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SURVEY OF RADIO FREQUENCY RADIATION HAZARDS

Constant

14 June 1960

Prepared under Navy, Bureau of Ships
Contract No. NObs-77142

Summary Report

20 May 1959 through 19 May 1960

MIDWEST RESEARCH INSTITUTE

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by

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M.R.I. Project No. 2307-E

Midwest Research Institute
Kansas City, Missouri

PREFACE

This program has been under the leadership of Mr. Paul C. Constant, Jr. Messrs. William H. Ashley, Jr., Burton R. Baldwin, Paul C. Constant, Jr., Bernard L. Jones, E. J. Martin, Jr., Robert F. Rice, and Lambert Runge have been responsible for the material contained in this report. Appendix I, Notes on Instrumentation, is a discussion prepared by personnel from the Welex Electronics Corporation, consultants to Midwest Research Institute on this project.

Approved for:

MIDWEST RESEARCH INSTITUTE

Warren E. Snyder

Warren E. Snyder, Manager
Engineering Division

14 June 1960

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SUMMARY

As part of a tri-service Radiation Hazards (RAD HAZ) program, Midwest Research Institute has been engaged in obtaining and analyzing data and information to provide a basis for formulating RAD HAZ standards. Approaches to the problem have been taken which required consideration of the RAD HAZ program from a broad and thorough viewpoint. Activities have included a review of the requirements of the program, an investigation of problems involved in radiation hazards, and investigations of the fundamental phenomena of r-f propagation. Specific emphases have been placed upon r-f measuring instrumentation and upon terminology.

During the period of the subject contract substantial progress has been made in the following:

1. Evolution of RAD HAZ Standards;

2. Determination of the subject matter to be contained in the RAD HAZ Standards;

3. Substantiation of the need for better r-f radiation measuring equipment;

4. Establishment of needed r-f radiation measuring equipment;

5. Origination of new concepts for sensing r-f radiation fields;

6. Use of the total r-f radiation field as a basis for design of measuring equipment;

7. Tentative definitions of pertinent RAD HAZ terms;

8. Compilation of a RAD HAZ bibliography; and

9. RAD HAZ Project Document File.

The evolution of RAD HAZ Standards is outlined in Fig. 1, p. 7, which presents the basic philosophy and organization of activities necessary for the formulation of standards.

The subject matter which composes the proposed standards is categorized in the following eight divisions:

1. Terminology;

2. Units of measurement;

3. Measurement techniques and procedures;

4. Tolerable levels of r-f radiation;

5. Safety regulations;

6. Protective materials;

7. Specifications for suitable r-f measurement instrumentation;

and

8. RH (Radiation Hazards) code system.

The substantiation of need for better r-f radiation measuring equipment and establishment of needed r-f radiation measuring equipment has been based upon basic engineering studies performed in the area of instrumentation, a survey of available commercial equipment, and witnessing of EMR (electromagnetic radiation) measurements aboard the USS Estes.

Two engineering studies undertaken in the area of instrumentation were (a) r-f propagation in the "near field", and (b) power density measurements. In addition, investigations of the Hall effect opened an avenue of research for a possible new piece of power density measuring equipment.

Use of the total r-f radiation field as a basis for design of measuring equipment was investigated. Initial calculations based upon a differential current element showed that the static and induction fields produce a large flow of instantaneous energy close to the radiating source although they do not contribute to the time average flux of energy at any point in the field. This indicates that it is necessary to understand the basic problem of a particular hazard, whether it is in the ignition of fuels or munitions, so that the proper type of instrument may be designed and used for measurements; that is, peak power, broad-band integrated power density instrument, etc.

A preliminary list of pertinent RAD HAZ terms and their tentative definitions has been made and is presented in Appendix K.

A RAD HAZ bibliography, comprised of approximately 500 references, has been compiled and is given in Appendix C.

A Project Document File system has been under trial whereby specific information contained therein may be readily retrieved. This project file contains pertinent documents in the RAD HAZ field, and the file system under trial has been proven to be efficient.

In addition to the project activities reported here, project personnel have taken an active part in the ASA C-95 Sectional Committee on Radio-Frequency Radiation Hazards.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been reached as a result of studies made on this project during the period covered by this report.

1. There is a lack of understanding of r-f propagation in the "near field" by many investigators working in the field of R-F Radiation Hazards. Considerable attention has been given to the problems of geometry and integration associated with "near field" calculations in published literature. Although these problems are important in the analysis of the near field produced by any antenna of finite size, they do not fully develop the fundamental differences between propagation energy in the near and far fields. An understanding of these differences is essential to considerations in the standards program for instrumentation and techniques to be used in near field measurements. The engineering study performed on this project of energy propagation in the near field by the calculation of the total electromagnetic field of a differential current element has enabled project personnel to delineate these differences for future use in preparing standards and equipment specifications.

2. Instruments based upon the Hall effect can be made for sensing r-f radiation fields.

3. There is need for better r-f radiation measuring equipment. The general types that are needed can be classified as:

a. Personnel warning instrument: This device must be capable of producing a local alarm (audible and/or visual) in addition to telemetering an analog signal, which is a function of power density, to a control station. It needs to be accurate, rapid in operation, and capable of being placed in potential r-f hazard areas for considerable lengths of time. The main function of this instrument is to rapidly alert personnel of the hazardous conditions of areas for personnel, ordnance equipment or material, and volatile liquids or gases.

b. Broad-band integrated power density instruments: This type must be capable of measuring the integrated average powers resulting from simultaneous multiple frequency transmission. It must be portable (lightweight), accurate, and able to rapidly indicate existing hazard conditions.

c. Peak power instrument: This type instrument must be capable of rapidly determining the peak power delivered at any instant from a particular frequency source. It must be portable, accurate, and capable of examining the portion of the frequency spectrum from 14 kc. to 20 kmc.

d. Special measuring instruments: This class includes special instruments for laboratory, research, and field uses; an example is an r-f power-indicating instrument built into a missile.

It has become evident from MRI investigations and endeavors under the subject contract that increased project effort must be expanded on engineering studies leading to the formulation of standards. Effort is needed over an extended period of time, in varying degrees, on each division of the proposed standards. It is estimated that interim standards may be compiled on most of the categories of the proposed standards in a year's time with a level of effort similar to that of the subject contract.

Recommended project activities are outlined generally in Fig. 1, page 7, of this report. Specifically, however, it is recommended that project efforts be continued toward the formulation of interim standards related to r-f radiation hazards. The scope of the activities should be:

1. Perform further engineering studies and evaluation of the factors involved in r-f radiation hazards;

2. Participate in ASA C-95 Sectional Committee on r-f radiation hazards;

3. Continue research and development activities on new concepts for sensing radiation fields; and

4. Evaluate currently available r-f radiation measuring equipment.

I. INTRODUCTION

Electromagnetic radiation of sufficient energy can create hazardous environmental conditions for humans and materials. The seriousness of EMR (electromagnetic radiation) hazards on board some U. S. Navy ships necessitated a thorough investigation of the problem with respect to (a) personnel, (b) ordnance items, and (c) flammable, volatile fuels. To effectively conduct the required investigations of radiation hazards (from r-f sources in the range of 10 kc. to 20 kmc.), a tri-service program, called the RAD HAZ (Radiation Hazards) program*, was established with the over-all responsibility vested in Code 450, Bureau of Ships, Department of the Navy.

Midwest Research Institute has been engaged in the RAD HAZ program to obtain and analyze data and information necessary to provide a basis for the formulation of RAD HAZ standards.

This summary report covers the work accomplished on the subject contract during the past year, 19 May 1959 - 20 May 1960. Discussions are given on the approaches taken in the preparation of standards, which include (a) programming the evolution of RAD HAZ standards, (b) basic engineering studies performed at MRI, and (c) engineering studies of the pertinent factors involved in the RAD HAZ program.

The evolution of standards will follow a program which was prepared to establish and control the avenues of approach used in preparing the standards.

The basic engineering studies performed were related to (a) r-f propagation in the near field, and (b) possible new EMR measuring techniques. These two areas needed investigation because a comprehensive understanding of the basic phenomena involved was pertinent to the formulation of standards.

Engineering studies of pertinent factors involved in the RAD HAZ program provide a basis for the formulation of standards, which are to include (a) terminology, (b) units of measurement, (c) EMR measuring techniques and procedures, (d) tolerable levels of EMR for humans, flammable,

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* The RAD HAZ program is composed of three programs, namely, Bio-Effects, HERO, and SPARKS. These are concerned with r-f radiation hazards to personnel, ordnance items, and flammable, volatile fuels, respectively.

volatile fuels, and electro-explosive ordnance items, (e) safety requirements, (f) protective materials, (g) specifications for suitable r-f measurement instrumentation, and (h) RH (Radiation Hazards) code system.

II. EVOLUTION OF RAD HAZ STANDARDS

It was necessary to outline a philosophy of approach to the preparation of RAD HAZ standards because of the number of technical disciplines involved. The philosophy and organization which have been derived are shown in Fig. 1. Included are present, continuing, and future activities with an interdependence between sources of information and project efforts.

Activities leading to the formulation of interim standards (blocks 11-20) entail the study and analysis (block 9) of information related to the RAD HAZ compatibility program. This information is derived from (a) experience in related research and engineering endeavors, (b) technical publications and reports, (c) technical symposia and conferences, (d) existing standards, (e) shipboard (field) tests, and (f) research and engineering studies at Midwest Research Institute. These information sources (blocks 1-6) form a basis for continuing activities in the evolution of standards. Also, information flows from these sources to future activities (blocks 8 and 23).

Progress in evolving satisfactory standards is highly dependent upon future activities. Evaluation (block 10) of r-f radiation measuring equipment is a major artery in the complex network of activities. Evaluation of currently available and new measuring equipment (blocks 7 and 8, respectively) is mandatory before selection of interim measuring equipment (block 21) and derivation of proper equipment measuring techniques and procedures (block 22) can be made. Further, evaluation activities result in a necessary source of information and data for (a) continuing study and analysis (block 9) for the formulation of interim standards (blocks 11-22), and (b) study and evaluation (block 23), a future activity, from which RAD HAZ standards (blocks 24-31) can be formed.

The evolution of standards by the system described will depend greatly on the type of engineering studies made. It is imperative that these studies be designed for the understanding of certain basic phenomena, described in Section IV of this report.

The results presented in this summary report cover mainly the activities leading to the formulation of interim standards (blocks 11-20).

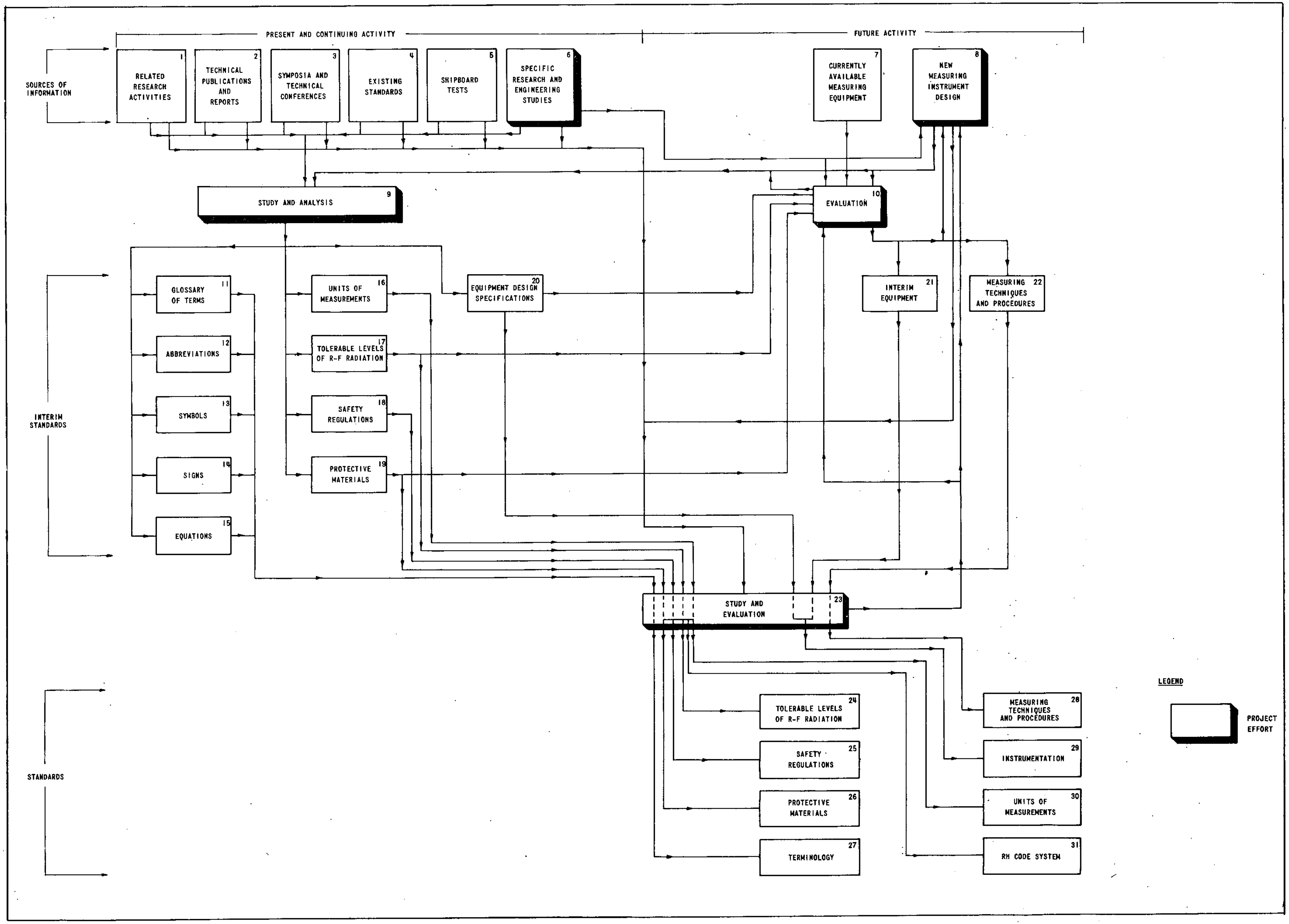


Fig. 1 - Evolution of RAD HAZ Standards

III. DOCUMENTATION

The subject contract necessitates the acquisition of considerable information and data for study and evaluation. This information comes from various sources (as shown in Fig. 1) and forms a documentation basis for the standards. The documentation process is a continuous collection of pertinent data and information.

A. Acquisition and Study of Pertinent Documents

The acquisition and study of pertinent documents has been an important activity on the project. These documents include such items as ASTIA reports, technical papers published in engineering and scientific journals, proceedings of related conferences and symposia, existing standards, and final reports on Government-sponsored work in influenced areas.

The documents acquired and/or reviewed have been obtained mainly as a result of (a) engineering studies (see Section IV of this report), (b) contact with contractors of existing Government-sponsored projects, and (c) research of the past and current literature.

Numerous documents have been reviewed. The deposition of these documents has formed a project document file which is discussed in Section III-F.

B. Symposia and Technical Conferences

Excellent sources of current information are symposia and technical conferences which have technical papers and discussions germane to the RAD HAZ standards.

As part of the project activity, project personnel attended several technical conferences. The purpose was to obtain information on the current state-of-the-art in the various areas of the RAD HAZ program, and to keep up to date in the various philosophies, aims, and problems. This activity aided greatly in planning the evolution of RAD HAZ Standards, shown in Fig. 1.

Six meetings have been attended. The first was a Radio Frequency Interference Seminar held in New York City during 15-16 June 1959, co-sponsored by the USAF Air Research and Development Command and the Institute of Radio Engineers - Professional Group on Radio Frequency Interference. The next two meetings were the third Annual Tri-Service Conference on Biological Effects of Microwave Radiation Equipments, held on 25-26-27 August 1959, and a HERO meeting (U. S. and U. K. personnel) in Washington, D. C., on 22 September 1959. The last three meetings were the Fifth Conference on Radio Interference Radiation and Electronic Compatibility, the 12th Annual Conference on Electrical Techniques in Medicine and Biology, and the Fourth Navy Science Symposium, which took place during 6-8 October 1959, 10-12 November 1959 and 9-11 March 1960, respectively.

C. Shipboard EMR Tests

In order to obtain a first-hand appreciation of RAD HAZ environmental conditions, radiation measuring equipment, and measuring techniques and procedures used aboard ships in RAD HAZ tests, project personnel witnessed such tests aboard the USS Estes while at sea during 8-11 February 1960.

A pictorial report of this field trip is given in Appendix A. The 25 pictures show the need for more suitable field instrumentation. This area of instrumentation is discussed in detail in Section V of this report.

D. American Standards Association C-95 Sectional Committee

The U.S. Navy has initiated a standardization project in radio frequency radiation hazards under the procedures available through the American Standards Association (ASA). A committee, ASA C-95 Sectional Committee: R-F Radiation Hazards, has been formed, sponsored by Bureau of Ships, Department of the Navy, and the American Institute of Electrical Engineers.

Project personnel have attended all committee and subcommittee meetings of the C-95 Sectional Committee, and have taken an active part in its functions. It is an excellent source of pertinent information and data for the subject contract. The following committee work assignments have been given to project personnel:

1. Investigate types of radiation measuring instrumentation needed for the RAD HAZ program;

2. Prepare reprints of the RAD HAZ bibliography which appeared as Appendix A of the Monthly Progress Report No. 7 on the subject contract for distribution to members of all of the ASA C-95 subcommittees; and

3. Investigate the literature for information for establishing energy susceptibility for fuels of concern on the RAD HAZ program.

