ESD-TDR-65-505

Quarterly Technical Summary

General Research

15 November 1965

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

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, with the support of the U.S. Air Force under Contract AF 19(628)-5167.

Distribution of this document is unlimited.

Quarterly Technical Summary

General Research

15 November 1965

Issued 20 January 1966

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

INTRODUCTION

This Quarterly Technical Summary covers the period from 1 August through 31 October 1965. 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

TABLE OF CONTENTS

DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 August through 31 October 1965 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1965

PUBLISHED REPORTS

Technical Reports

TR No.				DDC and Hayden Nos.
387	On-Line Documentation of the Compatible Time-Sharing System	J.M. Winett	12 May 1965	DDC*
398	Analog Generator for Real-Time Display of Curves	T.E. Johnson	28 July 1965	DDC*

Technical Note

TN No.				
1965-31	Bottom of the Spin-Wave Spectrum in a Magnetic Film	K.J. Harte	28 July 1965	DDC 619985 H-669

Journal Articles†

JA No.			
2353	Magneto-Optical Scattering from Multilayer Magnetic and Dielectric Films. I. General Theory. II. Applications of the General Theory	D.O. Smith	Optica Acta 12, 13 (1965), DDC 622307 Optica Acta 12, 193 (1965)
2411	The Scaling of Digital Differential Analyzers	H.K. Knudsen	IEEE Trans. Electron. Computers EC-14, 583 (1965)
2465	A Simple Local-Sufficiency Condition Based on the Second Variation	P.L. Falb	IEEE Trans. Automat. Control AC-10, 348 (1965)
2544	Telling a Computer How to Evaluate Multidimensional Situations	D.B. Yntema L. Klem	IEEE Trans. Human Factors Electron. HFE-6, 3 (1965)
2562	Magnetic Measurements with Lorentz Microscopy	M.S. Cohen	IEEE Trans. Magnetics MAG-1, 156 (1965)
2596	The Lorentz Force	M.S. Cohen K.J. Harte J.R. Szablya‡	Proc. IEEE (Correspondence) 53, 1145 (1965)

* Not yet assigned.

† Reprints available.

‡ Author not at Lincoln Laboratory.

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2387A	Redirecting the Search Process	U. Neisser A. Stoper*	Accepted by Brit. J. Psychol.
2444	Searching Through Word Lists	U. Neisser H. K. Beller*	Accepted by Brit. J. Psychol.
2694	On Some New Results in Shot-Noise	O. A. Z. Leneman	Accepted by Proc. IEEE

Meeting Speeches†

MS No.			
1367	Properties of NiFeAl Films	M. S. Cohen	International Symposium on Basic Problems in Thin Film Physics, Clausthal-Gottingen, Germany, 6-11 September 1965
1454	Films: I. Automatic Reduction of Filmed Data. II. Data Editing on a Computer	H. L. Kasnitz G. M. Shannon	Annual Meeting, SPIE, San Francisco, 16-20 August 1965
1487	The Design of High Performance NPN Silicon Transistors for Microcircuit Application	R. L. Luce*	NEREM, Boston, 3-5 November 1965

* Author not at Lincoln Laboratory.

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

DIGITAL COMPUTERS
GROUP 23

I. COMPUTER SYSTEMS

A. TX-2

The timing for the main frame is being improved to provide a 2.0-μsec memory cycle. Four new 2.0-μsec (16,384-word) memory modules, similar to the two already in service, have been ordered to replace the 6.4-μsec vacuum-tube-driven S-Memory. System performance will be further increased by utilizing the modularity to increase the possibilities for memory overlap and hence the effective computer speed. In order to achieve the memory overlap, a new Memory Bus Switch is being built which will expand the number of addressable modules from four to eight.

Other changes under way are the addition of several new instructions and expansion of the error-trapping hardware for the supervisor program (APEX).

B. Typewriter-Keyboard Consoles

A third console has been put on line this month. Documentation is such that minimum effort would be required for production of additional consoles.

C. V-Memory Multiplexer

The V-Memory Multiplexer and Executive Timer Register have been checked out and installed.

D. Memory Snatch

The installation of the Memory Snatch (SNAT) equipment in TX-2 has been completed and debugged. This feature allows efficient transfer of blocks of data words between selected in-out units and the TX-2 memory, with only one memory cycle required per word. Thus, SNAT cycles are interleaved with other programs without disturbing these programs. The in-out units that have the SNAT feature available are: Fastrand Drum, IBM Magnetic Tape, Analog-to-Digital Converter, and Displays.

E. Displays

A third display was put on line with a P-12 phosphor cathode-ray tube. This phosphor has less flicker and better general viewing characteristics than the P-7 now used; however, it burns very easily. A study of the effects of beam currents and vector drawing rates on phosphor burning will be undertaken after the study of light pen operation is completed.

II. CIRCUIT DEVELOPMENT

A. UHF Switching Transistors

1. Silicon Transistors

Two groups of improved SX3c (formerly referred to as LL-3) npn silicon switching transistors have been received from Philco (Lansdale). These are the best units we have measured, superior to any germanium devices we have examined.

Group I had an average peak gain-bandwidth product (f_T), at V_{cb} = 0 volts, of about 2.8 Gcps at 12 ma, and base resistances of 8 to 12 ohms.

Group II had an average peak f_T value, at V_{cb} = 0 volts, of 3.7 Gcps, and base resistances of 18 to 22 ohms. This group had an f_T, at V_{cb} = 0 volts, greater than 2 Gcps over a current range of 1 to 50 ma. The highest measured f_T for this group was 6.4 Gcps at 4 volts and 15 ma.

Future groups will be fabricated with 0.05-mil stripe widths in an attempt to gain further improvements in performance.

2. Sub-Nanosecond Integrated Circuits

The transistor described above has been adapted to simple, three-input gate circuits of the ECL and T^2L types. In this form, it has three stripes which are more suitable to low current operation than the original nine. The circuits occupy a very small area (about 10 square mils), and will therefore have a future large array capability as well as high-speed performance. Circuits of both types have been fabricated and DC measurements made.

3. Measurements

The automatic f_T plotting system is essentially completed and operating very satisfactorily. Recent measurements have been made at a source frequency ranging from 300 to 1000 Gcps. The f_T fall-off at the higher frequency is in general greater than 6 db per octave. This may be due to the device, the device package, or the test socket in the equipment. The socket will be redesigned for improved high frequency performance.

4. Commercial Microcircuits

Gain bandwidth (f_T) measurements were made on three transistors in commerical DTL circuits. The circuits were removed from the flat-pack encapsulation and the transistors isolated. Connections were made to the isolated transistors, and gain-bandwidth curves were then made on the automatic plotter. A summary of the results follows.

	Input Transistor	Output Transistor	High-Power Output Transistor
Peak f_T at V_{cb} = 0 volts	500 Mcps	500 Mcps	470 Mcps
Peak f_T at V_{cb} = 5 volts	620 Mcps	620 Mcps	570 Mcps
I_c, V_{cb} = 0 volts at peak f_T	3.5 ma	10 ma	20 ma

B. Integrated-Circuit Evaluation

An analysis of the basic DTL gate circuit indicates a strong dependence on resistor values for the propagation delay. This dependence motivated an examination of previous DC and propagation delay data to determine whether switching performance could have been predicted by DC measurements alone. Of the 472 gates tested, nine failed to meet the delay specification. Four would have been detected by DC measurements, and five would have gone undetected. It was decided to continue making propagation delay measurements.

C. Integrated-Circuit Tester

Work is nearly complete on the operational amplifier, programming, and forcing function modules of the second integrated-circuit tester.

D. Integrated-Circuit Modules

The basic units of a line of integrated-circuit logic modules for use in TX-2 peripheral equipment and for general laboratory use are now available. These include modules which contain two-input and four-input gates, four-input gated buffers, basic flip-flops, clocked flip-flops, single-shot multivibrators, selection gates, transfer gates, parallel counters, indicator drivers, line drivers, and cable terminators.

Approximately 110 of these modules were assembled and tested for the new TX-2 systems. The solder-reflow method of mounting flat integrated-circuit packages to the etched-wiring board worked well when proper precautions were taken.

Several new logic modules are being designed for the new systems. These include exclusive-or nets, Schmitt triggers, relay pullers, parity nets, and other gate combinations.

E. High-Speed Circuits and Memory Bus Switch

Two packages designated LA-8 and LA-44 were designed for the TX-2 Memory Bus Switch. One other package designated LA-11 is a modified version of the basic SPAT LA-1 circuit. The LA-8 and LA-44 use identical circuits (3-way ground AND followed by a 4-way OR circuit). Circuit delay is 10 nsec for 20 loads on each output with rise and fall times of 4 nsec. The LA-11 is similar to the SPAT LA-1 except that it has a 7-nsec delay instead of the 4-nsec delay of the LA-1. This increase in delay is the result of using transistors an order of magnitude less expensive than those used in the LA-1.

All hardware and components have been specified, and the Memory Bus Switch is in the initial stages of production.

Units for the T-2 tester have been designed to test the packages to be used in the Memory Bus Switch. A special unit which will test the large quantity of transistors (approximately 20,000) required for the packages has been designed. The average time to characterize a transistor should be under one minute.

III. MAGNETIC FILM ENGINEERING

A. Clean Room

Evaluation of the clean room with a Sinclair-Pheonix Aerosol Photometer has pointed out some deficiencies in the installation of the absolute filters in the main air supply to the room, resulting in an objectionally high level of contamination within the room. A temporary modification to the system has reduced contamination to a satisfactory level while a permanent modification is being planned and implemented.

The effort to reduce pinholes in evaporated films includes submicron filtration of critical solutions employed in substrate cleaning. The inability to filter spray-rinse water to a level of 0.45 micron has been traced to the presence of filter-clogging algae in the Laboratory water supply. More effective prefiltration equipment will be installed to climinate the difficulty.

B. Large Capacity Memory

Tests on the partially connected prototype stack have shown that voltage division by the capacitance of unselected word lines reduces read-time common-mode voltage on the digit line to such a low level (0.05 volt) that word noise can be held to acceptable levels by a simple common-mode filter. Word noise inductively coupled into digit-line imperfections remains a problem.

Recovery from the digit transient is adequate to permit operation in less than 0.7-μsec cycle time with optimum balance of the two digit lines connected to the digit-sense coupling circuit, and less than 1.0 μsec with 10-percent resistive and inductive imbalance.

Four 10-inch substrates have been tested in detail. One had low H_c and no operational digit current margin; good positions on the other three have digit current margins. Investigation of the effects of small defects on memory operation show that testing may have to be done at 0.002-inch increments along the word line. Since the entire word line is not switched in one write cycle, write and disturb history have a significant effect on the memory bit behavior.

A new Memory Stack structure is being designed. It is similar to the existing prototype, but will have a full digit complement, including digit connections as well as improved word switch connections.

C. LCM Line Quality

Intensive investigations are in progress to determine the cause of film peeling which makes it impossible to etch substrates without the resulting copper-permalloy word lines also peeling. This problem has never occurred before and appears to be common to all films made recently on our three vacuum systems.

The scribing apparatus has been upgraded to scribe various line patterns semiautomatically. Minor problems continue to exist with the scribable material; however, a number of excellent patterns have been generated.

Etching characteristics have been improved with regard to line-edge definition as the result of a modified rinse technique.

D. Content-Addressed Memory

It has been shown that "birotational" switching occurs in less than 0.1 μsec, and therefore is fast enough for the applications proposed thus far. The beryllium copper masks originally used were found to be unstable at the deposition temperature. Molybdenum masks are being procured in a pattern designed for memory use.

E. Saturable Shielding

It has been demonstrated, under conditions approaching those in a practical film memory, that a thin-film saturable magnetic shield, situated between a storage film and its transverse drive conductor, will produce a threshold in the relation between the applied transverse field and the effective transverse field at the storage film. The field at which the shield saturates is determined by its geometry. The shielding effect holds promise for coincident transverse selection, which so far has proved impractical with thin films.

A number of applications have been suggested. One is to use the nonlinear characteristic of the shield to provide word-line selection, in place of diodes, to simplify the construction of memories having line densities greater than 500 per inch. Another, true coincident writing, heretofore difficult, should now be possible with a saturable shield. Digit current will reduce the amount of shielding of a coincidently applied transverse field. Thus one unit of digit field should theoretically be able to produce an additional transverse field of one unit or more, depending on the ratio of shield film shape anisotropy to storage film anisotropy. Experiments will test these application ideas.

IV. SYSTEM PROGRAMMING AND APPLICATIONS

A. VITAL

A preliminary form of the TX-2 compiler-compiler, VITAL, has been completed. Current efforts are directed toward integrating this system with various editing and debugging packages, including INSIGHT.

B. Quadric Surface Display

An experimental display system for representation of quadric surfaces in four dimensions has been coded in APEX-M4 language and is in the debugging stage. The quadric surface is represented in homogeneous matrix notation. Parameter values and mode-selection "buttons" are displayed on the nonlinear portion of the CRT for light pen control of the display. The data describing the four-dimensional quadric surface are converted to an appropriate projection, clipped to fit the scope's linear display area, and displayed in "parabolized" form – i.e., conic sections approximated by smoothly fitted parabolic segments. Four of the basic parameters can be controlled by the Knob Register. The incomplete system is now running under APEX control, but lacks certain refinements and controls that will be needed for proper discernment of surface contours and hyperplane intersections.

