	J. Appl. Phys. 37, 4462 (1966)
2736	The Augmented Plane Wave Method and the Electronic Properties of Rare-Earth Metals	A. J. Freeman† J. O. Dimmock R. E. Watson†	Theory of Atoms, Molecules and Solids (Academic Press, New York, 1966)
2857	Unusual Crystal-Field Energy Levels and Efficient Laser Properties of YVO_4:Nd	J. R. O' Connor	Appl. Phys. Letters 9, 407 (1966)
2879	Electro-Optic Effect in Trigonal Selenium at 10.6 μm	M. C. Teich T. A. Kaplan	IEEE J. Quant. Electron. QE-2, 702 (1966)
2886	Stimulated Brillouin and Raman Scattering in Quartz at 2.1 to 293° Kelvin	P. E. Tannenwald J. B. Thaxter	Science 154, 1319 (1966)
2889	Stimulated Four-Photon Interaction and Its Influence on Stimulated Rayleigh-Wing Scattering	R. Y. Chiao† P. L. Kelley E. Garmire†	Phys. Rev. Letters 17, 1158 (1966)
2912	Optimum Heterodyne Detection at 10.6 μm in Photoconductive Ge:Cu	M. C. Teich R. J. Keyes R. H. Kingston	Appl. Phys. Letters 9, 357 (1966)
2937	Donor Level Associated with (100) Conduction Band in S-Doped GaSb	B. B. Kosicki† W. Paul† A. J. Strauss G. W. Iseler	Phys. Rev. Letters 17, 1175 (1966)
2942	Observation of Degenerate Stimulated Four-Photon Interaction and Four-Wave Parametric Amplification	R. L. Carman R. Y. Chiao† P. L. Kelley	Phys. Rev. Letters 17, 1281 (1966)

* Reprints available.

† Author not at Lincoln Laboratory.

MS No.			
1394	Magneto-Optical Effects in Solids	G. F. Dresselhaus M. S. Dresselhaus	Estratto Rend. E. Fermi School 34, 198 (1966)
1554	Spectroscopic Studies of Laser-Produced Hydrogen Plasma	M. M. Litvak D. F. Edwards	IEEE J. Quant. Electron. QE-2, 486 (1966)
1558	Possibility of Self-Focusing Due to Intensity Dependent Anomalous Dispersion	A. Javan* P. L. Kelley	IEEE J. Quant. Electron. QE-2, 470 (1966)
1577	Single-Crystal Growth and Electrical Transport Properties of the Spinel MgV_2O_4	A. Ferretti D. B. Rogers*	J. Phys. Chem. Solids Suppl. E9, 471 (1967)
1608	Oscillatory Magneto-Absorption in the Direct Transition in the Layer Compound Gallium Selenide at 1.50° K	J. Halpern	J. Phys. Soc. Japan 21S, 180 (1966)
1609	Polaron Induced Anomalies in InSb	D. M. Larsen E. J. Johnson	J. Phys. Soc. Japan 21S, 443 (1966)
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	J. Phys. Soc. Japan 21S, 230 (1966)
1611	Magneto-Piezo-Optical Experiments in Semiconductors	J. G. Mavroides M. S. Dresselhaus R. L. Aggarwal* G. F. Dresselhaus	J. Phys. Soc. Japan 21S, 184 (1966)
1612	Magneto-Acoustic Effects in n-InSb at 9 GHz	K. W. Nill A. L. McWhorter	J. Phys. Soc. Japan 21S, 755 (1966)
1814	Characterization of d Electrons in Solids by Structure. 1. Localized vs Collective Electrons	J. B. Goodenough	Materials Res. Bull. 2, 37 (1967)

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
2811	Superconducting Transition Temperature and Electronic Structure in the Pseudo-binaries Nb_3Al-Nb_3Sn and Nb_3Sb-Nb_3Sb	F. J. Bachner J. B. Goodenough H. C. Gatos*	Accepted by J. Phys. Chem. Solids

* Author not at Lincoln Laboratory.