E. Cognizance of Research and Engineering Work in Influenced Areas

Evaluation of past and current research and engineering work in the influenced areas, i.e., the HERO, SPARKS, Bio-Effects, and allied areas, is important in several respects. It is important to understand the various philosophies, aims and problems connected with radiation hazards. Communications, i.e., the terms, symbols, units of measurement, EMR measuring techniques and instrumentation, common to the different research groups should be clarified. Actual observation and performance of EMR measurements are necessary and vital to understanding the intricacies of the problems involved and to establish a basis upon which design specifications for instrumentation and measuring techniques and procedures can be made.

The capability of evaluating research and engineering work in the influenced areas entails a solid background in various engineering fields and technical areas such as, (a) r-f propagation in the near field, (b) theory of r-f absorption, (c) radiation producing sources (communication and radar antennas and missile guidance transmitters and control mechanisms), (d) electric and magnetic fields, (e) receiving antennas, and (f) ignition of flammable, volatile fuels.

The first step in the familiarization and the evaluation of research and engineering work in influenced areas was the acquisition and study of pertinent documents. This has been done by project personnel, as previously discussed in Section III-A.

Subsequent to and concurrent with the initial action, familiarization and evaluation of activities in influenced areas has been attained through functions cited in Sections III-B, III-C and III-D. In addition, personal visits have been made to companies actively engaged in related RAD HAZ work. Discussions on these visits are given in Appendix B.

F. Project Document File

During the performance of this project, a bibliography of pertinent references has been kept. The compilation to date is given in Appendix C.

For the efficient use of the bibliography a method has been under trial whereby specific information contained therein may be readily retrieved. This method was designed after consideration of various current methods.[1,2] An evaluation was made of such factors as (a) the anticipated maximum number of items, (b) the range of pertinent subjects within the scientific literature, (c) an effective cross-referencing system, and (d) categories of classification.

Each item is encoded according to author, subject, and ASTIA document number, if applicable.

McBee Keysort cards were selected for the medium on which to record the items in the bibliography. The basic selection categories of author, subject, and ASTIA document number are encoded on the periphery of the cards. An abstract, the source of availability (whether in the project file, the MRI library, the Linda Hall Library, etc.), and the appropriate library call number are shown on each card. All information about any item is contained on a single card.

Mechanical aids to indexing methods can only be advantageous if their use does not entail time-consuming hand manipulations. A manually operated system was preferred to a machine operated system, such as IBM punched cards, because of the economy of the manual method, and the relatively small number of items. However, it has been determined that the key sorting procedure can be partially mechanized to maintain a high system efficiency. The implementation of required mechanical devices has not been undertaken while the retrieval system was under test.

Use of the present retrieval system has indicated the need for an optimum number of index terms greater than the present system affords.. Although the basic method selected is as good as any system thus far examined and will suffice for the present, a greater number of index terms are needed for anticipated future growth of the document file. It is believed the relatively narrow field of RAD HAZ could be arbitrarily compressed into 27 index term categories; thus, the present McBee Keysort card can be used with minor changes in the coding system.

IV. ENGINEERING STUDIES

The purpose of engineering studies undertaken on this project is to obtain a clear understanding of the fundamental phenomena involved in r-f radiation measurements so good standards may be derived whether they be in the definition of terms, selection of proper symbols, derivation of new terminology, or preparation of equipment design specifications.

Two engineering studies have been conducted to obtain a better understanding of the basic physical phenomena with which the standards are to be associated. These were on (a) possible new radiation measuring techniques, and (b) r-f propagation in the near field.

A. Possible New Power Density Measuring Techniques

Realizing the need for new methods of measuring the power density at a point or volume in space, two phenomena have been considered.

Recent investigations at Armour Research Foundation utilized the Hall effect as a basis for an instrument to measure power density over a narrow band of frequencies (30 cps to 15 kc.). "Hall effect" refers to the establishment of an electric field within a conductor placed in a magnetic field. The electric field is perpendicular to the current flow in the conductor and is a result of the interaction between the current and the magnetic field.

In the Armour investigations, the Hall voltage in the frequency range of 30 cps to 15 kc., using an indium antimonide crystal, was independent of frequency. Consequently, efforts were made by project investigators to obtain information on the state-of-the-art of this phenomenon. Other effects have been identified, such as the Nernst, Ettingshausen and Righi-Leduc effects, which are discussed along with the Hall effect in Appendix D.

The use of the Hall effect as a basis for a power density sensor over a broad band of frequencies looks promising from past work that has been done. It appears that it is possible to develop a portable instrument capable of making an integrated average power density measurement. Additional studies need to be made, as it is important to find semiconductors that are frequency-independent over the frequency spectrum of 14 kc. to 20 kmc. Further, appropriate associated electronic circuitry is needed to compensate for several variables which can affect final measurements in Hall effect base instrumentation.

Another effect called "pearl chain formation" was studied during investigations in the Bio-Effects area as a possible power-measuring instrument because of its nonthermal action. A short discussion of this aspect is given in Appendix E. It does not appear that this method could be used for practical field-measuring instrumentation; however, sufficient study has not been given to it to draw any definite conclusions.

B. R-F Propagation in the Near Field

In ordinary problems of far-field antenna pattern calculation, certain approximations can be made to greatly simplify the process of summing the contributions to the total electromagnetic field from the various parts of a finite source. These approximations are of two general types relating, respectively, to:

1. The physical nature of the field produced by each infinitesimal portion of the finite source; and

2. The geometry involved in the summation of the various contributions and the effects of this geometry on (a) relative phase, and (b) relative amplitude.

The engineering study concerning the propagation of r-f energy in the near field has been carried out in order to provide a more complete understanding of the true nature of the total electromagnetic field that exists near a source of finite dimensions, and to indicate how indiscriminate use of the far-field approximations can lead to erroneous and incomplete evaluation of these fields by calculation and/or measurement. This engineering study has comprised two phases related to the two general types of far-field approximations. The results of the first phase are summarized in Appendix F through a consideration of the total electromagnetic field of a differential, linear, thin-wire current element and how the properties of this field vary with distance from the source. The second phase, which represents an attempt to apply certain "exact" and "semi-exact" analytical techniques to the solution of the total field produced by an arbitrary current sheet, is still in progress.

V. COMMERCIALLY AVAILABLE INSTRUMENTATION

Each laboratory or group working on its specific problem in the over-all RAD HAZ program is directly or indirectly interested in r-f energy instrumentation. These individuals are well aware of their basic objectives and are striving for solutions to their problems. Some of the current research efforts are directed toward the development of a specific type of energy measuring instrumentation. Other research efforts are basic in nature, i.e., studies to determine the variables affecting the transfer of energy (such as frequency, weather, personnel, ordnance, distance and power radiated) and the modes of coupling between transmitter and the EED (Electro-Explosive Device). In all cases, some sort of measuring equipment is required to obtain data for their investigations. Usually, commercially available equipment is used. Sometimes special instrumentation is either constructed from available equipment or designed for the specific needs.

The various aspects of radiation hazards which are presently being investigated and the variety of environmental (electrical and otherwise) conditions presented on board ship, plus the broad spectrum of frequencies involved, necessitates different types of energy measuring instrumentation. Present commercially available equipment can be classified as thermal and field intensity.

The measuring equipment now used in field studies is either cumbersome (of the laboratory type) or oversimplified. Both of these qualities make the equipment unsuitable for shipboard or field use. In fact, the equipment is often not even adequate for laboratory research studies.

A survey of commercial measuring equipment has been made. A list of this equipment is given in Appendix G. In general, currently available microwave measurement equipment does not suffice for r-f field intensity studies. Most of the equipment is not easily portable, and it does not suffice for rapid measurements over the broad frequency spectrum which must be covered. The lightweight equipment available has inaccuracies and frequency limitations. This is also true with some of the more suitable (from a measurements standpoint) laboratory-type equipment.

Some of the equipment shown in Appendix G has been used for field measurements on board ship as well as in laboratories where hazard investigations are being made. Although the measuring techniques are time-consuming, data have been obtained and used. There is a question, however, about the repeatability of measurements and, as a consequence, the accuracy of measurements. This includes the meaning of the information obtained. From investigations in the Bio-Effects field (see Appendix H), it is apparent that it would be difficult to correlate results at different laboratories because of the uncertainty about what field measurements were made. For instance, can the equipment be used to make field measurements in both the near and far fields without corrections being applied? Also, are the same measuring techniques and procedures being followed? Further, is average or peak power measurement required?

In the field (in contrast to the laboratory) there are similar questions to be answered. Are peak or average measurements required? Does an integrated average power measurement, i.e., the sum of powers at a particular location due to simultaneous multiple frequency transmissions, need to be made? Can a single instrument be designed to cover the broad frequency spectrum being used? Can portability (lightweight) and flexibility be had in a single unit?

All the questions cited should be answered before the selection of instrumentation for standard use is made. It is believed that currently available equipment cannot meet the requirements set down in the answers to these questions. However, some equipment may be used with the proper operational techniques as interim equipment if the quantities to be measured can be ascertained, i.e., peak, average, integrated power measurements or measurements of r-f energy translated into a quantity such as thermal energy.

Power density measurements of r-f radiated energy in "free space" are quite complex. A complete understanding of r-f propagation is necessary to evaluate present or future measuring systems. Such an analysis has been made and is discussed in Section IV-B and Appendix F.

As previously discussed, integrated power measurements may be required. This is a result of having to determine the heating effect of a multiplicity of transmitters simultaneously transmitting at different frequencies. Consequently, it becomes necessary to know the total available power at a discreet point or volume and then translate this measurement into power density, or to a more easily measurable quantity such as thermal energy. Presently power density measurements are being made in the frequency spectrum of 30 mc. and greater. To translate r-f energy to thermal energy, calorimeters, barretters, thermistors and infrared techniques can be used. A discussion of power density instrumentation has been prepared by Welex Corporation and appears as Appendix I.

Commercially available equipment is limited by (a) narrow-band characteristics of antennas or pickup devices, (b) need for a highly skilled operator, (c) complicated calculations and/or calibrations by the operator or other personnel, or (d) complicated operational techniques and testing procedures.

VI. STANDARDS

The establishment of a complete set of standards for the RAD HAZ program is a considerable undertaking which requires investigations in a number of areas. These endeavors are fundamental to laying a solid foundation upon which to base the necessary standards and are discussed in preceding sections of this report. Subsequent information contained in this section is devoted to the specific categories of the proposed standards, giving the status of each of the divisions of the standards.

A. Terminology

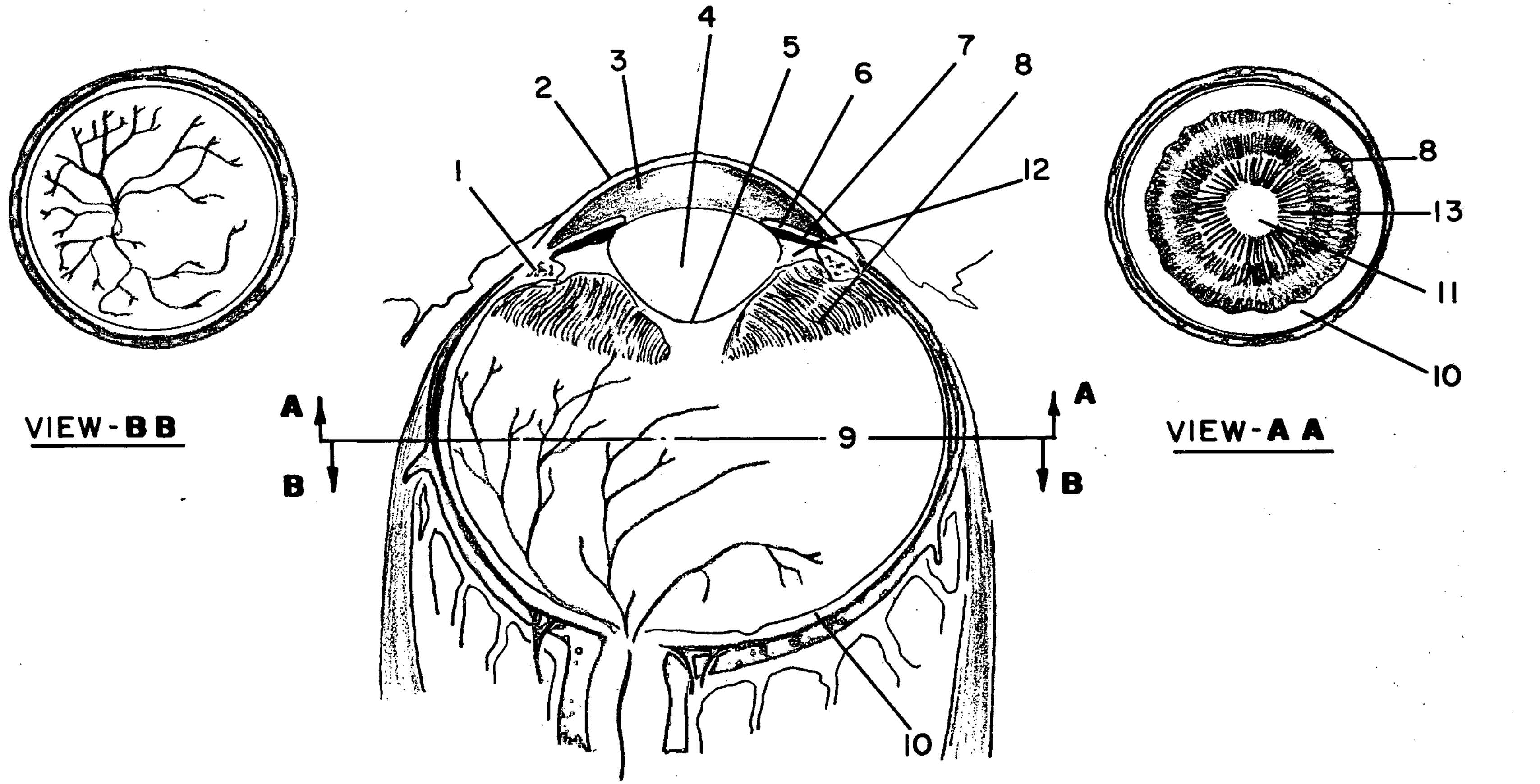
As used in connection with this project, the word "terminology" has been construed to include definitions of terms, abbreviations, symbols, signs, and equations. Standardization with respect to all of these items seems necessary in view of the many disciplines that are brought together under the RAD HAZ program. Since a considerable amount of established terminology exists in each of the various disciplines (physics, biology, communication engineering, etc.), and since conflicts in this terminology are known to occur within the various fields as well as between them, the standardization process is a complicated one. It is not only necessary to gather information concerning prevalent terminology from a large number of sources, but it is also necessary to determine a suitable compromise between conflicting terminology and how well this compromise will be accepted by the various companies, institutions and organizations using it. An outstanding example of conflicting terminology within a single field is presented in Appendix J.

The inherent difficulty in selecting the pertinent terms to define is in the development of the basic philosophy to follow. As an example, in the biological field, the human anatomy comprises an almost endless number of terms. Since it has been determined through research in the Bio-Effects area that the eyes and the testes are the most vulnerable organs to r-f radiation, these two organs require scrutiny for pertinent terms to be defined. Figure 2 shows 13 various anatomical structures of the eye and depicts the complexity of screening the terms for the most relevant ones. This screening requires discretion based upon knowledge of the state-of-the-art in the Bio-Effects field, analysis by various disciplines, compromises, and a considerable amount of time; however, it is a necessary and important consideration.

A preliminary list of terms and their tentative definitions appears in Appendix K. The philosophy that has been adopted in the preparation of this list demands that each definition should express the meaning which is generally associated with that term and which is to be specifically understood by the various disciplines involved in the RAD HAZ program. Insofar as is practicable, each definition presents a "word picture" of the term being defined. Each definition is a statement of fact, not necessarily a mandatory rule, and consequently the use of "shall", "will" and "must" has been avoided. Specifications, whether in words, figures, or drawings, do not form a part of the definition proper; when deemed necessary for full understanding, they accompany the definition as explanatory notes.

Selection of the terms appearing in Appendix K was made on the basis that only words which are not satisfactorily defined in the accepted English dictionaries should appear. The terms listed appear to be appropriate to the RAD HAZ field of interest, with little question. However, as the list is expanded, more specific criteria for including or excluding will be formulated.

Definitions of terms appearing in Appendix K were developed with the aid of the standards listed in Appendix L; dictionaries, glossaries, etc., listed in Appendix M; and indices to standards cited in Appendix N.



1. CILIARY MUSCLE
2. CORNEA
3. ANTERIOR CHAMBER
4. LENS
5. POSTERIOR SURFACE OF LENS
6. IRIS
7. POSTERIOR CHAMBER
8. CILIARY BODY
9. VITREOUS BODY
10. RETINA
11. PUPIL
12. CILIARY ZONULE
13. POSTERIOR SURFACE OF IRIS

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Fig. 2 - Anatomy of the Eye

Many of the terms defined in Appendix K can be found in more than one of the publications of Appendices L and M. On the other hand, a few of these terms were found only in textbooks or technical papers. Practically none of the definitions appearing in Appendix K are repeated verbatim from other sources. This is a result of the over-all philosophy that the definitions should be rigorous enough to be applicable throughout the many disciplines involved in the RAD HAZ program and should not be restricted in nature to any particular discipline.

It should be emphasized that the list of words and terms presented in Appendix K, as well as their definitions, are tentative. Although this list is the result of considerable screening of proposed terms, many more terms will be added and a few may be deleted. In addition, each definition should ultimately be subject to review by representatives of industry, educational institutions, governmental agencies, the armed forces, and certain professional organizations. In particular, it is felt that the final evaluation of each definition should be coordinated through the ASA, C-95 Subcommittee No. 2 on Terminology.

B. Units of Measurement

Units of measurement and experimental procedures must be mutually understood by people working in the RAD HAZ program for an efficient exchange of information.