COMPUTER COMPONENTS
GROUP 24

I. MAGNETIC FILMS

A. Anisotropy Spectrum of Magnetic Films

Major improvements in the instrumentation used to measure the magnitudes, period factors, and activation energies of the components of anisotropy in magnetic films are in progress. While retaining the basic principle of measurement,[1,2] the following improvements are in progress: (1) a more flexible arrangement of annealing and sensing fields is being provided which should also allow operation at higher temperatures; (2) the experiment is being transferred to an ion-pumped vacuum system with 10^{-9} torr capability; (3) the data will be recorded directly on magnetic tape in order to facilitate the use of a computer for data reduction.

B. Origin of Quadrature Flux in Magnetic Films

In order to investigate the quadrature flux in noninverted films ($H_w < H_k$), a strip line has been used to apply DC fields to the central portion of a film, thereby inhibiting wall nucleation. Preliminary results confirm the ripple hysteresis model, previously verified in inverted films.[3]

C. Magneto- and Electro-Optics

The theory of the longitudinal, transmission magneto-optical effect in thin magnetic film has been extended to include the effects of a birefringent substrate medium and a combination of birefringent incident and substrate media which are "crossed" in the sense that $n_{j\parallel} = n_{k\perp}$ and $n_{j\perp} = n_{k\parallel}$, where j and k refer to the incident and substrate media, respectively, and $\parallel$ and $\perp$ refer to the states of polarization. The crossed combination appears to have significant practical advantages in achieving high-conversion efficiency.

The theory of a thin-film transverse electro-optical phase shifter has also been worked out.[4] For a ZnS $\lambda/4$ film on a mirror substrate, phase shifts of 90° are predicted for only a few volts of control voltage.

D. Content-Addressed Memory

A content-addressed memory has been proposed[5] which uses magnetic film for storage and a light beam for interrogation. A separate beam is provided for each digit, and the key or address is transferred to these beams by means of electro-optical cells which might be, for example, of the type described in the preceding paragraph.

II. ELECTRON TRANSPORT

A. Triode Fabrication

Presently fabricated triodes do not have gain for two reasons: (1) discontinuities in the 100-Å-thick base provide undesirable direct interaction between the emitter and collector; (2) the

collector barrier thicknesses have not been correctly adjusted to have high impedance and still allow efficient hot-electron collection. Steps to solve these problems are in progress.

B. Oxidation of Aluminum

Recent experiments with a quartz crystal microbalance show that the previously reported[6] reversible work function change with pressure of aluminum-aluminum oxide surfaces does not correspond to reversible absorption-desorption of oxygen; no oxygen desorbs upon decreasing the pressure within an accuracy of about ±1/10 monolayer.

The thermodynamic argument which was previously developed is apparently still applicable. It is only necessary to assume that an equilibrium number of oxygen molecules exists at a given pressure and that the electron attaching to the oxygen molecule comes from the metal through the field of the surface potential. This equilibrium can exist because of the migration of aluminum ions to the surface to convert excess O_2 into oxide, in accordance with generally proposed mechanisms of aluminum oxide growth.[7] Further agreement is provided by the result that no reversibility of surface potential is obtained for thick oxide films that have been plasma grown. These films are thick enough so that aluminum ion migration is negligible.

C. Theory of Energy Loss in a Coupled Electron-Phonon System

The study of the rate of energy loss by a hot ($E > E_f$) electron injected into a solid has received considerable theoretical and experimental attention in recent years. Two "classical" papers which are pertinent are those of Quinn and Ferrell[8] and Quinn.[9] By utilizing a self-energy technique, these authors derive an expression for the rate of energy loss due to interaction with the electrons composing the Fermi sea. The rate of power absorption is essentially proportional to $\mathrm{Im}[1/\epsilon(\vec{q}, \omega)]$, where $\epsilon(\vec{q}, \omega)$ is the complex longitudinal dielectric constant of the solid. Quinn has studied the loss rate quantitatively by using the free electron RPA dielectric constant. Adler[10] has refined the theory somewhat by including local field corrections which may be important in a real solid.

We have recently extended the theory to include the indirect energy loss due to the interaction of the Fermi electrons with the phonon modes of the crystal. That is, in our model, the hot electron is allowed to interact directly with the thermal electrons which in turn are coupled to the phonons through an interaction of the form

$$\mathcal{V} = \sum_{\mu\gamma} \sum_{q'} e_{\mu\alpha}(q')\, \alpha^{+}_{\mu} \alpha_{\gamma} \left(b_{\vec{q}'} + b^{+}_{-\vec{q}'}\right)$$

The calculation is carried out by considering the equation of motion of the single-electron density matrix $\rho(t)$ for the model described above. Knowledge of $\rho(t)$ permits one to calculate $\epsilon(\vec{q}, \omega)$, and hence, the rate of power absorption. Fortunately, Argyres[11] has developed a formalism for computing $\rho(t)$, at least in principle, to any order in $\mathcal{V}$, and in particular, has carried out the calculation explicitly to order $\mathcal{V}^2$. Making use of his results, and ignoring local field corrections, we find a dielectric constant of the form

$$\epsilon(\vec{q}, \omega) = \epsilon^{(0)}(\vec{q}, \omega) + \epsilon^{(2)}(\vec{q}, \omega)$$

where $\epsilon^{(o)}(\vec{q}, \omega)$ is the usual RPA dielectric constant, and $\epsilon^{(2)}(\vec{q}, \omega)$ is the correction (to order $\mathcal{V}^2$) due to the electron-phonon interaction. The explicit expression for $\epsilon(\vec{q}, \omega)$ is rather lengthy and will not be given here.

Probably the simplest model for which one might attempt to evaluate $\epsilon^{(2)}(\vec{q}, \omega)$ is that of a system of otherwise free electrons interacting with Debye phonons at zero temperature. Preliminary calculations for this model indicate that $\epsilon^{(2)}(\vec{q}, \omega)$ is generally small compared to $\epsilon^{(o)}(\vec{q}, \omega)$, their ratio being typically of order c/v_f, where c is the sound velocity, and v_f is the Fermi velocity. This appears to be in agreement with the well-known result of Migdal[12] who has considered the same model using sophisticated field theoretic techniques. On the other hand, the expression we derive for $\epsilon^{(2)}(\vec{q}, \omega)$ may claim reasonable generality, and it is not at all clear that $\epsilon^{(2)}(\vec{q}, \omega)$ is negligible for more realistic electron and phonon energy bands, or for higher temperatures where phonons are more available.

D. Minority-Carrier Transport in Transistors[13]

An exact expression for the frequency-dependent minority carrier transport coefficient in the base region of a one-dimensional transistor $\beta(s)$ has been obtained in the form of a Fredholm series. The expression for $\beta(s)$ is obtained for a transistor base region in which the time independent electric field is an arbitrary function of position and the boundary conditions are linear by finding the Green's function for the small-signal, time-independent, transistor, diffusion equation. The factor $\beta(s)$ is then obtained directly from the Green's function of the system. Since the expression for $\beta(s)$ is valid for all values of the complex frequency s and is highly convergent except at the poles of $\beta(s)$, the leading terms of the series are sufficient to yield an approximate expression for $\beta(s)$ from which the cutoff frequency ω_β can be calculated. The resulting approximate expression for ω_β is quite accurate even for small electric field where the accuracy of existing approximations becomes quite poor.

REFERENCES

1. D. O. Smith, G. P. Weiss and K. J. Harte, "Measured Relaxatian Times far the Uniaxial-Anisatrapy Spectrum in Nan-Magnetastrictive Permallay Films," 11th Annual Canference an Magnetism and Magnetic Materials, San Francisca (Navember 1965), ta be published.
2. R. C. Johnstan, "A Sensitive Pulsed Magnetaresistive Measurement af Magnetic Film H_k," 11th Annual Canference an Magnetism and Magnetic Materials, San Francisca (Navember 1965), ta be published.
3. General Research Quarterly Technical Summary Report, Lincaln Laboratary, M. I. T. (15 August 1965), p. 10.
4. D. O. Smith, "Optical Scattering fram Cubic Electra-Optical Films," ta be published.
5. D. O. Smith and K. J. Harte, "Cantent-Addressed Memary Using Magneta- ar Electra-Optical Interragatian," ta be published.
6. General Research Quarterly Technical Summary Repart, Lincaln Laboratary, M. I. T. (15 August 1965), p. 9.
7. Far a review, see T. B. Grimley, "Oxidatian af Metals" in Chemistry af the Salid State, W. E. Garner, Editar (Butterwarths Scientific Publicatians, Landan, 1955).
8. J. Quinn and R. Ferrell, Phys. Rev. 112, 812 (1958).
9. J. Quinn, Phys. Rev. 126, 1453 (1962).
10. S. Adler, Phys. Rev. 130, 1653 (1963).
11. P. N. Argyres, Phys. Rev. 132, 1527 (1963).
12. A. B. Migdal, JETP, 34(7), 996 (1958).
13. C. T. Kirk, "A Green's Functian Appraach ta Salving the Transistar Diffusian Equatian far the Minarity-Carrier, Transport Factar, $\beta(s)$," ta be published.

PSYCHOLOGY
GROUP 25

I. MAN-COMPUTER INTERACTION

The APEX executive system, which time-shares the TX-2 computer among several on-line users, is now in everyday use by a few adventurous programmers. Although bugs are still being uncovered, and many desirable features are yet to be added, the level of effort devoted to APEX itself has declined slightly during the past quarter. Work on the library of users' routines that will exploit the system has increased accordingly.

A. APEX

During the past quarter, the Ghost Map feature has been installed. It is one of the more unconventional features of APEX: it allows a programmer to specify in a fairly convenient and economical fashion what his program is to do when a particular alarm or interrupt occurs. A new, improved routine has been installed to decide which blocks of core memory are to be retrieved from other users' programs when the current user's program needs more space. A user's program may now change the length of a file, and may indicate that a new file is to be auto-expandable, i.e., is to be lengthened automatically whenever the program tries to write in the page immediately following the current end of the file. The part of the executive that handles the Xerox printer has now been installed, as has an interim version of the part that handles CRT displays. There is also a primitive version of the Metabit Trap feature which is used by debugging routines to set break-points in programs that are to be debugged.

Work continues on the sections of the executive that will handle the magnetic tapes and the paper-tape punch, and on improved versions of the parts that now handle traps, CRT displays, and the Xerox printer.

Consideration is being given to the difficult problem of relaxing the restriction that a file must be confined to a single Book, and must therefore be no more than 8192 words long. Several other problems are also being investigated. One is the problem of routines that will monitor the amount of drum storage and the amount of core storage in use by each console. Another is the problem of allowing the user to define a File Group, i.e., a set of files to which he may refer by a single name. There is also the question of whether a more refined algorithm for retrieving core storage would be worth the trouble.

A general description of the APEX system will be published,* and preparation of a programmer's manual has begun.

B. Utility Routines

One of the utility routines that has existed for some time is the Basic Translator. It allows an on-line user to call a library routine by typing its name and a string of "parameters," which

* J. W. Forgie, Proceedings of the Fall Joint Computer Conference (1965), to be published.

are typically the names of the files and scalars on which the routine is to operate and the names to be given to the files and scalars that will be produced. An important routine now in preparation will allow the on-line user to define a series of such commands and give the whole series a name. The series may include conditional jumps to other commands in the series; some or all the names that appear in the series may be left free to be specified as parameters at the time the series is called. This new routine, called the Procedure Builder and Runner, is almost coded and is partially checked out.

With that exception, the set of utility routines available to programmers and other users seems to be fairly satisfactory for the moment. There are now facilities such as those for inspecting the names listed in the user's directory, for dumping the contents of a file in octal numbers or in instruction format, and for inspecting and altering a single register in a file.

C. Matrix Package

One of the chief purposes of APEX is to permit research on human factors in the interaction between scientists and computers. Matrix arithmetic was chosen as the field in which to begin, and preparation of a package of matrix-manipulation routines was undertaken. The routine that finds characteristic roots and vectors is now working, as is the one that solves simultaneous linear equations or finds the inverse and determinant of a square matrix. Routines that allow the user to print an existing matrix and enter a new matrix into the system are also working.

With these routines running, only two more are needed to complete the initial library of matrix operations. One, which changes a single element in a matrix, is being tested; the other is a routine for displaying on the CRT as many as three curves, each showing the components of one vector plotted against the corresponding components of another. The routine labels the axes and selects scales for them unless the user has done so. The specifications for this fairly complex routine have been set, with a considerable amount of code written, but debugging has not started.

The user will sometimes have to rearrange or transform his data to get them into such a form that matrix operations can be applied. A rudimentary language in which he can describe operations on n-dimensional arrays is therefore being provided. A contractor is writing a manual to explain the language and is constructing a compiler based on VITAL.*

II. HUMAN INFORMATION PROCESSING†

A. Discrimination of Recency

Studies described in previous reports show that discrimination of recency is better for pictorial material than for concrete nouns. A new study considered what happens when both classes of items, pictures and words, are included in the series of stimuli presented to the subject.

The hypothesis was that subjective recency of a picture, as measured by discrimination of its recency from the recency of another picture, would depend only on the number of pictures seen since the picture in question, and that the same would be true of words: the subjective

---

* See the Group 23 section of this report.

† One of the investigators was a National Institutes of Health postdoctoral fellow.

recency of a word would depend only on the number of words seen since the word in question. The hypothesis was rejected for both pictures and words. The number of items from the same class and the number from the other class both have an effect. A further experiment will be needed to compare the relative importance of items from the same class and items from the other class.

