D R A F T

HEADQUARTERS

The Signal School
Fort Monmouth, New Jersey

SIGNAL CORPS RESEARCH PROGRAM

FOREWARD

The close of World War II saw a change-over of Signal Corps technical effort from a short-term engineering type of activity to a longer-term research and development program. This compilation broadly indicates the scope of the RESEARCH phase of the Signal Corps post-war program, including work underway in the Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey and the contractual activity sponsored in industry, academic institutions and research foundations.

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August, 1949

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Introduction

The application of new scientific discoveries has brought on rapid and continuous changes in military materiel —— changes which radically alter the tactics and techniques of all the Arms and Services. As a result of World War II experience, it is now accepted that, in any future combat, victory will be directly associated with scientific superiority established during peacetime and concurrently applied to military devices which must be available immediately in event of sudden attack.

The Engineering and Technical Division of the Office of the Chief Signal Officer has certain assigned Department of Defense responsibilities pertaining to research on, and development of, equipments employed in communications, detection of aircraft and missiles, electronic countermeasures, meteorology, radiological instruments, photography and others. Supporting the engineering and development program, is an extensive research effort established with the view of continually providing additional scientific knowledge which can be applied in the improvement of existing equipment, techniques, or in providing the basic building blocks of knowledge from which entirely new devices will be constructed —— devices capable of military accomplishments, as yet undreamed of.

It is the purpose of this study to disclose, within the security limits established, the RESEARCH portion of the Signal Corps' technical program. The material to be presented will be drawn from work underway within the Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey and from contracts maintained by the Signal Corps with industry and academic institutions. A general discussion of Department of the Army research policy will also be included,

as well as a brief outline of how the Signal Corps coordinates its own technical activities with the other Services through the Research and Development Board.

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SECTION I - Policy on the Conduct of RESEARCH.

The following general principles governing the conduct of military research and development were established by the General Staff, Department of the Army:

(a) "Freedom of Direction in Basic Research. A farsighted and progressive research program for the armed services requires that the greatest possible freedom of action be given the scientists and engineers who carry it into execution. Only if research remains separate from production can the long-term studies and projects of research continue without being subordinated to the immediate needs of production and supply .....

(b) "Need for Research in the Army Program. Long-range technological progress is directly dependent upon the continuous flow of new scientific facts and knowledge derived from basic research. Therefore, a large proportion of the Army research and development program in peacetime must be devoted to basic and applied research ....

(c) "Free Exchange of Information. A wide and unrestricted exchange of scientific information is essential in order to provide the cross-fertilization of ideas which is essential to productive research. In general, contracts and reports involving basic research should remain unclassified ..... consistent with military security.....

(d) "Maximum Assistance from Civilian Science and Industry. The Department of the Army must utilize civilian talent, facilities and assistance to the maximum.....

(e) "Economy in the Operation of Military Facilities. Military research and development facilities will not be maintained and operated when commercial organizations, educational institutions and laboratories available to the Army offer comparable and dependable service to adequately meet the requirements of the Department of the Army.

(f) "Evaluation of Foreign Developments. In order to insure the superiority of United States Army materiel over that of foreign nations, there must be a continuing evaluation of foreign research and development activities, utilizing all available intelligence sources.

(g) "Need for Long-Range Planning. The results of research require a period of years to become evident and to be applied practically to military problems. The development of almost all the new weapons and devices employed in World War II resulted from research completed prior to the war. It cannot be expected that basic research which is initiated after hostilities began will be applied to the development and production of new items before a war comes to an end. Thus research and development planning, as well as other general staff planning which is affected thereby, must look much further ahead into the future if full advantage is to be derived from research in event of another war."

* * * *

SECTION II. Mission, facilities and personnel of the Signal Corps Engineering Laboratories.

In a broad scope the mission of the Signal Corps Engineering Laboratories may be summarized as follows:

> THE SIGNAL CORPS ENGINEERING LABORATORIES is an activity of Fort Monmouth, New Jersey, and is under the technical control of Engineering and Technical Division, Office of the Chief Signal Officer. The SCEL is responsible for research, and the development, design, and improvement of communication, radar, meteorological, and photographic equipments, related components, and special electronic devices for the U. S. Army and for other services when directed by the Secretary of Defense. This responsibility includes the following:
>
> a. Research pertaining to, and the development of, equipment to the point of standardization.
>
> b. Research pertaining to, and the development of, components to the point of standardization.
>
> c. Preparation of specifications, drawings, and associated procurement data for issue to procurement districts for quantity procurement.
>
> d. Pilot run inspection of such equipments in production.
>
> e. Establishment of procedures and methods, and determination of the requirements for test, maintenance, and repair of equipment in the field.
>
> f. Preparation and issue of necessary field modification instructions and revised procurement data to eliminate, in the field and in current or future production, technical difficulties, equipment failures, and other defects noted during production or during use in the field.
>
> g. Qualification testing of components submitted by the Armed Services Electro-Standards Agency.
>
> The SCEL consists of the Commanding General; Deputy Commander; a staff consisting of the Director of Research, the Director of Engineering, and the Control Officer; four operating divisions, namely, Research Division, Engineering Division, Administrative Division, and Procurement-Maintenance Engineering Division; three research and development laboratories, namely, Squier Signal Laboratory, Evans Signal Laboratory, and Coles Signal Laboratory; and the SCEL Development Detachment. Further detailed breakdown is shown in Fig. 1.

SIGNAL CORPS ENGINEERING LABORATORIES

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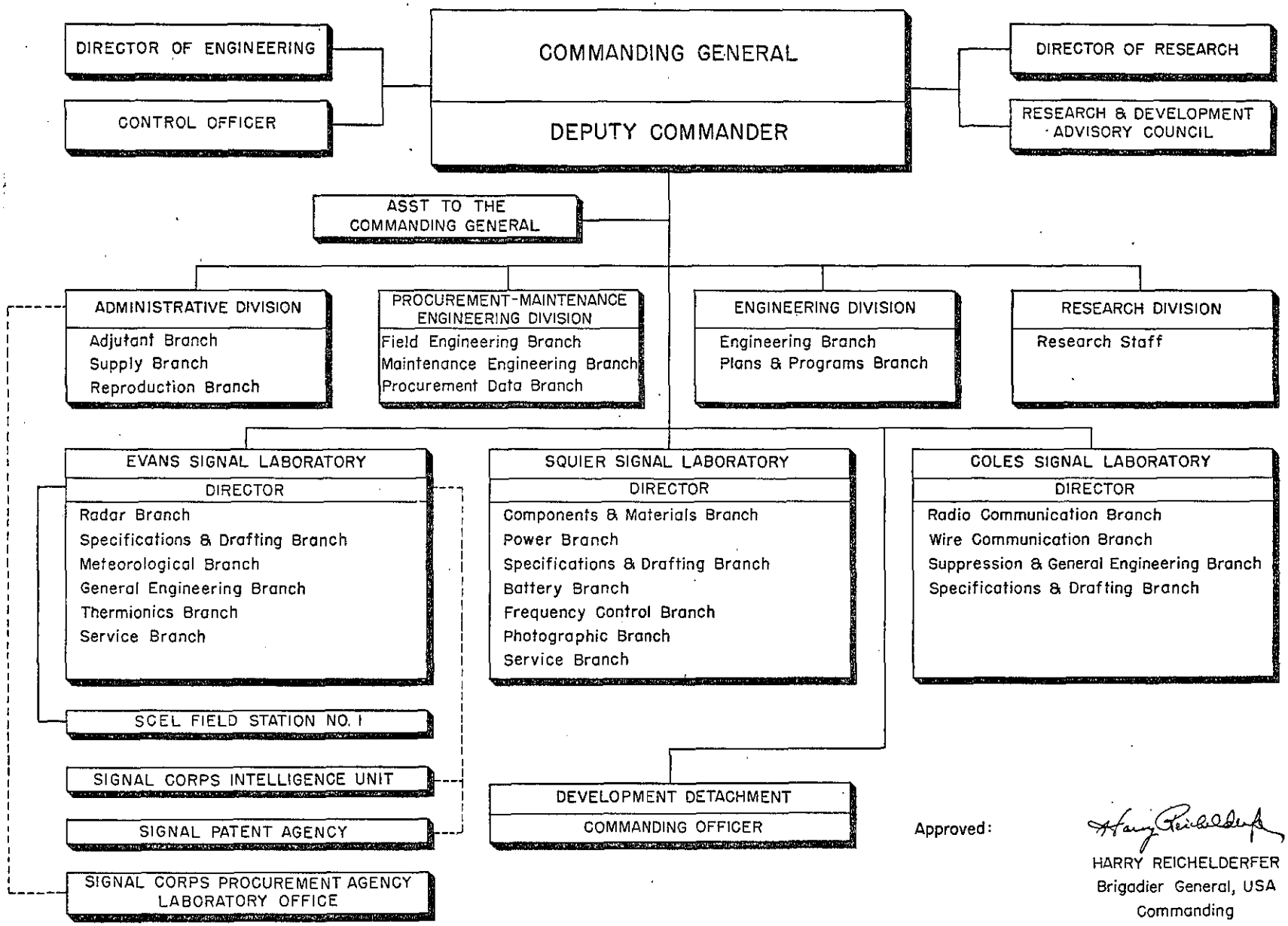

Approved:

HARRY REICHELDERFER
Brigadier General, USA
Commanding

FIGURE 1

The Laboratories are staffed with a total personnel complement of 80 officers, 250 enlisted men, and 2600 civilians. Out of the 2600 Civil Service employees, almost 1000 are classified as professional scientists or engineers; 250 as sub-professional; 700 as clerical; and 650 as ungraded. Of the total staff, approximately 20% are engaged, either directly in, or in a coordination or supervisory capacity of, the research which constitutes the material for this writing.

SECTION III. Broad aspects of the program.

Fig. 2 portrays the distribution of research effort as a function of categories, within the Signal Corps. The fields of effort are, for the most part, referenced against engineering terminology applicable to end item equipments for which the Signal Corps has full or partial responsibility within the Department of the Army or the DEPARTMENT of Defense such as: radio communications; telephone, telegraph and other wire systems; radiological instruments; photographic developments; detection projects involving sound or electromagnetic waves; electron tubes; facsimile and television; data transmission; aids to navigation; countermeasures against radio and radar systems; production of power by generators, primary and secondary batteries and thermopiles; meteorological equipment; electronic components such as crystals, resistors, condensers and numerous others. Development programs on devices as indicated above proceed continuously on the basis of the existing art. Related research, however, is also continuously underway extending the frontiers of knowledge with the realization that from many of the discoveries made, important applications will follow - - - frequently unpredictable, but as the history of science has so often proven - - - inevitably following. Research of this latter type may perhaps better be catagorized as being in the field of

DISTRIBUTION OF RESEARCH EFFORT

SIGNAL CORPS ENGINEERING LABORATORIES
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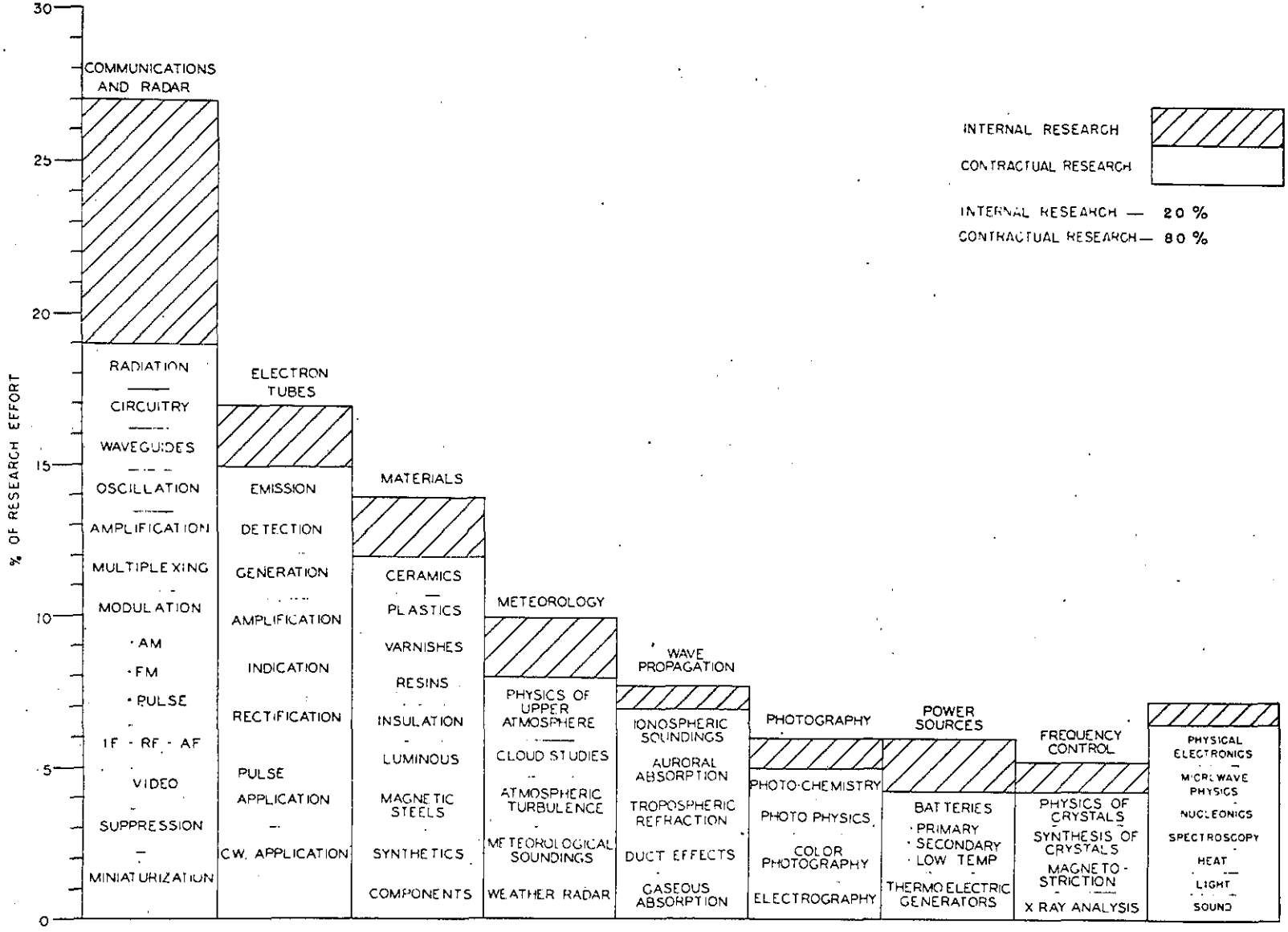

FIGURE 2

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magnetism and electricity, electron ballistics, microwaves, circuity, elementary particles and their interaction, particle accelerators, solid state, deterioration prevention, electro-chemistry, thermo-chemistry, polymers, mechanics, applied mathematics, computing devices, atmospheric physics, propagation, radiation and heat, acoustics, power generators, biophysics and others. A listing of such projects underway within the Signal Corps Engineering Laboratories is given in Table I following:

TABLE I

LIST OF INTERNAL RESEARCH PROJECTS

Communications & Radar

1. Calculation and Measurement of Radar Echoing Area Characteristics (Back Scattering Coefficient)
   a. Correlation of Measured Results with Theory.
   b. Study of Accuracy of Measuring Techniques.
2. Investigation of Space, Polarization and Frequency Diversity Reception.
3. Investigation of Various Skywave Radio Communications for Multichannel Teletype and Voice Communication.
4. Investigation of High and Low Level Single Sideband Transmission.
5. Model Antenna Studies
   a. Equipment and Instrumentation
   b. Model Earth Materials
   c. Theoretical Considerations
6. Application of Short Pulses to Transmitter for Timing Purposes
7. Multipath Transmission Simulator
8. High Frequency Transmission Diversity
9. Facsimile Research (Multipath Reception)
10. Mathematical & Experimental Determination of Relations Between Speech and Crosstalk Ratios per Voice Channel.
11. Theoretical Study of 2 and 4 Terminal Linear Networks.
12. Dial Calibration and Stability of Variable Frequency Oscillators.
13. Research on Miniature Filters

List of Internal Research Projects (cont'd)
Communications & Radar (cont'd)

14. Study of Telemetering Methods
15. Weather Radar Investigations.
16. Theoretical Investigations of Statistical Communications Methods

Electron Tubes

1. Pulsed Optical Spectra.
2. Tube Design and Research
   a. Electron Beam Interactions, Electron Deflection
   b. Fluorescence of Cathodes
   c. Emission of Cathodes
   d. Deflection, Focusing, Defocusing
   e. Multiple Beams, Orbital Beams, Helical Beams, Disc Beams, Hollow Beams
3. Hydrogen Tracer Studies
4. Tungsten Studies
5. Study of Basic Magnetron Phenomena
6. Research on Transistors
7. Secondary Electron Emission From Insulators
8. TR and ATR Tubes
9. Klystrons and Beam Modulation Tubes
10. Mathematical Treatment of Deflection Defocusing in Cathode Ray Tubes

Materials

1. Investigation of Magnetic Materials with Rectangular Hysteresis Loop
2. Dielectric, Piezoelectric and Electro-strictive Materials and Phenomena
   a. Lattice Parameters of Barium Titanate
   b. Optical Properties of Barium Titanate
   c. Polarization and Barkhausen Effects in Barium Titanate
   d. Polycrystalline Barium Titanate
   e. The Chemical Bond in Synthetic Aluminum Phosphate
   f. Optical Properties of Al_2O_3 Crystals, Electrolytically Produced
   g. Characteristics of Pinite for Possible Dielectric Applications.
   h. Structural Characteristics of Basic Lead Silicate
   i. Relation Between the Composition, Crystallization History and Physical Properties of Mica
   j. Ferro-Electric Barium Titanate Single Crystal Growth
3. Techniques & Instruments for Materials Research
   a. Electron Microscopy
   b. Electron Diffraction
   c. Special Techniques in Spectrochemical Analysis
   d. Investigation of Differential Thermal and Mass Analysis Techniques and Equipments

List of Internal Research Projects (cont'd)
Communications & Radar (cont'd)

e. Automatic Interferometry by Photoelectric Pickup
f. Vacuum Dilatometry at Low Temperatures
g. Quantitative Spectrochemical Analysis; Visual Comparison Densitometry
h. Methods of Photometric Calibration of Photographic Emulsions
i. An Automatically Operated Spectrograph
j. Recording Microphotometer
k. Particle Size Studies Turbidimetry and Sieving
l. Surface Area Measurements by Gas Adsorption

4. Electrochemical Materials and Phenomena
   a. Structural Characteristics of Carbonyl Nickel Powders
   b. Structural Characteristics of Carbon Blacks
   c. Structural Characteristics of Natural and Synthetic Manganese Dioxide
   d. Surface Protection
   e. Electrode Potentials of Strain for Metals
5. Semi-Conductor Materials and Phenomena
   a. A Study of the Barrier Layer
   b. Time Lag Phenomena in the Selenium Rectifier
   c. The Surface Resistance of Selenium as a Function of the Gas Which is Absorbed

Meteorology

1. Lower Atmosphere
   a. Time and Space Variation of Meteorological Data
   b. Liquid Water Content of Clouds
   c. Nature and Behavior of Freezing Nuclei
2. Ozonosphere Investigations
   a. Temperature and Wind Structure to 150,000 Ft.
   b. Pressure Measurements
   c. Balloons for High Altitude Flights
3. A Correlation Between Electrical Charge Centers and Turbulence in Thunderstorms
4. Meteorological Sounding Without Auxiliary Flight Equipment

Propagation

1. Ionospheric Propagation Research, and Low And Very Low Frequency Research In Polar Regions
2. Tropospheric Radio Propagation
3. Studies in Very Long Range Radio Propagation
4. Propagation Studies Directly Applicable to Signal Corps Communications Equipment

List of Internal Research Projects (cont'd)

Photography

1. Photo Optics
   a. Lens-Film Resolving Power
   b. Two Mirror Oblique Reflecting System
   c. Image Motion Compensation With a Rotating Prism
2. Photochemistry
   a. Ion Exchange
   b. Processing of Color Film
   c. Diazosensitization
   d. Acclimatized Silver Halide Film
   e. Black & White Film Processing
   f. Sensitometry
3. Photo Mechanics
   a. Shutter Techniques
4. Non-Conventional Photography
   a. Electrostatic Electrography
   b. Phosphorography

Power Sources

1. Investigation of Physical and Chemical Properties of Manganese Dioxide
   a. Electron Microscope, X-Ray Diffraction and Spectrographic Studies
   b. Chemical Analysis
   c. Fabrication of Cells
2. Investigation of Manganese As Anodic Material
3. Investigation of New Electrochemical Systems
4. Investigation of Battery Components for Low Temperature Operation
   a. Electrolyte Formulation
   b. Geometrical Configuration
   c. Physical & Chemical Construction of Cell
5. Study of Nickel Cadmium Electrodes
6. Thermoelectric Generation

Frequency Control

1. Synthesis of Crystals
   a. Aluminum Phosphate
   b. Aluminum Arsenate
   c. Scintillation Crystals
2. VHF Crystals
   a. Fundamental Mode Crystals
   b. Overtone Crystals

List of Internal Research Projects (cont'd)
Frequency Control (cont'd

3. Instrumentation
   a. Mode Analyzer
   b. Impedance Measuring Equipment
4. Low Frequency Crystals
   a. New Crystal Cuts
   b. Bar Crystals
5. Microwave Frequency Control and Measurement
6. Aging of Crystals

Sound

1. Ultrasonics
   a. Extended Frequency Range Recording System
   b. Ultrasonic Generation

Nucleonics

1. Scintillation Crystal Detectors
   a. Scintillation Counters
   b. Cadmium Sulfide Crystals
   c. Coincidence Measurements

Augmenting the work shown in Table I, and in many instances being a cooperative part thereof, is the even more extensive research program being carried on for the Signal Corps through contracts with industry, academic institutions and research foundations. This portion of the activity is dispersed among (somewhat over 100) research contracts, the coordination of which is one of the major tasks of the Laboratories. The breakdown of contractural research projects is shown in Table II, in which, it should be understood, ~~that~~ the items listed do not necessarily represent equal effort. In one instance the project may represent the effort of a lone investigator, or again it may represent a large-scale effort, as for example, from the staff of the Research Laboratory of Electronics, MIT, where over 200 scientists are aggressively attacking many electronic problems through support given in a Signal Corps contract which is equally financed by the three Services.

TABLE II

EXTERNAL RESEARCH PROJECTS

Project	Contractor
Electron Tubes	
Panel on Electron Tubes	New York University
Thermionic Emission	Battelle
Voltage Regulator Studies	Battelle
Tube and Circuit Laboratory	University of Michigan
H. P. CW Magnetron	General Electric
Oxide-Coated Cathodes	Westinghouse
Cold Cathode Tubes	Bendix
Semi-Conductors	Purdue
TR Tube Studies	Sylvania
Filamentary Alloys	Sylvania
Frequency Control	
Crystal Studies	Wesleyan
Crystals	Colorado A&M.
Quartz Oscillator Plates	Tufts
Aluminum Phosphate Crystals	Univ of Minnesota
Synthetic Quarts	Antioch
Synthetic Quarts	Brush Development Co
Synthetic Tourmaline	Baird Associates
Crystal Chemical Relations	Washken
Stroboscopic X-Ray Diffraction	Auburn Research Found
High-Frequency Crystal Circuitry	Georgia Tech
Oscillator Circuit Theory	University of Illinois
Magnetostriction Studies	Armour
Detwinning Quarts	Bureau of Standards
Meteorology	
Sferics Studies	University of Florida
Thunderstorm Studies	University of New Mexico
Humidity Elements	Arthur D. Little
Aneroid Capsules	Battelle
Project Cirrus	General Electric Co
Upper Atmosphere Research	University of Michigan
High-Altitude Balloons	Molded Latex
Computer	Stibitz
Crystals as Meteorological Elements	Armour
Wave Propagation	
Ionospheric Stations	CRPL (BuStandards)
Arctic Tropospheric Propagation	University of Alaska
Arctic Ionospheric Propagation	CRPL (BuStandards)
Field Intensity Monitoring	University of Alaska
Lower Ionospheric Propagation Studies	Cornell

Table II - External Research Projects (Contd)

Project	Contractor
Radar and Communications	
Carrier Telephone Cable	Okonite
Communications Integration Study	Western Electric
On-Spot Survey of Communications at WSPG	Langedin Co
On-Spot Survey of Communications between Anchorage and Fairbanks, Alaska	Western Electric
Conducting Alloys for Wire and Cable	Battelle
Television Techniques	DuMont Laboratories
Propagation Studies in Television Banks	DuMont Laboratories
Diversity Reception	Washington University
Radio Teletype Multiplex	RCA
90° Phase Differential Systems	Georgia Tech
High-Frequency Communications	Crosby Laboratories
Precision Dial	Servo Corp
Modulation Methods	Yale University
Circular Polarized Antennas	Federal Telecommunications
Stabilized Platform	Polytech Inst Brooklyn
Leakage and Radiation Tests	Rensselaer Polytech Inst
Homing Instinct of Pigeons	Pennsylvania State
Weather Radar	MIT
Dielectric Lens and Waveguides	Northwestern
Dielectric Antennas	Ohio State
Lens Antennas	Sperry Gyroscope Co
Corrugated or Ridge Antennas	Stanford Research Found
Power Sources	
Electrolytic Manganese Dioxide	Georgia Tech
Low-Temperature Battery	Ohio State
Magnesium Anodic Materials	Dow Chemical Co
Low-Temperature Batteries	Olin Industries
Storage Battery Materials	Eagle-Picher
Thermoelectric Generators	Franklin Institute
Reduction of Vibration Studies	Illinois Tech
Photography	
Field Color Film	Houston Corp
Electrography	Haloid Corp
Climatic Film Studies	Armour
Phosphorography	Polytech Inst Brooklyn
Photo Conductivity Compounds	Polytech Inst Brooklyn
Ion Exchange	Polytech Inst Brooklyn
Lens Resolution	University of Rochester

Table II - External Research Projects (Contd.)

Project	Contractor
Materials	
Plastics	Princeton University
Ceramics	Rutgers University
Lightweight Metals	Lehigh University
One-Coat Paint	New York University
Synthetic Mica	Colorado School Mines
Non-Corrosive Soldering Flux	Foster D. Snell
Magnetic Steels	Allegheny Ludlum
Insulation Research	MIT
Ultra-Thin Film	Bakco Research Labs
Ionization Chamber Insulation Materials	Federal Telecommunications
Insulating Materials	Polaroid
Dielectric Film	Sprague
Plating Waveguides	Armour
Waveguide Mode Filters	Polytech R&D Co
Pulse Transformer Studies	Stanford University
Low-Temperature Solution Study	Kentucky Research Found
Dry Disc Rectifiers	Louisiana State
Defect Lattice Structure	Polytech Inst Brooklyn
Magneto-Chemistry of Hydrous Oxides	Northwestern University
Measurement of Total Surface Areas	Georgia Tech
Barium Titanate Crystals	Harshaw Chemical Co
Emission Spectrography	Applied Research Labs
Luminous Materials	Whitehouse Products
Others	
Research Laboratory of Electronics	MIT
Cruft Laboratory	Harvard
Radiation Laboratory	Columbia
Electronics Research Laboratory	Stanford
IR Image Tube	Thos. L. Lee
Crystal Detectors	Princeton University
Atmospheric Physics	Pennsylvania State
Performance of Pulsed Systems	Sperry Gyroscope Co
Physics of crystals	New York University
Crystal Radiation Detectors	Naval Research Laboratory

SECTION IV - RESEARCH IN COMMUNICATIONS

(1) Introduction: The primary mission of the Signal Corps is the development of an integrated communication system for the Army Field Forces based on reported or foreseen needs of the eventual using organization. The system must provide the commander with constantly available, reliable and fast communications to all components of his fighting team, from any location within his command, by utilizing radio or wire channels or any combination thereof. The provision for such a service necessitates an engineered communication system that is completely integrated from the highest to lowest echelon as well as laterally. Since wire and radio represent the principle means of signal communication, the problem resolves itself into one of developing a signal system in which the respective advantages of the wire and radio systems are combined to provide the highest degree of communication circuit flexibility. It must provide not only for the vast amount of common and administrative traffic but also for the transmission of early warning and tracking radar data, telemetering data, television, facsimile, and all the other types of information necessary for modern mechanized remote control warfare.

The statements above express a combined engineering - military point of view with respect to communications but do not delineate research involved, or indicate the direction it should take to most effectively accomplish the desired military objectives. In its broadest scope it will involve many areas of engineering; it implies contributions arising throughout the entire field of the physical sciences and, in many cases, integration with biological studies so as to bring out the common elements in the functioning of inter-

mediary machines in combination with human sense organs, the nervous system and the brain.

In a purely physical sense, research in communications may be considered to enjoin four major categories of effort.

(a) Physical aspects pertaining to the conception, understanding, design, and construction of new types of terminal equipment based upon existing knowledge or upon entirely new approaches applicable to the transmission of information.

(b) Investigations pertaining to the physical behavior of the transmission media.

(c) Physical aspects pertaining to the conception, understanding, design, and construction of new components and materials contributing to the advancement of (a) and (b) above.

(d) Basic research not necessarily directed toward solution of problems falling within (a), (b), or (c), but which may later be found applicable.

Since, for the most part, items (b), (c) and (d) above pertain also to many other fields of application, discussion within this Section will be limited to (a) and a portion of (b), leaving the remainder for later sections in which a composite effort will be shown.