The procedure being followed for the selection of the most suitable units of measurement is similar to that for the selection of terms. The selection is complicated by having to know what type of measuring instrumentation is required; for example, equipment intended for power measurement might be basically different from equipment designed for voltage and current measurements.

Present-day instruments and measurements make use of the following units to represent field intensities and power densities: (a) milliwatt per square centimeter, (b) volts per meter, and (c) ampere-turns per meter.

The milliwatt per square centimeter is a unit of power density measurement commonly used where the frequency of the radiated wave is greater than 30 mc.

The volt per meter is a unit of measurement used to indicate the electric component (E) of an r-f field for frequencies below 30 mc.

The ampere-turn per meter is a unit of measurement used to indicate the magnetic component (H) of an r-f field for frequencies below 30 mc.

Another unit used in thermal energy investigations in some research activities in the SPARKS and Bio-Effects areas is the millijoule. This is a unit of work 10^4 times as large as the erg.

Selection of units of measurements has not been made as it is felt that further investigations are needed to determine better measuring instrumentation and the procedures for using the equipment. The basic work which has been done in the area of instrumentation is discussed in Sections V and VI-G.

C. Measurement Techniques and Procedures

Standards of measurement techniques and procedures are needed for the different types of measuring instruments. It is essential to have and to use these standards for correlation of information and certainty of results.

To insure proper standards of measurement techniques and procedures, currently available measuring instruments must be evaluated (Fig. 1, block 10). Evaluation of EMR measuring equipment is an essential activity from which pertinent information can be derived for the selection of interim and final measuring instruments as well as measuring techniques and procedures. In addition, the evaluation will give valuable data for continuing efforts in the establishment of (a) units of measurements, (b) tolerable levels of r-f radiation, and (c) safety regulations.

In order to properly evaluate currently available and future EMR measuring equipment and thus be able to effectively derive measurement techniques and procedures, a facility (a microwave anechoic chamber) capable of simulating shipboard r-f field intensities is required. It should include r-f sources capable of producing radiating fields of representative power and frequency ranges, and reflecting surfaces to simulate shipboard conditions which tend to vary the concentration of EMR radiation at a point. These obstacles also could be used in the study of protective materials. In addition, the facility should be equipped so that accurate field patterns can be determined for the evaluation of both current and future measuring equipment from an exact measurement standpoint.

Neither the scope nor the funds of the project on the subject contract allows for evaluation of EMR instrumentation and measurement techniques and procedures at a facility as previously discussed. Therefore, no action has been taken on this type of an evaluation. However, limited investigations on available test facilities have been made and are discussed in Appendix B. Also commercially available equipment has been studied (see Appendix G), and project personnel have witnessed RAD HAZ compatibility tests on board a Navy ship, which clearly exposed some of the field measuring procedures and techniques being used (see Appendix A).

D. Tolerable Levels of R-F Radiation

The problem of establishing tolerable levels of r-f radiation is complex. First, knowledge of susceptible materials or objects is required. Second, environmental conditions under which the materials or objects will be subjected are important factors. Some of these environmental conditions are humidity, temperature, wind velocity, frequencies of r-f fields, geometry of enclosures for susceptible objects, power of r-f fields and physical location of objects in r-f fields. Other complicating factors are the lack of understanding the fundamental phenomena causing ignition in the numerous susceptible items and lack of adequate instruments so that reliable measurements can be made.

Because of the complex network of causes and effects in the overall radiation hazards problem, it becomes apparent that different tolerable levels of r-f radiation will be possible. These different levels will depend upon the susceptible object or item, and cannot be ascertained until (a) the pertinent parameters of the hazard problem are determined, (b) basic causes of ignition are ascertained, and (c) effects of r-f energy to humans and susceptible objects are determined.

Presently, a tentative level for humans of 10 mw/cm^2 has been accepted by the armed forces. This level, however, is not an accepted standard, and should not be considered so until current research activities in the Bio-Effects area have been carefully evaluated (see Appendix H).

E. Safety Regulations

Existing U.S. Navy r-f hazard safety regulations have been reviewed and standardization of safety requirements has been considered. Further evaluation of pertinent data from current hazard investigations as well as additional information from RAD HAZ investigators is required before final safety regulations can be set up.

F. Protective Materials

Protective materials, for the purpose of this study, are considered to be those substances that could be used to protect human beings, explosive materials or volatile liquids and gases from intense r-f fields directly or indirectly. Examples are protective clothing for personnel and r-f energy absorbent material applied to bulkheads or other obstacles to reduce reflections.

Limited investigations have been made in this area of the standards through review of several publications[3-6] and a personal visit by project personnel with several companies (see Appendix B) in the field of r-f absorbent materials.

Most of the information contained in the reports reviewed is of a development nature. The materials which have been developed and are described in these reports have been produced to provide nonreflective surfaces rather than providing protection beyond or behind the absorber.

Sufficient efforts have not been expended on the study of protective materials to draw any conclusions at this time.

G. Specifications for Suitable R-F Measuring Instruments

Equipment design specifications must be based on the type of measurement, quantity to be measured, the environmental conditions, and whether the instrument is for field or laboratory use. Currently available equipment actually dictates, to some extent, the type of measurements that can be made today, i.e., power density and field intensity (E and H components of the r-f field). General types of instruments that are needed can be classified as:

1. Personnel warning instrument: This device must be capable of producing a local alarm (audible and/or visual) in addition to telemetering an analog signal, which is a function of power density, to a control station. It needs to be accurate, rapid in operation, and capable of being placed in potential r-f hazard areas for considerable lengths of time. The main function of this instrument is to rapidly alert personnel of the hazardous conditions of areas for personnel, ordnance equipment or material, and volatile liquids or gases.

2. Broad-band integrated power density instruments: This type must be capable of measuring the integrated average powers resulting from simultaneous multiple frequency transmissions. It must be portable (lightweight), accurate, and able to rapidly indicate existing hazard conditions.

3. Peak power instrument: This type instrument must be capable of rapidly determining the peak power delivered at any instant from a particular frequency source. It must be portable, accurate, and capable of examining the portion of the frequency spectrum from 14 kc. to 20 kmc.

4. Special measuring instruments: This class includes special instruments for laboratory, research, and field uses; an example is an r-f power-indicating instrument built into a missile.

H. RH Code System

A natural consequence of the complex RAD HAZ program insofar as tolerable levels of r-f and safety regulations are concerned, is the establishment of a code system for marking areas and individual susceptible items so that their tolerable levels are readily identified.

No conclusions have been made on the RH (Radiation Hazards) code system since the system must be based upon the findings and dtermination of the other phases of the standards.

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6. Proceedings of the First Annual RADC "RAM" Symposium at Rome Air Development Center, ASTIA AD 131314 (SECRET), 1958.

APPENDICES

APPENDIX A

RAD HAZ INSPECTION TRIP ABOARD THE USS ESTES

The purpose of this inspection trip was to witness EMR measurements on the USS Estes, AGC 12, a general communications and command ship. These measurements were made during the period of 8-11 February 1960 (while at sea, somewhere in the Pacific Ocean) to determine the degree of hazard to personnel and ordnance presented by the operation of high power radar and communication equipments. Similar tests have been carried out on other types of Navy vessels as part of the RAD HAZ compatibility program conducted by the Bureau of Ships. The participation in this test by MRI personnel was suggested in support of the objectives of MRI through the reference contract.

Personnel from the RCA Service Company conducted the measurements. The group consisted of Mr. Ken Howard, project leader, Mr. Robert Greenwell, consultant, Mr. William Bunch, Mr. John Waythal, and Mr. Donald E. Langkamp. Representatives from MRI were Mr. Paul C. Constant, Jr., and Mr. William H. Ashley, Jr. Also present was Dr. Alfred W. Richardson, Professor of Physiology, St. Louis University, to evaluate his miniature EMR dosimeter.

The description of the measurement operations is illustrated by the accompanying series of photographs which are explained by the discussion which ensues.

The measurements were made on the EMR of highest intensity. For convenience, and the fact that different frequency bands required different types of measuring equipment, two teams were set up for the conduct of operations. Enlisted personnel were provided from the ship's crew to act as communicators where special antenna positions and conditions of equipment involved coordination between the measurement teams and ship operators. In general, the ship was traversed from bow to stern by each team.

Figure A-1 shows a closeup of the calibrated horn and X-band antenna used to pick up EMR of radar frequencies. Associated directional coupler attenuators are shown which were used with the horns to reduce the EMR energy to levels compatible with the instrumentation. Figure A-2 shows the L-band horn antenna in a setup for a measurement. Since the L-band consists of lower radar frequencies, the size of the corresponding horn is greater. Figure A-3 shows two of the high-frequency power density measuring instruments. In many cases, these two devices were used to cross-check measurements as a means of verification. Figures A-4 and A-5 are two views of the instrument used to measure the communication frequencies.

One of the horn pickup antennas is mounted on a tripod and in place for measurements in Figure A-6. This position is in the forward 5-in. gun tub above the forecastle looking aft. The port forward kingpost is at right in the picture. EMR from the large antenna, more easily identifiable in Figures A-12 and A-19, is being measured. An operator is shown making an adjustment of the horn in Figure A-7. Figure A-8 is another view at the same location showing the instrumentation and interconnections of a typical complete measurement setup. Figure A-9 shows the arrangement of equipment and personnel for measurement of EMR on the 5-in. gun platform from the L-band radar atop the port forward kingpost. This radar antenna can be seen at left in Figure A-14 and at right in Figure A-20.

Dr. Alfred W. Richardson is shown in Figures A-10 and A-11 holding an EMR measuring device which he designed for the Office of Naval Research. He used the device at several locations on the ship, but no correlation was made with data obtained with the other instruments illustrated.

Figure A-12 shows the port forward kingpost atop which various antennas are mounted. These antennas are shown clearly in Figures A-14 and A-20. Figure A-13 shows the radiation warning sign posted at bottom of the kingpost. Figures A-15 and A-16 show additional measurements taken about the bridge house. In Figure A-17, Mr. Constant is shown witnessing a measurement. Figures A-18 and A-19 show measurements of EMR from antennas forward on the kingposts and from those directly above the superstructure over the bridge house. In the latter case, EMR from the back side of the antenna was strongest.

In Figure A-21, the consultant, Mr. Robert Greenwell, is shown briefing Captain Gray on the progress of the tests. Figures A-22 and A-23 show the communication frequency instrument in use on the after well deck. Figures A-24 and A-25 show measurements and activity on the flight deck.

The direct observation of the measurements described above, especially in the presence of actual field environment where EMR hazards can develop, will very materially benefit the program now being conducted by MRI. For example, any recommendation for new measuring equipment will emphasize portability and completely self-contained operational capability. The instruments used for the above described measurements required 110 v. 60 cps power which was almost never conveniently available. When this power was supplied through drop cords strung across decks and up the masts, other shipboard activities were interfered with, in addition to the line losses and interruptions afforded the instruments themselves. It is felt, therefore, that the over-all process of formulating definitions and standards relating to the SPARKS, HERO, and Bio-Effects investigations will be much more realistic and useful to the Navy.

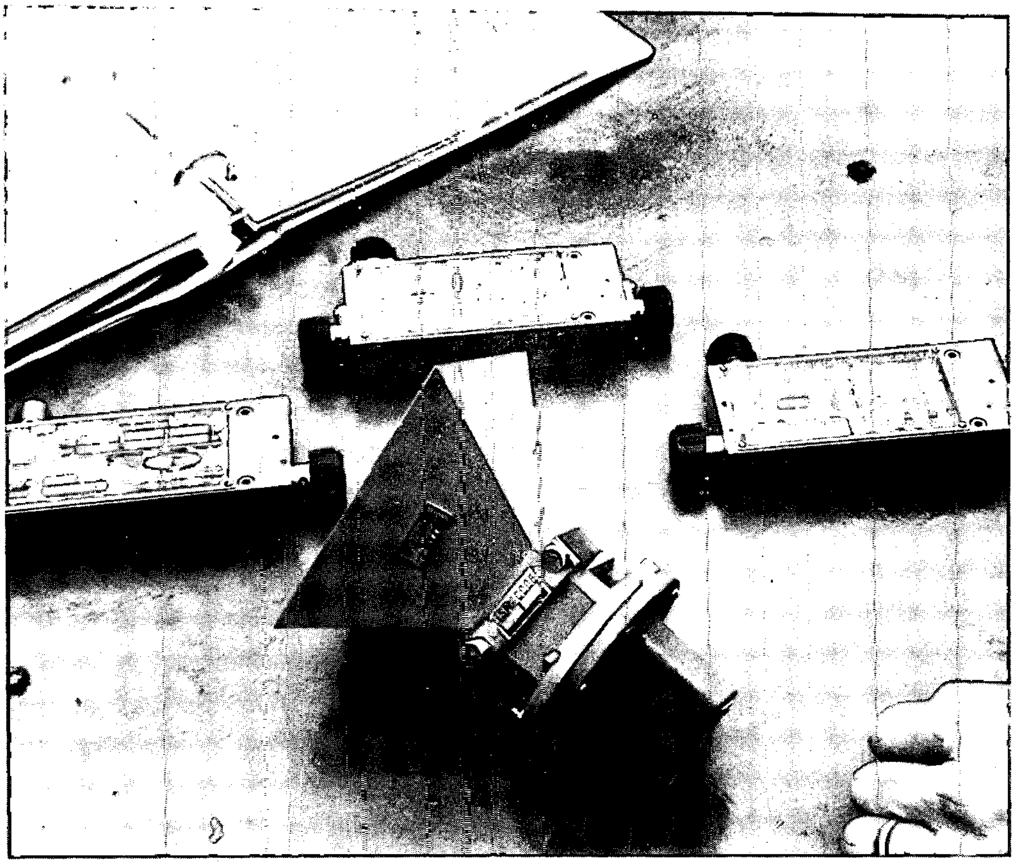

Fig. A-1 - X-, S-Band Horn Antenna, Directional Couplers, Computing Tables

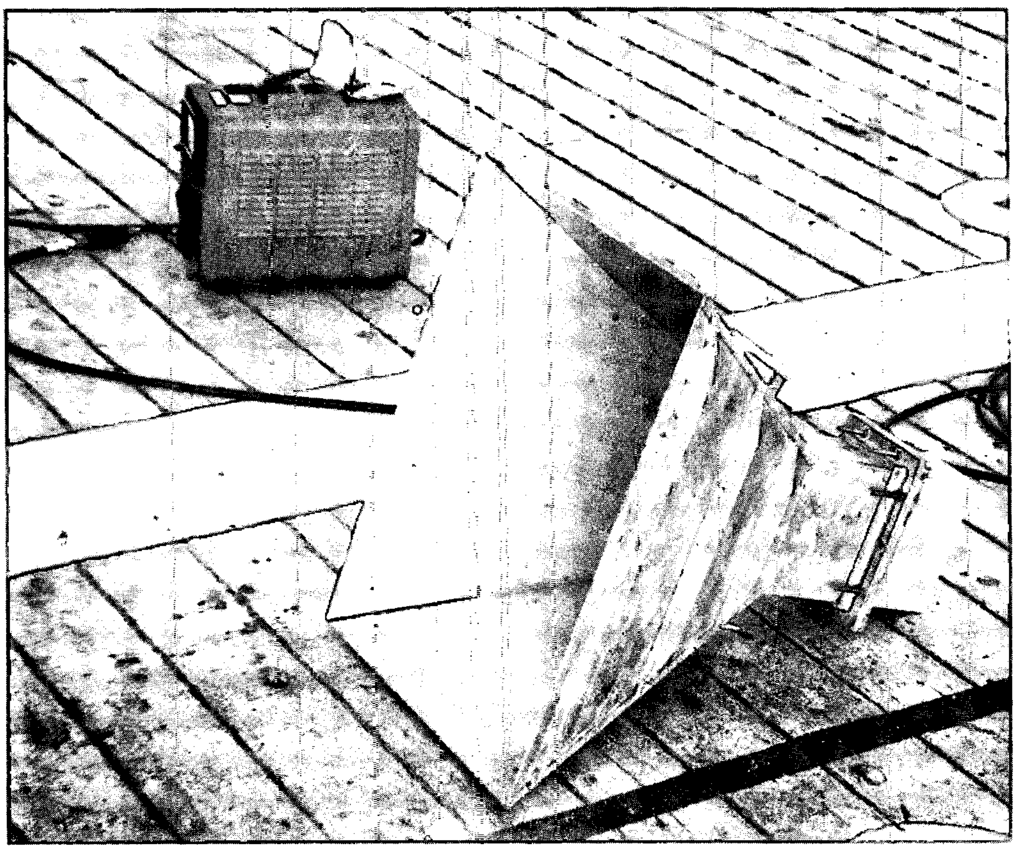

Fig. A-2 - An L-Band Horn Antenna Used for EMR Measurements

Fig. A-3 - EMR Power Density Measuring Instruments

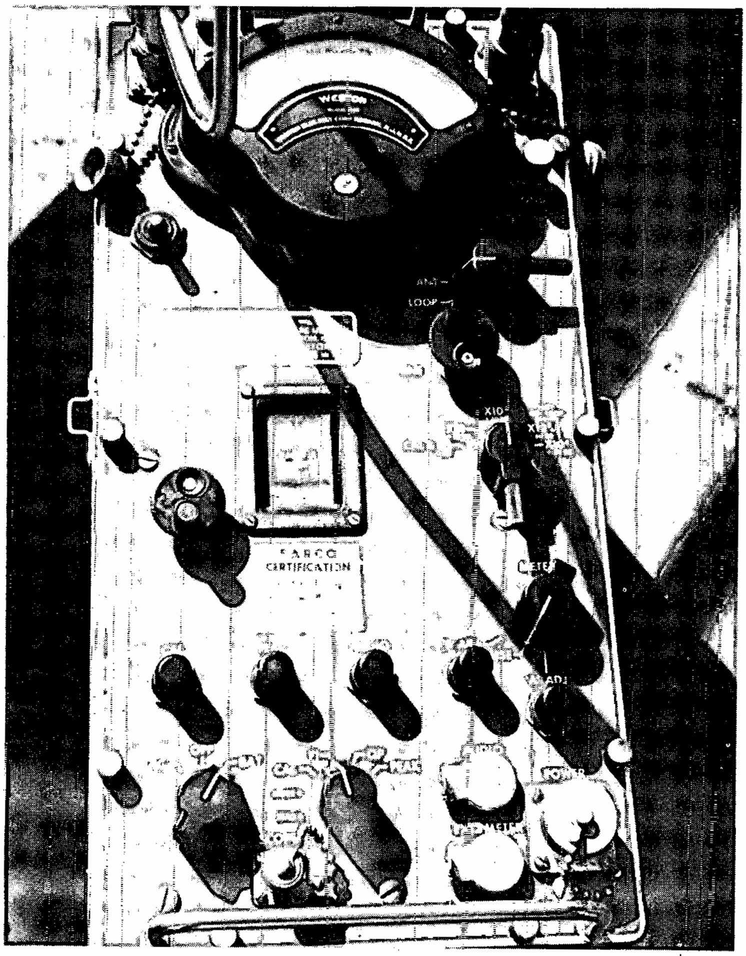

Fig. A-4 - Field Intensity Measuring Instrument PRM-1
(top view)