B. Perceptibility and Memorability

Previous reports described experiments in which the subject was presented with two meaningless garbled sounds and asked to say whether they were the same or different. It was found that his performance is better when a random noise is added to the second garble than when the same noise is added to the first, a finding which seems to imply that the memory trace of a sound that has been perceived clearly is retained better than the trace of a sound to which noise has been added. The experiment has now been repeated using, in place of the garbles, three-digit numbers spoken by the TX-2 computer. To the experimenters' considerable surprise, the effect was, if anything, stronger with numbers than with garbles. It appears that further experiments of this type should help to reveal the way in which auditory stimuli are abstracted or recoded for storage in short-term memory.

C. Keeping Track of Several Things at Once

It is now widely accepted that chunking results in a dramatic increase in the capacity of short-term memory. (Chunking is the process of organizing into a single mnemonic unit – i.e., a single "chunk" – several of the items that are to be remembered.) Two experiments have investigated the effeets of chunking on the task of keeping track of several things at once.*

In one experiment, the subject was asked to keep track of the present states of six variables which were divided into two groups of three. The states of the variables in one group were letters that almost always formed a eommon word, an excellent chunk. The states of the other variables were two animals and one geometrical figure, items that are not readily organized into a chunk. Contrary to expectation, performance on the letters was, at most, trivially superior to performance on the other items.

The other experiment had two conditions: in one, the subject kept track of two groups of variables whose states formed two words; in the other, he kept track of two groups in which the states were animals and geometrical figures instead of letters. Again there was, if anything, a trivial difference in performance.

These results seem to imply that chunking is not nearly so effective in the task of keeping track as in other tasks involving short-item memory. Perhaps taking a chunk out of storage, decomposing it into its component items, replaeing one of the items, and forming a new chunk is too much labor to be profitable.

* For a description of the general procedure used in experiments on keeping track of several things at once, see D. B. Yntema, Human Factors 4, 7 (1963).

CONTROL RESEARCH
GROUP 28

I. COMPUTATION CENTER DEVELOPMENT

The first stage in a program of updating the Laboratory's computer center was carried out during this quarter. The center, which has been badly overloaded, will be converted from its present batch-processing operation with an IBM 7094 Model II computer to a multi-programmed (time-shared) system of expanded capability using a dual-processor IBM 360 Model 67. This program includes the following principal steps:

(a) Installation of an IBM 360 Model 40 to replace gradually the present 1401 peripheral processors during the conversion period and for initial programming developments.

(b) Start of translation of Laboratory programs from the 7094 to 360 machine form.

(c) Installation of an IBM 360 Model 65 computer system to augment the 7094 operations until the arrival of the Model 67.

(d) Installation of the dual-processor Model 67 to replace the 7094 and the Model 65 operations with a high capacity batch-processing system with some initial multi-programming capabilities.

(e) Extension of the Model 67's operations to include highly parallel multi-programmed operations and conversational on-line access by Laboratory staff.

The final facilities will provide substantial improvements over the 7094 system in processing speed, storage capacity, and input/output rates. Other features of particular pertinence to the Laboratory's experimental needs include a highly modular system structure, capability for partitioning into separate systems, and hardware aids for efficient time-sharing (memory protection, dynamic relocation, and a comprehensive interrupt-handling system).

The Model 65 is scheduled for delivery in early December 1965 and the Model 67 in April 1966. Extension of the operations to include extensive multi-programming is planned for mid-1966, with initial conversational access from Laboratory consoles expected in the late fall.

During the past quarter, the Model 40 has been installed and has begun regular operations in peripheral processing. One of the three 1401's has been released; the other two are scheduled for release during the coming quarter.

Also during this quarter, a multi-programming supervisor has been designed and implemented on the Model 40 to overlap peripheral operations, such as tape-to-print, tape copying, and card-to-tape, under operator control by simple typewriter commands.

II. HYBRID COMPUTATIONAL FACILITY

The major activity in equipment construction for the past three months has been in finishing the DDA wiring and connecting its high-speed core memory. The wiring of the DDA for operation with the LINC is now complete, and the memory system has been operated satisfactorily. Designs for a number of interface circuits have been completed and prototypes have been

checked. An interface system also has been designed and built that connects the LINC to the DDA and enables the LINC to receive data from a MAC teletype or from an IBM 2701 Data Adapter Unit in the future IBM 360 system. It is expected that this entire system (with the exception of reading from the IBM 360) will be in full operation within two months.

The mapping and scaling programs have been operated on test problems, and transmission of the binary information from the Project MAC computer to the LINC has been done successfully.

RADIO PHYSICS
DIVISION 3

INTRODUCTION

This section summarizes the research and development efforts of Division 3 for the period 1 August through 31 October 1965. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semi-annual Technical Summary Report and the Quarterly Letter Report to ARPA.

S.H. Dodd
Head, Division 3

M.A. Herlin
Associate Head

DIVISION 3 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1965

PUBLISHED REPORTS

Journal Articles*

JA No.			
2553	A Comparison of Rocket, Satellite, and Radar Determinations of Electron Temperature at Midlatitudes	J.V. Evans	J. Geophys. Res. 70, 4365 (1965)
2568	More on Wet Radomes	J. Ruze	IEEE Trans. Antennas Propag. AP-13, 823 (1965)
2573	Radio Echo Observations of Venus and Mercury at 23 cm Wavelength	J.V. Evans R.A. Brockelman J.C. Henry G.M. Hyde L.G. Kraft W.A. Reid W.W. Smith	Astron. J. 70, 486 (1965)

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2451A	Radar Observations of Meteor Deceleration	J.V. Evans	Accepted by J. Geophys. Res.
2521A	Radio-Echo Studies of Meteors at 68 cm Wavelength	J.V. Evans	Accepted by J. Geophys. Res.
2627	Evidence of a Tenuous Surface Layer on the Moon as Derived from Radar Observations	T. Hagfors R.A. Brockelman H.H. Danforth L.B. Hanson G.M. Hyde	Accepted by Science
2664	Semiconductor Laser Communications Through Multiple-Scatter Paths	E.J. Chatterton	Accepted by Proc. IEEE
2677	Radar Astronomy at Millimeter and Submillimeter Wavelengths	J.W. Meyer	Accepted by Proc. IEEE

* Reprints available.

Unpublished Reports (Continued)

Meeting Speeches*

MS No.			
1244B	Radar Studies of the Moon	J. V. Evans	NASA Manned Space Science Study Group, University of Colorado, 6 August 1965
1353	Scattering and Transmission of Electromagnetic Waves at a Statistically Rough Boundary Between Two Dielectric Media	T. Hagfors	URSI Symposium on Electromagnetic Wave Theory, Technological University, Delft, The Netherlands, 6-11 September 1965
1392	Radar Ground-Clutter Shields	J. Ruze F. I. Sheftman D. A. Cahlander	1965 International Antenna and Propagation Symposium, Washington, D. C., 30 August – 1 September 1965
1393	Radar Astronomy at Lincoln Laboratory	J. V. Evans	
1465	Aperture Tolerance Theory – A Review	J. Ruze	

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

SURVEILLANCE TECHNIQUES
GROUP 31

Group 31 operates, maintains, and conducts research programs with the Millstone radar complex and the Haystack research facility of the Laboratory's Millstone Hill Field Station. Research efforts include satellite observation techniques and studies of the ionosphere, including auroras. Significant programs in radio and radar astronomy are also in progress at both Millstone and Haystack. Participation in propagation studies and other work of interest to the Space Communications Program is becoming a major interest at Haystack.

Of particular interest this period is the discovery of highly polarized emission lines of OH in the W3 region. The origin of the polarization of these lines is poorly understood and is currently stimulating considerable interest.

I. SPACE SURVEILLANCE

A. Observational Program

Routine satellite tracking took place on approximately a one-day-per-week schedule, in addition to a number of special tracking observations at other times. During the quarter, data on 151 tracks representing 51 different objects on the Space Track priority list were forwarded.

Observations of a special nature were as follows:

Molnia I, the USSR communications satellite, was tracked at the request of Space Track on 20 September. This object (designated No. 1324) is in an orbit with an apogee of 20,000 miles and a perigee of 300 miles. Millstone acquired at closest approach, approximately 3300 miles, and tracked to nearly 7000 miles. Cross-section data were also recorded.

On 15 October, the second in a series of Lincoln Calibration Spheres was launched from Cape Kennedy aboard a Titan III C rocket. Millstone stood by in a tracking mode for the first revolution, which was just visible over the horizon, as well as for a number of succeeding revolutions. It was suspected that a malfunction had caused an explosion during the early phases of the orbiting maneuvers, and Millstone was requested by Space Track to track the pieces of debris that resulted. A summary of Millstone observations follows.

Revolution No.	Number of Objects Tracked	Additional Objects Counted
1	1	1
11	4	0
12	4	19
13	12	22
42	10	7

B. Sensor Improvement Program

The Sensor Improvement Program (SIP) has two goals. One is to improve the accuracy of measurements on targets which can be tracked with the present system; the other is to extend

the range capability of the radar by adapting signal integration techniques used in radar astronomy to the detection and tracking of artificial earth satellites. The first depends heavily on improving the hardware in the signal routes all the way from the receiver to computer; the second needs the improved hardware, but depends for its success upon the development of adequate signal processing programs.

1. SIP Hardware

A thorough study has been made of the L-band radar receiving system. A large part of this system is from the original UHF radar. Except for the front ends and first converters, the predetection electronics date back to 1956 and 1957. The aging equipment presents a growing maintenance problem. Also, it is hard to justify the integration of obsolete receiving equipment into the design of the extended-range tracking system.

The outcome of the study has been the design of a system which, in addition to new electronics, provides a more accurate amplitude calibrating system. The calibrating system includes an external reference wide-band noise source and local sine wave and noise generators. Calibration satellites such as LCS-1 will serve as the reference standard for converting echo strengths to equivalent radar cross sections.

The Digital Monopulse System (DIGIMON) has been shelved for the present because of analog-to-digital converter problems mentioned in the last quarterly report. The functions which would have been performed by DIGIMON in the all-digital monopulse tracking system will be handled in the SDS-9300 computer in conjunction with the proven Multiplexed Analog Converter System (MACS).

Acceptance tests of the SDS-9300 computer were satisfactorily completed at the start of this reporting period, and a number of new programs have been written, mostly in Fortran. Several of the more important CG-24 computer programs are being rewritten for the SDS-9300.

A great deal of work has been done on interfacing the SDS-9300 with the radar. There are two basic input systems to the computer that are essential both to normal, i.e., single-pulse detection satellite tracking, and to extended-range tracking. They are the MACS, which provides phase-detected digitized amplitude data from as many as four receiver channels, and BORGIA, which is the Millstone computer interface.

The MACS interfacing has been designed so that a single 24-bit digital word can be preassembled in modules of 6-bit words. In this way, four 6-bit words can be transferred simultaneously at considerable saving of computer input time.

The BORGIA has successfully been interfaced to the SDS-9300. The present arrangement allows three modes of operation. The six words of radar data, i.e., range, doppler, azimuth, elevation, echo amplitude, and target detection time can be transferred to the SDS-9300 or to the CG-24, or to both computers in parallel. It is also possible to transfer data to the computer at Haystack in parallel with any one of these three modes.

2. SIP Studies and Software

A detailed study was made of the problem of detecting and tracking a distant weak target by the use of coherent signal integration. The parameters chosen in the study were those for

the LES-2 satellite. The problem was handled in two parts. The first was to determine the integration period, the volume in space to be scanned, and the number of hypotheses that must be tested in order to determine the presence of the target. The second was to determine whether the data processing problem could be handled in the SDS-9300 computer.

The outcome of this study indicated that it would be possible to detect and track an LES-2 satellite target at a nominal range of 12,000 nm. The study also produced a definition of the programming problems and the outline of a program in Fortran for performing the required computations.

Close contact has been maintained with TRW Systems Group (STL) which is under contract to produce an orbit upgrading program (ESPOD) for Millstone. Progress on this work was satisfactory during this reporting period.

II. RADIOMETRY

A. Radiometric Observations

During the current reporting period, the Radiometer Box was on the Haystack antenna 72 days and on the cornucopia horn antenna 17 days.

As in the previous quarter, two objectives were pursued: (1) continuing evaluation and calibration of the antenna, and (2) observations of radio sources.

1. Antenna Evaluation

A complete set of data for calibration of the pointing of Haystack has been acquired and analyzed. Pointing errors for repeated position measurements on the sources Cassiopeia A, Cygnus A, Taurus A, Virgo A, and 3C273 were fitted by the method of least squares to estimate instrumental error parameters. When the least-squares estimates of the instrumental errors were used to compute corrections to the pointing, the spread of residual pointing errors was reduced significantly. Instrumental corrections will be incorporated into the antenna-pointing program for the Haystack antenna.

Measurements of the polarization of radio sources at 8 Gcps have disclosed an instrumental polarization effect. Observations of the unpolarized radio source Orion A (angular diameter 4 arc minutes) have disclosed a small variation in antenna gain as the plane of polarization is rotated. This effect is such that the unpolarized source appears to have a linearly polarized component of 1.6 percent at an angle of 109° from the vertical plane with the angle measured clockwise looking toward the source.

Measurements of the sources Cassiopeia A and Taurus A were made at 8 Gcps on the gain-calibrated cornucopia antenna. These measurements, which will be used to obtain more precise values of the Haystack antenna gain, gave flux values of 535 ± 22 MKS flux units for Cassiopeia A and 445 ± 18 flux units for Taurus A. [An MKS flux unit is 10^{-26} watts m^{-2} $(cps)^{-1}$.]