(2) Transmission of Information: The thoughts on transmission of information immediately following were largely taken from a contractual report prepared by Professor Fano of MIT.....The objective of almost all electrical communications systems has been, up to now, to eliminate distance in some form of human activity or relationship with men. Telegraph, telephone, television, teletype, telecontrol, telemetering, facsimile are examples of such communications systems. Communication is basically any form of transmission of information regardless of the distance between the transmitter and receiver. In a broader sense, the field of communication includes any handling

combining, comparing or employing of information, since such processes involve and are intimately connected with the transmission of such information. Thinking itself, in fact, involves a natural communication system of a complexity far beyond that conceivable for any man-made system * * * Early studies made by Norbert Wiener of MIT led him to the realization that all communication problems are fundamentally of a statistical nature and must be handled accordingly. He argued that the signal to be transmitted in a communication system can never be considered as a known function of time, because if it were a priori known, it could not convey any new information and therefore would not need to be transmitted. On the other hand what can be known a priori about a signal to be transmitted is its statistical character --- that is, for instance, the probability distribution of its amplitude. In addition, it is equally clear, that noise, which plays such an important part in communication problems, can be described only in statistical terms. It follows that all communication problems are inherently statistical in nature. The statistical theory of optimum prediction and filtering developed by Wiener led further to the realization of the need for a basic and general criterion for judging the quality of communications systems. The search for a more appropriate criterion leads naturally to the question - what is the operation that a communication system must perform? If we take as an example a telegraph system, it might seem at first obvious that such a system must reproduce at the output each and every letter of the input message in the proper order. We may observe, however, that if one letter is received incorrectly, the word containing it is still understandable, in most cases, and so, of course, is the whole message. On the

other hand, the incorrect transmission of a digit in a number would make the received message incorrect * * * It appears therefore, that the transmission of the information conveyed by a written message is what we wish to obtain and that this is not necessarily equivalent to the transmission of all the letters contained in the written message. More precisely, it appears that the different symbols, letters or figures contained in a written message do not contribute equally to the transmission of information - - - so much so, that some of them may be considered completely unnecessary. Similar conclusions are reached by considering other types of communications systems * * * These considerations are relevant to another problem with which communication engineers are becoming more and more concerned, namely that of bandwidth reduction. It is clear that if different parts of a message are not equally important, some savings in bandwidth might be possible by providing transmission facilities which are proportional to the importance of these different parts. The bandwidth problem, in turn is intimately connected with the noise-reduction problem. In fact, all the different types of modulation developed for the purpose of noise and interference reduction requires a bandwidth wider than that required by amplitude modulation. This method of paying for an improved signal-to-noise ratio with an increased bandwidth appears to be the result of some fundamental limitation which, however, the conventional approach to communication problems has failed to clarify * * * Application of the statistical communications concepts preceding, for the most part, still remain for the future. It is however the opinion of many workers in the field that the communications art is today at a major turning point in its development. The Signal Corps research and development will increasingly reflect the influence of these new, interesting, and highly important concepts.

(3) Modulation and Multiplexing: Investigations have been conducted in the field of modulation and multiplexing covering an evaluation of all the factors which govern the characteristics of the intelligence channel for all known types of modulation and to provide a method of determining the type of modulation most suitable for the transmission of various types of intelligence from the viewpoint of bandwidth economy, low noise and distortion, efficiency and other such parameters. Work has included factors involved in forward area, intermediate area, and rear area radio relay equipment. Consideration has been given to the problems of a 96-telephone channel system operating at 2000 mc. It has been found that crosstalk requirements of the system could not be met by demodulation to intelligence bandwidth at each relay station, even with the use of negative RF feedback. Work also is including the development of broadband component for the 1500-2000 mc range * * * As another phase of the general problem, a theoretical analysis of crosstalk in critically coupled intermediate frequency amplifier was made using both frequency and phase modulated signals, results of which study were later verified experimentally. As an interesting side-line, it appears that simulation of multi-channel speech modulation may be had by random noise modulation which, if proven experimentally, may lead to a simple means of measuring performance characteristics of radio relay equipment * * * Investigations are also underway with the objective of analyzing the factors which limit the bandwidth of an intelligence channel, and which may be transmitted by pulse modulation techniques. The faithful transmission of intelligence by pulse modulation requires that the signal to be transmitted be sampled at a rate equal to at least twice the highest frequency contained in the signal * * * In double tuned oscillators,

the admittance characteristics of certain multiple excited, externally modulated, nonlinear elements have been investigated. Heterodyne modulation of a double-tuned oscillator has been observed to create a voltage spectrum containing, as a rule, only a few voltages of appreciable magnitude. Since the frequency differences in this spectrum are observed to be commensurate with the modulation frequencies impressed, it is possible to approximate the excitation spectrum and hence find the type of admittance variation occuring in the oscillator. The interference characteristics of pulse-time modulation have been analyzed mathematically and experimentally; particular forms examined are pulse-duration and pulse-position modulation. Both two-station and two-path interference were considered. The theoretical analysis consists, first of a quantitative formulation of the defects imparted on the pulses by the interference; second of a detailed evaluation of the resulting disturbance in the receiver output, based on auto-correlation analysis. The experimental investigation was directed at close duplication of the various conditions encountered in practice: two station interference was produced by separate transmitters; while two path interference was simulated by means of a mercury delay line. Two-station interference is characterized by a virtually complete predominance of the stronger of the two signals, and by noise of more or less random character. Under some conditions, the noise is sufficiently weak to permit fair reception when the two signal levels differ by less than 1 db, while other situations permit acceptable reception only with level difference larger than 6 db. These general statements apply to both pulse-duration and pulse-position modulation, simplex and multiplex. Two path interference in the case of simplex pulse-duration modulation is characterized

by the linear superposition of the two identical but time-staggered modulating signals. All interference effects, both in theory and in practice were found to be directly dependent on the all-important slicing practice * * * A study is underway to evaluate the comparative merits of a number of communications method by skywave propagation for military application in the 1.5 to 30 mc frequency range. Particularly the work is directed toward evaluating the relative desirability of various modulation systems with respect to multitone printer and subcarrier facsimile operation, since theoretical considerations suggest that the use of phase-modulation indicate the possibility of somewhat greater harmonic and cross-modulation distortion than is present with amplitude modulation. Transmissions from Red Bank, New Jersey to Mineola, Long Island, New York were started in May 1949. First tests use available phase-modulation equipment and involve only the transmission of a single tone on phase-modulation and on amplitude modulation with the view of obtaining initially the relative degrees of distortion and other effects involved. Later, more complex combinations of tones will be applied using a specially developed phase-modulation exciter.

(4) Multipath Transmission: Equipment has been designed to simulate the effects of multipath transmission on various types of signals in the high-frequency range under varying controlled conditions. Extensive tests were made by comparing the results achieved on a series of voice tests over an actual multipath radio circuit with the same series of tests using the simulator. Agreement was excellent * * * An experiment is underway setting up a simple two-path system for the study of ghosts produced by reflection of television signals off buildings and other objects in the path of the transmitter. The study will be made both under AM and FM conditions * * *

An investigation of the feasibility and applicability to military communication requirements of transmitter diversity systems was undertaken cooperatively with RCA following a demonstration of a system RCA has in operation between New York and Bolinas, California. At Bolinas message signals were used to modulate two 1-KW transmitters, each connected to its own rhombic antenna spaced approximately 1500 feet apart. At Red Bank, New Jersey a noticeable improvement of approximately 3:1 was in evidence using the diversity system against the single transmitter. The system has a number of military applications where insufficient ground for an antenna park exists at one end of the circuit * * * In a link between Red Bank, New Jersey and Weldon Spring, Missouri experimentation continues on the characteristics of diversity receiving systems consisting of space diversity, polarization diversity and the frequency diversity in the range of 1.5 to 30 megacycles, particular attention being directed towards learning methods and techniques for reducing fading conditions * * * In connection with multipath transmission, experiments have also been set up to determine the degree of crosstalk introduced in multichannel radio communication circuits by multipath transmission. Twelve carrier channels were connected to a radio transmitter at the Earle, New Jersey test site and displayed on the screen of a cathode-ray oscilloscope after reception at Mineola, Long Island. That multipath transmission affects a few channels at a time was quite evident. Experimental changes are now underway so that, by means of electronic switching circuits, the upper and lower sideband contributions can be viewed separately. * * * An investigation pertaining to radio-facsimile was conducted over an ionospheric path selected to favor multipath transmission. Modulations ~~were~~ employed were carrier and sub-carrier frequency modulation applied to an amplitude modulation transmitter and to a phase modulation

transmitter. Amplitude modulation signals were received on a conventional amplitude modulation receiver and also on an exalted carrier circuit. Phase modulated signals were received on both an exalted modulation carrier circuit and by a frequency modulation receiver followed by a deemphasis circuit. The purpose of the test was to compare the performance of these types of modulation under multipath transmission conditions. It was found that the carrier shift gave the best results, followed closely by those obtained with amplitude modulation received on an exalted carrier circuit. This test is being repeated with the transmission taking place through a multipath transmission simulation instead of over an actual ionospheric circuit. This permits the same comparison of modulation methods under controlled conditions, making it a more severe test as well as providing an opportunity to obtain more definite information as to the capabilities of the various types of transmitting and receiving circuits.

(5) Direction Finding: The most widely recognized of the propagational factors which affect direction finding is the variability of the received signal's polarization characteristics. Even with the most carefully designed space collector direction finders, cyclic fading of signal strength and wandering of the indicated bearings are usually present, and these factors are almost invariably associated with changing polarization. The errors are usually largest when the horizontally polarized component predominates over the vertically polarized component and, for this reason it has become customary to regard the energy contained in the horizontally polarized components of a down-coming received wave as inherently troublesome and "unwanted". Recent investigations have shown that the D/F errors and difficulties known

as "polarization effects" are, in reality, due to an instrument inadequacy rather than to a fundamental limitation imposed by propagation phenomena. This inadequacy can be corrected, and the "polarization effect" errors can be largely eliminated if the simple vertical collector elements possess the proper characteristics. *** As part of the program indicated by the above, an investigation is underway toward study of antenna collector elements with the following general characteristics: (1) Omni-directional response in the horizontal plane; (2) Efficient response to elliptically or circularly polarized waves of a particular arbitrary sense of rotation; (3) Response to linearly polarized waves having any arbitrary orientation of the electric vector perpendicular to the direction of propagation; (4) Reasonably uniform impedance over a broadband of frequencies; and (5) Single ended output at frequencies below approximately 60 cm where it is physically impractical to employ elevated balanced antennas. Further study in the field of direction finders concerns propagation phenomena in the frequency range of 1 to 30 mc. The study consists primarily of the correlation existing between various characteristics of arriving radio waves, such as the angle of incidence, type of polarization, etc., and the accuracy to which the horizontal angle of arrival can be measured by phase comparison type of direction finders. An investigation is also being made of practical methods of determining the various characteristics of radio waves which influence direction finding accuracy as well as utilizing the accuracy of such systems.

(6) Investigations Pertaining to Frequency Modulation: One investigation recently completed concerned IF filters particularly with respect to improved selectivity and stability with the hope that results would lead to units adequate for the replacement of the standard IF systems in present FM communications radio receivers. Characteristics derived were bandpass and selectivity

with stability such that no realignment of circuits is required in the field lending itself to making channel spacings of 50 kc available instead of the present 100 kc spacing. Crystal filters with quartz elements appeared to be an obvious solution but proved unsatisfactory. A second possible solution appears through the use of a double IF system with two complex L-C filter networks, one at 185 kc for selectivity and one at 4.3 mc for spurious response rejection. It is felt that such a complex filter version of the double IF system will make the 50 kc channel spacing feasible

in present HF and VHF ranges provided that improvements are made in the present system frequency stability * * * Another investigation underway concerns the effect of noise on the reception of a frequency modulated carrier, and to compare the results with the corresponding amplitude modulated cases. Present effort is mainly directed toward the explicit determination in a useful form of the probability densities for impulsive noise, where the number of elementary effects per second is sufficiently small so that there is comparatively little overlapping of the impulses. Once this probability distribution has been determined, it will be possible to extend the theory of FM reception in noise to include the important practical cases of static, ignition, noise, and other types of impulsive interference. It is also planned to apply these results to AM reception. Studies will also include waveform, power and spectra of signal and noise in FM transmission.

(7) Military Television Techniques: An extensive program has been established with the view of exploiting all military applications of television systems, components, and techniques. Because of great commercial research emphasis in the strictly technical phases of television, the major effort will be directed more toward discovery of applications of the existing art, rather than heavily embark on scientific investigations presently covered in industrial research programs. Particularly close coordination with Army Field Forces is contemplated in the operational research phases of this investigation.

(8) Wire and Cable Research: A number of metalurgical investigations have been directed toward finding improved alloys for wires and cables. Field tests for the more promising are contemplated * * * In the same field, general studies are being made covering types of transmission circuits, limiting factors in transmission, conducting, insulating and protective materials,

and physical and electrical characteristics of carrier cables suitable for military use with a frequency range of 10 kc to 1.5 mc. Tin-copper braid followed by two steel tapes wrapped in opposite directions and covered by a braid of the highest conductivity consistent with sufficient tensile strength appear to be the best design presently available. Tests covering the range 10 kc to 4 mc indicate the shielding can be greatly improved over that which is possible with three or four copper braids. At frequencies above 1 mc the tests indicate a need for reduced leakage of the electromagnetic field through the interstices in the shielding, which accounts for most of the loss at the higher frequencies. Attention will be focussed during the next few months on such points as connector design, method of attaching the shields to the connector in a manner that will give tensile strength of at least 600 lbs., and bonding the insulating material which will be applied both to the connector itself and to the cable jacket.

SECTION V - RESEARCH IN RADAR

(1) Introduction: The development of radar is surely one of the finest examples of the mobilization of scientific effort for accomplishment of an urgent military objective created by the invention of the airplane and later developments in the field of missiles. Branching out from its pre-war start as a method for locating aircraft primarily for warning and fire-control purposes, radar has expanded into the fields of navigation, weather prediction, mapping and surveying, and numbrous other uses which have civilian as well as military application * * * as in communications, radar's growth stems from many contributions in various engineering fields, the physical sciences, components, materials, etc. Advancement in radar is thus the story of achievement in complex circuity, microwave techniques, propagation, electron tubes,

other specialized purposes, such as chemical and radiological warfare * * * Prior to World War II meteorology was generally confined to the measurement of certain basic meteorological parameters; i.e., temperature, pressure, humidity. Wind speed and direction, both on the surface and aloft as well as cloud heights, were also measured. The techniques were not in keeping with the accuracy desired and the application of electronics to the meteorological field was somewhat elementary * * * During the war the need for more accurate measurements was quickly realized and electronic techniques were introduced with immediate and far-reaching improvements. The Signal Corps is now on the threshold of a new era in both research and in the development of instruments and equipment for the gathering of meteorological data. The utilization of radar and radio direction finding techniques have opened new vistas in the determination of what weather is and where. New and improved methods of measuring air temperature, pressure, and humidity have been and are being developed to permit routine soundings of the upper air to altitudes of 100,000 feet and higher, providing an accurate third dimension to meteorological observations. Higher and faster rising balloons have been and are being developed to carry the sounding equipment to these high altitudes. Experimental sounding to 140,000 feet has already been accomplished. Special electronic components such as electron tubes, resistors and batteries have been and are being developed for the radiosohde unit which is carried aloft by these balloons. Meteorological rockets are under development which have attained altitudes impossible for balloons to attain.. Special devices, components and techniques have been developed for such use * * * Upon the conclusion of World War II, it was increasingly apparent that adequate weather forcasting depends on complete coverage of the earth with a network of meteor-

ological observation stations. Due to the large water masses of the earth, the many remote and inaccessible areas, and to the difficulties of obtaining weather data in hostile territory, means other than the normal surface weather stations and upper air sounding stations must necessarily be an important complement to the land weather net. This requires a wide variety of meteorological equipment for obtaining upper air sounding and strategically placed automatic weather stations to obtain specialized weather data. The advent of the high altitude, long-range rocket, and of jet-propelled aircraft have also made it increasingly imperative that higher altitude meteorological data be obtained * * * Some of the specific projects in the current research program follow.