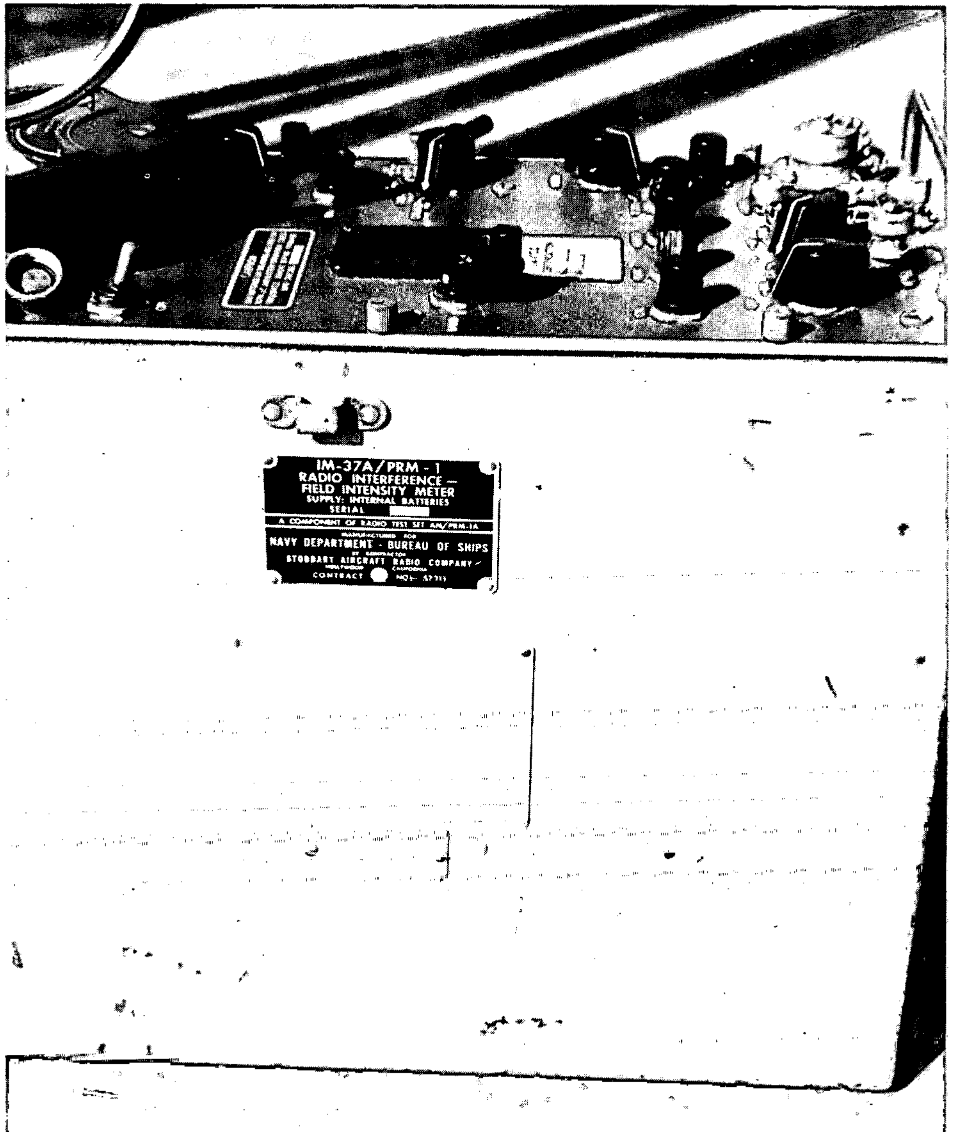

Fig. A-5 - Field Intensity Measuring Instrument PRM-1 (side view)

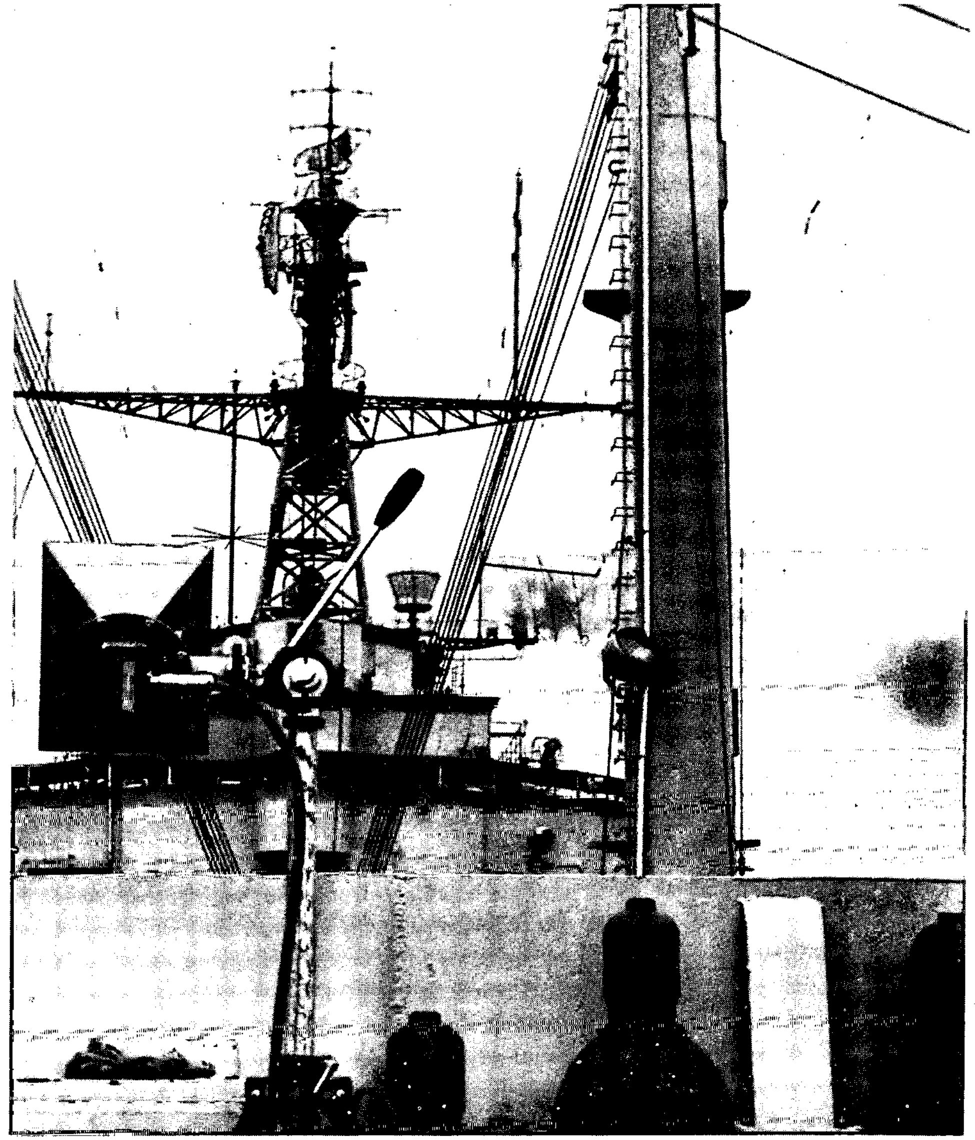

Fig. A-6 - X-Band Horn Antenna Set Up for Measurements

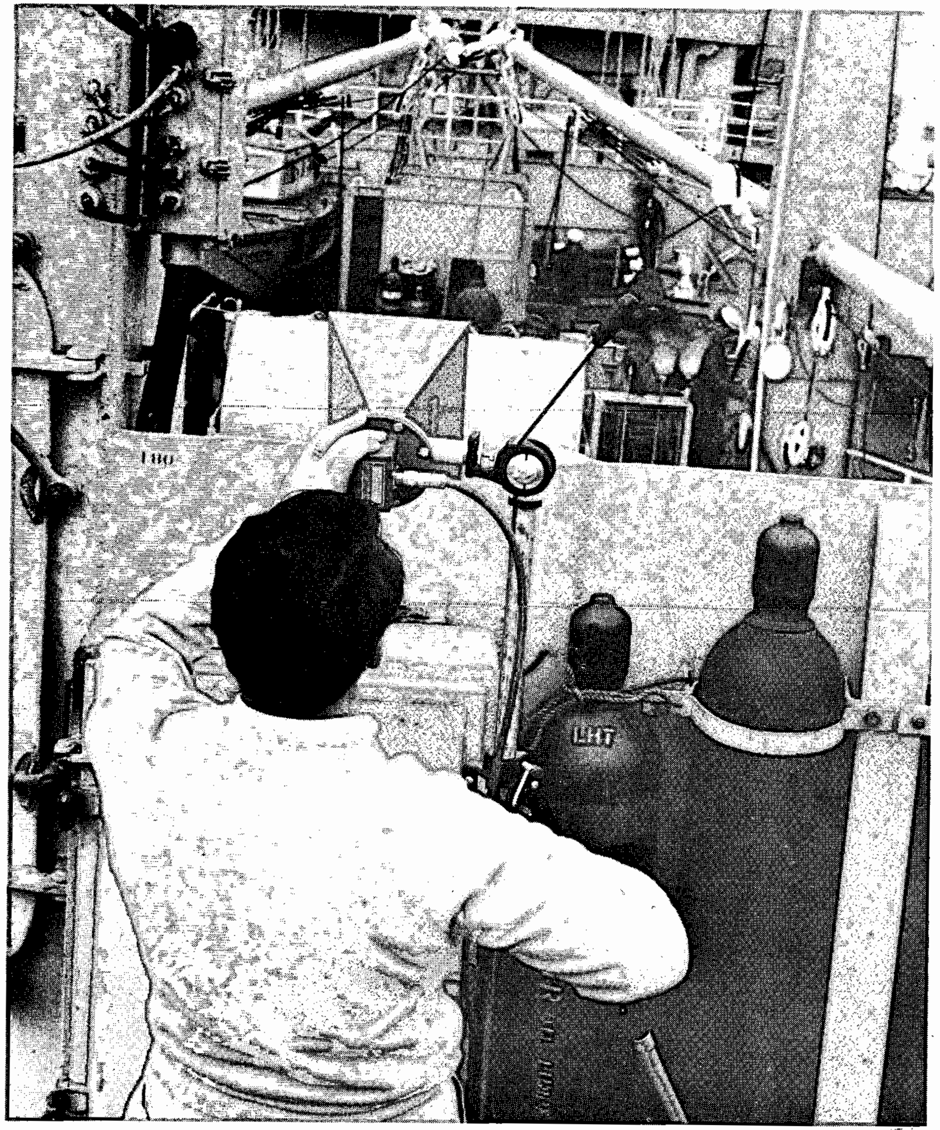

Fig. A-7 - Adjusting a Horn Antenna for Maximum Pickup

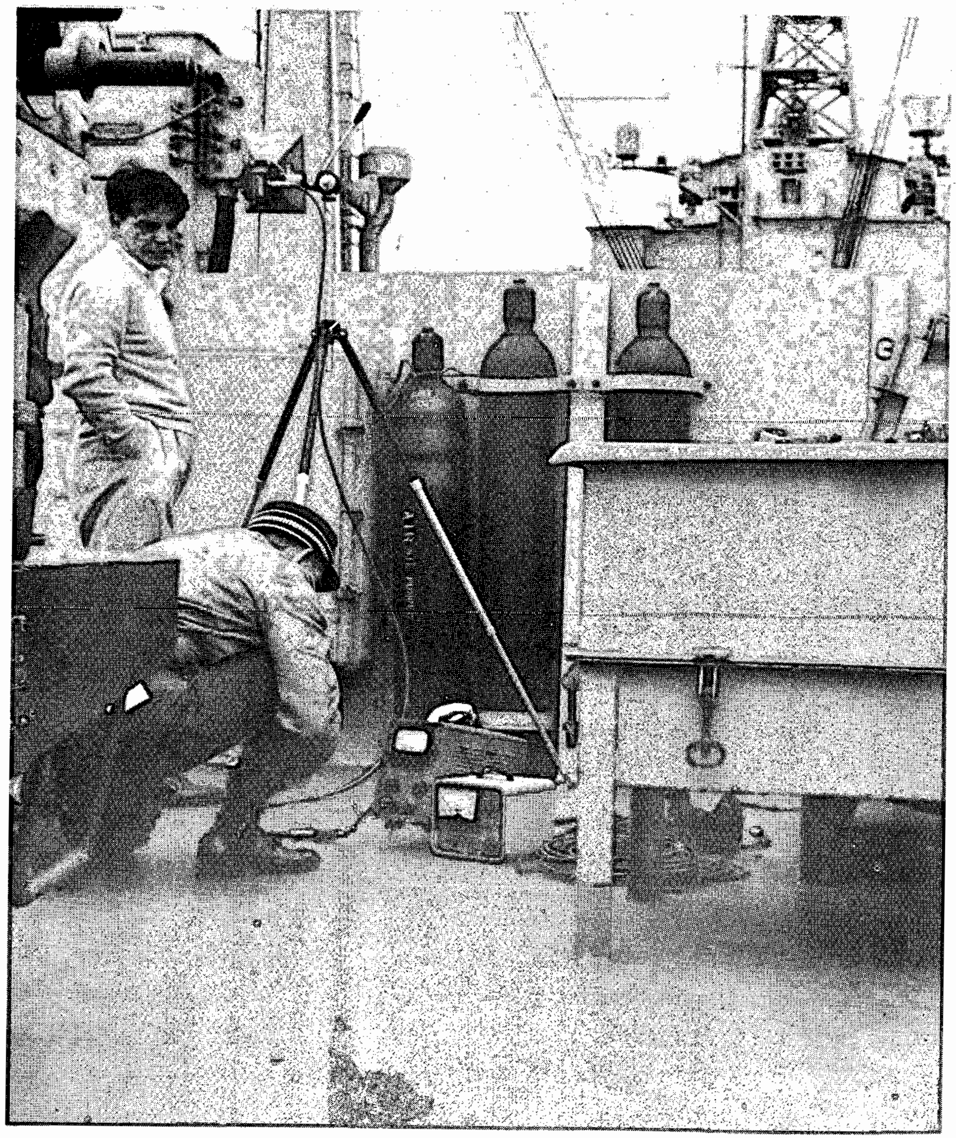

Fig. A-8 - Setup for Measuring EMR's at the Bow of the Ship. Position is in Forward 5-In. Gun Tub