2. Observations

The most significant observations to date with the Haystack antenna were made during the current reporting period. The spectral-line radiometric system (see Sec. II-B) came into operation on August 14 at OH-line frequencies. Observations of a source in the H II region, designated Westerhout 3, or simply W3, led to detection of polarized spectral-line emission at 1665 Mcps. Some of the OH-emission features were polarized over 25 percent. The details of the W3 observations were published in a letter to Nature (London), now in press.

Measurements of emission from the region toward the center of our galaxy were made during July and August at 8 and 15 Gcps. Maps of the radio brightness distribution of the central region, covering an area 0.5° by 0.5°, have been prepared manually from a series of drift scans. A computer program was written to produce processed maps from the same data. The computer maps appear slightly superior to the manual maps, and the computer mapping technique can now be used easily to produce maps of other regions from digital recordings of radiometric data. A paper reporting the results of the galactic center mapping has been prepared and will be published in Nature (London) within the next few months.

B. Radiometric Equipment

Haystack's radiometer system has been improved by the addition of a spectral-line receiver which became operable near the end of August. This receiver can determine the power spectrum of a signal over bandwidths up to 4 Mcps and centered anywhere in the range of 1600 to 1750 Mcps, a range which includes the OH lines.

To achieve high sensitivity, the receiver uses a low-noise room-temperature parametric amplifier (80°K noise temperature, 50-Mcps bandwidth) followed by a tunnel-diode amplifier (150-Mcps bandwidth). The tunnel-diode amplifier output is heterodyned to a 10-Mcps band centered at 30 Mcps. Following additional amplification at 30 Mcps, further heterodyning and filtering is used to obtain a video signal with a high-frequency cutoff equal to the total bandwidth to be analyzed. Cutoff frequencies of 40, 120, and 400 kcps, and of 1.2 or 4 Mcps are available. The video signal is then hard-clipped, producing a binary signal with random zero crossings. A digital correlator samples this binary signal and forms a one-hundred point autocorrelation function representing it. This function is fed directly into the Univac 490 computer, along with a measure of the total power of the video signal, since amplitude information is lost when the video signal is clipped. At the end of an integration period (which may range from 30 sec to several hours), the computer produces a plot of antenna temperature as a function of frequency with a resolution of 1/40 of the bandwidth analyzed. New parametric and tunnel-diode amplifiers which will allow the spectral-line receiver to operate at 1420 Mcps, the H-line frequency, are under construction.

On 21 September, the 1600-Mcps spectral-line receiver was burned out, presumably from intense L-band radiation received from the Millstone radar some 2000 feet away. Procedures have been outlined and safety devices installed to prevent a recurrence of the difficulty. Although approximately a month was required to repair the OH-line receiver, no interference with other observing activities at Haystack was experienced.

III. RADAR ASTRONOMY

A. Lunar Studies

Work is continuing at Haystack to implement in part some of the polarization studies of the moon which represent a continuation of measurements started at the Millstone radar. A numher of program refinements have been incorporated in connection with the more accurate ephemeris predictions required in order to carry out the planned detailed lunar mapping with the Haystack radar. Work is proceeding in this area in order to solve certain problems with incoherent integration posed by the high resolution requirements.

At Millstone, the circular-to-linear depolarization experiment described in the previous quarterly report has been repeated and the results confirmed. In addition, both circular-to-circular and linear-to-linear depolarization studies have been carried out at 23 cm. The two types of depolarization experiments have been found to be in good agreement with a lunar surface model which, when illuminated at oblique incidence, scatters back as if consisting partly of flat facets (responsible for about 40 percent of the scattered energy) and partly of randomly oriented dipoles (responsible for the remaining backscattered energy). It has been found that the amount of depolarization of the echo toward the lunar limbs is somewhat greater at 23 cm than it is at 68 cm. It has also been possible to conclude that the major part of the depolarization is caused by small scale structure. Further analysis of data already obtained is in progress.

An extremely accurate determination of the total cross section of the moon has heen possible through the use of the Lincoln Calibration Sphere as a reference target. It was found that the total cross section of the moon is 0.065 ± 0.008 of the physical cross section. This is in good agreement with previous results.

B. Planetary Studies

Planetary radar observations during the report period were confined to the Millstone Hill radar which made observations of Venus on 22 and 29 October. These measurements constitute the first range determinations made against Venus since the planet passed out of the field of view of the Arecibo radar in August. It is anticipated that Millstone will be able to follow the motion of Venus for the six-month period from November 1965 to April 1966 when Venus will once more pass out of range. Arecibo will not be able to observe Venus in this interval because of antenna pointing limitations; the range and doppler measurements obtained at Millstone are therefore of considerable importance. Previous work performed at Millstone has been reported in a separate paper.*

IV. ATMOSPHERIC STUDIES

A. Ionospheric Observations

The ionospheric backscatter program has been continued throughout the report period. The UHF vertical-looking radar is operated for a 48-hour period once a month. This radar provides

* J. V. Evans, et al., "Radio-Echo Studies of Venus and Mercury at 23-cm Wavelength," Astron. J. 70, 486 (September 1965).

information concerning the density and temperature of the ionized constituents in the height range 200 to 800 km. Results obtained from measurements in 1963 have provided material for six papers that have appeared in the Journal of Geophysical Research. The last two of these papers appeared in the September issue.*

Observations made in the first half of 1964 have now been analyzed and appear to confirm the behavior observed in 1963. New observations are being made with the L-band radar which permit the region below 200 km to be investigated. These observations are made for a 12-hour period once a month. Unfortunately, the echo strength is adequate for useful observations only during daylight hours. A preliminary analysis of some of the data furnished in these measurements suggests that the ratio of the ions O^+ to NO^+ may be determined over the height interval 120 to 240 km. It will also be possible to determine the electron temperature, but in order to obtain these results, it will be necessary to derive the ion temperature by using atmospheric models that have been compiled as the result of observations of satellite drag. Fortunately, these are now thought to be reasonably reliable.

B. Auroral Studies

L-band radar echoes from the aurora were obtained on some 30 percent of the days on which observations were scheduled. Computer programs for determining the range-angle distribution of the echoes and the spectral distribution of their energy have been completed and are now in use. With the cooperation of MITRE, and using their 1000:1 compressed pulse, a program to determine the effectiveness of pulse compression techniques in the rejection of auroral clutter was recently begun.

Analysis of data to obtain the doppler spectrum is just getting under way using the filter bank recently enlarged for the ionospheric backscatter program. Because of the great amount of time required in this analysis, the possibility of using the Scientific Data Systems computer at Millstone is being considered.

V. SPACE COMMUNICATIONS

A highly successful full-duplex vocoded voice communications experiment was carried out between Haystack and Lexington via the moon. The Haystack facility was utilized by Group 62 to check out their LET-2 (Haystack site) and LET-1 terminals in a demonstration of their digital voice communications system on 29 and 30 September. Haystack transmitted 25 kw at X-band and received a signal at a different X-band frequency using a liquid-nitrogen-cooled parametric amplifier. Group 62 used the link to make experimental checks on their system under operational conditions.

On 1 October, a radiometric observation of the West Ford dipole belt was carried out using the Haystack system. Camp Parks illuminated the belt with an 8350-Mcps signal. A frequency shift radiometer was used for reception of the signal. Unfortunately, data were contaminated by rain noise and transmitter problems at Camp Parks; nonetheless, a successful detection of the belt was achieved.

---

*J. V. Evans, "A Comparison of Rocket, Satellite and Radar Determinations of Electron Temperature at Midlatitudes," J. Geophys. Res. 70, 4365 (September 1965); "Cause of the Midlatitude Winter Night Increase in f_0F2," J. Geophys. Res. 70, 4331 (September 1965), DDC 614310.

VI. STATION EQUIPMENT HIGHLIGHTS

A. Millstone

The counter-torque antenna drive system has been debugged and has been in operation on both the elevation and azimuth axes for most of this reporting period. The work of converting the spare motor-generator set to the counter-torque mode was started near the end of the period.

A CalComp off-line plotting system, including basic software, was received and installed in the computer room. The present plotter uses the CG-24 computer as the driver. SDS-9300 computation programs for preparing CalComp magnetic tapes are being written. The new plotting system will permit greater efficiency in both computer and operator time.

A Hewlett-Packard digital frequency synthesizer has been acquired and will be used in the SDS-9300 computer-based tracking system for digital control of the receiver local oscillator. For the present, it is being used as a manually adjusted oscillator in connection with the Venus experiment.

B. Haystack

Haystack antenna improvements were directed toward reliability and smoothness of servo operation. Off-line hydraulic test facilities were completed in a "clean" room which will make unnecessary further use of the antenna for component testing. Thermal environmental studies in the radome area, as well as an investigation of merits, methods, and costs for antenna surface rerigging, continue. It seems probable that operation at a frequency of 35 Gcps, with an efficiency equivalent to that now achieved at 15 Gcps, is possible with the Haystack antenna design.

New data processing equipment was installed which will significantly extend the efficiency of antenna use. The major items include: A CDC 3200 computer, two A/D converter channels capable of megacycle sampling rates, and a Univac 1004 III printer-processor which will currently augment and eventually replace the present high-speed printer. Components to interface the computer to the receiver and clock are being wired into a subsystem which will provide for real-time processing of phase and amplitude data.

In the radar/communications (R/C) box, the most important advance was the delivery by the Radar Division of a new parametric amplifier which achieved a 35°K flange temperature. Attempts to achieve 100-kw operation were thwarted twice: first with a klystron failure at the 75-kw power level due to a window fracture caused by arcing, a second time when the spare tube developed an internal intermittent in the filament connection. Both klystrons were returned to the factory for repair.

Software improvements were directed toward test programs, e.g., computer-aided antenna pattern generation, control programs which supplement the pointing software in the Univac 490 for use on sources and targets appropriate to the Station experiments, and data-processing programs principally aimed at phase-coherent processing in real time.

A system design was completed for CW (receive only) tracking of the X-band beacon transmission from the Lincoln Experimental Satellite (LES) 4. The design, recently modified to provide for closing the tracking loop through the Univac 490 computer, is scheduled for system testing in November of this year.

C. High-Power Planetary Radar Development for Haystack

Preliminary designs for most major microwave components have been completed, and a wooden mock-up of the high-powered waveguide components and the associated monitoring equipment have been installed in a full-scale replica of the 500-kw planetary radar (PR) box. Members of Groups 46, 71, and 76 are now preparing final design plans for the assembly of the box.

Group 46 performed a high-powered test on the waveguide power splitter which Varian Associates proposes to use with the VA-949 AM klystron. Members of Group 71 have made extensive studies of the problem of handling the heavy weights in the restricted space of the PR box. The amplifier and its associated beam control unit will weigh approximately one ton.

Work is continuing on an RF test breadboard which will study the phasing problems presented in the final configuration of the 500-kw amplifier.

Prototypes of a new high-sensitivity, high-speed photomultiplier-type arc detector and a high-voltage standing-wave-ratio indicator were developed by personnel of Group 46 and installed in the R/C box for evaluation. In addition, a "Fast Logic Unit" was developed by members of Group 31 to enable the rapid extinction of the RF drive upon detecting a fault. This unit is capable of ascertaining the sequence of events which take place under fault conditions.

RADAR
DIVISION 4

INTRODUCTION

This report summarizes the General Research activities of Division 4 during the period 1 August through 31 October 1965. The major portion of Division 4's aetivities is devoted to PRESS, Radar Discrimination Technology, BMRS, and Space Communieations, which are described in separate reports. The General Research activities in Division 4 are earried out by Group 46, whieh is engaged in work on Haystack instrumentation, millimeter radar, and mierowave eomponent development.

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head

DIVISION 4 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1965

PUBLISHED REPORTS

Technical Note

TN No.				DDC and Hayden No.
1965-30	A Noise Rejection Filter for Waveguide Carrying High Power	W. J. Getsinger	3 August 1965	DDC 619580 H-666

Journal Article

JA No.			
2676	The Special Issue on Ultrasonics	J. J. G. McCue R. W. Damon*	Proc. IEEE 53, 1286 (1965)

* * * * *

UNPUBLISHED REPORTS

Meeting Speeches†

MS No.			
1256A	Haystack Experimental Facility	H. G. Weiss	URSI, Dartmouth College, 5 October 1965
1392	Radar Ground-Clutter Shields	J. Ruze‡ F. I. Sheftman D. A. Cahlander	1965 International Antenna and Propagation Symposium, Washington, D. C., 30 August-1 September 1965

* Author not at Lincoln Laboratory.

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

‡ Division 3.

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 and receivers for space communications, participation in a millimeter-wavelength program, and studies of very-high-gain antennas and antenna feeds.

II. HAYSTACK MICROWAVE COMPONENTS

A. Planetary Radar Box

Work continues on the construction of a new plug-in box for the Haystack radar to be used for planetary radar work. The box will contain a 500-kw CW transmitter operating at a frequency of approximately 8 GHz. Two developmental 250-kw klystrons (Varian Associates, VA-949 AM) will provide the power. Each tube will have two separate output waveguides, each carrying 125 kw. The four output waveguides will connect to a monopulse arithmetic network and a multimode feed horn for the Cassegrain, 120-foot-diameter antenna. Present plans call for the use of one receiver on the channel orthogonal to that being transmitted. A maser is being built by Microwave Electronics Corporation for this purpose.