(2) The Lower Atmosphere (Troposphere): The portion of atmosphere designated as the "troposphere" is really an oblate spheroid ranging in height from ten miles at the equator to five miles at the poles. The volume thus contained accounts for almost 80% of the earth's total air mass and nearly all of the clouds in the sky. * * * Investigations are underway directed toward determining the magnitude of space and time variations of meteorological data in this part of the atmosphere. Most effort so far has been specifically devoted to the time and space variations in wind velocity aloft. Preliminary calculations indicate that the primary causes for variations of wind velocity are the eddies which exist in the atmosphere * * * Another investigation underway concerns measurement of the liquid water content of clouds from measurements of visibility and particle size * * * Another investigation regarding atmospheric disturbances of an electrical character centers around position finding of such disturbances as one of the few means of easily determining weather conditions over enemy territory

or remote and inaccessible land and ocean areas. This work includes: (1) research on the determination of height of the 10 to 20 kc reflecting layer of the ionosphere; (2) use of static direction finding equipment in locating atmospheric disturbances other than thunderstorms; (3) Investigation of the frequency of atmospheric disturbances as a function of the distance from the origin; (4) study of the correlation of the atmospheric wave shape with simultaneously observed network fixes; (5) development of circuits which will resolve ambiguities in multipath propagation of sferics disturbances; and (6) development of single station techniques for use in finding the atmospheric discharge sources with an accuracy comparable to that obtained with existing triangulation methods. * * * With the view of determining the mechanics of electrical charge production and electrical charge separation within thunderstorms, studies are underway in New Mexico where such storms are quite frequent. In this investigation the electrical properties of water will be explored under conditions judged compatible with thunderstorm environment. It is anticipated that the results of such investigations will provide a better understanding of the phenomena of electromagnetic waves produced by lightning and may also prove useful in the field of storm detection and analysis by electronic means. Several airplane flights have been made through thunderstorms with the objective of obtaining a correlation between electrical charge centers and turbulence and to confirm existing theories of thunderstorms * * * Another investigation involving the study of weather by electrical means employs radar techniques with the view of associating various reflections with atmospheric disturbances. This work is conducted through simultaneous observations by radar on an airplane flying in the disturbances at

the same time weather parameters are being measured by personnel in the airplane. Simultaneous records are made of the radar reflections from the area under observation. Some of the problems particularly under investigation are: (1) determination of the effect of frequency, pulse length, pulse repetition frequency, ~~pulse~~ and peak power on radar echoes from cloud formations, rain, snow, or other weather phenomena; (2) correlation of radar echoes with type and intensity of associated atmospheric phenomena; (3) measurement of scattering and attenuation of radar pulses through various types of weather and correlation of these with radar range and frequency; and (4) measurement of water content, particle size and distribution, proportion of liquid and solid particles, turbulence and correlation of these items with weather radar * * * Related to the preceding experiments are several other experiments based on vertically directed narrow-beam pulses at frequencies of 100, 2800, 10,000 mc, and higher. At 100 mc theoretical studies indicate that vertical incidence transmissions are likely to produce measurable and recordable reflections from tropospheric layers and that such data may be of considerable value in interpreting meteorological phenomena. At higher frequencies, tropospheric echoes from clouds, rain and snow have long been experienced with major emphasis now required in establishing understanding of the meteorological significance of data received at various frequencies. * * * In work pertaining to the troposphere, under title "Project Cirrus" cloud studies are underway in which every measurable parameter is being studied with respect to influence on controlled modifications of clouds through the introduction of nuclei, such as carbon dioxide, or silver iodide, on which condensation may occur. This is a joint Service project, and field experiments pertaining there to are conducted with all services participat-

ing. Numerous flight experiments have been made in various regions within ~~the eastern part of~~ the U. S., and several in Caribbean areas, ~~Panama~~ and ~~New Mexico~~. Research continues along very basic lines.

(3) The Upper Atmosphere (Stratosphere and Ionosphere): The stratosphere extends from the top of the troposphere to a height of about 50 miles and contains about 20% of the total atmosphere's mass. Beyond lies the huge rarefied shell of the ionosphere rising to 2,000 miles or more but containing less than one half percent of the total atmospheric mass. In probing the lower fringe of the upper atmosphere, balloons have served as the principal carrier for measuring equipments. While some flights have been made as high as 140,000 feet, 120,000 feet represents the maximum height from which significant information on temperature and wind fields have been received * * * While there is good promise that eventually balloons capable of reliable daytime soundings of 150,000 ft. will become available, to significantly probe the upper atmosphere, rockets appear at this time to offer the most satisfactory approach. Accordingly, the Signal Corps' upper atmosphere program has largely been built around use of rockets . . . . first the Ordnance constructed Wac Corporal, later German V-2's as they became available, and more recently, Aerobees procured from the Navy. * * * One phase of Signal Corps upper atmosphere research involves the development of techniques for the 30 - 80 kilometer region leading to measurements of pressure, temperature, winds, composition of the atmosphere and other associated atmospheric phenomena which are meteorologically significant. Efforts to determine pressure and composition look promising. Upper air samples have been obtained and are being analyzed. In the field of temperature measurements, it is

hoped that by measuring the position of the shock wave off a wedge on the nose of a rocket, and knowing the Mach Number, accurate temperature calculations will be possible. Measurements made at Langley Field in the low-density wind tunnel indicate that good results may be expected to a height of 60 kilometers. Another approach to high altitude temperature determination involves the measurement of travel time to earth for sound arising from grenade bursts ejected from rockets during flight. Aerobee rockets are now being equipped with nine four-pound grenades, explosions of which will occur at pre-arranged intervals as the rocket passes through that part of space for which temperature measurements are desired. Time of explosion will be telemetered to the earth and the sound arrival of each burst will be later detected with microphones. With such data, temperatures at various altitudes may easily be computed, since the velocity of sound is dependent upon the temperatures of the transmission media. In the field of wind measurements, major hope is placed in generating a smoke trail which can be photographed from the ground as it yields to the various strata and wind velocities at high altitudes. Several flights have already been made, and the technique is developing satisfactorily. *** A number of experiments are underway in which the upper atmosphere is probed, with assistance coming from beyond the earth, through measurements made on phenomena associated with the passage of meteors. This is accomplished through study of radio reflections from meteor ionization trails. Both pulse and continuous-wave (Doppler) measuring techniques are being used. In the investigation, emphasis has been particularly toward obtaining an accurate and detailed picture of the physical processes occurring along the meteor's path. With new techniques developed, it has been possible to study the time variation of the spatial distribution of the electron density in the usual type of ionization cloud. Results indicate the clouds to be formed virtually instantly by a radiation-type process, and that decay of these clouds results from a recombination-type law.

(4) Instrumentation Research: Basic studies are underway directed toward improving certain elements involved in conventional meteorological measurements. For example, humidity elements are being worked on with objectives of: (1) no polarization; (2) high sensitivity at high humidities; (3) small temperature coefficient of resistance; (4) no deterioriation at high humidities; and (5) short time of response. *** Another investigation concerns

ways and means for minimizing hysteresis and drift in aneroid capsules and capsule material with the object of obtaining improved capsules for operation over the temperature range of + 60° C to - 90° C * * * Other investigations include: (1) thermo-elastic bimetals for low temperatures;(2) residual stress measurements; and (3) creep measurements.

SECTION VII - RESEARCH IN PROPAGATION

(1) Introduction: This Section deals with research being done in that field where the media through which information is to be transmitted is the earth's atmosphere. The findings from such research may be related to a number of fields of Signal Corps interest such as radio communications, radar, meteorology, optical signalling, sound ranging, photography, etc. In the electromagnetic spectrum the area of interest includes the entire spectrum ranging from very long waves which follow the surface of the earth, intermediate length waves which are confined to the earth's atmosphere by reflection from the ionosphere, the extremely short waves which, for the most part, follow a line - of - sight type of transmission, and lastly, that part of the spectrum including the infrared, visible, ultra-violet and upwards into x-rays and cosmic rays. In the sound spectrum interest also exists at all wavelengths but particularly at very low frequencies where long range transmissions offer considerable military interest, both from the point of view of sound-ranging and from consideration that certain meteorological parameters may be deduced from transmission data. * * * Elements of the propagation program which have been mentioned earlier as integral parts of other work will be omitted from the following presentation.

(2) The Electromagnetic Spectrum: As a first priority in the field of propagation, research activities are underway to fill in requirements

established by equipment developments now underway. From a rational point of view, such an orientation of thinking is desirable to minimize the occurrence of previously unsuspected atmospheric or transmission phenomena after an item of equipment has been developed; as for example, during the war when a K-band radar was developed which later was found to fall squarely on a strong absorption wave length for water vapor so the invisible molecules effectively absorbed and blocked the radar signals * * * A portion of the present effort has been concerned with studies of progagation effects in frequency ranges suitable for radio relay service. Equipment capable of sweeping a wide range of frequencies is being constructed so that field measurements can be made of the fading, and the effectiveness of diversity reception in overcoming such phenomena. Such tests usually require data taken in the area of later potential use. Arctic studies have and are being made, and a Caribbean study is now underway on joint Long Range Proving Ground requirements. * * * On the central eastern seaboard wave propagation studies in the L-band are underway in which terrain and weather are given particular consideration in order that explanation for anomolies may be studied and better understood * * * In the eastern portion of U. S. and in Alaska studies are also underway pertaining to transmission time for propagation in an atmosphere of varying refractive index with the objective of: (1)improving current methods of eliciting from a vertical ionospheric sounding, information concerning oblique sky-wave transmission, such as maximum usable frequency, skip distance, etc.; and(2) to utilize oblique incidence relationships in obtaining further information regarding electron distribution in the ionosphere * * * Related to this program is a study of sky-wave propagation with continuous inospheric observations at

the center of the path. An experimental transmission channel has been set up with transmitters and receivers symetrically located at equal distances from a central ionospheric laboratory. The experiments involve examination of all measurable characteristics of the radio wave as it arrives at the receiving point and to check these characteristics against the continuous measurements of ionospheric behavior at the main reflection point, the measurements being made at all reasonable frequencies and under all sorts of ionospheric conditions. Fixed-frequency steady-carrier transmissions and fixed-frequency pulse transmissions are provided for initially, with the possibility of additional facilities to be added as the study progresses * * * The largest part of the ionospheric program includes the cooperative establishment of sites for measurement of vertical incidence and radio absorption data over a complete 11-year solar cycle in Alaska, Canada, Greenland and elsewhere throughout the world. In addition to this long-term program, a temporary network of five stations has been established in Alaska to study operational requirements on a short-term basis. This work is to be further supplemented by activity in the lower auroral regions for the determination of the most suitable frequencies which can be employed for communications, radar and countermeasures purposes, particularly during atmospheric disturbances caused by Aurora Borealis. * * * Other studies involving ionospheric research include, recording of standard Loran signals, recording of sky-wave signals, recording of sky-wave signals over long baselines, ionospheric polarization experiments, and non-polarization measurements. * * * As a continuation of research conducted in 1946, studies are being made in very long range radio propagation in which the moon is used as a reflecting signal for radar pulses. Since such experiments involve

the double passage of the waves through the ionosphere, valuable information pertaining to detection, tracking and guiding of high-flying missiles should follow. Present effort is mainly toward improving early radar techniques and constructing a mechanical system capable of supporting the radar antenna for automatically tracking the moon over its orbit in the sky.

(3) The Sound Spectrum: Studies are underway involving the propagation of sonic and ultra-sonic sound through the lower atmosphere and the ground. Particular stress is being placed on the attenuation of supersonic sound at low temperatures, and as mentioned earlier, at very low frequencies. Further mention of work in this field appears in Sections VI and XIII.

SECTION VIII - RESEARCH IN ELECTRON TUBES

(1) Introduction: No single field of scientific endeavor occupies a more important position in the annals of Signal Corps scientific achievement than does research related to the electron tube. In fact, the history of modern communications and radar owe their beginning to, and show a new electron tube development as the starting point for almost every subsequent major advance. *** Basic research in electron tubes must be thought of primarily as a study of the behavior of charged particles in vacua solid state or in some gas at a reduced pressure. When some particularly interesting behavior is observed, ingenious minds conceive such conduct as part of an electrical circuit set up to perform a specific function, and a new electron tube is born when the desired physical conditions are perpetuated in a sealed off glass, metal or ceramic envelope. Applied research starts mostly with known principles or existing electron tubes with an objective of improving such tubes, or perhaps with new materials or changed geometry, producing an entirely new device capable of functions heretofore impossible. *** The Signal Corps has an extensive research program underway, both in the basic and in

the applied field, of which the first and portions of the second will be described in the text following.

(2) Basic Research: Study is being made to measure the first and second secondary electron emission crossover potentials of thin insulating sheets. In this study an electron beam is caused to approach the insulating target at velocities corresponding to various potentials. By measuring the potential of the holder of the insulating target, the accelerating potentials of the primary beam at which the secondary emission ratio changes from greater than unity to less than unity have been measured. * * * A theory is being developed to account for the action of an oxy-hydrogen flame in an intense high frequency field in which a marked lengthening, broadening, and increase in intensity of the flame was observed when the flame was parallel to the electric vector. Related effects have also been observed in a tube containing neon at 38 cm pressure. * * * Experiments are underway to determine the order of appearance of spectral lines and the intensity function during driving appearance from optical excitation produced by high energy pulses of extremely short duration. It is hoped thereby to experimentally determine certain probability factors suggested by Einstein's transition coefficient. * * * Tritium hydrogen studies will be used in conjunction with tracer work to determine where, when and why hydrogen cleans up in tubes such as hydrogen thyratrons. * * * After the announcement of transistors by the Bell Telephone Laboratories, the basic experiments were repeated leading to a more detailed picture of the interaction between the emitter and the collector and of the range of holes injected from the emitter. Related to this is solid state research involving particularly germanium to determine: number of electrons and their mobility as a function of temperature; optical properties of semiconductors of the classical non-degenerate type as the semi-conductor is

made to approach the behavior of an insulator; and, response of semi-conductors and insulators both in the purest form(as well as properly "doped",) as a function of temperature, down to that of liquid helium. * * * Work is continuing on the fine structure of the hydrogen atom employing microwave techniques. In this experiment a beam of hydrogen atoms passes through a strong magnetic field toward a distant detector with conditions established that only atoms which had their electrons in a certain orbit could register at the detector. A microwave beam intersects the atomic beam and when the energy quanta of the microwave beam possesses a particular critical value electrons shift from the registering level to the non-registering level. Thus the quantum of energy required to change the electron's orbit may be observed. In this particular experiment, energy discrepancies occurred not explanable by the long-standing Dirac theory of the hydrogen atom, and as a consequence great activity to explain this discrepancy was precipitated throughout the world, and microwave techniques were further recognized as a powerful tool for atomic physicists. * * * The use of microwaves as just illustrated has opened up many new fields for physical exploration. Research is underway on numerous projects, such as: the fine and hyperfine structure of the hydrogen atom; ionized helium fine structure; theory of nuclear effects in microwave spectra; resonance absorption of microwaves by gas molecules; electron polarization and resonance experiments; nuclear resonances at low temperatures; reflection of microwaves from an electronic space charge; dipole moments; transient discharge characteristics and ambipolar diffusion and electron-ion recombination, use of molecular resonances as precise time standards, the Hall and Kerr effects at microwave frequencies, and many others. * * * Much activity is underway in the basic field of emission studies. For example, there is research directed to study the factors which tend to

limit high voltage pulse operation of tubes with oxide coated cathodes, and the factors affecting primary emission from grids in tubes with oxide-coated cathodes. There is work directed toward producing a material, having a high secondary emission ratio, capable of long life when functioning in combination with a hot primary cathode to which it may be exposed . Studies are underway to learn more about the factors which affect and limit cold cathode electron tubes operating in pulsed modulator applications. There is activity on both thermionic and secondary emission phenomena with the object of developing cathodes superior in electronic emission per unit area, life expectancy, mechanical qualities and efficiency over those now available. In this field surprising results have been obtained with cold pure metal cathodes operating in pulsed magnetrons, for if a small amount of thermionic emission is available, experimental observations have indicated that magnetron-type emission of the order of 1000 times the thermionic value can be obtained. Another experiment involves an observed phenomenon that without heating the cathode of a magnetron, an anode current can be produced by feeding low-level RF power into the tube while maintaining the cyclotron magnetic field at a low anode voltage. With 50 volts on the anode and RF power of the order of microwatts, a microampere of current can be obtained with a cold cathode. A tentative theoretical explanation has been formulated. Another project includes research on work function and electrical conductivity of oxide-coated cathodes, determination of the thermionic-emission and the field emission properties of single tungsten crystals by photometric methods, determination of the migration of barium ions in barium oxide cathodes through use of tracer techniques, and others.