Fig. A-9 - L-Band Measurements on Forward
5-In. Gun Platform

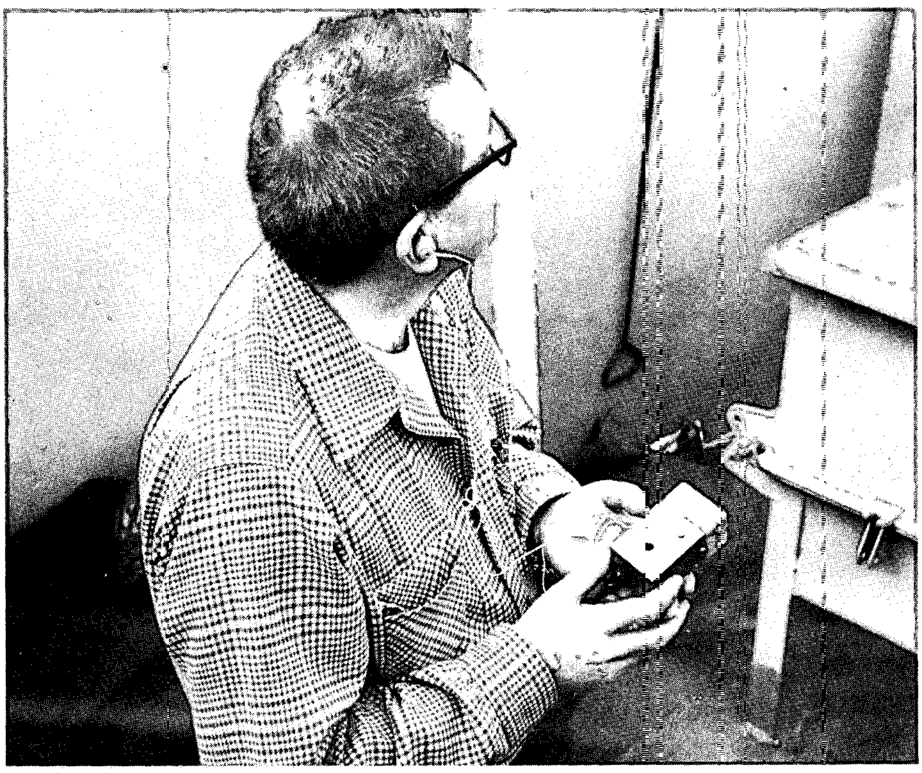

Fig. A-10 - Dr. A. W. Richardson using his Specially
Designed Intensity Meter

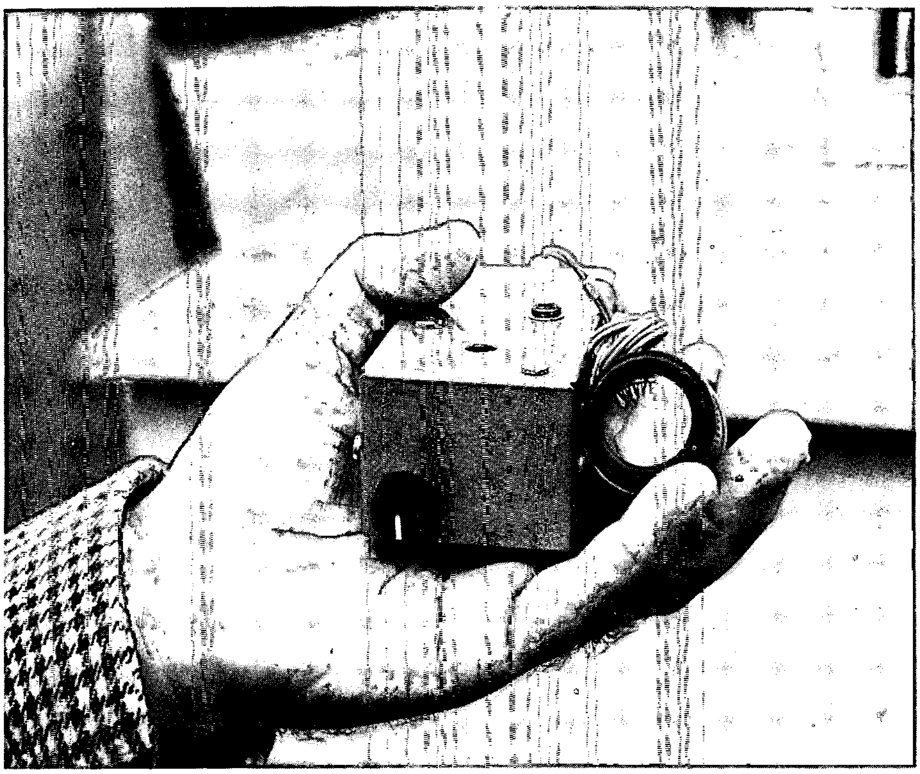

Fig. A-11 - Closeup of Dr. Richardson's Miniaturized Field Intensity Meter

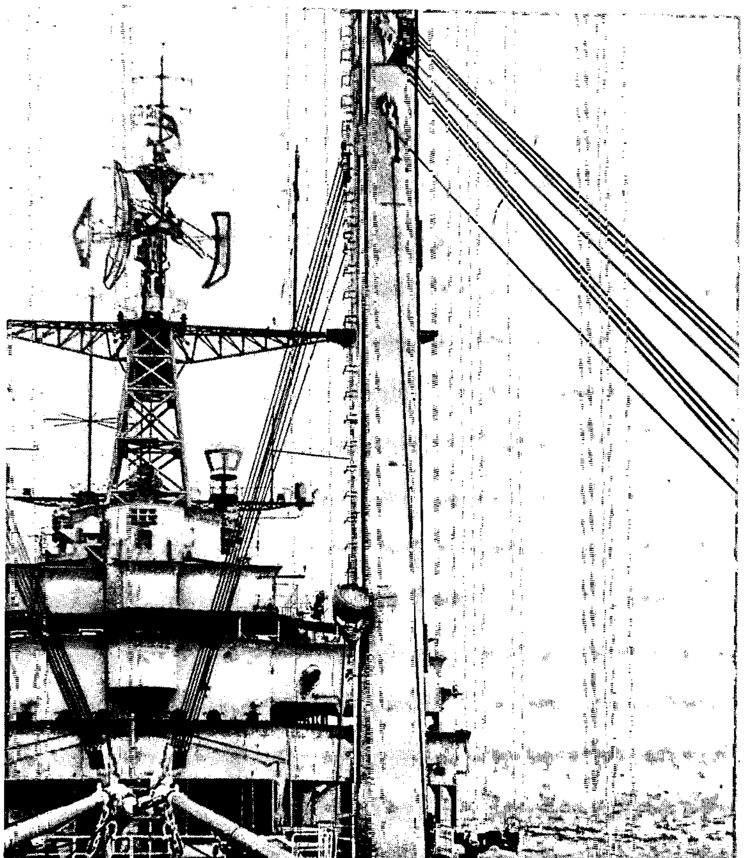

Fig. A-12 - Port Forward Kingpost Atop which Antennas are Mounted, shown in Fig. A-14

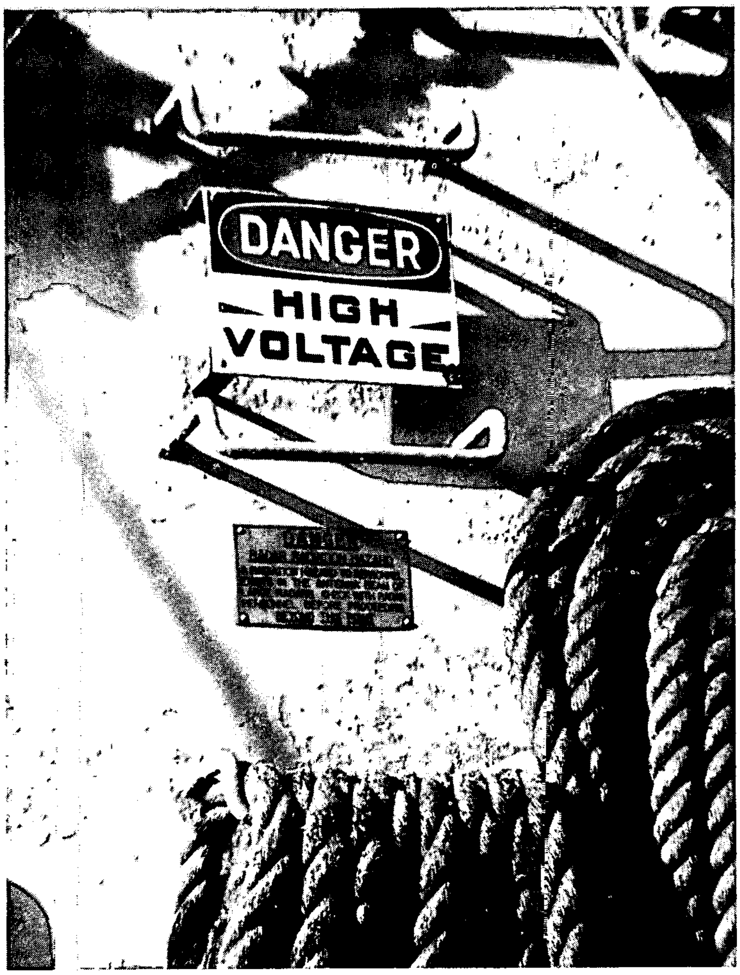

Fig. A-13 - Radiation Warning Sign Posted at Base of Kingpost of Fig. A-12

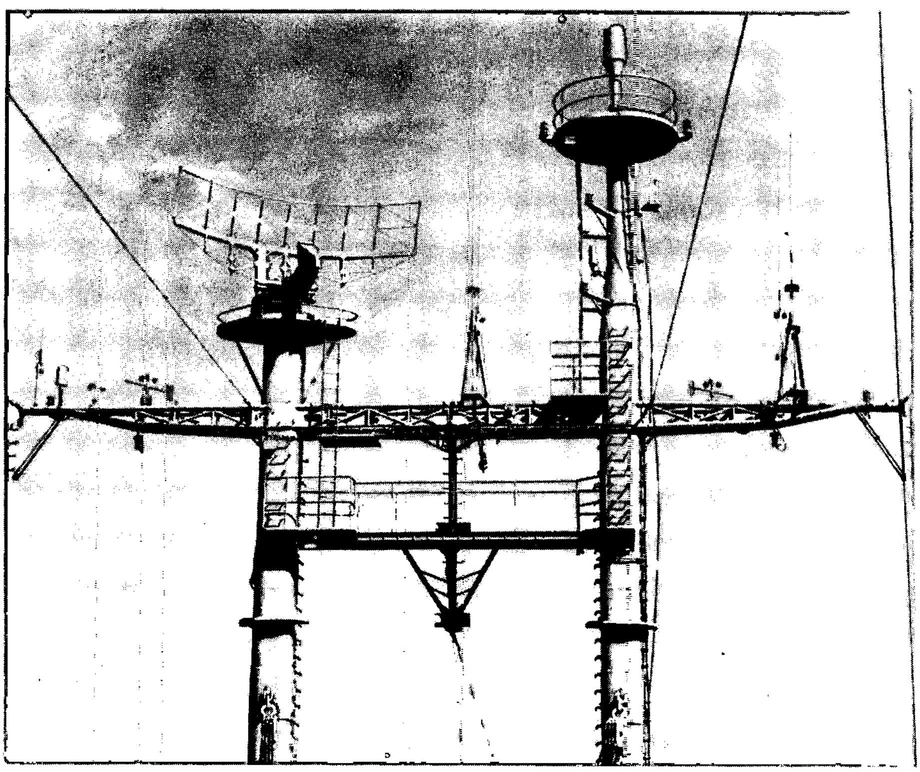

Fig. A-14 - Antenna Installation Atop Forward Kingposts Shown in Figs. A-6, A-7, A-12, A-13

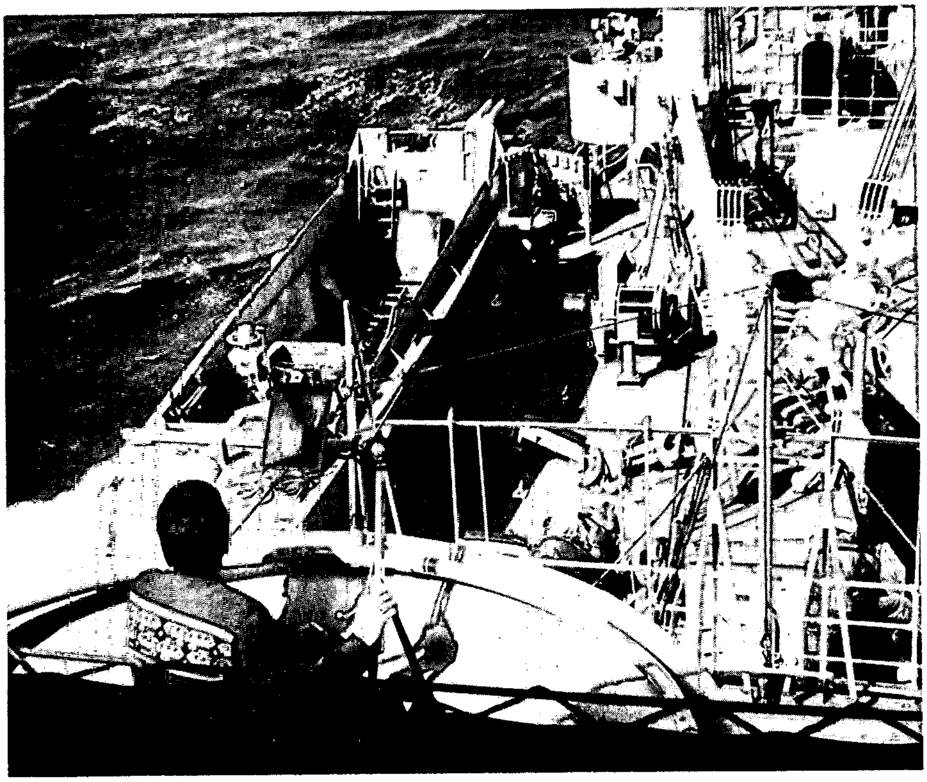

Fig. A-15 - Adjusting Horn Antenna at a Position Amidships

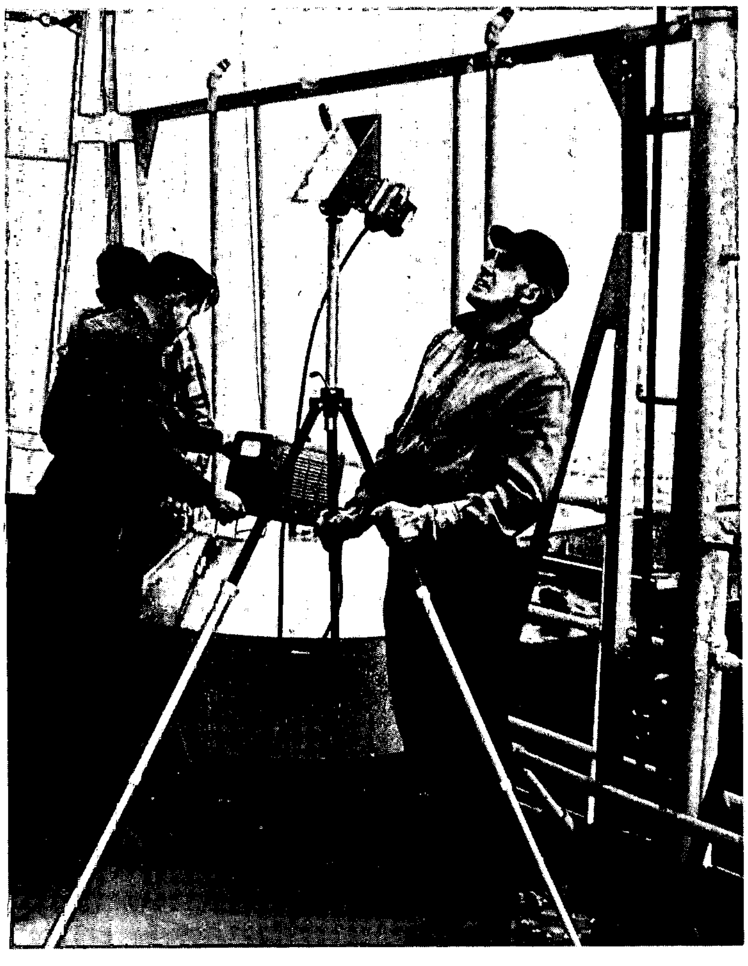

Fig. A-16 - Power Density Measurements Amidships

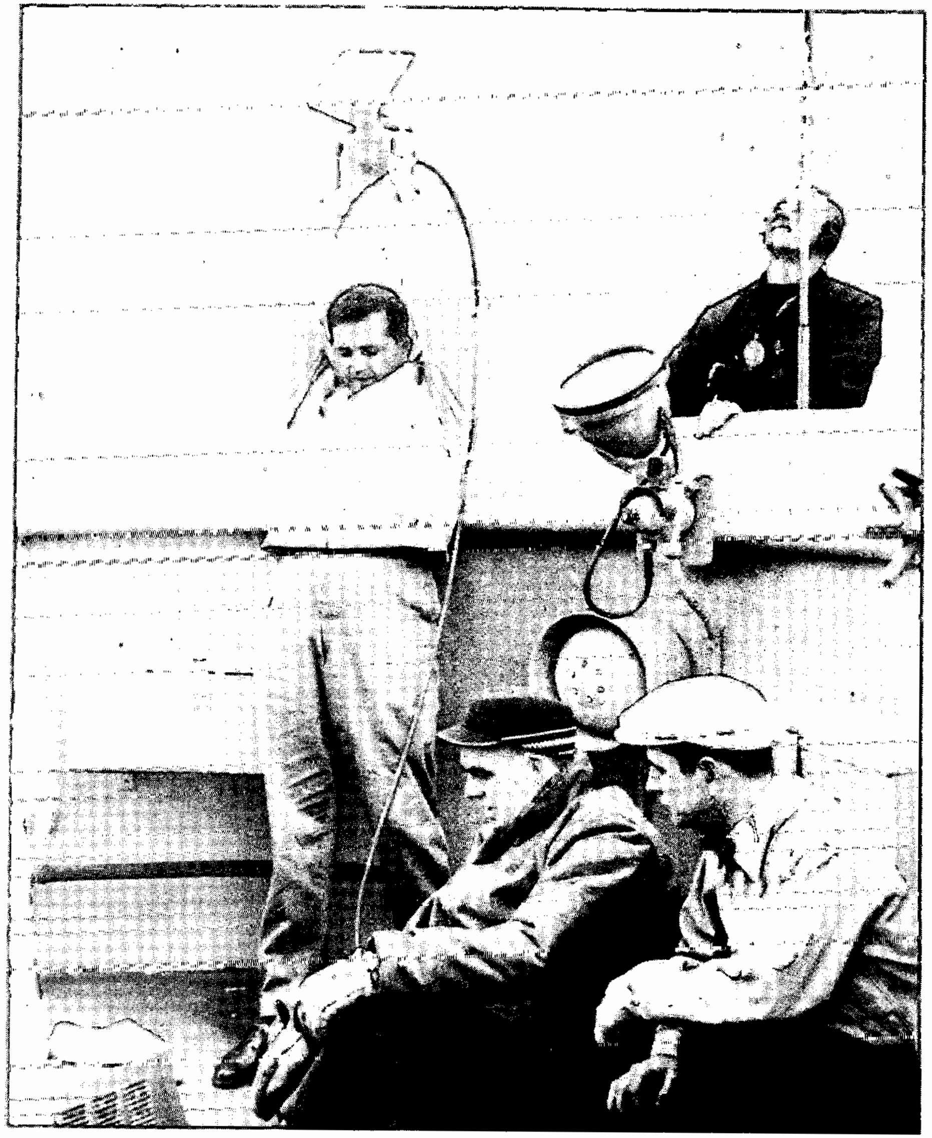

Fig. A-17 - Mr. P. C. Constant, Jr., M.R.I. (lower right), Witnessing Power Density Measurements on Board the USS Estes Somewhere in the Pacific Ocean