JA No.			
2854A	The Structure of $PbRuO_3$ and Its Illustration of a Trap-Mediated Cation-Cation Bond	J. M. Longo P. M. Raccah J. B. Goodenough	Accepted by J. Chem. Phys.
2890	Interband Magneto-Optical Studies of Semiconductors and Semimetals	B. Lax* J. G. Mavroides	Accepted by Appl. Optics
2891	New Phase Transformation in InSb at High Pressure and High Temperature	M. D. Banus M. C. Lavine	Accepted by J. Appl. Phys.
2918	Semiconductor-to-Metal Transitions in Transition Metal Compounds	D. Adler* J. Feinleib H. Brooks* W. Paul*	Accepted by Phys. Rev.
2920	Semiconductor-to-Metal Transition in V_2O_3	J. Feinleib W. Paul*	Accepted by Phys. Rev.
2921	On the Thermodynamic Properties of Several Solid Phases of the Compound InSb	A. K. Jena* M. B. Bever* M. D. Banus	Accepted by Trans. Met. Soc. AIME
2923	Diode Lasers of $Pb_{1-y}Sn_ySe$ and $Pb_{1-x}Sn_xTe$	J. F. Butler A. R. Calawa T. C. Harman	Accepted by Appl. Phys. Letters
2932	High Power and Efficiency in CdS Electron Beam Pumped Lasers	C. E. Hurwitz	Accepted by Appl. Phys. Letters
2941	Retrograde Solubility in n-Type PbS	A. J. Strauss	Accepted by Trans. Met. Soc. AIME
2946	InSb MOS Infrared Detector	R. J. Phelan, Jr. J. O. Dimmock	Accepted by Appl. Phys. Letters
2948	The Electrical Properties and Band Structure of Doped $LaInO_3$	D. B. Rogers* J. M. Honig J. B. Goodenough	Accepted by Materials Res. Bull.
2955	Photo and Thermal Effects in Compensated Zinc Doped Germanium	R. J. Keyes	Accepted by J. Appl. Phys.
2962	The GaAs-InSb Graded-Gap Heterojunction	E. D. Hinkley R. H. Rediker	Accepted by Solid-State Electron.
2963A	Inversion of Conduction and Valence Bands in $Pb_{1-x}Sn_xSe$ Alloys	A. J. Strauss	Accepted by Phys. Rev.

* Author not at Lincoln Laboratory.

Division 8

JA No.			
2967	Landau Damping of Magnetoplasma Waves for General Closed Fermi Surfaces	A. L. McWhorter J. N. Walpole	Accepted by Phys. Rev.
2968	Nonlocal Effects in Low-Field Helicon Propagation in PbTe	J. N. Walpole A. L. McWhorter	Accepted by Phys. Rev.

MS No.			
1746	Dependence of the Critical Properties of Heisenberg Magnets on Spin and Lattice	H. E. Stanley T. A. Kaplan	Accepted by J. Appl. Phys.
1747	Possibility of a Phase Transition for the Two-Dimensional Heisenberg Ferromagnet	H. E. Stanley T. A. Kaplan	Accepted by J. Appl. Phys.
1791	Spontaneous Band Magnetism	J. B. Goodenough	Accepted by J. Appl. Phys.
1815	Experimental Techniques with General Applicability for the Study of Magnetic Phenomena	K. Dwight	Accepted by J. Appl. Phys.

Meeting Speeches†

MS No.			
1612A	Magnetoacoustic Effects and Ultrasonic Amplification in n-InSb at 9 GHz	K. W. Nill	Seminar, M.I.T., 21 November 1966
1661A	The Fourier Expansion for Electronic Energy Bands	G. F. Dresselhaus	Seminar, Ford Motor Scientific Research Laboratory, Dearborn, Michigan, 17 November 1966
1719C	Interstellar 18 cm OH Maser Emission	M. M. Litvak A. L. McWhorter M. L. Meeks‡ H. J. Zeiger	American Astronomical Society, Los Angeles, California, 27 – 30 December 1966
1719D	Interstellar OH Maser Emission	A. L. McWhorter	Seminar, M.I. T., 22 November 1966
1745A	Recent Results for the Heisenberg Model from High-Temperature Expansions	H. E. Stanley	Seminar, Yeshiva University, New York, 1 December 1966
1787A	Spin Waves in Paramagnetic Fermi Gases	L. L. Van Zandt	Seminar, United Aircraft, Hartford, Connecticut, 26 January 1967

* Author not at Lincoln Laboratory.