(3) Applied Research: Methods of generating microwave frequencies more efficiently, or learning how to generate super-high frequencies in regions as yet not possible, constitute one of the major objectives of the program appearing under the applied research heading. While magnetron techniques have advanced to where wavelengths of only a few millimeters may be generated, new approaches are necessary, since such magnetrons involve extremely small mechanical dimensions and are quite limited in power output. Other methods under study include investigations of harmonic generators, use of klystron theory and techniques and the rather radical approach of using charged mercury drops to produce damped oscillations. Along other lines is an investigation involving the interchange of energy between electrons and electromagnetic waves due to interaction in a tuned cavity as an axial electron beam passes through the cavity on which a steady magnetic field is superimposed. The thought is that r-f energy may be coupled into the beam at cavity resonance frequency or ~~resonance frequency x n~~ higher. Another possible method of generating millimeter or infrared radiation now under investigation involves the use of a staggered magnetic field to impose small lateral accelerations on a beam of electrons. In the present work a study of several electron trajectories has been made with the objective of seeing if a millimeter or infrared generator based on the radiation from accelerated electrons would be feasible. More conventional work includes studies on interdigital magnetrons, inverted magnetrons with cathodes surrounding the anode structure, and others. Along entirely conventional lines for pulsed magnetron, powers have continually been extended upward. Outputs of 10 megawatts at S-band, for example, have been obtained with pulses 1 microsecond in duration and at 80 kilovolts pulse voltage. In the field of magnetrons, for continuous rather than pulse operation,

work is underway involving extension of theory and improvements in techniques concerning generation, amplification, and modulation problems covering the frequency range of 1000 to 30,000 mc. Average powers as high as 50 kw have been obtained at 1200 mc. * * * The problem of amplification, and particularly broadband amplication, at microwave frequencies is now receiving considerable attention. In the field of traveling wave tubes work is underway to extend the use and understanding of the mechanism of continuous interaction between waves and electrons. Theoretical and experimental studies as well as complete operating tubes are being constructed in a number of experiments. Questions under consideration include lowering the noise figure, increasing the gain, extending the power level and frequency of operation, understanding the effects of gaps and concentrated and distributed loss along wave carrying structures; development of new forms of circuits and tubes, compression studies, and electron beam production and focussing studies. * * * In numerous other categories of electron tubes, or directly related fields, Signal Corps effort represents more of a combined applied research with engineering objectives, and accordingly, will not be stressed herein. Such categories are: mechanical, chemical and physical test techniques; statistical control techniques; materials and construction methods; receiving tubes; power tubes; gas tubes; microwave electron tubes, such as magnetrons, klystrons, planar types, crystal rectifiers, switching types; cathode ray tubes; phototubes; storage or memory tubes; tubes for radiological purposes, etc.

SECTION IX - RESEARCH IN FREQUENCY CONTROL

(1) Introduction: Approximately 70,000,000 quarts crystals were purchased during World War II for use as frequency stabilisers, particularly for communication purposes. The world's supply of natural quarts is very limited and most of the raw material used in the U. S. must be imported. This fact, coupled with increasingly severe requirements on spectrum conservation, suggesting an increasing rather than a decreasing demand for frequency stabilization materials or techniques, places research in this field in a position of considerable importance in the Signal Corps program. In addition to usages of the World War II type for communications, the microwave spectrum is now continually bringing about new requirements for frequency stabilization, most of which are quite unrealizable with oscillating crystals. Accordingly an entirely new field of frequency control requirements is emerging where crystal techniques can no longer serve. * * * In the discussion which follows, the overall subject will be divided broadly into: first, that part dealing with the synthesis of quartz or of possible substitutes; second, fundamental studies on the piezoelectric activity of crystals; third, studies pertaining to circuitry applicable to precise frequency control; and fourth, new methods under investigation which hold promise for frequency stabilization purposes.

(2) Synthesis of Piezoelectric Crystals: Within the past year quarts has been successfully synthesized in crystal sizes of such magnitude that there is now good reason to look forward to synthetic production of useful sizes after scaling up presently used experimental procedures. * * * The technique found successful involves a hydro-thermal process utilizing the temperature gradient within an autoclave. In this process the autoclave is

partially filled with natural quartz scraps, quartz sand, or fused silica. An aqueous solution of either sodium chloride or sodium carbonate is added. Within the autoclave, a small seed crystal on which the growth will take place, is fixed appropriately. Temperature is raised to approximately 400° C, which is somewhat above the critical temperature for water, at which time pressures of 10,000 - 20,000 per square inch develop and crystal growth starts. For example, one clear specimen was grown on a seed cut parallel to a minor rhombohedral face and increased in weight by 16 grams or 530% and in thickness by 9 mm in 47 days. * * * As a further part of studies to bring about a better understanding of the phenomena of quartz growth, in dilute alkanized salt solutions, the following have been confirmed: in the Na Cl, pH 10 solutions, the examination of dilutions to N/200 and of charges from 45% to 60% did not disclose greater yields than N/40 at 50% charge; the minimum amount of fused silica source material to give maximum growth in 48 hours was determined to be about six times the weight of the seed plate; more growth occurred with cristobalite source material than with microcystalline natural quartz; and several salts analogous to Na Cl yield growth, the Na Br results being comparable in amount to Na Cl. * * * Plans are now underway for larger growth type of equipment and a two chamber thermal - circulation autoclave of about 19 liters capacity is in the process of fabrication. * * * Another crystal widely known for its piezoelectric properties is tourmaline and while sources of this material exist throughout this country and elsewhere only a small amount mined is of sufficiently high quality to be suitable for frequency control piezoelectric purposes. With selected pieces, fabrication of fundamental mode oscillator plates to 400 mc have been accomplished. Accordingly work has been initiated to investigate techniques, methods and equipments for the synthesis of single

crystals of substances of tourmaline type which may be suitable for controlling elements as a substitute for quartz. Methods employed are quite similar to those described earlier for quartz. Incidently, quite recent studies have shown that boracite holds promise exceeding, perhaps, that shown by tourmaline. Consideration is, therefore, now being given, to shifting emphasis in this particular project from tourmaline to boracite. * * * Another portion of the "synthetics" program concerns the growth of nepheline which also appears to offer promise as a piezoelectric material although information on this subject is not abundant. An objective has, therefore, been established to grow single crystals of sufficient size so that complete scientific data may be obtained on this interesting material. * * * Other crystals which are being grown for the purpose of obtaining their piezoelectric and other characteristics, and accordingly as potential replacements for quartz include aluminum phosphate, aluminum arsenate and boron phosphate. As in other synthetics, the objective is initially one of obtaining large, clear untwinned crystals from which to make relative comparisons.

(3) Fundamental Studies: Work is under way in the improvement of techniques in the VHF range with the objective of establishing accurate frequency measurement equipments and techniques up to 300 mc. * * * In the low frequency field an instrument has been developed capable of making very accurate impedance measurements in the frequency range of 5 kc. As related work, investigations have, and are being, conducted with the objective of obtaining a new crystal cut more stable in frequency, and easy to manufacture, than heretofor possible. Theoretical studies of the quartz structure have led to an approach through which low frequency cuts with low temperature coefficient may be found. Preliminary tests

show such cuts to have a frequency tolerance of plus or minus .005% over the temperature range of -40° to 70° C. * * * Other studies are underway to determine methods and techniques for measuring the circuit properties of high frequency quartz crystals and to interpret these in terms of basic piezoelectric theory. From this study it is expected to develop a means for systematic standardization of the various types of crystal units, and a means for the application of circuit analysis to the peculiar problems of the crystal oscillator which, of course, is a combination of the crystal unit and the oscillator circuit. Also related to this study is research on the factors which effect the rate of change of equivalent reactance of the crystal unit with frequency and to investigate methods and techniques for controlling these characteristics, for example: temperature studies were undertaken on the fundamental modes of contoured AT - cut crystals to examine relationships between temperature stability and degree of contour. Cylindrical contours on square AT - cuts were further explored to determine if a variation of angle between the cylindrical and the crystallographic axis would cause any appreciable change in overtone separation. This did not seem to be the case. Dust pattern studies of Y - cuts were continued and a beginning made on investigating the inharmonic overtones associated with the third harmonic. The results obtained have already lead indirectly to a revised design for 1 mc, 1/2" plated, wire-mounted unit. The few units made so far all resonate on their fundamental modes. However, the resistances are rather high; between 200 and 300 ohms. Form factors for 2.9 mc contoured units have been calculated. Measurements of dynamic capacitance of several contoured 2 and 4 mc plates seem to indicate that, contrary to flat crystals, the capacitance increases with decreasing

frequency. * * * In addition to studies of the type just indicated research is underway on techniques for removing the phenomena which appears in many quartz crystals under name "twinning". Quartz characterized by this defect shows variations in the elastic constants of the lattice structure and the presence of such strains has a deleterious effect on some of the more important properties of the oscillator plate. * * * Very recently experiments have been made on a high temperature annealing process which appears to offer great possibility in removing the necessity for etching improvement in frequency stability, as a crystal treatment, yielding a higher Q, coupled with an apparent freedom from aging. In effect, the process consists only in heating to a temperature close to the inversion point for quartz and then slowly annealing. Further experimentation and theoretical studies on the underlying cause for the observed phenomenon are now underway.

(4) Circuitry Studies: One phase of circuitry research concerns investigations in which a crystal, operating on a mechanical overtone, controls the frequency of an oscillator circuit. This work includes: investigations of circuits in which no tuning adjustment is required when crystal units of different nominal frequencies are used; and, circuits in which the operation is at frequencies so high that the crystal units themselves appear to be capacitive elements, including cases in which the crystal unit is incorporated in a bridge circuit, and circuits in which the crystal unit is used as a frequency reference and causes error voltages to be developed which are used to control a free-running oscillator. * * * Another phase of this work concerns studies involving: effective power dissipated within oscillating crystals; effective capacitance across crystals; and, quality of the crystal and studies of oscillator synchronisation. In the

latter case the problem is being considered in three parts: (1) two oscillators operating on the same frequency; (2) one oscillator operating on frequencies which are integral multiples of the crystal-controlled oscillator frequency; and, (3) one oscillator operating on frequencies which are sub-multiples of the crystal-controlled oscillator frequency.

(5) Non-Piezoelectric Methods: Utilization of magnetostrictive materials for frequency control purposes is not new to the art. Rods of such material, however, are quite limited in frequency range and had earlier been discarded chiefly because of their low electro-mechanical efficiency and high temperature coefficient of frequency. The combination of certain new alloys and resonator designs, has recently, however, enhanced the possibilities of magnetostrictive methods finding application. Accordingly, work is now underway on a study involving the utilization of this principle over a frequency range of 50 kc to 3 mc, or higher. A number of units have been fabricated which show considerable promise. * * * Because of the extremely low temperature coefficient of expansion for fused quartz, studies also are being conducted in which such material is fabricated into resonators for frequency control purposes. A particular investigation is directed toward use in the frequency range between 8000 and 8500 mc . . . . . stability within 1/2 mc over a temperature range of -40° to $+65^{\circ}$ C. In construction, the main body of the cavity is of fuzed quartz, completely metallized and then silver plated. Invar "36" is the alloy employed in the construction of the tuning elements of the cavity. Since the resonating cavity requires evacuation for optimum stabilization, considerable difficulty was initially experienced in securing a vacuum seal between the quartz body and the invar end plates. This was accomplished, however, and the work is proceeding. * * *

With the rapid development of the new field of physics called microwave spectroscopy it has become increasingly apparent that molecular absorption phenomena suggests the possibility of application as a time standard for microwave stabilisation purposes. For example, a strong absorption line of ammonia exists at 23,870 mc which is in the frequency range of radar and proposed radio relay communication equipment. In the plan now being worked upon, a microwave beam is passed through a wave guide cell containing ammonia. Error voltages are developed as the transmitted frequency deviates from the center frequency of the ammonia absorption line. These error voltages, which are indicative of deviations from 23,870 mc, are used to change the oscillating frequency of a klystron which it is desired to synchronize with the frequency of the absorption line. Unfortunately, the frequency deviation which serves to correct the oscillator is sensitive to the pressure and temperature of the ammonia in the controlling cell. While further research may eventually lead to ways of effecting some reduction in the uncertainties so caused, at this time stabilities possible do not exceed that possible through the use of good crystal stabilized oscillators being of the order of one part in 10^7 *** In the same general field, but far more advanced in its research complexities, lies the molecular beam method of frequency control. This method would employ a different physical approach and is independent of temperature and pressure, since the molecules serving for a reference frequency pass through a highly evacuated tube without collisions among themselves or with the walls of the container. Such equipment, has never yet been constructed, because of cost and complexity. However, theoretical studies do indicate that molecular beam time standards

could be built and accuracies of one part in 10^{12} would not be out of reason. Such accuracy, of course, would be far greater than possible today with the best of crystal controlled time standards. In fact, if applied as a timing device, such a clock could run, without re-setting, for 1000 years with an error of only a small fraction of one second.

SECTION X - RESEARCH IN COMPONENTS AND MATERIALS

(1) Introduction: The necessity that most military equipment must operate satisfactorily and reliably over the entire gamut of climatic conditions found on this earth, or in some instances beyond, imposes a requirement of perfection upon the integral military components rarely required by related commercial products manufactured for temperate zone operation. It is thus necessary that the Signal Corps participate in a research and development program leading to new materials and components specifically directed toward improving military equipments; it being happily recognized, however, that in many instances, end items which have civilian interest also appear from such research. * * * In general, most of the work related to component development involves an engineering fabrication of such piece-parts as a result of new materials or techniques separately developed, and as such will therefor not be stressed in this discussion except where research may be involved.