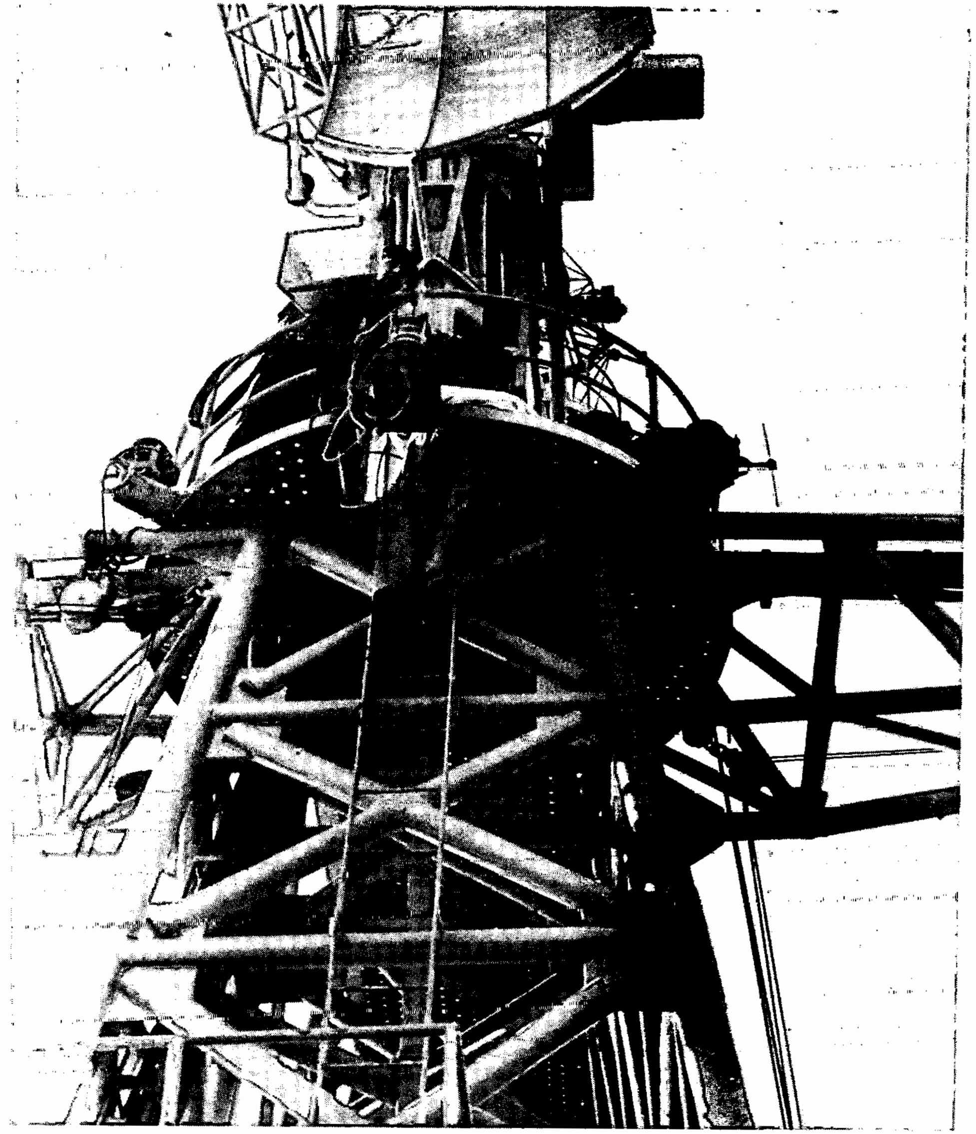

Fig. A-18 - Measurements Being Taken at the Topmost Ship Level. These Antennas can be seen in Figs. A-6, A-12 and A-19

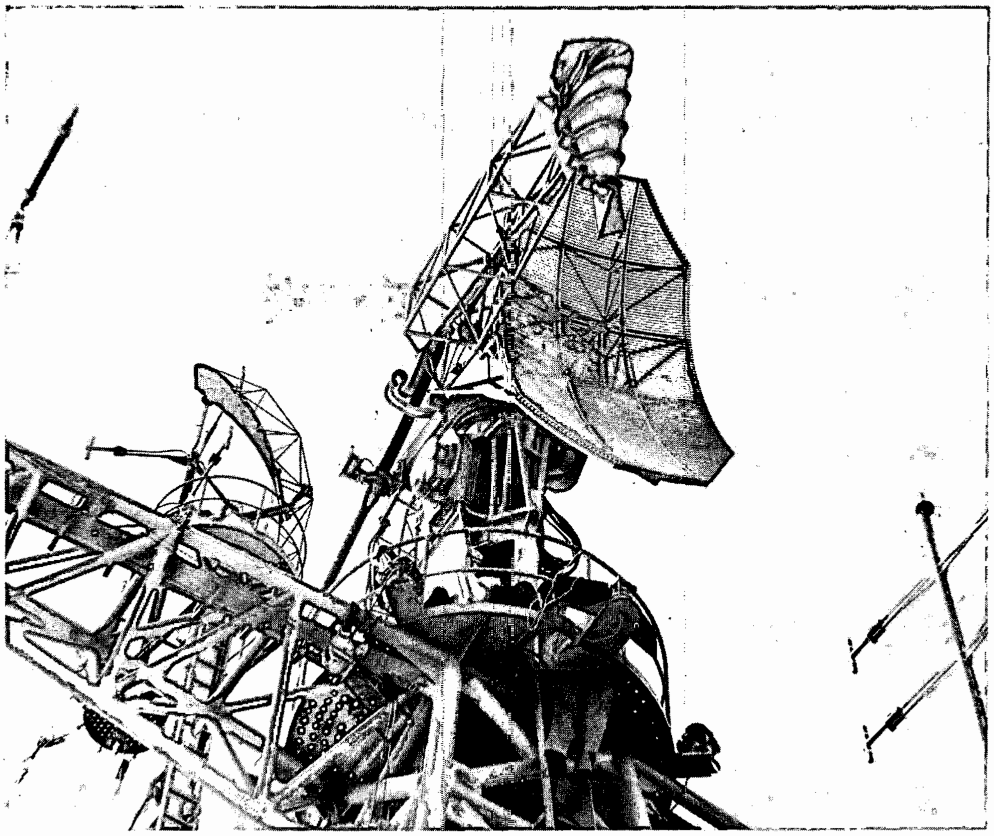

Fig. A-19 - Antennas Atop Central Mast Structure, Back Scatter Measurements

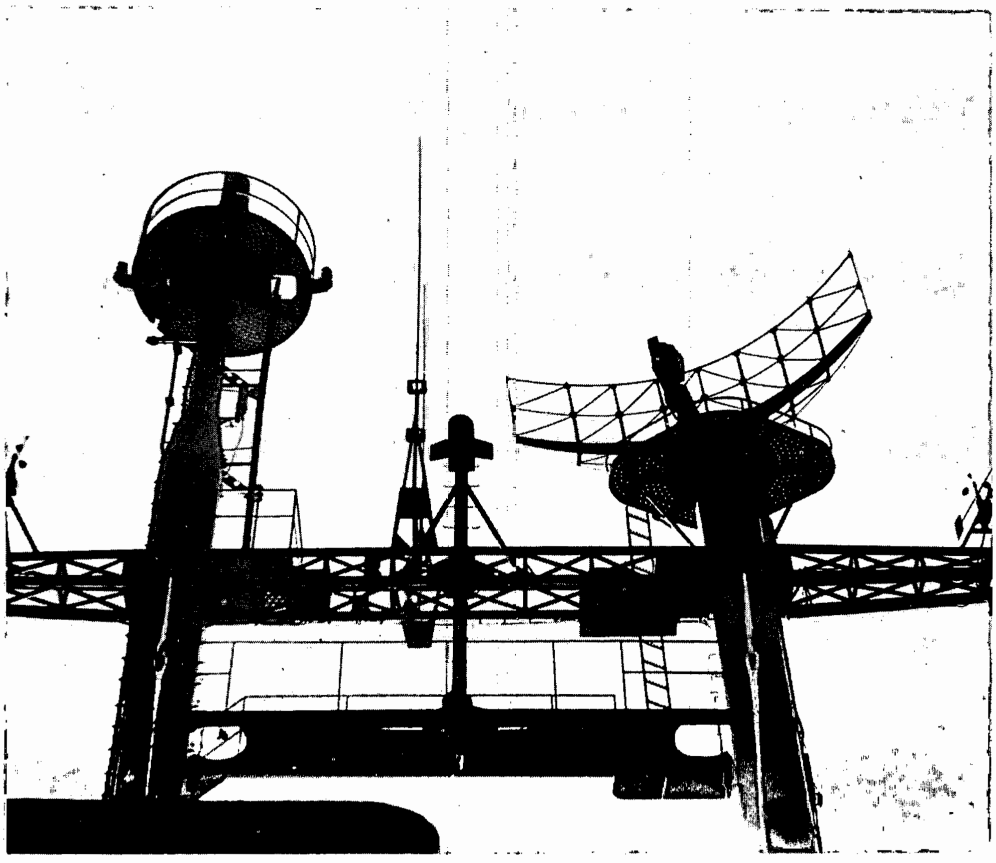

Fig. A-20 - Forward Antenna Structures

Fig. A-21 - Ship's Captain Checks Progress
with Project Consultant

Fig. A-22 - Communication Frequency Field Intensity
Measurements

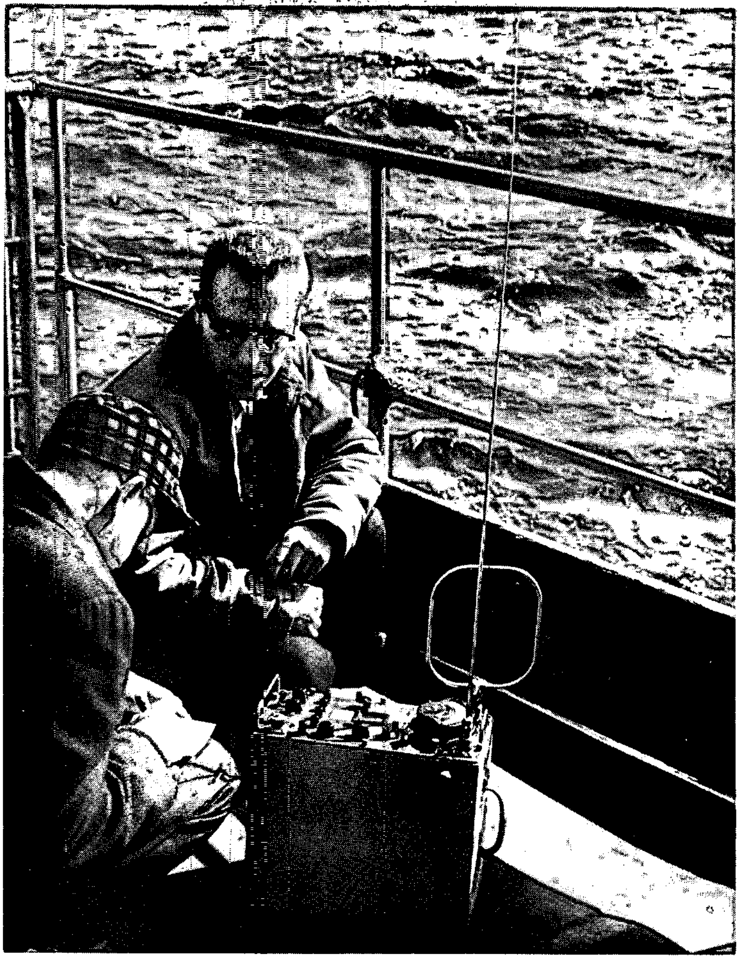

Fig. A-23 - Using the PRM-1 Field Intensity Instrument Shown in Figs. A-4, A-5 and A-22

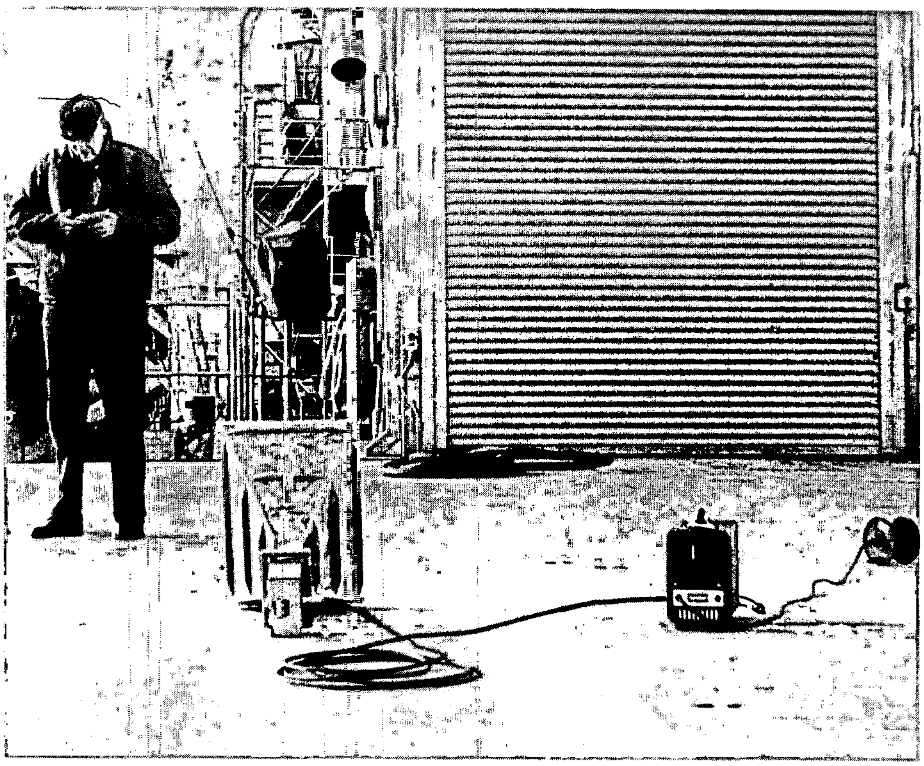

Fig. A-24 - EMR Power Density Measurements on Helicopter Flight Deck

Fig. A-25 - Helicopter Landing on the Flight Deck

APPENDIX B

PROJECT PERSONNEL VISITS TO ORGANIZATIONS ENGAGED IN ACTIVITIES RELATED TO THE RAD HAZ PROGRAM

A course of action taken to obtain first-hand information on activities related to the RAD HAZ program is presented subsequently in the form of reports on trips made to several organizations by project personnel. The function of these visits is to supplement and integrate information obtained through:

1. Study of pertinent documents;

2. Symposia and technical conferences;

3. Shipboard RAD HAZ tests; and

4. ASA activities related to the RAD HAZ program.

Trip I

Place: U. S. Naval Proving Ground, Dahlgren, Virginia

Date: 31 July 1959

Party: Messrs. J. N. Payne, J. Roman, R. R. Potter, C. J. Hinkle, C. M. Cormack, B. C. Algeo, T. W. Frantz, P. C. Constant and W. H. Ashley.

During the meeting, the role of MRI in RAD HAZ work was explained. One of the questions prepared for discussion, about incidental rectification, offered a new idea which could have been the cause of some past accidents of unknown origin. It was confirmed that high r-f power levels can initiate certain detonations independently of the time of exposure.

The work in the radiation hazards field at the Naval Proving Ground was explained by Mr. Potter with a chalkboard drawing of a box on the left marked "TX", a box to the right marked "EED" (Electro-Explosive Device), and the designation of the region between by a larger box marked "db". It is desired to determine how energy from the transmitter arrives at the EED and ignites the bridge wire. The variables affecting the transfer of energy include frequency, weather, personnel, ordnance, distance, power radiated, and others. To facilitate the acquisition of this information, a contract was awarded to Jansky and Bailey of New York to determine the variables, catalog them, and determine the modes of coupling between transmitter and EED. For the present, the EED energy requirements vs. excitation are unknown. Examples were given to explain how accidents have happened, such as by touching the rocket while in position on an airplane at the time of making a cable connection. Most of those present had seen the film presentation by Mr. Fisher in which these accidents were illustrated. Thus, it was partly summarized that the Naval Proving Ground is finding out what measurements are needed and BuShips will seek to standardize these measurements.

Jansky and Bailey, Inc., began a contract on 1 August 1959 for which the objectives to be obtained are:

1. To determine the various modes of coupling of radio frequency energy from a transmitter to an electro-explosive element in an ordnance system;

2. To identify the characteristics of a transmitter, ordnance system, and environment which most significantly affect coupling; and

3. To develop practical methods for predicting the coupling in a given situation by extrapolation of the coupling measured values of significant characteristics.

The HERO personnel at the U. S. Naval Proving Ground are in the early stage of their work and at present are awaiting delivery of new recording equipment. They are presently limited to the use of a 30 cps mirror oscillograph.

Much of the discussion dealt with EED's. These are the initiators which carry out the first action in the discharge of a rocket or a projectile. The Denver Research Institute is doing work in RAD HAZ on detector development. The detectors are small devices which enable the simulation of an EED discharge by measuring the temperature rise in the bridge wires of an EED. Several detectors and bridge wires were displayed. One device consisted of a small bead of carbonyl iron through which two wires to the EED were passed. This small bead was designed to absorb radio frequency energy and minimize the energy transmitted to the bridge wire from radio frequency fields.