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

‡ Division 3.

MS No.			
1793	Observation of Polaron Effects on the Interband Magnetoabsorption of InSb	E. J. Johnson D. H. Dickey D. M. Larsen	American Physical Society, Nashville, Tennessee, 1 – 3 December 1966
1796	Landau Level Raman Scattering	P. L. Kelley G. B. Wright	
1797	Current-Modulated Magnetoreflectivity in InSb	J. Feinleib C. R. Pidgeon* S. H. Groves	
1798	The Raman Spectrum of Trigonal Selenium	A. Mooradian G. B. Wright	
1799	Current-Modulated Reflectance of Gold from 2 – 10eV	W. J. Scouler	
1800	Stimulated Brillouin and Raman Scattering in Quartz at 2.1 to 293° Kelvin	P. E. Tannenwald J. B. Thaxter	
1801	The Raman Spectrum of GaS and GaSe	G. B. Wright A. Mooradian	
1821	Polaron Energy Spectrum	D. M. Larsen	
1808	Magnetoreflection Experiments in Arsenic	M. S. Maltz* S. Fischler M. S. Dresselhaus	American Physical Society, Stanford, California, 28 – 30 December 1966
1809	Amplification of 9 GHz Ultrasonic Waves in n-InSb	K. W. Nill	
1818	Fourier Expansion for the Energy Bands in Silicon	M. S. Dresselhaus G. F. Dresselhaus	American Physical Society, New York, 30 January – 2 February 1967
1819	Raman Excitation of Collective Waves in Solids	A. L. McWhorter P. N. Argyres	
1820	High-Temperature Expansion of the Magnetic Susceptibility for the Classical Heisenberg Model	H. E. Stanley	
1885	Stimulated Four-Photon Interaction	R. L. Carman R. Y. Chiao* E. Garmire* P. L. Kelley	
1822	Recent Work on High Electric Field Effects in GaAs	A. G. Foyt	Seminar, Cornell University, 21 November 1966

* Author not at Lincoln Laboratory.

Division 8

MS No.			
1830	Metallic Properties of Certain Metal Oxides	J. M. Honig	Colloquium, Brown University, 5 January 1967
1838	Laser Principles and State-of-the-Art Crystal and Semiconductor Lasers	R. H. Kingston	American Association for the Advancement of Science, Washington, D.C., 30 December 1966
1839	Low Field Avalanche in n-CdTe	M. R. Oliver A. G. Foyt	Conference on Active Microwave Effects in Bulk Semiconductors, New York, 2 – 3 February 1967
1841	Recent Progress in Infrared Lasers and Detectors	J. O. Dimmock	Solid State Physics Colloquium, Washington, D.C., 5 January 1967
1842	Light-by-Light Scattering Due to Molecular Orientation	P. L. Kelley R. Y. Chiao*	Seminar, M.I.T., 16 December 1966
1843	Interstellar OH Maser Emission	H. J. Zeiger	Seminar, Northeastern University, 20 December 1966
1846	An Effective Hamiltonian for the Optical Properties of Si and Ge	G. F. Dresselhaus	Seminar, M.I.T., 6 January 1967
1857	Effective Mass Hamiltonian and the Dielectric Constant for Si and Ge	G. F. Dresselhaus M. S. Dresselhaus	Winter Institute in Quantum Chemistry, Solid-State Physics, and Quantum Biology, Sanibel Island, Florida, 5 December 1966 – 21 January 1967
1859	Proof of the Virial Theorem for the Electron Gas	P. N. Argyres	
1871	Critical Phenomena in Heisenberg Models of Magnetism	H. E. Stanley	Colloquium, Brandeis University, 17 January 1967

* Author not at Lincoln Laboratory.