(2) Materials: Magnetic materials with rectangular hysteresis characteristics are being investigated for numerous power and communication purposes mainly because size, weight and losses could be reduced with materials retaining essential properties coupled with an inherently higher saturation flux density. One approach to the problem was through modifying the magnetic prop-

erties by annealing in a magnetic field. Known characteristics such as magnetostriction, crystal energy, and Curie temperature, indicated that alloys with 35 to 50 percent cobalt, balance iron, and others, might respond to this treatment. Another phase of the same problem involves a magnetic annealing study of the ternary cobalt - iron - nickel system suggested by the known excellent response in "Perminvar" (35 cobalt, 30 iron and 45 nickel) and fair response of cobalt iron (50:50). No connecting lines of composition however were found in the intermediate composition range . . . . in fact, rather wide areas of composition occur having extremely poor magnetic properties. Present activity is now directed toward a search for some quaternary addition through which the apparent heterogeneity may be suppressed. * * * Other investigations in the same field include: (1) studies of a 50 per cent nickel-iron alloy in light gauges with rectangular hysteresis loop characteristics similar to the German alloy Permenorm 5000-Z; investigation of light gauge oriented silicon steel strips suitable for the manufacture of wound core transformers operating at high flux densities and high frequencies; and (3), studies of cobalt-iron alloys for operating at extremely high flux densities and further extension of the work in developing rectangular hysteresis loops characteristics in these alloys * * * In the basic research field of plastics, synthetic resins, flexible insulations and insulating oils, work is proceeding on a number of problems including: (1) mechanical studies of polymerized ring silicones; (2) transformation of silicone rings to chains; (3) preparation of liquid polymers and copolymers incorporating diene monomers; (4) modification of melamine resins with long linear difunctional

chains; (5) chemical modification on intermediates for resins having a composition and structure believed to be inherently arc resistant; (6) study of the ferrocyanide complexes to learn of any relationship existing between the size of the metal ion in the metal ferrocyanides and the dielectric constant of the complex; (7) preparation of porphyrins; (8) study on the dielectric constant and dissipation factor of liquid binary mixtures; (9) studies on the effect on the dielectric strength of loading polystyrene with TiO_2; (10) measurements of dielectric constant and power factor at high frequencies; (11) studies on the effect of high frequency arc discharges across the surface of organic materials; (13) studies on crazing involving effects of orientation, reversibility, growth of cracks, effect of contamination with organic materials, and others; (14) study of the rheological properties of polystyrene directed toward development of non-crazing polystyrene; (15) study of the impact strength of plastics directed toward development of a mechanical electrical plastic; and others. * * * In a more applied field investigations are also underway to develop plastic materials suitable for the casting of precision optical lenses, prisms, mirrors, etc., and a plastic material suitable for embedding electrical components such as RF and loading coils. In the optical phase, numerous monomers have been synthesized and successfully polymerized and copolymerized yielding material for study as optical elements. In the electrical embedding phase, studies of a number of commercial and experimental monomers were made, and it was determined that curing recommendations given by manufacturers were in most cases not applicable to casting techniques leading to a requirement for investigations on the effect of catalysts, catalyst concentrations, and polymer accelerators on curing time, internal temperature rise, and physical properties. Such data will be used to determine optimum curing procedures

for those monomers prepared for electrical testing. * * * Another phase of the materials research program is directed toward improving existing ceramics, particularly toward expanding the temperature and humidity ranges under which they retain desired mechanical and electrical properties; more specifically, high thermal conductivity with low loss, the ability to withstand severe thermal shock, an inherently moisture repellent surface or glaze of high electrical surface resistivity when exposed to high humidity or wet conditions, and development of ceramic bodies free of electrolytic action. Specific parts of the program include: (1) work concentrated on measuring the thermal conductivity of the experimental bodies, and developing a vitreous body composed of 100% BeO with a maximum maturing temperature of 1750° C, as yet, a vitrified body of 100% BeO remains to be developed; (2) all known ceramic compositions have been evaluated for thermal endurance with type-compositions found to be (in order of decreasing thermal endurance) cordierite, sillimanite, zircon, alumina, beryllia, electrical porcelain and steatite. . . . two particular crystalline phases which increased the thermal endurance of some alumina type - compositions were prepared as ceramic bodies and evaluated for thermal endurance and physical and electrical properties / . . . results were very unsatisfactory; (3) comparative tests on various base coatings from the point of view of freedom from electrolytic action . . . . best coating found to date is a glaze consisting of 99% lead monosilicate and 1% Cr_2O_3; and (4), in the development of dense cordierite bodies, barium was found to benefit dielectric properties and exert a noticeable fluxing action in "raw" bodies providing an excess of SiO_2 . . . . . barium pyrophosphate as a calcine component increased the fluxing action of the calcine, but had little effect on the dielectric properties of the bodies

formed . . . . a low expansion enamel was tested as a glaze for dense cordierite with results indicating that a modified enameling procedure may be adapted to gloss firing of these bodies. * * * As a further part of the ceramic program, investigations have been made to the establishment of methods of quantitative spectrographic analysis of raw and processed titanium oxide, alkaline earth titanates and other materials used in the manufacture of ceramic bodies. Several methods to accomplish this, including Briquetting, have been successfully demonstrated. For muscovite and phlogopite micas two methods of standardization have been established both providing means of synthesizing samples of suitable range of composition to establish working curves. The methods are: (1) DC arc method which provides the least systematic variations, since any variable of crystal form that might remain after fusion is minimized; and (2), average of triplicate analyses . . . . however, once a proper Briquetting procedure is developed it should be superior in precision and accuracy. * * * On a quite practical basis, investigations have also been underway directed toward developing a process for injection molding of steatite, zircon or other ceramic insulators. Some of the present conclusions of this investigation may be tabulated as follows: (1) Ethyl cellulose is the best thermoplastic resin tested, with butyl stearate being the most generally satisfactory plasticizer; (2) a careful, slow baking schedule is required for successful elimination of auxiliary "binders" and success is further dependent upon the elimination of invisible laminations, weld lined, and internal strains. Such factors as injection pressure, injection - cylinder temperature, and injection speed, vary with the material formulation and dependent plasticity. Other conclusions from this applied research will not be listed because they are only of specialized technical interest. * * * In the field of semi-conductors,

reference has already been made in Section VII to that portion of the work bearing particularly on the field related to electron tube applications. In addition to the work referenced, studies are being made to more fully understand the function of the barrier layer in the operation of rectifiers. Numerous experiments have been carried on with selenium because of its importance in dry disk rectifiers. Measurements were made of the impedance at various frequencies when a small AC current is superimposed on a bias. Results of the measurements indicate that the barrier layer is not an exhaustion layer as previously believed. In the same field, studies of the activation energy and time lag phenomena have been made in both experimental and theoretical. Investigations underway are being directed toward a study of the surface resistance of selenium as a function of absorbed gas; it being expected that such gas will influence the impedance characteristics of a rectifier, since the properties of the barrier layer are strongly dependent on surface energy states and work function. Selenium research also includes optical absorption of its various modifications, measurements of viscosity and the effect of addition agents on viscosity, and research on the crystallization properties, and electrical studies on the effect of addition agents. Along more practical lines, the results of research as indicated above have been studied specifically with the thought of utilizing new information in improving dry disc rectifiers, particularly in the direction of high temperature and humidity characteristics. Other work in semi-conductors includes studies of the conductivity of titanium dioxide as a function of oxygen defect, temperature, field strength and frequency. This investigation comprises ceramics as well as single crystals in order to establish the influence of grain boundaries on the electrical properties and will include study of the

oxydation-reduction cycle, conductivity, Hall effect, thermo-effect and paramagnetism. * * * Barium titanate is one of the most interesting materials under extensive research today because of its very unusual electrostrictive, piezoelectric and dielectric properties. Research includes many studies involving both single crystal and polycrystalline preparations, the latter, being studies both separately and on ceramic sheets. Since it has been only recently possible to synthesize individual single domain crystals approximately 5/8" diameter by 1-1/4" high and cylindrical in shape, even further acceleration may be expected in this field since many applications will follow once this material is fully understood. Some of the above investigations underway on this material include: (1) atomic parameters of the crystal lattice studied by x-ray methods; (2) optical properties studied through noting the parallelism between changes produced by temperature variations, AC and DC fields with optical anisotropy as observed with a petrographic microscope; (3) permanent and spontaneous polarization and Barkhausen effects in single or twinned crystals as revealed by the field versus charge hysteresis loops, and the relationship of these effects to AC and DC field variations; (4) electro-mechanical coupling with respect to performance of crystals as transducers; (5) factors determining the optimum temperatures for nucleation and growth rates of pure barium titanate; and (6), general establishment of theory pertaining to domain structure and transition points. * * * Another interesting study underway pertains to the development of ultra-thin films of barium titanate or barium strontium titanate type ceramics which it is hoped will retain the dielectric properties of the single crystals of these materials. Work is progressing with the objective of the ceramic having as favorable a crystal-

lographic, orientation as possible, film thicknesses to be from one to one-tenth microns, and temperature coefficient of dielectric constant to peak at ambient. Whether objectives as indicated can be met is not yet known. Other investigations of interest in the field of dielectrics include: (1) study of the characteristics of pinite (a massive microcrystalline variety of muscovite mica) for possible dielectric applications; (2) structural characteristics of basic lead silicate; (3)relation between the composition, crystallization history and physical properties of mica; (4) the chemical bond in synthetic aluminum phosphate; (5) growth of magnetite single crystals; electric and magnetic properties of Fe_3O_4; (6) electric strength measurements of materials against transients of rise times as fast as 3×10^{-10} seconds; and in generalization, research on crystal structure and compositional variations in inorganic materials as related to their physical properties, especially dielectric, piezoelectric and electrostrictive, and to correlate such studies with observed phenomena of these materials with a final objective of discovering new electronic applications. * * * As a specific applied research project, which often follows studies of the type just indicated, the evolution of synthetic mica is of interest. Mica is of great importance in the field of electronics because of its high dielectric strength and desirable mechanical properties. During the late war almost every radio or radar equipment was dependent upon mica in some form or other. As a result of this great demand basic studies were made which eventually led to small-scale production of mica-like material. Further research continued promising, and today a pilot production plant for synthetic mica is in operation. * * * In the field of luminous materials

research is primarily directed toward development of ultraviolet - sensitive and longer persistence materials than now available. In this same category of effort, work on infrared sensitive phosphors is also underway. Numerous phosphors have been synthesized and studied. The work has resulted in the discovery of ten new infrared - sensitive base materials, and while these must be excited with very short ultraviolet radiations their excellent stability warrants considerable further research. As another part of the program, a series of panels was made up with various phosphorescent pigments incorporated in four different paint vehicles. Results showed that zinc - cadmium sulfide deteriorated least rapidly after 12 months interior exposure, zinc sulfide and calcium sulfide were intermediate, while strontium sulfide was the least durable. Methacrylate and urea - formaldehyde vehicles gave paints which retained phosphorescent brightness better than vinyl and silicone formulations. Other related work covers use of fluorescent dyes and materials in a wide range of fabric types, various weaves and backings. * * *

In concluding discussion of research on materials, several miscellaneous problems will be briefly passed over: (1) investigations on non-corrosive lightweight alloys, iron, and plating surfaces, leading toward improved mechanical properties; (2) investigation of methods for developing techniques for producing improved microwave surfaces on waveguides and other microwave equipments; (3) to acquire basic data for the development of an improved type paint which will provide adequate corrosion protection and adhesion without the need for primers or extensive pretreatment of surfaces; (4) improved solvents for use in dry batteries, electrolytic capacitor rectifiers, photographic processes and phosphors . . . . particularly at low temperatures . . . . and data on the solubility, viscosity, and electrical conductivity

of inorganic materials dissolved in organic solvents; (5) studies for the purpose of developing a non-corrosive soldering flux for universal application; (6) studies leading to the standardization of surface properties of fine particles from the point of view of specific absorption as a function of particle surface area and pre-surface treatment.

(3) Components: As indicated earlier in this Section, most of the Signal Corps work on components, as such, appears under development projects and therefore does not fall within the scope of this writing. Some applied research, however, is involved in a few components of which the following are illustrations. * * * Work is underway toward the establishment of techniques for design and construction of mode filters for waveguide systems. The trend toward higher power levels and higher frequencies has resulted in smaller waveguide dimensions, higher attenuation, and low power handling ability when the waveguide is operated in the lowest mode. A solution to this problem is being sought by the use of a higher mode of propagation or by the use of a low mode in a guide size suitable for higher modes. Either of these possible solutions, utilizing larger guide sizes requires a special filter, because the power source usually generates more than one mode capable of propagation through the guide. Accordingly, this research is directed toward the study of filters applicable to waveguides with the hope of overcoming the referenced problems. * * * Research studies have been initiated on the corona losses in RF transformers, this research to be coupled with investigations leading to the design of improved pulse transformers. * * *

SECTION XI - RESEARCH IN POWER SOURCES

(1) Introduction: Military power sources for electronic equipment are

primarily electrochemical or mechanical. The first named category is the well known wet or dry battery, while the latter represents, for the most part, the conventional motor generator set * * * Motor generator sets used during World War II were adapted from commercial designs and proved generally unsatisfactory. The Signal Corps research program in this field is mostly of an applied nature, integrated and coordinated with the Corps of Engineers' program. Effort is directed toward improved engines and generators of various types with emphasis on reduction in weight and noise, greater dependability, fuel economy, and the ability to operate over a wide range of temperature. Work in the field of permanent magnet generators has been pioneered by the Signal Corps, and such generators are now being constructed based upon research leading to the most suitable materials and theoretical studies pertaining to optimum design features. However, since much of this work is of an advance development character, such basic research as is applicable to this portion of the Signal Corps program will appear in other Sections which are providing specialized support in the advancement of particular phases of the power source problem * * * This Section will therefore primarily be concerned with electrochemical methods of power generation, concluding with a brief discussion on thermoelectric generator research.