1. Transmitter

Considerable thought has been given to the problems involved in driving the multimode feed from the two high-power klystrons in parallel. The main effect of an imbalance in the outputs of the two tubes will be a squinting of the antenna beam. Computer studies show that an amplitude imbalance of 20 percent or a phase imbalance of 11.5 electrical degrees would shift the antenna beam by less than 0.003 degree or about one-twentieth of the 3-db beamwidth.

In operation, samples of the outputs of the two klystrons will be subtracted in a hybrid, and the difference will be nulled by means of suitable phase and amplitude adjustments. The phases will be adjusted by variable phase shifters at the inputs to the tubes. A grid-control unit, which will allow control of the grid voltages of the klystrons and thus their perveance and output power, is being designed and built by Energy Systems, Inc. This unit will also allow on-off control of the output klystrons with switching times of 5 to 10 μsec.

The output power splitter employed with the VA-949 AM klystrons has been tested at power levels up to 380 kw. No breakdown or overheating was observed.

2. Antenna Feed and Circular Polarizer

The necessary parts for conducting high-power tests of the 500-kw multimode feed have been designed and are near completion. Testing of the feed will be carried out in the near future. The circular polarizer has been designed and is under construction.

3. 125-kw Circulators

High-power tests have been performed on essentially half of a Raytheon Manufacturing Company CXH-26 circulator, with a view to the possible use of such a unit in the planetary radar (PR) box. The tests were conducted at power levels up to 150 kw, at which level trouble was experienced with the high-power resonant ring. High-power tests were also conducted on a sample phase shifter related to those employed in the circulator.

During tests, some hot spots occurred at the interfaces between the alumina matching slabs and the ferrite slabs employed in the phase shifters. The hot spots were eliminated by separating the alumina and ferrite slabs. Tests on the sample phase shifter indicated that the phase-shift sections could each handle up to 100 kw (equivalent to 400 kw for the CXH-26 circulator). These tests also verified pulse measurements by Raytheon which indicated that saturation of the ferrite employed in the phase shifters could be expected at power levels of 90 to 100 kw.

4. Liquid-Helium Cooled Noise Source

A liquid-helium cooled noise source is being designed that will permit a determination of the noise temperature of a maser to within ±1°K. A memorandum describing the need for the noise source and its design is in preparation.

B. High-Speed Fault Protection

The high-power klystrons used with the Haystack transmitters are particularly susceptible to faults occurring in the output waveguides. Arc detectors and reflected power or VSWR detectors are normally used for such fault detection. Two improvements have been made in the particular devices employed in the R/C box. The first involved a change in the arc-detector light sensor from a solid-state photodiode to a photomultiplier tube. This change increased the sensitivity by about two orders of magnitude and reduced the response time to about 0.5 μsec. The second change involved the replacement of practically all the electronic circuitry associated with fast-fault protection with standard operational amplifiers and computer-logic circuits. Such amplifiers and logic circuits are conservatively designed, well understood and documented, and readily available.

The operational amplifiers provide a standardized gain, a wide bandwidth, and the proper input impedance for each sensor along with a very low output impedance. The sensor outputs can easily be relayed to the ground over coaxial cables where both DC and video signals can be observed and recorded. The outputs of the operational amplifiers feed Schmitt trigger circuits that set the levels at which faults will be detected and standardize the fault voltages to standard-fault or no-fault levels for the computer logic circuits. The use of computer logic allows the faults and the sequence in which they occur to be readily recorded. The computer logic circuits have a very fast response, so that the delay in turning off the RF is only 0.1 μsec longer than the response time of the fault sensors used. The elapsed time between the occurrence of a fault and the removal of the RF drive by means of microwave diode switches depends on the rate of change and the amplitude of the quantity sensed. This time is about 0.5 μsec for sudden faults of twice the value necessary to trip the Schmitt circuits.

A Varian Associates V-9000 arc detector-amplifier unit has been obtained for evaluation. The unit employs a photomultiplier tube as an arc sensor. On the basis of limited experience, it appears that the sensitivity and speed of the device are normally sufficient to prevent any but minor damage as a result of arcs or hot spots inside a waveguide. The arc detector is currently in use with the resonant ring which is employed to test Haystack components. When a fault is initiated, a PIN diode switch attenuates the RF drive by over 35 db. Since the installation of the arc detector and associated diode switch, arcs have not been observed to produce the typical audible click and spurt of air at the waveguide viewing ports.

C. Effect of Shock Waves on Ceramic Vacuum Windows

A high-power RF arc in waveguide is known to produce a shock wave. An investigation has begun to determine if the impact of such a shock wave on a ceramic vacuum window is sufficient to fracture the ceramic. Waveguide components have been designed to produce and measure shock waves resulting from a triggered RF breakdown for various RF pulse amplitudes and widths.

As part of the experimental program, shock waves with overpressures of 15 to 500 millibars have been generated by the arc of a capacitive discharge. The rise time of the shock wave is certainly less than 5 μsec as sensed with a pressure transducer of 5-μsec rise time. The shock waves have been used to confirm the calibration of the pressure transducer by comparing measured overpressure with shock Mach number. Also, the shock attenuation due to various waveguide components has been observed. The attenuation due to bends is the same as that which would result from an equivalent length of straight waveguide. Vacuum windows of various thicknesses are being fabricated to determine their fracture resistance when subjected to these shock waves.

D. Low-Noise Receivers

Four parametric amplifier assemblies packaged to operate at cryogenic temperatures have been delivered to the Haystack site. Three of the assemblies will operate at both liquid-nitrogen and liquid-helium temperatures. At 4.2°K, the units exhibit receiver noise temperatures of from 35° to 50°K. The fourth parametric amplifier assembly will not tune to all the Haystack frequencies when cooled. It will be employed as a room-temperature amplifier. A liquid-nitrogen cooled noise source has been constructed for use at the site in measuring receiver noise temperature.

E. Antenna Patterns at Low Elevation Angles

In an effort to explain some deformations and beam broadening in the elevation cuts of the Haystack antenna, measured at a low elevation angle in conjunction with the Pack Monadnock Mountain transmitter, the field under the radome was probed. This was done by means of a four-foot-diameter antenna which was moved vertically up to and above the center of the radome. It was found that the field had regions where the intensity was 10 db lower than at other places in the vicinity. In fact, several such low-intensity regions occurred within 30 feet of the center of the radome. Considerably more experimentation will be required to satisfactorily explain this.

III. SOLID-STATE AMPLIFIERS

A. Wide-Band, Low-Noise X-Band Parametric Amplifier

Construction of an engineering model of the wide-band, X-band parametric amplifier has been completed. The unit is currently undergoing bench tests. An accurate equivalent circuit of the amplifier has been determined on the basis of analytical techniques previously developed. This equivalent circuit has been programmed for an electronic computer to allow a comparison of measured and theoretical performance of the parametric amplifier. In addition, the program will permit a study of the effects of variation of circuit parameters.

B. Diode Procurement

A contract has been placed with the Micro Optics Company for the development of a diode package with smaller parasitic element values than those of presently available diode packages. The prospective package will be used in an X-band parametric amplifier designed to have a very low uncooled noise temperature.

A contract has also been awarded to Micro Optics for the delivery of GaAs diffused varactors and Schottky barrier diodes. The GaAs diffused varactors fabricated by Micro Optics change resistance by less than three to one when cooled from room to liquid-helium temperature.

IV. MILLIMETER-WAVELENGTH PROGRAM

A. 8-mm Lunar Radar

The 28-foot-diameter spun-cast antenna, which for the past two years has been used only for radiometry, is being returned to radar use. The radar will be employed to gather data on the reflectivity of the moon at 35 GHz. Such data were taken in 1963, but by improving the radar and using the more sophisticated concepts and procedures that have been developed since that time, it should be possible to procure better information.

As a first step, the radar is being reassembled in essentially the same form it had in 1963, with a 10- or 12-watt transmitter and a 3300°K receiver. Tubes for increasing the oscillator power to 50 watts are on order. An amplifier tube designed for 1 kw, and probably operable at more than 100 watts, is on hand. A quotation on a power supply for this tube has been received; the power supply is expected to serve also for an improved 1-kw tube that will be ordered when funds become available.

While the radar is being rebuilt, the penthouse-to-radar cabling is being reworked, and some functional improvements are being introduced. The oscillator tube will henceforth be run with its body grounded; appropriate changes have been made in the old modulator, and suitable supplies for powering the tube with its body grounded have been procured.

The reconstituted RF head will be mounted behind the dish as before, except that the mounting plate will be divided into two pieces. The receiver and 35-GHz oscillator will occupy one of these, and the other will carry the traveling-wave-tube amplifier stage. The latter will be readily removable for replacement by a radiometer receiver.

For the radiometer studies, the drive on the antenna mount has operated as an open loop, so that the rate of motion has been affected by factors such as wind loading and grease

temperature. S. H. Prince of Group 76 has undertaken to close the servo loop, so that the rate of scan can be held at a desired value. Because the positioning of the dish can be done more accurately than was supposed when the mount was installed, the position indicators need to be replaced by units that can be read more precisely.

Improvement of the receiver could be accomplished in any of several ways. A maser seems beyond the monetary and manpower resources of the project. A parametric amplifier with a noise temperature of about 2300°K may become available to the project. A tunnel-diode amplifier now under development by Aertech will be purchased if it has good performance at 35 GHz.

Several schemes are under consideration to reduce the antenna feed-line loss, which now has a two-way value of about 3 db. One proposal involves the use of oversized waveguide, but this may be inadvisable because of the existence of unterminated modes with the possibility of many resonances and high loss. Another scheme involves converting the antenna to a more normal Cassegrain geometry. In this case, it might be difficult to realize the mechanical tolerances required, particularly without a radome to temper the environment.

B. 8-mm Radiometry

The quarterly period was primarily devoted to equipment improvement, radio astronomical observations, and data analysis and interpretation.

The redesign of the antenna feed-line assembly constituted the major effort in equipment improvement. Such redesign was necessitated by the desire to use the antenna at 19 GHz, as anticipated in proposed observations of Venus during the impending conjunction. These observations will be performed by personnel from the M.I.T. Research Laboratory of Electronics in order to confirm and refine their current evidence for resonant absorption in the atmosphere of Venus. The new feed consists of oversized OFHC circular waveguide. New transitions from circular to rectangular waveguide were also designed to mate with both WR-28 and WR-42 waveguides.

In the area of radio astronomical observations, measurements at 8.6 mm were made on the moon and sun. The moon was observed during the first few weeks of the reporting period in order to complete a lunation study begun in the previous reporting period. The object of the study was to record changes in the intensity and polarization of lunar thermal radiation throughout a lunar month. Such variations admit to interpretation in terms of the thermal and electromagnetic properties of the lunar surface.

Observations of the sun were made to determine the antenna effects involved in the reception of polarized radiation from extended sources such as the moon. The sun proves to be an ideal source for such a study, since its radiation is unpolarized at millimeter wavelengths and its apparent size and shape are approximately those of the moon. Spurious indications of polarization were strong at the edges of the source where effects due to differences between the orthogonal patterns of the antenna are especially pronounced. The study of the sun provided an empirical evaluation of such effects and permitted their partial removal in the lunar study.

In the area of data reduction and analysis, efforts have concentrated on lunar studies. The measurements taken during the 19 December 1964 lunar eclipse are still the object of much work. A definite drop of the lunar radio temperature during the eclipse has been detected, and

early indications are that the changes are as our model predicts. Continued work should reveal variations in the temperature changes with selenographic longitude for a stronger test of our model.

Analysis of the lunation data is proceeding normally. These data consist of from six to twenty scans of the moon's temperature profile taken on approximately fifteen days during the month. As stated before, changes in the intensity and polarization of the radiation indicate the surface properties of the moon. Computer programs have been produced which calibrate and average a day's measurements. Work in the interpretation of the results is just beginning.

V. EVALUATION OF REFLECTOR SURFACE TOLERANCE COMPENSATION TECHNIQUE

The possibility of correcting surface imperfections in a large reflector by compensatory deformations of the Cassegrain subreflector is being examined. The computer program that has been written to study the problem uses the laws of geometrical optics and ray tracing to predict the contour of the subreflector required to bring all rays to a common focus and in phase with one another. This program constitutes a somewhat imperfect solution to the problem, since small deviations from Snell's laws are required to satisfy all the other conditions involved. The subreflector form can be approximated by segmenting a perfect hyperboloid of revolution radially and circumferentially and then properly displacing the individual segments parallel to the optical axis. This process was effected by a second computer program which calculates the on-axis signal strength with (a) no distortions in either reflector, (b) with a distortion in the large reflector only, and (c) with a distortion in the large reflector and compensatory distortions in the subreflector. The second program is required to verify that the gain loss due to the distortion of the main reflector has been minimized.

It is too early to report any conclusions based on these computer programs. Furthermore, it will be necessary to experimentally check the validity of the prediction based on the computer studies.

VI. PROJECT PRESS

A 20-db S-band horn has been constructed for the purpose of testing a PRESS tracking array. The horn is capable of any of the following polarizations: LHCP, RHCP, horizontal linear or vertical linear. The polarizations can be remotely selected. The horn has a VSWR of less than 1.2 and an axial ratio of less than 1.06 over a 10-percent frequency band. At the 2.8-GHz frequency of operation, the VSWR is 1.1 and the axial ratio is 1.02. A report describing the horn has been prepared.

VII. VHF MODIFICATION TO TRADEX ERROR HORNS

The addition of high-power VHF capability to the present UHF error horns appears feasible. The most successful approach envisioned at Lincoln Laboratory requires the attachment of dipoles to the error horn ridges. The matching problem then becomes manageable. Since the VHF feed is electrically small, a substantial back lobe is expected. A full-size model of a single error horn is now ready for radiation pattern measurements. Further work will be needed to decouple the VHF from the UHF line and also to reduce the overall dipole length.