Another example of the serious aspect of radiation hazards was described as the situation when destroyers, cruisers, or battleships are brought alongside aircraft carriers at dockside, such that energy from the antennae of the lower ships is brought to bear directly upon the flight deck of the carrier.

Jansky and Bailey, Inc., have another project which requires the compilation of pertinent ordnance characteristics.

The foreseeable upper limit of power was given as 100 Mw., to which someone added the words "average power". Several known high-power transmitters were mentioned, among them a 500 kw. station at Annapolis and a 100 kw. peak power station near the NPG.

It was emphasized by Mr. Cormack, the HERO coordinator, that we are interested only in radio frequency hazards and will not deal with hazards resulting from such things as static electricity, lightning, 60 cycle and 400 cycle power circuits and their transients, even though they are suspected of being the cause of some accidents. The question of who shall continue the bibliography begun by the International Electronics Manufacturing Company was uncertain; it was, however, felt that a contract for the continuance of the bibliography would be let.

The role in the RAD HAZ work which MRI is to undertake was further clarified and elucidated. It was explained that BuShips is acting as the "doer" in the American Standards Association format for the preparation of standards, and that MRI's work could serve as a basis for such a standard.

Mr. Algeo discussed the RAD HAZ work at BuAer. They are concentrating on measurements inside the ordnance round. One test for safety involves the placement of a 125 milliamp Littlefuse across a missile control circuit to be connected.

The fuse has been found to blow if a dangerous level of radio frequency energy is present. Of course, this test is made before firing energy is applied to the round. Tests are being made on equipment with frequencies up to 30 mc. Their testing is more on a system basis by which tests in actual firing situations are simulated. Other methods involve the use of thermocouples, their outputs amplified, and fed to an indicating meter. Thermistors have been used with bridge amplifiers. The Naval Air Development Center (NADC) has designed amplifiers using magamps. Some progress is being made on the temperature measurement of the bridge wire by means of small infrared sensitive photocells, principal among which are those made by indium arsenide. Another method utilizes an IR transparent material which can be placed right on the wire in such a way as to maximize the close association between the detector and the detected quantity. The temperature range of interest is from room temperature to 500°F.

It was observed that, in general, explosive sensitivity increases with temperature and that when the temperature is maintained constant it is to the advantage of the ordnance stability.

Among the methods used to protect the bridge wire from unintended applications of energy were lumped and distributive means for the attenuation of the energy. Selective signaling was also described. Picatinny Arsenal is doing similar work. The Atlas Products Company is working with a Bakelite-type of plug similar to the carbonyl iron, and it was stated that some 20 db. attenuation can be achieved from 500 mc. upward.

The meeting adjourned with a tour of the Naval Proving Ground facilities, during which time firing of a Zoonie rocket was observed.

Trip II

Place: Experiment, Inc., Richmond, Virginia

Date: 3 August 1959

Party: Dr. L. E. Line, Messrs. C. M. Slough, P. C. Constant, and W. H. Ashley.

The personnel at Experiment were unable to attend the meeting on Friday, 31 July 1959; therefore, copies of that meeting agenda were distributed and the points were discussed one by one. Experiment, Inc., has a research project to determine the minimum spark energy for ignition of various volatile mixtures. They have found that, using condenser discharge methods, less energy is required for ignition of certain gas-air mixtures by the addition of a coil or resistor in the discharge circuit.

The broad question of the lack of coordinated terminology was clearly in evidence when Dr. Line used such terms as monopropellant and biopropellant. A distinction was made between monopropellant and hypergolic propellants. Hypergolic materials are those which when brought together produce ignition without external stimuli. Monopropellants are chemical substitutes which can be explosively composed with the liberation of heat in the absence of air. For example, dynamite is not a monopropellant because it is not self-igniting. Some very excellent references were given in the form of the liquid propellant handbook, the authors of which are thought to be at Battelle Memorial Research Institute. It was further clarified that the organizations LPIA and SPIA would be rich sources of information on fuels; LPIA stands for Liquid Propellant Information Agency; and it, as well as the SPIA, are continued through the cognizance of the Applied Physics Laboratory of the Johns Hopkins University.

The meeting adjourned with a tour of the laboratory facilities of Experiment, Inc.

Trip III

Place: Electronic Test Section Facilities, Pautuxent River Naval Air Station

Date: 26 January 1960

Party: Messrs. Patrick Hannegan, John Lefort, and Leon Findley

The purpose of the visit was to ascertain the usefulness of the facilities for evaluating EMR measuring equipment.

The facility consists of a huge hangar which has been thoroughly lined with copper screening. Within the hangar are several small screen rooms. However, the whole facility is aimed at establishing an area which is free of radiation and electrical noise from outside sources. It has not been designed to contain radiating sources. There are no anechoic facilities, no radiation absorbing facilities at all. It appears the facility is not what is needed for measuring equipment evaluation work.

Trip IV

Place: New York and Massachusetts Area

Date: 5-8 February 1960

Party: Messrs. R. L. Clarke and C. L. Emerson

On 5 February 1960, Mr. Richard L. Clarke contacted several organizations in the New York area who were engaged in the production of insulation and dielectric materials. His objective was to ascertain information on absorbing and reflective material at r-f frequencies. None of the concerns contacted were actively engaged in research into these materials.

On February 8, Mr. Clarke contacted Mr. C. L. Emerson of Emerson and Cuming, of Canton, Massachusetts, concerning their activity in the field of r-f insulating and absorbing materials. Mr. Emerson contributed considerable information on both the activities of his company and the other individuals. The company produces a variety of absorbent materials ranging from rigid to cloth types. Anechoic chambers were discussed and a tour was made of the company's chambers at Canton. Mr. Emerson pointed out that most chambers are designed to operate in a specific radio frequency band since broad band chambers are rather expensive. In answer to questions of availability of existing commercial facilities, it was his experience that most companies using their own facilities kept them well scheduled in addition to having designed them for specific equipment or purposes.

In discussing knowledgeable individuals in the material field, Mr. Emerson suggested contacting Dr. Rufus Wright, at the Naval Research Laboratory, at Washington, as well as Mr. William Bahret at Wright Air Development Division, Ohio. These two men seem to be cognizant of most of the activity in the absorbent field.

APPENDIX C

BIBLIOGRAPHY

The references contained in this bibliography are a result of the numerous investigations made on this project. All references are catalogued on McBee Keysort cards in the project file.

It is to be noted that the last word on the references indicates where it can be obtained.*

This bibliography does not include references contained in the "Bibliography of Radio Frequency Hazards" (Confidential) prepared by International Electronics Manufacturing Company under Contract by Department of the Navy, Bureau of Ships, Electronics Ships Design Section. This particular bibliography appears as reference 211 in the bibliography of this Appendix.

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* M.R.I. indicates article in Midwest Research Institute Library.
A file number indicates article in project file.
L.H. indicates article in Linda Hall Library.
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APPENDIX D

THERMOMAGNETIC PHENOMENA

I. INTRODUCTION

The Armour Research Foundation[1/] has shown that a phenomenon known as the "Hall effect" can be used to measure the power in electromagnetic radiation within the frequency range of DC to 20 kc. From this work, Midwest Research Institute personnel postulated that this effect and three other associated effects might be used in a power measuring device which would be small, portable, accurate, independent of frequency, and sensitive. The following appendix is a brief resume of the principles and theory involved and the results of some experimentation conducted by the scientists referred to in the bibliography that appears at the end of this section.

II. DESCRIPTION

A. Hall Effect

The classic description of the Hall effect considers an electron gas moving uniformly through a conductor in which the current density is constant over any cross section of the conductor. If a magnet is placed so the lines of flux are perpendicular to the motion of the electrons, the beam of electrons will be displaced in a direction perpendicular to both their motion and the lines of magnetic flux. This displacement results in a nonuniform current distribution "down-stream" from the magnet, because there are more electrons on one side of the conductor than the other. This population density difference constitutes an electric field, and this field can be measured.

The classic description is actually inadequate in many respects, but suffices to give a pictorial explanation. Quantum mechanics, thermodynamics, and solid state physics are needed to give a true picture.

Three analogous effects, the Nernst, Ettingshausen and Righi-Leduc effects, are predictable. Indeed, theoretical treatments show that 560 separate and distinct thermomagnetic effects are possible, 16 of which are independent; the Hall voltage is the largest of all of these, however.

B. Ettingshausen Effect

Concomitant with the voltage gradient described above is a temperature gradient. Ettingshausen was the first to describe this phenomenon. (The temperature difference is quite small, usually between 10^{-1} and 10^{-2} times as large as the Hall voltage.)

C. Nernst Effect

If the flow of electrons is replaced by a flow of heat in the Hall effect description, a potential difference perpendicular to both the flow of heat and the magnetic flux results. The Nernst voltage is usually a few per cent of the equivalent Hall voltage for a unit current or heat flow.

D. Righi-Leduc Effect

Analogous to the Ettingshausen effect, there is a temperature gradient perpendicular to both the magnetic flux and the energy transporting mechanism (in this case, a heat flow).

III. THEORETICAL DEVELOPMENT OF THE HALL EFFECT

A. DC Excitation in Conductors

The force $\bar{F}$ exerted on an electron of charge e moving with a velocity $\bar{V}$ in a magnetic field whose magnetic induction is $\bar{B}$ is given by

$$\bar{F} = e\bar{V} \times \bar{B} \tag{1}$$

(barred letters are vectors). Likewise, the force exerted on an electron is an electric field of magnitude $\bar{E}$ is given by

$$\bar{F} = e\bar{E} \quad . \tag{2}$$

If, in crossed magnetic and electric fields these forces are equal, (1) and (2) may be combined to give

$$\bar{E} = \bar{V} \times \bar{B} \quad . \tag{3}$$

If $\bar{J}$ is the current density, and n is the charge carrier density, then $\bar{J}$ may be expressed as

$$\bar{J} = ne\bar{V} \quad . \tag{4}$$

Substituting $\bar{V}$ from (4) into (3),

$$\bar{E} = \frac{\bar{J} \times \bar{B}}{en} \tag{5}$$

Referring to Fig. D-1a, the dimension across which $\bar{E}$ is to be found is called d ; therefore, the voltage which appears across those two surfaces is given by

$$\bar{V} = \bar{E}d = \frac{\bar{J} \times \bar{B}}{en} d \quad . \tag{6}$$

This voltage is called the Hall voltage, and will be referred to as $\bar{V}_H$. The current density, provided $\bar{I}$ is the total current, may be found from the relation

$$\bar{J} = \frac{\bar{I}}{td} \quad . \tag{7}$$

$\bar{V}_H$ may be equivalently written as

$$\bar{V}_H = R_H \frac{\bar{I} \times \bar{B}}{t} \quad , \tag{8}$$

provided $R_H = - \frac{1}{en} = \frac{\mu}{\sigma}$, where μ is the mobility of the charge carriers in m^2/volt-sec and σ is the conductivity in reciprocal ohmmeters. R_H is then defined to be the Hall coefficient.

B. DC Excitation in Semiconductors

The Hall coefficient for a semiconductor depends on the charge carrier involved (where p is equivalent to n of opposite sign):

$$\text{(n-type)} \qquad R_H = -\frac{3\pi}{8\ en} \tag{9-a}$$

$$\text{(p-type)} \qquad R_H = \frac{3\pi}{8\ ep} \tag{9-b}$$

$$\text{(mixed)} \qquad R_H = -\frac{3\pi(nb^2-p)}{8e(nb+p)^2} \tag{10}$$

$$\text{and} \qquad b = \mu_n/\mu_p \tag{11}$$

C. DC Excitation in Ferro-Magnetic Materials

In ferro-magnetic materials[6], an effective field

$$\bar{H}_{eff} = \bar{H} + 4\pi\alpha\,\bar{M} \tag{12}$$

is substituted for the applied field, where $\bar{M}$ is the microscopic magnitization within the material and α is a constant of the material.

IV. GENERAL EQUATIONS FOR THE NERNST, RIGHI-LEDUC AND ETTINGSHAUSEN EFFECTS

The Nernst effect is analogous to the Hall effect except that the flow of charge is replaced by a flow of heat. The Ettingshausen and Righi-Leduc effects are temperature differences found between the surfaces upon which the Hall or Nernst voltage probes are placed. The development of the appropriate theory is likewise parallel to the Hall effect.

The general form of the equations which describe these four effects for conductors are (see Fig. D-1):

Nernst: $$\overline{V}_N = \left[N \overline{\nabla T} \times \overline{H} \right] d \tag{13-a}$$

Righi-Leduc: $$\overline{T}_{R-L} = \left[S \overline{H} \times \overline{\nabla T} \right] d \tag{13-b}$$

Ettingshausen: $$\overline{T}_E = \left[P \overline{J} \times \overline{H} \right] d \tag{13-c}$$

Hall: $$\overline{V}_H = \left[R \overline{J} \times \overline{B} \right] d \tag{13-d}$$

where in each case P , N , R , and S are the coefficients (Hall coefficient, etc.) of the material and d is the thickness of the sample. For semiconductors the isothermal Nernst coefficient[2] at temperatures high enough for classical statistics to apply is:

(n-type) $$N = -\frac{3\pi k}{16e} \mu_n \tag{14-a}$$

(p-type) $$N = \frac{3\pi k}{16e} \mu_p \tag{14-b}$$

where k is Boltzmann's constant.

V. GENERAL FORM OF THE TOTAL EQUATION

The general equations comprising all four of these effects are, in terms of the charge current density $\overline{J}$ and the heat current density $\overline{W}$:[3]

$$\overline{J} = A_1 \overline{\nabla V} + A_2 \overline{\nabla V} \times \overline{H} + A_3 \overline{\nabla T} + A_4 \overline{\nabla T} \times \overline{H} \tag{15}$$

and

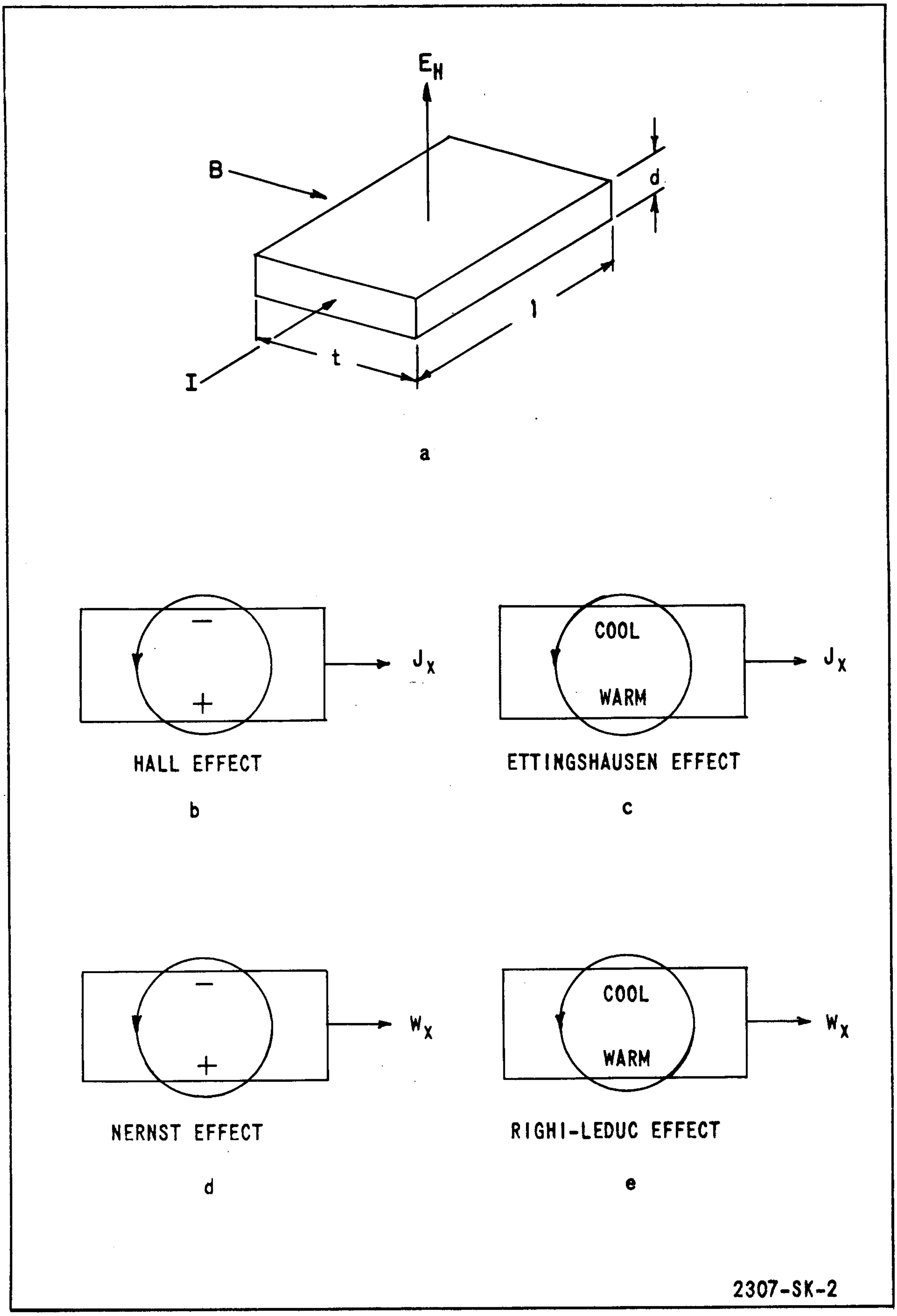

Fig. D-1 - Thermomagnetic Effects

$$\overline{W} = B_1 \overline{\nabla V} + B_2 \overline{\nabla V} \times \overline{H} + B_3 \overline{\nabla T} + B_4 \overline{\nabla T} \times \overline{H} \tag{16}$$

where $\overline{\nabla V}$ is the potential gradient, $\overline{\nabla T}$ is the temperature gradient, $\overline{H}$ is the magnetic field strength and the A's and B's are coefficients. Since $\overline{J}$ and $\overline{\nabla T}$ are experimentally determined, the equations usually are rewritten as

$$\overline{\nabla V} = C_1 \overline{J} + C_2 \overline{J} \times \overline{H} + C_3 \overline{\nabla T} + C_4 \overline{\nabla T} \times \overline{H} \tag{17}$$

and

$$\overline{W} = D_1 \overline{J} + D_2 J \times \overline{H} + D_3 \overline{\nabla T} + D_4 \overline{\nabla T} \times \overline{H} \quad . \tag{18}$$

Referring to Figs. D-1b through D-1e and using (17) and (18), the definitions of the Hall, etc., coefficients are as follows (the subscript i refers to the isothermal case $[\partial T/\partial y = 0]$ and the subscript a refers to the adiabatic case $[W_y = 0]$):

Hall effect:

$$\left.\begin{matrix} R_i \\ R_a \end{matrix}\right\} = - \frac{\partial V/\partial y}{J_x H_z} \quad , \quad J_y = \partial T/\partial x = \left\{\frac{\partial T/\partial y}{W_y}\right\} = 0 \tag{19}$$

Ettingshausen effect:

$$P = - \frac{\partial T/\partial y}{J_x H_z} \quad , \quad J_y = \partial T/\partial x = W_y = 0 \tag{20}$$

Nernst effect:

$$\left.\begin{matrix} N_i \\ N_a \end{matrix}\right\} = \frac{\partial V/\partial y}{(\partial T/\partial x) H_z} \quad , \quad J_y = J_x = \left\{\frac{\partial T/\partial y}{W_y}\right\} = 0 \tag{21}$$

Righi-Leduc effect:

$$S = \frac{\partial T/\partial y}{(\partial T/\partial x)H_z} \quad , \quad J_y = J_x = W_y = 0 \tag{22}$$

Electrical resistivity:

$$\rho_i = \frac{\partial V/\partial x}{J_x} \qquad J = \partial T/\partial x = \partial T/\partial y = 0 \tag{23}$$

Thermal conductivity:

$$\overline{K}_i = - \frac{W_x}{\partial T/\partial x} \quad , \quad J_y = J_x = \partial T/\partial y = 0. \tag{24}$$

The subscripts x , y , and z refer to the direction in which the parameter is to be measured.