(2) Electrochemical: For many military applications, such as guided missiles, radiosonde equipment, and other very high rate applications under unusual discharge conditions, batteries are required which are capable of very high discharge rates and which, in addition, will meet stringent requirements as to weight, size, operating temperature, activation time, shelf life, etc. Standard type batteries are not capable of meeting these specialized requirements. Therefore, research on new electrochemical sys-

tems and ways of improving the performance of existing systems has been undertaken. Among the systems on which extensive physical, chemical, and electrochemical data have been compiled are the calcium / acid / lead peroxide, zinc / potassium hydroxide / silver peroxide, lead / sulphuric acid / lead peroxide, cadmium / potassium hydroxide / nickel oxide, and the magnesium / water / copper chloride or silver chloride systems. Work on these systems has included single electrode studies as well as tests on actual batteries to determine designs and constructions giving optimum performance under all conditions. The effect of such factors as size and design of plates, formulation of the active materials, insulation, method of activation, composition of electrolyte, and charge and discharge characteristics are being considered. * * * One of the principal research tasks on battery components has been research on manganese dioxide, the depolarizer used in the LeClanche battery. Various manganese dioxide samples, though chemically identical by standard methods of analysis, do not perform equally in batteries. Prior to the start of the Signal Corps program, the only way of predicting the performance of manganese dioxide was to fabricate cells from each sample, store them for predetermined periods, and then discharge them to determine actual capacity characteristics. The Signal Corps program has taken three lines of investigation: (1) Extensive electron microscope, x-ray diffraction, and spectrographic studies have been made of samples of natural and synthetic manganese dioxide from many sources to determine differences in the physical structure of various samples and to predict the effect of these differences on battery performance; (2) investigation is underway to develop methods of chemical analysis which will detect potential differences in the battery capacities of various samples of manganese dioxide; and (3), actual cells

have been fabricated from various samples of manganese dioxide and subjected to initial and delayed capacity tests as a check on physical and chemical predictions . . . . . similar work is being done to obtain a method for evaluation of carbon blacks, the second component of dry cell depolarizers * * * Considerable work also has been done on the development of a dry cell using magnesium rather than zinc as the anodic material. Magnesium cans have been fabricated into test cells and subjected to an extensive testing program consisting of initial and delayed capacity tests of several cell sizes at various drains and temperatures. The magnesium anode shows promise of being superior to the zinc anode for use in dry cell batteries both from a performance and strategic materials point of view * * * Since military batteries must perform under all temperature conditions, the Signal Corps has conducted extensive investigations into the low-temperature design and operation of batteries. Experiments have been made using various electrolyte formations, modification of the geometrical design, modifications of the physical and chemical construction of battery components to determine the low-temperature effects of these variables * * * Extensive research has been conducted on the preparation and evaluation of positive and negative sintered plate nickel-cadmium electrodes using different amounts of active materials to evaluate optimum conditions for manufacturing these electrodes, with particular emphasis on their use at high current drains and low temperatures. In these studies sintered plates of varying dimensions were used. These plates were impregnated with active materials under varying conditions, such as different pregnating solutions, impregnation under vacuum and atmospheric pressures, at various temperatures, various soaking periods and different impregnation-procedures. The capacities of these

variously prepared electrodes were determined under different conditions at temperatures varying - 40° to+27° C and with different electrolytic conditions * * * In the nickel-cadmium storage battery, domestic nickel powders have proven unsatisfactory. To uncover the reason for this, nickel powder from various domestic and foreign sources has been investigated with respect to microstructural characterization by electron and optical microscopy, surface energy characteristics, and sensitivity to electron bombardment. It is hoped this work will lead to a satisfactory nickel powder specification for nickel cadmium battery application * * * Dry cell batteries for military use require carbon blacks not presently manufactured in this country. Research is directed toward investigating all available sources giving particular attention to the effects of structural characteristics on the electrical properties of the blacks as used. A variety of carbon blacks has been investigated with respect to: (1) crystalline structure characteristics by means of x-ray and electron diffraction; (2) microstructure, particle size and state of aggregation by electron and optical microscopy and other physical chemical methods; (3) relation of type of source material to microstructure and crystal structure; and (4), relation of method of manufacture to physical characteristics. Several types tested show promise as being a suitable manufacturing material * * * The electrochemical reactivity and stability of manganese dioxide used in dry cell batteries varies significantly from one ore deposit to another or with its method of synthesis. At present the United States is dependent upon a single foreign deposit for manganese dioxide suitable for military dry batteries. Complete analyses of a large number of domestic, foreign, and synthetic samples have been made. A large number of manganese oredeposits have been characterized by their utility in dry cell batteries. The influence of the synthetic processes on

on the crystallographic microstructural and chemical characteristics of manganese dioxide have been determined for a large number of synthetic samples. Manganese dioxide with desirable dry battery characteristics has been prepared by the thermal decomposition of manganese carbonate * * * Basic investigations on electrochemical combinations for both primary and secondary cell types are underway directed toward the development of a primary battery more suitable for military application, including such features as longer operating life, lighter weight, greater ampere-hour capacity, longer storage life and improved low temperature operating characteristics. This research includes electrochemical combinations which are reversible and therefore applicable to storage batteries. The ferric chloride and liquid sulphur dioxide systems appear particularly promising at this time * * * In other investigations particular attention is being given to the problem of low temperature operation for both primary and secondary batteries with an objective of satisfactory operation down to -60° C. Specific problems being studied in one phase of this investigation include: (1) Polarization of zinc and mercuric oxide electrodes in the RM electrolyte; (2) storage tests of the Zn/I_2 cell; (3) cells of the type Zn/Eut LiCl plus $NaCrO_4/MnO_2$; and (4), physical properties of solvent - electrolyte systems. Another investigation is directed toward the design of a dry cell which will operate at -54° C and which will give at that temperature at least 50% of the capacity delivered by a standard dry cell at 21° C under the same discharge conditions * * * In the field of special purpose storage batteries, investigations are under way with the objective of finding an electrochemical system, other than the lead - acid, capable of high rate discharge capacities at temperatures ranging from -55° to $+70^{\circ}$ C. Encouraging results are appear-

ing with a pile-type of construction using magnesium and cuprous chloride. Such a battery appears particularly promising for meteorological upper atmosphere probing, which application imposes a most stringent requirement on the batteries used * * * Another investigation receiving considerable support is directed toward the development of techniques whereby magnesium may be used in place of zinc for the anodic material in dry cell batteries. Specific phases of the investigation include studies on: (1) electrochemical properties of magnesium with reference to dry cell construction; (2) corrosion of magnesium when used as the anodic material in dry cells; and (3), theories of reaction taking place in cells constructed with magnesium anodes. This work is yielding very promising results in that the magnesium dry cell shows indication of having twice the watt hour capacity of the equivalent sized zinc cell. Added features are that magnesium is available in great abundance, and that the same machinery can be used for the manufacture of either the magnesium or zinc cell * * *

(3) Thermoelectric: For many military applications thermoelectric generators would be ideal were it possible to increase the efficiency of present devices by an order of magnitude of two. They are noiseless in operation, could use available fuels, and in cold weather use could be made as a combination heater and power supply. Basic research, therefore, is underway for the purpose of improving the understanding of thermoelectric properties of materials, and for developing a thermocouple of improved efficiency for use in thermoelectric generators. In this work, theoretical expressions for obtaining maximum efficiency were set up and based on this study a group of the most promising materials were selected for experimental purposes, such as carbon, silicon, gallium, germanium, arsenic, selenium, tin, antimony,

tellurium, iodine, bismuth and polonium. On materials selected from this list, studies have been conducted on trace impurities. Particular attention was first paid to germanium and germanium - phosphorous alloys which, on a theoretical basis, seemed ideal for use in thermoelectric generators. While the theory proved accurate for small samples tested over a narrow range of temperatures, it was not accurate when applied to large samples and large temperature gradients present in thermoelectric generator applications. Germanium, therefore, was abandoned. Work is now being directed, particularly, to attempt to obtain a more favorable ratio of thermal conductivity to electrical conductivity in various thermocouple materials, particularly zinc and antimony alloys, by altering the physical structure of the material. For example, initial tests on bismuth indicate that compressed powdered has about 65% of the thermal and 90% of the electrical conductivity of solid bismuth * * * Related investigations also include a search for a fluid with good heat transfer properties which will withstand temperatures of approximately 550°C. Also, attempts have been made to develop a zinc-constantin thermocouple with improved characteristics as to breakage from the brittle nature of the material, oxidation at the hot junction, and migration of the zinc.

SECTION XII- RESEARCH ON PHOTOGRAPHY

(1) Introduction: As herein applied, photography is intended to cover all aspects of taking and projecting still and motion pictures, including cameras and projectors, lighting units, flash equipment, exposure meters and general accessories, as well as enlargers, and developing, printing and processing equipment. Primary responsibility for all research and development in photography for the Army, with the exception of photomechanical (printing) processes and mapping, is assigned to the Chief Signal Officer. In the discussion which follows the above field will be limited to research underway in the fields of photophysics and photochemistry, including emulsions, sensitization, film bases, processing compounds, light sensitive materials, phosphors, optics of lenses and mirrors, photoconductivity, optical compensation, intermittents, camera control, interlocks, lens-rangefinder coupling, etc.

(2) Photophysics: Typical of the problems carried under the subject of photophysics are: (1) studies of factors affecting lens-film resolving power; (2) studies of factors involved in the design of two-mirror oblique reflecting systems; (3) investigation into the problem of image motion compensation with a rotating prism; (4) studies on the Zeiss lens collection; (5) studies of electro-viscous intermittent movement as required for motion picture projection equipment; and (6), some types of non-conventional photography * * * As part of (6) above, electrostatic electrography is now receiving considerable research effort. The basic physical concept centers around use of materials having high insulative properties in darkness which change to conductive upon exposure to light, that is, photo-conductors. Such a material in thin sheet form, if electrically charged under conditions

of darkness will, if exposed to an illuminated subject through a conventional optical system, assume a surface charge distribution corresponding to the incident light pattern if the photoconductive sheet is backed by a conducting plate so the electrical charges in the illuminated areas may be drawn away during the period of illumination when the exposed regions become conductive. The latent image thus acquired may be developed by several methods. The entire process is termed electrography. Based on results obtained to date, it appears that eventual achievement may lead to: (1) 20-30 lines per millimeter in permanent dry prints with high-quality continuous tone reproduction; (2) exposure speeds equivalent to ASA 64 (daylight) with a spectral response equivalent to panchromatic film and extending to the far infrared; (3) retention of sensitivity for a period of 12 hours or more with initial photoconductive materials, while present indications with CdS and ZnS suggest far greater retention with erasure only by infrared radiation; (4) uniformity of plates or films; (5) sensitization, development and printing procedures which are simple and easily operable; and (6) satisfactory operation over extreme humidities and high temperature ranges. Most of the objectives listed are today not realizable and, accordingly, constitute the goals of an extensive applied research program on the more important phases, for example: (1) the preparation of electrographic plates, experimenting with many types of materials through detailed study of their various optical and physical characteristics; (2) sensitization and printing techniques; (3) increasing plate speed and spectral sensitivity, particularly in the region of longer wavelengths; (4) synthesis of photoconductive compounds to determine their physical constants and optical properties with particular reference to materials containing highly condensed ring structures having extended conjugated systems; and lastly (5) the general problem of theoretical studies of various physical and chemical processes which may result in shortening or eliminating the necessity of somewhat empirical approaches now being taken on certain phases of the work.

(3) Photochemical: The problem of removing contaminants in photographic wash water has been under study for some time. The best solution found so far involves an ion exchange process for the selective removal of specific interfering ions resulting thereby in the rejuvenation of processing solutions. In this process demineralization studies on photographic wash water were made at rapid rates of recycling through a model system, and it was found that thiosulfuric acid was taken up as such, and silver in the complex anionic form. Little decomposition of thiosulfate was found to occur. It has also been established that the resin acid bed employed could be regenerated successfully, and present indications are that this is also true of the anion bed. Applied research in this field has advanced to where the utilization of the process appears definitely within reason, and effort is now primarily directed toward synthesizing the best possible material for selective removal of the undesirable ions. *** In the field of color film, research has continued directly toward reducing the time required for processing. Some of the investigations underway are: (1) study of the possible application of spray processing techniques at elevated temperatures; (2) investigation of the use of sodium arsenite as a possible substitute in the present use of either sulfite or bisulfite ions; (3) studies of the chemistry involved in the development process at temperatures as low as 20° C. *** Research is being directed toward increasing the light sensitivity of diazo type substances, with the hope that the light sensitivity and continuous tone reproduction of presently known silver halide emulsions can be approached. The military objective of this research is to evolve a light-sensitive material, which after exposure, may be developed by dry or gaseous means, it

being known, for example, that diazo materials are developed by exposure to ammonia vapor. Accordingly, the photodecomposition of diazonium compounds are being studied to determine the quantum efficiency of such materials and to ascertain whether or not a sufficiently high efficiency is possible to achieve the desired objective * * * Studies are underway towards evolving an acclimatized silver halide film having properties suitable for Arctic as well as tropical regions. The problem is essentially one of finding a temperature stable film base and of applying the proper suitably treated silver halide emulsion to such a base giving a mutually compatible material for use in the temperature range of -55° to $+60^{\circ}$ C. Major effort in this field is being concentrated on film base development beginning with cellulosics, and on their high molecular weight fractions. This work will later be extended to other possible polymers. At this time it appears promising that a suitable film base can eventually be synthesized by the proper choice and balancing of the effects of substituent ether and ester groups on the cellulose molecule * * * Investigations of means for expediting the processing of black and white film is under study with the most promising results appearing through use of high temperature, high energy developers. Monobaths consisting of a combined developer and fixer have been studied for application in processing of films and prints. The effect of wetting agents upon the sensitometric characteristics of black and white film have been investigated. Ten second development of black and white film has been found practical through the use of high temperature, high energy developers. Further research involving the use of the monobaths and wetting agents is underway * * * Investigations have been started directly toward the development of sensitometric procedures suitable for the evaluation of various photographic materials and processes. During

the initial phases of this work the scope of this effort has been limited to time-scale studies of black and white film and paper * * *. In the field of infrared photography, research is underway to improve or discover new phosphors potentially suitable for such utilization. Work underway includes investigations on stimulation type phosphors, such as copper-lead activated zinc sulfides; effects of activator concentration, impurities, and additions of selenide and cadmium in quenching type phosphors such as the class of copper-cobalt activated zinc sulfide; and increasing infrared sensitivity by substitution of cobalt by iron or nickel or other transition elements.

SECTION XIII - MISCELANEOUS SUBJECTS

(1) Radiation Physics: The Signal Corps has recently been assigned certain Department of the Army responsibilities in the development of instruments for radiological detection purposes. Accordingly, instruments are being designed for the event of conflict, should it involve use of nuclear energy or attendant by-products. The research aspects of this program are directed toward providing basic physical data necessary to ascertain new and improved methods or techniques for indicating the presence of nuclear disintegration products such as alpha particles, beta particles, neutrons and gamma rays. A few research projects now underway are briefly discussed below * * * A recent addition to the field of radiological detection instruments is built around certain crystals which emit light scintillations upon stoppage of a nuclear disintegration product. When such materials are transparent to their own resonance radiation, an effective radiological detector can be constructed by placing the crystal in a light-proof cell in front of a photo-multiplier tube which responds to each individual scintillation caused by collision. The limiting factor in the sensitivity of such a device is noise generated within the photomultiplier circuity. Recent work has resulted in a plan for greatly reducing such undesirable noise. The system devised involves a single stilbene crystal which serves as the source of scintillations. Surrounding this crystal are three individual photomultipliers, each with its own amplification system. The output of one photomultiplier is connected to the horizontal plates of a cathode ray tube, another to the vertical plates, and the third serves to modulate the intensity grid of the tube. Thus a single count produces a bright line extending between the horizontal and the vertical axis. Random noise affects each photomultiplier separately and the probability of coincidence on a noise

pulse on one or both of the other counters is very small. For example, where a single photomultiplier cell might show noise counts as high as 2000 per second, the combination of three such cells and the requirement for simultaneity reduces the same noise count to one every four seconds .... with of course, a corresponding greatly improved sensitivity of response to scintillations which occurs simultaneously on each of the three photoelectric pickup. Work in this field is continuing. * * * Related to the above, a number of materials are being investigated for purposes of determining optimum conditions for instrument development. Excellent naphthalene crystals have already been synthesized. The projected program includes work on anthracene, sodium iodide, potassium iodide, zinc sulfide, and other. In the search for materials which will give the greatest signal-to-noise ratio for the counting of gamma rays, factors as follows are being investigated: study of crystal growth; investigation of the existence of a counting plateau; dependence of the signal on the size and the shapes of the crystals; dependence of the signal on crystal structure, impurities and strains; temperature dependence of signal and noise; photomultiplier design and color matching in the case of the scintillation counter; circuit designs for amplifiers, scalers, etc; and investigation of the resolving times of the counters.