VIII. CASSEGRAIN SUBREFLECTOR SUPPORT STRUCTURES

Experimental work related to the study of subreflector support members was discontinued early in the quarter. The results clearly showed that the optical blocking of the support members does not give a valid estimate of the scattered energy. Polarization effects and the particular placement of the supports are frequently more important than their size. A report on this work will be prepared at a later date.

ENGINEERING
DIVISION 7

INTRODUCTION

Mechanical, construction, and control systems engineering support of the General Research Program during the quarterly period ending 31 October was largely concerned with improvement of the Haystack Hill research facility. In addition, high-pressure apparatus was designed and fabricated for use in solid-state research, and computer-aided systems for structural analysis were further improved.

J. F. Hutzenlaub
Head, Division 7

MECHANICAL ENGINEERING
GROUP 71

I. HAYSTACK

A. Planetary Radar Equipment

Design of the planetary radar equipment box and related facilities is continuing. The basic structure has been received from the supplier. Critical weld areas have been radiographed and have revealed limited penetration and in some cases considerable porosity. A stress analysis is being made to determine the significance of these defects.

The configuration and location of the detachable dual klystron carriage have been determined. A separate four-wheel dolly with hydraulic lift will be used for removing the carriage and klystrons from the equipment box and handling them in the test dock area.

Two electronic racks have been positioned to extend through the rear wall on either side of the three-foot-wide access door; a third rack has been located at the left side of the forward wall of the box.

Detail design is continuing on the maser assembly, water manifold, air conditioning, electrical junction panels, and interconnecting waveguide.

Detail drawings are being prepared for the one-inch core Alply sandwich panels which will form the outside wall of the equipment box.

A full-scale wooden mock-up of the equipment box has been constructed as well as mock-ups of the high-power waveguide runs, arithmetic network, cryogenics, dual klystron, and carriage and equipment racks. Minor modifications may be required as final klystron data become available.

Manufacture of long lead-time items, primarily electroformed parts, such as circular polarizers, orthogonal mode transducers, and phasing sections, has been initiated. Because of high-power levels and low-loss requirements, it is necessary to use high conductivity copper with stainless steel flanges for microwave components. The present technique of hard soldering the flanges to the electroformed parts by using an oxyacetylene torch has proved unsatisfactory. A sample assembly is being furnace-brazed at the M.I.T. Research Laboratory of Electronics by using a gold-nickel alloy; this should prove satisfactory. In addition, it has been suggested that certain additives in the Lincoln Laboratory electroforming bath be eliminated. The additives which are intended to achieve a fine grain structure become troublesome at the temperatures required for hard soldering.

B. Strain Gage Program

On 27 August, the Haystack radome strain gage recording system became fully operative and is being kept on a standby basis, ready to record strains during periods of high wind levels.

The system monitors strains in 23 radome beams at various locations, from the radome base up to the radome apex. Each beam is monitored for bending strains along the two main orthogonal axes and also for axial strain. Three channels of a Sanborn recorder simultaneously

monitor these three strains. A rotary stepping switch sequences the monitoring of the 23 beams, with "on" time for each beam adjustable from 1 to 22 sec. The fourth and fifth channels on the recorder monitor wind speed and azimuth. The sixth channel records the rotary stepping-switch position for beam identification.

All gage locations utilize 4-arm bridges to maximize strain signals and obtain full temperature compensation. Gages are fully waterproofed with Di-jell wax and have an outer wrap of aluminum foil.

II. SOLID STATE

A. Gas Apparatus

A system consisting of a compressor, a booster, and an intensifier to develop gas pressures up to 200,000 psi has been installed in a safety-shielded mobile unit. The first two stages have been successfully tested, and testing of the third-stage intensifier is in process. Helium gas was used on each occasion.

The apparatus will be used to generate true hydrostatic pressures in reaction vessels or bombs. The latter were designed for special purposes in research programs such as:

(1) Phenomena studies under true hydrostatic conditions.
(2) Crystal growing under pressure.
(3) Hall measurements in a pressurized environment.

The mobile safety-shielding unit has been designed around the high-pressure gas apparatus to protect the operator from possible explosion hazards. Shielding-plate thicknesses were derived from Petry's depth of penetration formula.* As an added safety precaution, all plates are hinge-mounted.

B. Extrusion Die

The frequent use of silver chloride pellets or cylinders in high-pressure applications created a need for an extrusion device to produce silver chloride rods of a specified diameter. A pressure extrusion apparatus with interchangeable nozzles has been designed and is being fabricated.

C. Hydrostatic Pressure Apparatus

A requirement for carrying seven electrical leads into a 600,000-psi liquid cell led to the design of a closure based on a pressure differential self-sealing system. Experiments thus far have shown the effectiveness of the method up to 250,000 psi. Slight modifications to the design are neeessary for sealing at higher pressures.

D. Crystal Puller

This device, which will be fabricated during the next quarter, has been designed to meet the following requirements:

* "Design of Protective Structures," Naval Docks P-51, Bureau of Yards and Docks, Department of the Navy, Washington, D. C. (August 1950).

(1) Turn and draw the crystal seed with extreme smoothness within a vacuum. The speed of both linear and rotary motions shall be variable and both motions shall be reversible.

(2) Provision for 18 inches of seed travel.

(3) Provision for verneuil fusion technique.

(4) Provision for horizontal gradient work.

E. Hot Press

This apparatus is actually a die to be used for sintering processes. Maximum operating conditions are 100,000 psi at 1000 °C. The device was tested and behaved extremely well at maximum conditions for more than two hours. An actual experiment, however, showed a reaction of the die material with the specimen, so that modification of the unit is required.

III. STRUCTURES RESEARCH

Work has continued on paraboloidal shell analysis, the improvement and development of computer programs for the analysis of framed structures, and a basic study dealing with matrix ill-conditioning in the field of structural analysis. A new study program has been initiated on the problems associated with structural stability of radomes.

A. Paraboloidal Shell Analysis

Chapter IV of the LLAPS (Lincoln Laboratory Analysis of Paraboloidal Shells) User's Manual has been completed and should be issued shortly. A paper entitled "The Influence of Shell Behavior on the Design of Large Antennas" has been written and will be published in the proceedings of the XVIth International Congress of Astronautics.

B. Framed Structures Analysis

The modifications to the STAIR program and the expansion of the dynamic analysis program have been completed. Documentation of this effort is well under way and should be completed during the next quarter.

C. Ill-Conditioned Matrix Study

The initial phases of this study program have been completed. A qualitative discussion on the error propagation and its distribution in analyzing structures by the stiffness method has been written. A physical interpretation of the error sources and their manner of propagation has been attempted. Based on this work, methods of predicting, detecting, and minimizing these errors have been formulated. A test structure was devised, and some initial tests were performed whose results appeared to be in agreement with the qualitative theoretical investigation.

D. Radome Stability

A study has begun on the problems associated with the structural stability of radomes. The static strength of a radome is approximately inversely proportional to the radius, whereas the instability strength is approximately inversely proportional to the square of the radius. The

static strength of radomes in the Haystack diameter range is considerably lower than the instability strength and thus controls the structural design. As the radome diameter increases, the instability strength decreases with respect to the static strength, and for the larger diameters, it becomes the controlling criterion in the design.

The simplified stability analysis of the Haystack radome was sufficient to show that stability was not a problem. The analysis did not and could not determine the actual instability strength. Thus, the knowledge presently available is insufficient to determine if a radome much larger than Haystack should be designed by static or instability strength considerations. It seems likely that the instability characteristics of the larger structure will be as important if not more so than the static strength. This implies that detailed and exacting instability analyses will be required.

Methods for analysis of the stability of a radome need to be developed. There are two general approaches under consideration. One approach considers the radome as a shell, the other considers the radome as a space framework. For both approaches, the state of stress and deformation just prior to buckling is likely to be important. Unfortunately, the stability analyses will not only be more difficult than the static analyses, but the state-of-the-art is correspondingly much less developed.

CONSTRUCTION ENGINEERING
GROUP 75

I. INTRODUCTION

Group 75 provides the Laboratory with in-house construction engineering services in the eivil, struetural, eleetrieal, heating, ventilating, and air conditioning fields. The following items give a brief description of the major accomplishments of Group 75 for the General Research Program during the quarter.

II. HAYSTACK HILL

A. Facilities Building Addition

A 3000-square-foot extension to the Haystack Faeilities Building (the steel work-center building behind Haystaek) is now under construction. This extension is 50 feet wide by 60 feet long, has a 14-foot eave height, and comprises three bays. A pit, 9 feet wide by 16 feet long by 4 feet deep, has been east in the building foundation at the rear of the eenter bay of the addition to support a proposed future test dock.

In addition to a test dock, the purpose of the additional spaee will be to provide a laboratory for fitting out, servicing, and altering RF boxes designed for the various Haystack experiments.

Present construction activity includes the foundation, grading and paving, and an insulated building shell. Future requirements include heating, ventilation, lighting, and standard utility power for the addition.

B. Operations Building Addition

An 8000-square-foot addition to the Haystack Operations Building (north and west of existing Area D) is now in the design stage, with construction presently scheduled to begin early in 1966.

This structure will be a one story, steel framed, metal insulated, sandwich panel wall construction. A portion of the area will have a raised access floor (computer floor) and close environmental control to house the new CDC 3200 computer. The remainder of the area will supply laboratory and office space.

A separate 900-square-foot building shell loeated north of the above addition will provide aeeommodation for the many motor-generator sets now ineonveniently deployed around the Haystack plant. This separate metal building will eliminate the expensive ventilating problems of a eomposite motor-generator set installation in the main Operations Building.

C. Corrosion of Electronic Components

Corrosion of eleetronie eomponents in the eontrol room area raeks beeame evident during the summer months. It was felt that the corrosion was due to sulfur gases from the boiler stacks entering the fresh air inlets and to the high relative humidity of the air serving these racks. To confirm the souree of eorrosive materials and prevent further damage, Air Pollution Researeh Company was engaged to perform various tests and make reeommendations. A report has reeently been submitted which is now being evaluated by Group 75 for further action.

D. Standby Fire Protection Systems for Haystack/Millstone Hill

Each system consists of an 8000-gallon, insulated, heated water tank and a metal building containing a portable gasoline-driven pump and hose cart. Six hundred feet of $1\frac{1}{2}$-inch hose is provided in order to reach all areas of the sites and the adjacent woods. A Poweron nozzle is provided to permit a foolproof, nonadjustable stream approved for electrical fires. The capacity of the tank and pump through one $1\frac{1}{2}$-inch hose is estimated at two through four hours. Two of these hoses can be operated from each pump. Valving at the tank is arranged to permit local fire departments to connect to and use the stored water.

E. CO_2 Protection for RF Boxes

Fire hazard in the RF boxes is of concern, especially when they are mounted on the antenna. Here, there would probably be damage to the antenna due to poor accessibility in combating fires on the mounts. Other locations of the RF boxes, at the test dock inside the radome and at the cornucopia test dock, will also be protected.

One-hundred-pound cylinders of CO_2 will be installed near each location to service the RF boxes with quick-disconnect hoses. Because of the hazard which could result from CO_2 being released into the box while people are inside, the system will have the safeguards of a mechanical shutoff valve, a door interlock, a time delay, and an audible alarm. Design assistance for this system is being provided by Group 75, with installation to be done under the supervision of Group 31.

III. MILLSTONE HILL

A. Nike-Ajax/Laser Installation on Tower 3

A Nike-Ajax pedestal with a high-power laser and a 10-inch reflecting telescope will be mounted on the gun mount tower at Millstone Hill in place of the present 60-foot antenna.

A structural steel adapter will be bolted to the top of the concrete tower to support the pedestal. The top of the tower will be sealed from rain and snow by a wood deck with a hatch for access of personnel. Plywood and wood-framed walls will enclose the lower part of the pedestal, and on top of the walls a canvas shelter on aluminum "hoops" will provide a quickly removable weather shelter over the telescope and laser.

B. Air Conditioning Compressor Installation

A spare compressor with a new air-cooled condenser is presently being installed at the Millstone Hill complex. It is anticipated that this compressor, operating at 1450 rpm, will handle the existing load; its capacity at design conditions is 40.15 tons. The existing compressor's speed will be reduced to 1160 rpm to provide an additional capacity of 32.4 tons, thereby providing a total available tonnage of 72.55 tons. Additional capacity can be obtained by increasing the speed of the existing compressor to 1450 rpm.

A new feeder is being brought into the equipment room to provide power for the spare compressor. The existing control wiring is being revised, and it is anticipated that these changes will facilitate maintenance and troubleshooting.

CONTROL SYSTEMS
GROUP 76

Effort is continuing in support of the Haystack site antenna operations and its drive-control system development. Reliability of the servo control system and angle data system has been greatly improved. The primary activities in the last quarter were preparation for reinstalling the antenna hydrostatic bearing interlock system, hydraulic servo valve work, and hydraulic test stand implementation.

Hydrostatic Bearing:– All components to permit hydraulic stand adjustment of flow control valves and hardware for antenna reinstallation of flow control valves and new pressure switch assemblies are on hand. Actual adjustment, reinstallation, and checkout is awaiting the availability of adequate time in the site operational schedule.

Servo Valves:– Two competitive two-stage electrical feedback assemblies are in process. One assembly is being designed and constructed by Pegasus Laboratories, Inc., the other is an in-house design using commercially available hydraulic and electrical components.