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Electron beam excitation of CdS crystals grown in an atmosphere of excess Cd has resulted in laser emission near 4900 Å with 350 W of peak output power and 26.5-percent overall (35-percent internal) power efficiency at temperatures as high as 110°K. These values of power and efficiency represent more than an order of magnitude improvement over previously reported results. Laser action was observed, although at considerably reduced levels of power and efficiency, at temperatures up to 250°K. By using liquid helium as a coolant, an average output power of about 0.5 W could be maintained. Liquid nitrogen cooled samples produced up to 0.2 W of average power. The high performance of these new lasers appears to be due to increased crystal uniformity and to the introduction or enhancement of highly efficient radiative transitions, both of which result from the Cd-rich growth conditions.

Infrared photovoltaic response and a quantum efficiency of up to 25-percent have been observed at liquid nitrogen temperature in large-area InSb, metal-oxide-semiconductor structures. These structures consist of an InSb sample on which a 500-Å oxide layer was formed on one surface. A 100-Å thick semitransparent nickel film was then deposited on the oxide layer, and the infrared radiation was incident on the InSb through the film and the oxide layer. Spectral measurements indicate that the photoresponse is due to the generation of electron-hole pairs in a depletion region of the n-type InSb at the InSb-oxide interface. Pulsed current measurements yield a clear diode characteristic and the overall results are equivalent to what one would expect to obtain from a photodiode in series with a MOS capacitor.

Single crystals of $Pb_{1-x}Sn_xTe$ alloys have been prepared by the Bridgman technique and by the vapor growth process. The overall results indicate that very large single crystals of a predetermined composition can be grown with a high degree of homogeneity by the Bridgman technique. These crystals, however, possess high carrier concentrations, and must be annealed before useful devices can be fabricated from them.

$Pb_{1-x}Sn_xTe$ crystals were also vapor grown at various temperatures between 700 and 825°C. For $0.16 \leqslant x \leqslant 0.20$, p-type crystals were grown using metal-saturated source powders. An n-type skin, which is believed to form because of the preferential loss of Te (and probably Sn) from the surface during the cooling process, was observed on the crystals. For $x \leqslant 0.10$, only n-type crystals were grown from metal-saturated sources.

Gunn oscillation waveforms which are consistent with the electric-field-controlled differential negative resistivity of the transferred-electron model have been studied in CdTe. However, a current runaway process has also been observed which competes with the Gunn effect. During the runaway, band-gap radiation (~9000 Å) is emitted in filaments reaching from one contact to the other. These latter effects are characteristic of a current-density-controlled differential negative resistivity.

II. OPTICAL TECHNIQUES AND DEVICES

Further measurements of heterodyne sensitivity have been made at 10.6 μm using Cu-doped Ge detectors. The results are now in excellent agreement with the theoretically predicted value of the $2h\nu B/\eta$ for the minimum detectable power, where B is the bandwidth and η the quantum efficiency.

Preliminary measurements have established the feasibility of $Pb_xSn_{1-x}Te$ as a heterodyne detector for 10.6 μm operating at liquid nitrogen temperature (77°K). Initial measurements have yielded sensitivities much poorer than the theoretical value; however, modifications in the detector design are expected to improve the performance.

Two stable CO_2 laser oscillators have been successfully operated and their frequency stability measured by observation of the beat frequency. The short term stability is of the order of 9 and 20 kHz for observation times of 0.03 and 1 sec, respectively.

Further measurements have been made on a sealed-off CO_2 laser to determine the processes presently limiting operating lifetime. Studies of optical emission, power output, and mass spectrum analyses as a function of lifetime indicate that the principal performance degradation is caused by conversion of the carbon dioxide to carbon monoxide and oxygen.

III. MATERIALS RESEARCH

A crystal puller has been developed for the Czochralski growth of single crystals from melts produced by the arc-melting technique. Use of this apparatus eliminates the difficulty of finding crucible materials suitable for high-temperature growth, since the melt is contained by a solid shell of the same substance, which is in contact with a water-cooled copper hearth.

Single crystals of MnI_2, a compound with the CdI_2 layer structure, have been prepared by freezing from the melt and by condensation from the vapor phase. Both types of growth were obtained when helium gas was used to transport MnI_2 vapor through a resistance-heated quartz tube with a suitable temperature profile.