(2) Sound: Theoretical and experimental investigations are underway directed toward developing magnetic recording techniques to the highest possible frequency. Recorders of this type are required in connection with studies on shock and vibration, and for panoramic receiver; and other applications in which it is desired to store or delay transient electrical signals for eventual undestorted presentation by optical or aural means. Frequency ranges of approximately 100 kc are realizable at this time * * * A mag-

netostrictive supersonic generator operating at 100 kc has been designed and constructed in connection with supersonic pulse reflection equipment studies. *** Other work in this field is centered about condenser type supersonic transducers, and units have been produced which have relatively flat response up to about 100 kc. Very small transducers (about 1/16" cube) using barium titanate have been constructed and preliminary tests of the first units indicate a sensitivity about 20 db. lower than previously used crystal units. It is expected that these barium titanate transducers will prove exceedingly valuable in probing very-high frequency sound fields. In the same field, work on absorption of supersonic waves in air at low temperature is continuing.

(3) Infrared: Work is underway in the design and construction of a solar spectrograph for the purpose of investigating the very-far infrared region of the solar spectrum up to and including ultra-high radio frequencies. This work is of particular interest in that this investigation will tend to bridge the gap between that portion of the spectrum generated by incoherent radiation from a heated body as compared to coherent radiation generated by microwave oscillators such as magnetrons, klystrons, etc.

(4) Radiating Systems: Whenever electromagnetic energy is to be transmitted through free space, requirements exist for terminal equipment through which to initiate radiation, and later to intercept such radiation after passage through space. Since military interest in the electromagnetic spectrum includes wavelengths ranging in length from in excess of 1000 meters down to a few millimeters, it is apparent that a most diverse field for research exists under the general terminology of "radiating systems." However, some of the Signal Corps research in this field is so closely

related to specific end items that any discussions thereof would necessarily require that the end item itself serve as the point of departure to adequately explain the terminal equipments involved. In part, such discussions appear elsewhere in this writing. Other portions of research in the field of radiating systems are of such a basic nature that results are applicable to many particular equipments under development, or only yet being contemplated. In the brief summary which follows, certain problems illustrative of the latter category will be mentioned. *** A model system is being constructed associated with an artificial earth with the objective of being able to study and predict performance of, through use of microwaves, phenomena to be expected from full scale devices under engineering design. As a related part of this program, and for free-space predictions, an automatic pattern-measuring device operating in the microwave range, is also being set up for determining field patterns of antennas and arrays. *** A basic study is underway with the objective of devising means of modifying metallic surfaces so as to cause them to radiate a beam of energy whose shape can be controlled. The surface may be excited by slots or by a horn directing energy tangential to the surface. One such means of controlling this energy would be a series of ridges or corrugations on the metal surface and, in fact, has been used in the past to guide electromagnetic energy across a metallic surface between two points. It is proposed in this research to extend this principle still further in order to direct the radiation into outer space. *** Another related investigation involves studies of various types of metallic delay lenses for antennas in which the phase velocity of the RF energy is decreased rather than increased as in earlier types of metallic lens antennas. The proposed type will retain the light-weight

advantage and in addition, appears to not be as frequency sensitive over wide ranges of frequency. *** Another study involves investigations of the characteristics of antennas placed in a dissipative medium. This study includes: (1) The propagation of electromagnetic waves across the boundary of two media, one of which is dissipative; (2) Radiation from an ideal dipole; (3) Extension of the integral equation method to cylindrical antennas placed in a dissipative medium; and (4) Analysis of insulated radiating systems based on biconical antenna theory. *** A study is underway involving antenna measurements on two-wire lines with objectives to: (1) Make impedance measurements of symmetrical antennas when driven by various ways; (2) Investigate difficulties involved in the use of open-wire lines for impedance measurements; and (3) Investigate self / and mutual impedances of coupled antennas. *** Other basic studies in the field of radiation systems include: (1) Impedance measurements on a receiving antenna; (2) The spherically capped conical antenna; (3) Measurements on an open-wire image-plane line; (4) Cylindrical antenna and other loads center-driven from two-wire open line; (5) Graphical representation of the characteristics of cylindrical antennas; (6) radiation from two-wire lines and certain types of antennas over conducting planes; (7) Investigation of gap effects for antennas driven by coaxial lines; and (8) The theory of coupled antennas.

(5) Low-Temperature Physics: The study of low-temperature phenomena constitutes one of the most fertile fields for research today. Little is known of the behavior of matter as thermal motion, always present at normal temperatures, is reduced by lowering the temperature toward absolute zero. Work in this field is now giving broader conceptions of the real meaning

of statistically derived entities such as heat, entropy and temperatures. Strange applications will undoubtedly spring forth as new discoveries are made. It is already known that at extremely low temperatures, matter exhibits novel responses to the stimuli of electricity, magnetism and heat. Some materials become superconductors, others screen against magnetism, still others show propagation of a new form of wave motion, while one form of helium appears as a fourth state of matter not being definable as either a solid, liquid or gas. The Signal Corps program includes a number of projects delving into the low-temperature frontier. *** There is work underway in semi-conductors such as germanium which even at room temperature show mysterious and little understood properties, as exemplified by the transistor, which although being a solid, possesses many of the properties of electrons acting in vacua. Exploration of germanium and other similar materials will be made at temperatures down to that of liquid helium. *** Work is underway in studying the microwave surface impedance of conductors such as copper, silver, tin and lead from 300° K to 5° K, at frequencies as high as 24,000 mc. *** Magnetic cooling techniques are being studied in which a paramagnetic salt such as ferric ammonium alum is sealed off in a glass tube with a low pressure of helium transfer gas. The isothermal heat of magnetization is conducted into the liquid-helium bath by the transfer gas, but this gas is absorbed during demagnetization, leaving the process practically adiabatic. The flow of heat by thermal contact of the corners of the salt crystals with the glass tube immersed in the liquid helium bath is very small. Temperature measurements are accomplished through determination of the susceptibility of the salt using mutual inductances and a ballistic galvanometer. With a magnetic field of 30,000 gauss, a

temperature of .024° K has been obtained. *** Other work underway in the low-temperature field includes studies on the elastic and inelastic behavior of metals and x-ray structure of superconductors, in the latter problem, it being thought that small structural changes may take place in superconductors below their transition temperatures.

SECTION XIV - COORDINATION OF RESEARCH

(1) The Research and Development Board: The research activities described in the preceding Sections are, for the most part coordinated, with related activities of the other Services, through the organizational structure of the Research and Development Board under the Chairmanship of Dr. K. T. Compton. In the many Committees, Panels and Sub-Panels, all related work is continuously subjected to review in order to avoid duplication, filter out and terminate mediocre or wasteful effort, plan future programs for maximum effectiveness within budget limitations..... and more recently, assign cognizance in specific areas of activity to a single Service with the objective of improving unification and even further reducing the possibility of duplication in effort among the three Services. In basic research, however, some of these tasks have been difficult, for truly fundamental scientific endeavor appears to thrive best under competition, and parallel, (not identical) approaches to the same problem is often most beneficial and gives a greater assurance of ultimate success. A skeleton chart of the Research and Development Board is given in Figure 3 in which those elements of the organization in which the Signal Corps has membership are indicated.

RESEARCH & DEVELOPMENT BOARD

SECRETARIAT

COMMITTEE ON AERONAUTICS *

PANELS:
- PILOTED AIRCRAFT
- AIRCRAFT ARMAMENT
- AIRCRAFT PROPULSION SYSTEMS
- FACILITIES
- AIRCRAFT EQUIPMENT
- AIRCRAFT MATERIAL

COMMITTEE ON ATOMIC ENERGY

COMMITTEE ON BASIC PHYSICAL SCIENCES *

PANELS:
- CHEMISTRY [a]
- PHYSICS & MATHEMATICS [a]
- MECHANICS
- METALLURGY [a]
- JOINT PANEL ON METALLURGY
- INTERCOMMITTEE PANEL ON METALLURGY

COMMITTEE ON CHEMICAL WARFARE

COMMITTEE ON ELECTRONICS *

PANELS:
- *ACOUSTICS [a]
- *ELECTRON TUBES [a]
- *RADIATING SYSTEMS [a]
- *COMMUNICATIONS [a]
- *INTERFERENCE REDUCTION [a]
- *RADAR [a]
- *COMPONENTS [a]
- *ELECTRONIC COUNTERMEASURES [a]
- *INFRARED [a]
- *TEST EQUIPMENT [a]
- *TELEVISION WORKING GROUP [a]

COMMITTEE ON EQUIPMENT & MATERIALS *

PANELS:
- *ELECTRICAL EQUIPMENT
- *PHOTOGRAPHY & OPTICS

COMMITTEE ON FUELS & LUBRICANTS

COMMITTEE ON GEOGRAPHICAL EXPLORATION

PANELS:
- EXPEDITIONS
- GEOGRAPHIC ENVIRONMENT
- PHYSIOLOGY

COMMITTEE ON GEOPHYSICS & GEOGRAPHY *

PANELS:
- *ATMOSPHERE
- *GEOLOGY
- HYDROLOGY
- OCEANOGRAPHY
- SEISMOLOGY, SOIL MECHANICS, VOLCANOLOGY
- CARTOGRAPHY AND GEODESY
- GEOPHYSICAL INSTRUMENTATION
- *ARCTIC ENVIRONMENT
- *DESERT & TROPICAL ENVIRONMENT
- TERRESTIAL MAGNETISM & ELECTRICITY

COMMITTEE ON GUIDED MISSILES *

PANELS:
- AERODYNAMIC & STRUCTURES
- *COUNTERMEASURES [a]
- FACILITIES
- GUIDANCE & CONTROL [a]
- LAUNCHING & HANDLING
- PROPULSION & FUELS
- WARHEADS & FUSES
- TEST RANGE PROCEDURES & INSTRUMENTATION [a]

COMMITTEE ON HUMAN RESOURCES

PANELS:
- HUMAN RELATIONS & MORALE
- MANPOWER
- PERSONNEL & TRAINING
- PSYCHOPHYSIOLOGY

COMMITTEE ON MEDICAL SCIENCES

PANELS:
- AVIATION MEDICINE
- MILITARY & FIELD MEDICINE
- SHIPBOARD & SUBMARINE MEDICINE

COMMITTEE ON NAVIGATION *

PANELS:
- *AIR NAVIGATION
- *LAND NAVIGATION
- *MARINE NAVIGATION

COMMITTEE ON ORDNANCE

PANELS:
- AMMUNITION & EXPLOSIVES
- ARMOR & VEHICLES
- *FIRE CONTROL
- GUNS
- ORDNANCE MATERIALS
- *PROXIMITY FUSES
- UNDERWATER ORDNANCE

AD HOC COMMITTEE ON SCIENTIFIC & SYNTHETIC WARFARE

PANELS:
- SUBPANEL ON SYNTHETIC ACTIVATION OF MILITARY COMMAND SYSTEMS [a]
- SUBPANELS ON INTERCONNECTION OF COMPUTERS [a]

SPECIAL COMMITTEE ON TECHNICAL INFORMATION

SPECIAL COMMITTEES & PANELS

COMMITTEE ON LOGISTICAL TECHNIQUES

COMMITTEE ON VESSELS

SPECIAL COMMITTEES & PANELS

*- DENOTES SIGNAL CORPS MEMBERSHIP ON COMMITTEES AND PANELS.

FIGURE 2

(2) Joint Service Contracts: In compliance with the spirit of the Unification Act, a number of the large research contracts, in which more than one Service has direct interest, have been established on a Joint Service basis, each Service contributing funds and directly assuming the responsibility for the integration of such effort into its own respective applications. On such contracts, Joint Service Advisory Committee Meetings are held periodically with the contractors' scientific personnel. Inter-Service coordination on such contractual activities therefore follows automatically. Table 3 shows contracts of this type in which the Signal Corps has direct interest.

SECTION XV - CLOSING REMARKS

In compiling the material presented herein, it was obvious from the start that any degree of completeness in a field as broad as the entire Signal Corps research program would be impossible within the space limitations set for this presentation. Many complex projects were passed with only a single sentence description while hundreds, and even thousands, of words together with photographs and graphs might be required to effectively portray a single specialized activity. It is hoped, however, that an appreciation of the broad scope of the program will be of value to the reader, and further, that the presentation may have additional value in some cases by showing the existence of particular research, with the realization that if a military requirement for detailed information exists, the reader may obtain such through established channels. *** As a closing word, the writer wishes to extend his apologies for not having been able to individually recognize the many scientists whose combined effort this writing portrays..... civilian scientists in the employment of the Signal

Corps Engineering Laboratories and members of industrial or academic staffs under contract..... all working together in a combined effort for improving this Nation's strongest line of defense..... scientific advancement!

JOINT SERVICE CONTRACTS

Institution	Fields of Investigation	Contract No.	Supporting Services	Remarks
Research Lab. of Electronics, MIT	Microwave, Electronics, Physics, Communication & associated problems	W36-039 sc-32037	SigC AMC ONR	
Cruft Laboratory Harvard University	Electromagnetic Radiation & Wave Propagation, Microwave Circuits, Physical Electronics	N5ori-76 T.O.1 & T.O.28	ONR SigC AMC	
Plastics Laboratory Princeton University	Plastics, Synthetic Resins, Flexible Insulations & Insulating Oils	W36-039 sc-32011	SigC ONR AMC	BuShips also has representation.
General Electric Co.	Cloud Studies, Techniques for Artificial Nucleation of Clouds, Instrumentation	W36-039 sc-38141	SigC ONR	Aircraft & assoc. personnel furnished by USAF.
Radiation Laboratory Columbia University	Generation of Supermicrowaves, Microwave Techniques & Apparatus, Microwave Physics, Tube Fabrication.	W36-039 sc-32003	SigC ONR	
Stanford University	Tunable Circuits and Non-Scanning Spectrum Analysis, Wideband Oscillators, Traveling Wave Tube Principles, Propagation Effects of Ionization Due to Meteors.	N6onr-251 T.O.VII	ONR SigC	
Laboratory for Insulation Research MIT	Dielectric Materials, Microwave Research Spectroscopy, X-Ray & Electron Diffraction, High Voltage Breakdown	N5ori-78 T.O.1	ONR SigC AMC	
Armour Research Foundation	Magnetostriction Frequency Control	W33-038 ac-21118	AMC SigC	
New York University	Serves in Coordinating all Govt. sponsored Electron Tube Research and Development.	W36-039 sc-44585	SigC AMC Bu Ships	Secretariat for Panel on Electron Tubes, RDB

TABLE 3

JOINT SERVICE CONTRACTS

Institution	Fields of Investigation	Contract No.	Supporting Services	Remarks
Electro-Technical Lab., Bureau of Mines	Studies on Production of Synthetic Mica	Na-ONR 35-47	ONR SigC	
Univ of Alaska	Arctic Tropospheric Propagation	W28-099 ac-414	AMC SigC	
Western Elec. Co.	Studies pertaining to the application of transistors.	W36-039 sc-44497	SigC AMC BuShips	