Hydraulic Test Stand:– A special control manifold block which simulates antenna valving for servo motor stand control has been completed and awaits hydraulic stand checkout. A spare antenna drive motor has been mounted next to the stand and fitted with a tachometer takeoff in preparation for closed-loop operation.

Construction has been completed on a bidirectional flow meter for observing the extremely low earth rate flow control of servo valves during stand testing.

The stand cooling tower for oil temperature cooling has been brought into operation and checked for temperature regulation.

Measurement:– A three-day measurement program was carried out in connection with the antenna rerigging study in order to evaluate the performance of the new Kern theodolite for this application. Results indicate that the theodolite has the capability necessary for optical control of a rerigging process.

TV Mount:– The installation of two television cameras and one movie camera on the Powertronic mount is being considered.

SOLID STATE
DIVISION 8

INTRODUCTION

This abbreviated report covers the work of Division 8 from 1 August through 31 October 1965. A more detailed presentation is covered by the Solid State Research Report for the same period.

A.L. McWhorter
Head, Division 8

P.E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1965

PUBLISHED REPORTS

Technical Reports

TR No.				DDC Nos.
390	Elements of the Hijmans-de Boer Approximation to Order-Disorder Theory	J.M. Honig	26 May 1965	DDC*

Journal Articles†

JA No.			
2495	The Effect of Trivalent Manganese on the Crystal Symmetry of Some Lithium Spinels	D.B. Rogers R.W. Germann R.J. Arnott	J. Appl. Phys. 36, 2338 (1965), DDC 622323
2516	Chemical Inhomogeneities and Square B-H Loops	J.B. Goodenough	J. Appl. Phys. 36, 2342 (1965), DDC 622927
2523	Field Effect on Magnetoresistance of n-Type Indium Antimonide	S. Kawaji‡ H. Huff‡ H.C. Gatos	Surface Sci. 3, 234 (1965)
2530	Preparation and Paramagnetism of the Rare Earth Trifluorides	S. Kern P.M. Raccah	J. Phys. Chem. Solids 26, 1625 (1965)
2550	Spin-Orbit Interaction in Graphite	G.F. Dresselhaus M.S. Dresselhaus	Phys. Rev. 140, A401 (1965)
2556	Long-Range Exchange Interactions from Spin-Wave Resonance	R. Weber P.E. Tannenwald	Phys. Rev. 140, A498 (1965)
2579	Impurity and Exciton Effects on the Infrared Absorption Edges of III-V Compounds	E.J. Johnson H.Y. Fan‡	Phys. Rev. 139, A1991 (1965)
2588	Quenching of Dy^{+2} Fluorescence by Y^{+2} in CaF_2:Dy^{+2} Lasers	J.R. O'Connor	Appl. Phys. Letters 7, 54 (1965)

*Not yet assigned.

†Reprints available.

‡Author not at Lincoln Laboratory.

Published Journal Articles (Continued)

JA No.			
2589	Effect of Y^{+3} on the Reduction of Sm^{+3} in CaF_2	J.R. O'Connor R.M. Hilton	Appl. Phys. Letters 7, 53 (1965)
2590	Simple Apparatus for Applying Uniaxial Pressure at Very Low Temperatures	J.H.R. Ward	Rev. Sci. Instr. 36, 1376 (1965)
2604	PbS Diode Laser	J.F. Butler A.R. Calawa	J. Electrochem. Soc. 112, 1056 (1965)
2629	Physics of Quantum Electronics – A Conference Report	P.E. Tannenwald P.L. Kelley B. Lax	Phys. Today 18, No. 9, 58 (1965)
2636	Pressure-Tuned PbSe Diode Laser	J.M. Besson* J.F. Butler A.R. Calawa W. Paul* R.H. Rediker	Appl. Phys. Letters 7, 206 (1965)
2638	Absolute Instabilities with Drifted Helicons	A. Bers* A.L. McWhorter	Phys. Rev. Letters 15, 755 (1965)
MS No.			
1383	Electrical and Electro-Optical Properties of GaAs-InSb "Schottky" Heterojunctions (Abstract)	E.D. Hinkley R.H. Rediker	IEEE Trans. Electron Devices ED-12, 511 (1965)
1384	Transients and Hot Carrier Effects in InSb Bulk Injection Lasers (Abstract)	I. Melngailis	IEEE Trans. Electron Devices ED-12, 506 (1965)
1385	Properties of Optically Pumped Semiconductor Lasers (Abstract)	R.J. Phelan, Jr.	IEEE Trans. Electron Devices ED-12, 506 (1965)

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2591	Properties of InAs Lasers	I. Melngailis R.H. Rediker	Accepted by J. Appl. Phys.
2609	deHaas-van Alphen Effect in Pyrolytic and Single Crystal Graphite	S.J. Williamson* S. Foner* M.S. Dresselhaus	Accepted by Phys. Rev.

* Author not at Lincoln Laboratory.

Unpublished Journal Articles (Continued)

JA No.			
2610	Pressures of Hg and Selenium over HgSe(c) from Optical Density Measurements	R. F. Brebrick	Accepted by J. Chem. Phys.
2621	Superconductivity in the Transition Metal Carbides: $Mo_{4.8}Si_3C_{0.6}$, $Mo_{0.95}Hf_{0.05}C_{0.75}$ and Mo_2C	V. Sadagopan* H. C. Gatos	Accepted by J. Phys. Chem. Solids
2622	Towards a Theory of the Anomalous Thermoelectric Effect in Magnetically Dilute Alloys	L. L. Van Zandt A. W. Overhauser*	Accepted by Phys. Rev.
2626	Photocurrent Spectrum and Photoelectron Counts Produced by a Gaseous Laser	C. Freed H. A. Haus*	Accepted by Phys. Rev.
2633	A Note Concerning the Temperature Profile Within a Thermomagnetic Energy Converter	T. C. Harman J. M. Honig	Accepted by Adv. Energy Conversion
2637	Non-Stoichiometry in Binary Semiconductor Compounds, $M_{\frac{1}{2}-\delta}N_{\frac{1}{2}+\delta}$(c)	R. F. Brebrick	Accepted as chapter in Progress in Chemistry of the Solid State, Vol. 3 (Pergamon Press, New York)
2641	Magnetic and Electric Properties of ReO_2: Theoretical Interpretations	J. B. Goodenough P. Gibart* J. Brenet*	Accepted by Compt. rend.
2642	Solution Regrowth of Planar InSb Laser Structures	I. Melngailis A. R. Calawa	Accepted by J. Electrochem. Soc.
2644	The Gunn Effect in Polar Semiconductors	A. G. Foyt A. L. McWhorter	Accepted by IEEE Trans. Electron Devices
2653	Resistance-Heated Crystal Puller for Operation at 2000°C	T. B. Reed R. E. Fahey	Accepted by Rev. Sci. Instr.
2697	Bulk GaAs Microwave Amplifiers	A. G. Foyt T. M. Quist	Accepted by IEEE Trans. Electron Devices

Meeting Speeches†

MS No.			
1374	Semiconductor Lasers	R. H. Rediker	Symposium on Materials Science and Engineering, M.I.T., 30 September 1965
1377	Surface Characteristics of Compound Semiconductors	H. C. Gatos	

* Author not at Lincoln Laboratory.

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

Unpublished Meeting Speeches (Continued)

MS No.			
1394A	Magneto-Optical Effects in Solids	G. F. Dresselhaus	Seminar, Ford Scientific Laboratory, Dearborn, Michigan, 25 October 1965
1419	Influence of Metal-Metal Bonding on Structures Derived from the NiAs Structure	J. B. Goodenough	CIC Symposium, Dalhousie University, Halifax, Canada, 1-3 September 1965
1431	Atomistic Approach to Electronic Materials	H. C. Gatos	NATO Summer School, Salonica, Greece, 16-20 August 1965
1438	Optical Properties of Rare-Earth Metals	A. J. Freeman* J. O. Dimmock R. E. Watson*	International Colloquium on Optical Properties and Electronic Structure of Metals and Alloys, Paris, 13-16 September 1965
1451	Magnetoreflection Studies in the Band Structure of Antimony	M. S. Dresselhaus J. G. Mavroides	
1447	Semiconductor Bulk Injection Lasers	I. Melngailis	NEREM, Boston, 3-5 November 1965
1460	Application of Magneto-Optical Phenomena	M. S. Dresselhaus	IEEE, French Section, Paris, 14 September 1965
1461	Color Centers in Alkaline Earth Fluorides	J. H. Chen* J. R. O'Connor	International Conference on Color Centers, University of Illinois, 11-13 October 1965
1462	Thermoluminescence and Dynamical Jahn-Teller Effects in Irradiated CaF_2(Y)	J. R. O'Connor J. H. Chen*	
1475A	A Covalency Criterion for Ligand-Field vs Band Electrons in Oxides with the Perovskite Structure	J. B. Goodenough	Seminar, Tufts University, 27 October 1965
1481	Description of Transition-Metal Compounds: Application to Several Sulfides	J. B. Goodenough	Colloque International sur les Derives Semi-metalliques, University of Paris, 27 September – 1 October 1965
1482	Principles of Lasers	I. Melngailis	Latvian League of Boston, Boston, 25 September 1965
1488	A Structural Criterion for Band vs Localized d Electrons	J. B. Goodenough	Seminar, University of Bordeaux, 5-6 October 1965
1492	The Gunn Effect in Polar Semiconductors	A. L. McWhorter	1965 Electron Devices Meeting, Washington, D. C., 20-22 October 1965

* Author not at Lincoln Laboratory.

Unpublished Meeting Speeches (Continued)

MS No.			
1492A	Transferred Electron Effects in Polar Semiconductors	A.G. Foyt	Seminar, Naval Ordnance Laboratory, Silver Spring, Maryland, 4 November 1965
1497	Time Inversion and Transport Coefficients for Magnetic Crystals	W.H. Kleiner	American Physical Society, Chicago, Illinois, 29 October 1965
1499	Excitation Spectra of Group III Impurities in Germanium Under Uniaxial Stress	D.H. Dickey J.O. Dimmock	
1522	Evidence for Impurity States Associated with High Energy Conduction Band Extrema in n-CdTe	A.G. Foyt R.E. Halsted* W. Paul*	
1509	Electrical Properties of Metal Oxides	J.M. Honig	Seminar, Purdue University, 27 October 1965
1511	Deviations from Stoichiometry in Electronic Materials	A.J. Strauss	Seminar, Tyco Laboratories, Inc., Waltham, Massachusetts, 20 October 1965
1517	The Symmetry of Hartree-Fock Ground States	W.H. Kleiner	Seminar, Monsanto Company, St. Louis, Missouri, 27 October 1965
1520	Self-Focusing of Optical Beams	P.L. Kelley	Seminar, M.I.T., 29 October 1965
1521	Determination of Band Structure of GaSe from Magneto-Optical Absorption Experiments	J. Halpern	Seminar, National Magnet Laboratory, M.I.T., 27 October 1965

* Author not at Lincoln Laboratory.

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

The output wavelength of PbSe diode lasers operating at 77°K has been tuned in the range from 7.5 to over 22 μ by applying hydrostatic pressures of up to 14 kbar. Extension to wavelengths above 13 μ was made possible by the development of polycrystalline germanium and silicon windows capable of withstanding the high pressures involved. These windows have been tested to 20 kbar with no evidence of deterioration. Germanium windows were used in the wavelength range to 20 μ in order to eliminate transmission difficulties due to lattice absorption bands in silicon; above 20 μ, where germanium has lattice absorption bands, silicon windows were used. Our range of tuning has been limited because the helium pressure-transmitting fluid freezes at 14.15 ± 0.03 kbar at 77°K. Since hydrostatic pressure cannot be transmitted reliably through solid helium, we plan to extend the diode emission to longer wavelengths by first pressurizing the system to above 14 kbar at room temperature (where helium is still a gas), and then cooling it to 77°K and below. With constant current through the diode, an increasing pressure has been observed to produce no significant change in the intensity of either the coherent or spontaneous emission, until the freezing point of the helium is reached. The large reduction in the intensity of emission that occurred when the helium froze is attributed to diffuse scattering of the radiation by the solid helium.

A new technique has been developed for growing a thin layer of InSb on an InSb substrate from a saturated In-InSb melt. This type of growth from a solution has been previously used in the fabrication of GaAs and Ge p-n junctions; however, at the lower temperatures required for InSb (about 300°C), certain modifications were made, such as the use of hot liquid stearic acid which covers the InSb substrate and the In-InSb melt during the growth process. By suitably doping the melt, uniform planar InSb n^+-p junctions were grown on substrate areas of about 2 cm^2. Such InSb junctions have been used in large-volume injection lasers which emit coherent light in a direction normal to the junction plane.

Injection of carriers into InSb n^+pp^+ structures similar to those used as bulk lasers has been studied by determining the distribution of potential and electric field along the p-region at various current levels. The measurements were made using a movable potential probe with the sample at 77°K. These measurements indicate that at currents of less than 1 A/cm^2 the dominating mechanism is the injection of electrons into the p-region from the n^+ contact, which causes a saturation of electron traps and an increased lifetime in the p-type bulk. At higher currents an appreciable number of holes is injected from the p^+ region in order to neutralize the large number of injected electrons. This changeover from "single" to "double" injection produces changes in the potential distribution as well as changes in the region of bulk InSb from which the laser radiation is emitted.