X-ray diffraction and superconducting transition measurements have been made on InSb samples annealed at 65 kbars. The results show that at this pressure the transition from the room-temperature orthorhombic phase to the high-temperature InSb-III phase occurs between 175° and 225°C.

Single crystal films of $Pb_{1-x}Sn_xSe$ alloys with rocksalt structure have been deposited by evaporation on cleaved (100) faces of KCl substrates. The composition and temperature dependence of the energy gap, as determined from infrared transmission data, show that these alloys exhibit the inversion of conduction and valence bands recently proposed for the $Pb_{1-x}Sn_xTe$ alloys.

Magnetic susceptibility data, which have been obtained for $MnYb_2S_4$, show that there is no appreciable magnetic interaction between the Mn^{2+} and Yb^{3+} ions. It has been established by x-ray diffraction measurements that this compound has a normal spinel structure with Mn^{2+} ions in the tetrahedral positions and Yb^{3+} ions in the octahedral positions.

IV. PHYSICS OF SOLIDS

Exciton fine structure in the interband magnetoabsorption spectrum of InSb has been observed and studied as a function of magnetic field. Some of the structure cannot be explained by the theory of Elliot and Loudon.

In the magneto-optical investigation of GaSe, measurements on vapor transport grown samples have yielded sharper lines as well as two additional new series of lines. Presumably, this improvement in spectra is due to the absence of strain in crystals prepared by this technique.

The analysis of the HgTe interband magnetoreflection measurements has been completed. A least squares fit of the data gives an energy gap $E_g = -0.283 \pm 0.001$ eV and a momentum matrix element parameter $E_p = 18.1 \pm 1.0$ eV; these values are quite different from previous determinations which were not so direct.

The study of oscillations in the magnetoreflection of arsenic continues. Some of the experimental results are in contradiction with the Lin-Falicov band model.

The Fourier expansion technique, previously applied to the calculation of the electronic energy bands and the dielectric constant of silicon and germanium, has now been used to obtain the lattice vibration spectrum for solids which crystallize in the diamond structure. Because of the availability of a large amount of experimental data, the band parameters for the phonon problem can be determined to a high degree of accuracy.

The zero field Cr^{53} nuclear resonance in the ferromagnetic state of the spinel, $CdCr_2Se_4$, has been studied from liquid helium temperature to 115°K. Surprisingly, in the interval from 4.2°K to liquid nitrogen temperature the hyperfine field decreased linearly with temperature.

Calculation of the high-temperature expansion of the spin correlation function for the classical Heisenberg model, up to nine coefficients for the loose-packed lattices and eight coefficients for the close-packed lattices, has been completed. The results are being applied to problems in magnetic ordering and neutron diffraction.

Resonant stimulated Raman scattering has been observed at ~20°K in a quartz sample cavity with plane, parallel end faces which formed a Fabry-Perot etalon. The measured Stokes line splittings indicate an index of refraction 10 to 20 percent larger than the usual index – presumably because of the nonlinear response of the material under high electric field.

The Raman spectra of trigonal, α-monoclinic, and amorphous selenium have been measured at room temperature with a YAG:Nd^{3+} laser. For the trigonal form mode, symmetries have been identified by polarization measurements and the second-order spectrum has been explained in terms of two phonon transitions.

A general technique for calculating Raman scattering from collective electron waves in solids has been developed, in which the coupling to the collective wave is expressed in terms of the thermally fluctuating vector and scalar potentials of the many-body system. The method can be used for longitudinal or transverse plasma waves and for mixed plasmon-phonon waves, and can also include the effect of magnetic fields.

By using a guiding-center distribution function, an expression for Landau damping of magnetoplasma waves has been derived for closed Fermi surfaces of arbitrary shape in the case where the cyclotron frequency is much greater than the collision frequency. The strength of the damping is found to be determined by the average over the cyclotron orbit of the power delivered by the wave to the resonant electrons.

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13. ABSTRACT

This Quarterly Technical Summary covers the period from 1 November 1966 through 31 January 1967. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

14. KEY WORDS

data systems
digital computers
computer components
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space surveillance
radar
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mechanical and structural engineering
solid state physics