Microwave amplification has been observed in bulk n-GaAs at room temperature. The samples were 50-μ-thick rectangular parallelepipeds with a mobility of about 5000 cm^2/V-sec

and a resistivity of approximately 100 ohm-cm. The frequency at which the maximum gain occurs agrees fairly well with the frequency at which Gunn oscillations occur in lower resistivity samples (~ 1 ohm-cm) of the same thickness, but the average applied electric field necessary for gain is about 7000 V/cm – about twice the value usually required for Gunn oscillations. The amplifier sample exhibits only a slight tendency toward current saturation with increasing voltage, whereas the oscillator sample begins to saturate even below the threshold of oscillation, and above threshold exhibits a range of current oscillation relatively independent of voltage. The existence of a positive resistance in the amplifier samples for average applied electric fields much higher than the field at which Gunn oscillation normally occurs suggests that the usual domain formation does not take place in these high-resistivity samples. This agrees with recent calculations of McCumber and Chynoweth who have found that for sufficiently small products of carrier concentration and sample length, the transferred electron effect leads to a negative conductance at frequencies near the reciprocal of the transit time, even though the DC solution displays only positive resistance.

II. LASER RESEARCH

Absolute (nonconvective) instabilities were not found from an analysis of the dispersion relation for Stokes and anti-Stokes modes in an infinite Raman-active medium. Absolute instabilities were found at zero frequency and second harmonic frequency of the laser, but inaccuracy of the dispersion relation at these frequencies makes dubious the physical realization of these instabilities, which have approximately millisecond growth times.

Calculations have been made of the focusing distance and intensification of a self-focused high-power laser beam. Self-focusing is due to an increase of the index of refraction of the propagation medium which is proportional to the local laser intensity. Computer solutions were obtained from an approximate nonlinear wave equation, which is valid when the intensity varies slowly over a wavelength, for an input beam with a plane wavefront and a Gaussian radial intensity profile. Typically, a 1-MW beam of 2-mm diameter would focus itself in about 50 cm of CS_2.

Dielectric breakdown in water produced by a focused Q-switched ruby laser resulted in an unexplained blue emission with wavelengths ranging from 3200 to 4500 Å, with a minimum at 3600 Å. The emission lasted 20 nsec or less, aside from a long but weak afterglow.

Fluorescence from limonene, possibly produced by multiple-photon absorption from a plane-polarized ruby laser beam, showed little depolarization due to Brownian rotation of the excited molecules during their radiative lifetime. Considering the value of the rotation relaxation time, one estimates that the radiative lifetime is less than 0.1 nsec, which is consistent with direct measurements of the fluorescent decay.

Analysis of the symmetry of molecular polarizability tensors shows that no incoherent emission of sum frequency light will arise from density fluctuations, unless the medium is optically active and unless the two primary frequencies are different; otherwise, the sum frequency emission may arise from orientation fluctuations.

Stimulated Stokes and anti-Stokes lines have been obtained in quartz using a high-power ruby laser as a source. As part of an investigation of the interference between Brillouin and

Raman effects in solids, details of the spectrum have been compared with spontaneous Raman scattering in quartz.

The Bose-Einstein distribution has been confirmed for the photoelectron counts from a photomultiplier which is illuminated by a gas laser operating just below threshold, as expected for a narrow-band Gaussian source when the counting interval is less than the inverse bandwidth of the light.

III. MATERIALS RESEARCH

Liquidus temperatures for the portions of the Hg-Te system from 3 to 25 and from 50 to 100 atomic-percent Te have been determined by differential thermal analysis. These results have been combined with liquidus points obtained earlier from partial pressure data to establish the Hg-Te phase diagram.

The pressures of mercury and selenium in the vapor over Hg-saturated, Se-saturated, and congruently subliming HgSe(c) between 450° and 800°C have been determined by measuring the optical absorption of the vapor. The pressure data have been used to obtain the first reported values for the standard Gibbs free energy of formation of HgSe(c).

At sufficiently low temperatures, the high-pressure phase of InTe can be retained at atmospheric pressure as a metastable phase. The heat evolved when this metastable phase is transformed at atmospheric pressure into the stable low-pressure form has been measured by both metal-solution and differential-scanning calorimetry. The heat of transformation is 0.44 kcal/g-atom.

High-pressure phases can also be retained at atmospheric pressure in $InSb(II)_{1-x}(2\,In)_x$ samples kept at sufficiently low temperatures. Qualitative results on the amount of heat liberated when such samples are transformed at atmospheric pressure indicate the existence of a high-pressure phase different in structure from either InSb(II) or indium. This phase lies between x = 0.17 and x = 0.60, but its exact composition has not been determined.

The temperature at which the phase of MnAs with B8 structure is transformed into the high-temperature B31 form has been measured as a function of hydrostatic pressure. The transition temperature decreases from 44°C at atmospheric pressure to −72°C at 4.5 kbar. The functional dependence of transition temperature on pressure indicates that the B31 phase is stable at all temperatures for pressures exceeding 4.5 kbar.

Electrical measurements have been made on Ti_2O_3 single crystals containing considerably less nitrogen, the principal impurity, than earlier samples. In contrast to previous results, both resistivity and Hall coefficient depend strongly on orientation. The magnetoresistance, $\Delta\rho/\rho_o$, is 2.5 at 4.2°K and 170 kG, compared with the previous maximum value of 0.12.

The concept of a Jahn-Teller theorem for narrow-band electrons has been formalized and applied to the interpretation of the localized vs collective character of outer d-electrons in a wide range of transition-metal compounds.

Wet chemical methods have been developed for determining cobalt and the rare earth element in the lanthanum and yttrium cobalt oxides, and for determining all three major components in iron-nickel-copper thin films.

IV. PHYSICS OF SOLIDS

A. Electronic Band Structure

The reflectivity measurements in ReO_3, which were previously reported in the range from 0.2 to 3.8 eV, have now been extended to 12 eV. Results indicate a Drude-like behavior in the energy region below 2 eV and peaks at 4.6 and 9.6 eV arising from interband transitions. A Kramers-Kronig analysis of the reflectivity has been used to obtain the real and imaginary parts of the dielectric constant, and a further separation of the dielectric constant components into free electron and interband contributions has been made.

Concurrently, a tight binding scheme is being used to investigate the electronic band structure of ReO_3. The energy levels have been found to separate into σ and π bonding and antibonding bands, and into a set of nonbonding π bands. Estimates of the various parameters are being made, using the augmented plane-wave method to calculate the energy values at the high symmetry points of the Brillouin zone. This calculation will be used to predict optical, magnetic, and transport properties.

The experimental investigation of the band structure of GaSe is continuing. A reduced effective mass $m^* = 0.14\,m$ and an energy gap $\mathcal{E}_g = 2.130$ eV have been obtained from more highly resolved oscillatory magnetoabsorption data at 1.5°K in the Faraday configuration. The data in the Voigt configuration are smaller in amplitude and more complex, suggesting that more than one transition is involved. In the zero-field data, three clearly defined exciton peaks have been resolved; these have been used to calculate a binding energy of 21 meV and a reduced effective mass $m^* = 0.17\,m$, which is consistent with the results of the magneto-optical data. Several models for GaSe which are consistent with this experimental data have been proposed.

GaSe is also being examined in the microwave region at 70 GHz in order to observe intraband cyclotron resonance. So far, a well-resolved magnetoabsorption peak corresponding to an effective mass $m^* = 0.02\,m$ and an $\omega\tau \sim 1.5$ has been observed, but only in one sample.

Another microwave resonance experiment, on p-type PbSe, is continuing. Marked structure has been obtained below 3 kG and identified with dielectric anomalies; this behavior is consistent with that predicted on the basis of a classical skin effect theory, using an infinite relaxation time and values of effective mass and anisotropy obtained from previous Shubnikov-de Haas measurements on the same sample.

A new approaeh to the tight-binding technique for phenomenologically obtaining the energy bands in solids has been developed. This method involves a Fourier expansion for the energy bands in k-space in which the symmetry of the lattice and the degeneracies of the bands at high symmetry points are included. The Fourier coefficients of the expansion are evaluated from experimentally observed parameters. This approach is being tested on the metal, aluminum, and the semimetal, antimony.

B. Hypersonic Waves in Solids

An electron-beam technique has been developed for the vapor deposition of piezoelectric semi-insulating CdS thin films on various substrates. By proper orientation of the electric field, either longitudinal or transverse hypersonic waves can be excited. Acoustically active

films have been deposited on metals, semiconductors, and insulators; pulse-echo techniques have been used to test the acoustical activity of a film. The range of frequency excitation in the longitudinal mode for active films varied from 12.4 MHz for thick films deposited on aluminum to 70 GHz for thin films deposited on a z-cut quartz rod.

C. Magnetism

The study of the magnetic properties of the spinels ACr_2X_4, where A is nonmagnetic zinc or cadmium and X is oxygen, sulfur, or selenium, is continuing. Magnetic measurements on $CdCr_2O_4$, an antiferromagnet with a Néel temperature $T_N = 9°K$, have been completed; $CdCr_2S_4$ has been found to be ferromagnetic with a Curie temperature $T_C = 86°K$. It has been found that in addition to the large dependence on lattice size for a given type of A-site ion, T_A, the asymptotic Curie temperature, in this entire series of compounds depends strongly on whether the A-site ion is zinc or cadmium. Since T_A is proportional to the sum of all magnetic exchange interactions, this indicates that the diamagnetic A-site cation significantly affects these interactions. Specifically, substituting zinc for cadmium tends to decrease the ferromagnetic nearest-neighbor interaction, or to increase the antiferromagnetic next-nearest-neighbor interaction, or both.

In order to resolve inconsistencies in $MnCr_2O_4$ between the nuclear magnetic resonance and neutron diffraction results for the manganese cone angle, these properties were reinvestigated. The new data are in general agreement with the earlier findings, but indicate that the Mn^{++} ions possess a reduced magnetic moment of about $4.3\mu_\beta$, rather than the previously assumed value of $5.0\mu_\beta$. However, while use of this reduced moment improves the agreement between the theoretical and experimental neutron diffraction patterns, the discrepancy with the nuclear magnetic resonance result remains.

An experimental study of the temperature variation of the spin wave dispersion relation $\epsilon_k = Dk^2 - Fk^4$ has indicated that for a 63% Ni-37% Fe film 6950 Å thick, both the quartic and the quadratic coefficients vary as $T^{5/2}$ up to 80°K and approximately as $T^{3/2}$ up to 298°K. A theoretical justification for the temperature dependence of D and F in the spin wave dispersion relation can be simply made by extending a model proposed by W. Marshall for treating a system of interacting spins which gave the $T^{5/2}$ dependence of D. Higher order terms occurring in D, as well as the temperature dependence of F, predict a $T^{5/2}$ dependence for F, a higher order $T^{7/2}$ term for D, and a relation between the three temperature coefficients of D and F.

An expression has been derived that relates the fluctuation scattering of light expected from a ferromagnet to the observed Faraday- or Kerr-effect coefficient and to the spin-spin correlation function. An estimate is made of the fluctuation scattering to be anticipated near the Curie temperature.

Experimental methods of observing zero sound modes in metals are considered. It is concluded that a mode characterized by a paramagnetic spin wave is likeliest to exist, and should most readily be observed in metals which show superconductivity. It is argued that these zero sound modes may exist in the superconducting state as well.

D. Quantum Transport Theory

A simple and general argument has been found for considering pseudomomentum for an ensemble of interacting phonons. It is shown that the anticipated selection rule on pseudomomentum holds for any process produced by phonon-phonon interaction.

The energy spectrum of a polaron has been considered in the region where its excitation energy is close to that of an optical phonon. Both a variational and weak coupling calculation, which are consistent with each other, have been performed. It is found that the dispersion relation in the weak coupling theory becomes flat as the polaron momentum approaches the value at which the polaron excitation energy and the optical phonon energy become equal.

A treatment has been formulated of the kinetic equations for a system of electrons under the action of arbitrary space- and time-varying fields and a random distribution of impurities. The results can be used to derive a Boltzmann equation for the system. Kinetic equations for other situations, including the presence of a quantizing magnetic field, can be readily obtained.

The interaction of photons with charged particles in a plasma modifies the dispersion relation for electromagnetic propagation in a well-known way. It is shown that this result can be obtained quite simply from quantized field theory, and that it arises because of the $\vec{A}^2$ term in the electromagnetic energy, averaged over the charged particles of the medium.

DOCUMENT CONTROL DATA – R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Lincoln Laboratory, M.I.T.

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP
None

3. REPORT TITLE
General Research Quarterly Technical Summary Report

4. OESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Quarterly Technical Summary for 1 August through 31 October 1965

5. AUTHOR(S) *(Last name, first name, initial)*
Frick, Frederick C. Dodd, Stephen H. Freedman, Jerome Hutzenlaub, John F.
Nedzel, V. Alexander Herlin, Melvin A. Weiss, Herbert G. McWhorter, Alan L.
Tannenwald, Peter E.

6. REPORT OATE
15 November 1965

7a. TOTAL NO. OF PAGES
76

7b. NO. OF REFS
19

8a. CONTRACT OR GRANT NO.
AF 19(628)-5167

b. PROJECT NO.
649L

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
General Research QTS
for 15 November 1965

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
ESD-TDR-65-505

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES
None

12. SPONSORING MILITARY ACTIVITY
Air Force Systems Command, USAF

13. ABSTRACT

This Quarterly Technical Summary covers the period from 1 August through 31 October 1965. 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 WOROS
data systems
digital computers
computer components
psychology
control research
radio physics
space surveillance
radar
microwave equipment
mechanical and structural engineering
solid state physics