Using the above definitions, (17) and (18) can be written:

$$\overline{\nabla V} = - \rho_i \overline{J} + R_i \overline{J} \times \overline{H} + C_3 \overline{\nabla T} - N_i \overline{\nabla T} \times \overline{H} \tag{25}$$

and

$$\overline{W} = D_1 \overline{J} + K_i P \overline{J} \times \overline{H} - K_i \overline{\nabla T} - SK_i \overline{\nabla T} \times \overline{H} \quad . \tag{26}$$

The following relations are then derivable from (25) and (26):

$$R_a = R_i + C_3 P \tag{27}$$

and

$$N_a = N_i + C_3S \quad . \tag{28}$$

R. D. Redin[3] takes the case of adiabatic Hall effect ($J_y = W_y = 0$) and transforms the equation into a form which is experimentally useful:

$$V_H = - \left\{ \left[1-Q/(R_i/P)\right] R_iHI/t - \left[1-Q/(N_i/S)\right] N_iHd\,\partial T/\partial x \right\}, \tag{29}$$

where Q is defined by the equation,

$$V_s = - Q\Delta T \tag{30}$$

and V_s is ordinary Seebeck emf and Q is the absolute thermoelectric power.

The last term of (29) contains d , the thickness of the semiconductor. This dimension should be as small as is structurally feasible, and, as can be seen from (29), will also reduce the Righi-Leduc and Nernst effects. Linearity between Hall voltage and input power is enhanced if d is small, provided the Hall coefficient is constant within the range of interest.

VI. SIMPLIFICATION OF THE GENERAL EQUATION

Putley[4] gives for PbSe at 300°K, $R_i = - 8 \times 10^{-8}$ (volt-cm)/(amp-gauss), $P = 4.4 \times 10^{-6}$(°C-cm)/(amp-gauss), $N_i = 2.3 \times 10^{-10}$ volt/(gauss-°C) and $S = 2.5 \times 10^{-8}$ gauss^{-1}. Hence, dropping the last term of (29), V_H becomes:

$$V_H = - \left[1 - \frac{QP}{R_i} R_i\right] \frac{HI}{t} \tag{31}$$

The term $\frac{QP}{R_i}$ for PbSe is 0.0115 since the thermoelectric power (volts/°C) for PbSe is 2.1×10^{-4} volts/°C. Since $\frac{QP}{R_i} << 1$, Eq. (31) becomes:

$$V_H = \frac{R_i HI}{t} \quad . \tag{32}$$

VII. AC EXCITATION[5]

The conductivity and permittivity of semiconductors vary little from their DC values. The Hall coefficient varies roughly as the square root of the frequency. Barlow[5] and Kataoka, have constructed wattmeters suitable for use at microwave frequencies, and this discussion parallels their various presentations.

In the discussion that insues, the Hall effect and its application to power measurement is given for a slab of germanium crystal erected in a waveguide.[5]

According to the theory developed by Kronig,[6] the microwave conductivity of a semiconductor is given, for extrinsic conditions, by

$$\sigma(\omega) = \frac{\sigma_{dc}}{1+(\omega\tau)^2} \tag{33}$$

where ω is the angular frequency and τ is the mean free time for the carriers (holes or electrons). For intrinsic conditions the conductivity is given by

$$\sigma(\omega) = 1/2\sigma_{dc}\left[\frac{1}{1+(\omega\tau_p)^2} + \frac{1}{1+(\omega\tau_n)^2}\right] \quad . \tag{34}$$

For high purity germanium, τ is on the order of 10^{-12} seconds and $\sigma(\omega)$ would be expected to be nearly the same as σ_{dc} . At 10 kmc, the displacement current is nearly as large as the conduction current, but it is not known to affect the Hall voltage substantially.

The instantaneous Hall voltage is given by

$$V_H = \left(\frac{R_H}{d}\right)\left|\bar{i} \times \bar{b}\right| \quad , \tag{35}$$

where $\bar{i}$ = instantaneous current in the crystal unit (direction parallel to the applied electric field and $\bar{b} = \mu_0 h$ = instantaneous flux density in the crystal unit (h is instantaneous magnetic field). The time average of the Hall voltage is therefore

$$V_{av} = \text{Re}\left[\left(\frac{R_H}{d}\right)\bar{I} \times \bar{B}^*\right] \quad , \tag{36}$$

where $\bar{B}^*$ is the complex conjugate of $\bar{B}$ ($\bar{B}$ = complex r.m.s. value of b), and "Re" refers to the real part of the equation.

Since the Poynting vector of the power flux density is $\bar{S} = \bar{E} \times \bar{H}$ and its time average is $S_{av} = \text{Re}(\bar{E} \times \bar{H}^*)$, V_{ave} will be directly proportional to $S_{x,av}$ (component in the longitudinal direction) when the values of $\bar{I}$ and $\bar{B}$ are suitably related to $\bar{E}$ and $\bar{H}$,respectively ($\bar{E}$ and $\bar{H}$ are the complex r.m.s. values of the instantaneous electric (e) and magnetic fields).

In particular, it is important to insure proper adjustment of the phase of the current through the crystal with respect to the microwave magnetic field. This can be established conveniently when the time average of the Hall voltage is zero with the waveguide terminated in a short circuit. The device should then operate as a wattmeter for power passing through the waveguide (in a longitudinal direction), this power being equal to S_x integrated over the guide cross section. To obtain these conditions, the crystal is mounted with one end attached to the side of the waveguide and the other attached to the center conductor of a coaxial line making a perpendicular connection with the waveguide. The coaxial line has an adjustable piston for phasing the current through the crystal. The effect of the crystal is assumed to be a shunt wave impedance Z across the waveguide at the point where the crystal is placed. The total impedance at this point, looking from the generator to the load when the waveguide is terminated in a short circuit at a distance ℓ , is

$$Z_s = \frac{jZZ_o \tan\beta\ell}{Z+jZ_o \tan\beta\ell} \quad , \tag{37}$$

and the corresponding reflection coefficient is

$$\rho_s = \frac{-Z+j(Z-Z_o)\tan\beta\ell}{Z+j(Z-Z_o)\tan\beta\ell} \quad , \tag{38}$$

where β is the imaginary part of the transmission line coefficient and Z is the characteristic impedance of the transmission line.

When the waveguide has a matched termination, the impedance Z_L (load impedance) and the reflection coefficient ρ_L looking toward the load from the generator will be,

$$Z_L = \frac{ZZ_o}{Z+Z_o} \tag{39}$$

$$\rho_L = \frac{-Z_o}{2Z+Z_o} \quad . \tag{40}$$

When an electric field E_y^+ is incident on the crystal circuit, a current $\bar{I}$ is induced in it and a secondary electric field E_y^- is produced, related to the total current $\bar{I}$ through the crystal by the equation,

$$E_y^- = -\sqrt{\frac{u_o}{\epsilon_o}}\,\frac{\lambda g}{\lambda}\,\frac{I_y}{b}\,\sin\left(\frac{\pi Z}{b}\right)e^{\mp j\beta x} \tag{41}$$

where u_o and ϵ_o are permeability and permittivity of free space, respectively, and b is the width of the waveguide. This assumes the crystal and wires are straight filaments causing only slight disturbances.

Since the crystal is on the axis of the waveguide at $x = 0$, and $E_y^- = \rho_L E_y^+$,

$$I_y = -\,\rho_L E_y^+ \sqrt{\left(\frac{\epsilon_o}{u_o}\right)}\;\frac{\lambda}{\lambda_g}\,b \quad . \tag{42}$$

If ρ_L is small, such that the field in the waveguide remains relatively undisturbed, the total power along the guide is

$$P_x = E_y^+ H_z^+ \left(\frac{ab}{2}\right) \quad , \tag{43}$$

where a is the height of the waveguide, and

$$E_y^+ \Big/ H_z^+ = Z_o = \frac{\lambda g}{\lambda} \sqrt{\frac{u_o}{\epsilon_o}} \quad . \tag{44}$$

Therefore,

$$P_x = 1/2 (E_y^+)^2 \frac{\lambda}{\lambda_g} \sqrt{\frac{\epsilon_o}{u_o}} \, ab \quad . \tag{45}$$

Since we do not know the amount of the displacement current in the crystal, we assume a Hall coefficient R_c for the conduction current and a Hall coefficient R_d for the displacement current. The ratio of these Hall coefficients is

$$R = \frac{R_d}{R_c} \quad . \tag{46}$$

Then remembering it is only the displacement current through the material that is effective in supplementing the conduction current, the time average of the Hall voltage will be

$$V_{av} = \mathrm{Re}\left[\frac{R_c}{d} \frac{\sigma + j\omega r(\epsilon - \epsilon_o)}{\sigma + j\omega\epsilon} I_y B_z^*\right] \quad . \tag{47}$$

Noting that E_y^+ is purely real for a matched load, i.e., $B_z^* = u_o H_z^+ = E_y^+ \sqrt{u_o \epsilon_o} \; \frac{\lambda}{\lambda_g}$, we obtain the time average of the Hall voltage, V_L, at the load by combining (42), (45) and (47):

$$V_L = \left[\frac{R_c}{d} (E_y^+)^2 b \; \epsilon_o \left(\frac{\lambda}{\lambda_g}\right)^2 \right] \text{Re} \left[\rho_L \frac{\sigma + j\omega r(\epsilon - \epsilon_o)}{\sigma + j\omega\epsilon} \right] \tag{48}$$

or

$$V_L = \left[\frac{2R_c}{ad} \frac{\lambda}{\lambda_g} \sqrt{\epsilon_o u_o} \; P_x \right] \text{Re} \left[\rho_L \frac{\sigma + j\omega r(\epsilon - \epsilon_o)}{\sigma + j\omega\epsilon} \right] \quad . \tag{49}$$

Hence, the average Hall voltage for a matched load is directly proportional to the power.

Barlow reached this same conclusion in a previous paper[7] when he developed the equation $V_{Hall} \approx (R_c u \sigma d) P_x$ by assuming that the crystal attenuates the power and the Hall voltage is a measure of the power absorbed by the load.

Success in applying the Hall effect depends largely upon the preparation of the semiconductor element. It is obviously desirable to make the crystal as small as possible and of high impedance to avoid disturbing the field in the waveguide unnecessarily.

With appropriate changes in the structure of the equations above, the arguments for the waveguide measurement also apply when measuring the power of a wave traveling through free space.

VIII. EXPERIMENTAL FINDINGS

The previously developed theories were based on an ideal free electron model; they allowed for no anisotropy, temperature, current, or magnet intensity dependence nor for circumstances other than isothermal or adiabatic. In practice such ideal experiments are not found. Depending upon the type and amount of doping of the semiconductor, the Hall coefficient has a very rapid positive or negative temperature dependence. With care, however, the Hall coefficient can, over a limited but variable range, be essentially independent of temperature.

Putley[4], Antell[8], Folberth[9], Rupprecht[10], and Appel[11] discuss the temperature dependence of the Hall, Nernst and Ettingshausen coefficients. Appel presents theoretical support for his graphical presentation of these experiments which show the temperature dependence upon the type and concentration of the carriers.

Rupprecht and Folberth show how the temperature dependence of the Hall coefficient can be minimized at room temperatures.

Rinder[12] discusses these considerations in the Righi-Leduc as well as Hall effects.

Much of the experimentation at radio frequencies has been done at certain frequencies only; no broad frequency results from any worker has been noted. Enough data can be compiled, however, to indicate that there should be no great difficulty achieving a broad-band instrument.

Stephenson[13], who conducted experiments at 4 kmc, showed that the Hall coefficient actually increased by 195 per cent over its value at DC.

Bogomolov[14] has shown that, if the current and magnetic field are the same frequency, the resulting DC Hall voltage is proportional to the amplitude of the alternating current. This indicates that an instrument, if properly designed, could give an indication of both the total power and the frequencies which contribute to that power.

The most promising material to date is indium antimonide (InSb), since it has the highest mobility. In view of the great amount of semiconductor research conducted today, better materials should be forthcoming. Organic semiconductors may prove to be applicable to this purpose as well. Hughes and General Electric are now conducting research on organic semiconductors.

IX. CONCLUSIONS

Thermomagnetic properties of various types of materials are seen to be useful in r-f power, frequency and magnetic field strength measurements. These properties are controllable and, therefore, a power density measuring unit based upon the Hall effect for RAD HAZ power measurements appears to be plausible.

TABLE D-I

EXPRESSIONS FOR COEFFICIENTS FOR ENERGY INDEPENDENT MEAN FREE PATH[3]

	Fermi-Dirac Statistics (Use in Conductors)	Boltzmann Statistics (Use in Semiconductors)
R_i	$-1/(ne)$	$-3\pi/(8ne)$
R_a	$-1/(ne)$	$-27\pi/(64ne)$
P	$-(T/T_f)/(2nk)$	$-3\pi/(32nk)$
N_i	$-(\pi^2/6)(k/3)(T/T_f)\mu$	$-(3\pi/16)(k/e)\mu$
N_a	$-(\pi^2/3)(k/e)(T/T_f)\mu$	$-(45\pi/128)(k/e)\mu$
S	$-\mu$	$-(21\pi/64)\mu$
ρ_i	$1/(ne\mu)$	$1/(ne\mu)$
K_i	$(\pi^2/3)(k^2Tn\mu/e)$	$2k^2Tn\mu/e$
μ	$eL(2mkT_f)^{-1/2}$	$(4/3)eL(2\pi mkT_f)^{-1/2}$
R_i/P	$2(k/2)(T_f/T)$	$4(k/e)$
N_i/S	$(\pi^2/6)(k/3)(T/T_f)$	$(4/7)(k/e)$
A_3'	$(\pi^2/6)(k/3)(T/T_f)$	$(1/2)(k/e)$

n = the electron concentration.
e = the electron charge.
m = the electron mass.
k = Boltzmann's constant.
L = the mean free path of the carrier.
T = absolute temperature
kT_f = the Fermi energy.

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APPENDIX E

PEARL-CHAIN FORMATION[1]

Pearl-chain formation was observed many years prior to this time. It is not a new phenomenon. Interest in it has been revived lately due to the rapid increase in power output of radar and communication equipment available to both civilian and military organizations.

Pearl-chain formation was first reported by Muth;[2] Krasny-Ergen[3,4] undertook a theoretical analysis of it. A particle, suspended in a fluid whose dielectric constant is different from the particle, is assumed to become electrically polarized with the result that electrical charges appear at the particle's boundary. In effect, therefore, an electric dipole is formed which then is influenced by the electric field to align with the field. The orientation of the dipole will follow the changing field as long as the alternations are not too rapid. If the distance between the particles is small enough and the field strength large enough, the characteristic chains will form. Random thermal energy (Brownian movement) as well as kinetic energy of moving fluids tend to disrupt the chain formation. If the probability of chain formation is expressed as a ratio of the potential energy of the alignment forces (E_p) to the potential energy of the disruptive forces (E_d) the following equation is obtained for stationary (non-moving fluids) conditions:

$$\frac{E_p}{E_d} \doteq \frac{1.4\epsilon r^3 E_o^2}{kT} \qquad (1)$$

where ϵ = dielectric constant of the suspending fluid;

r = radius of particle;

E_o = electric field strength without particles present;

k = Boltzmann's constant; and

T = absolute temperature, Kelvin.

Alignment is anticipated when the value of the ratio is greater than unity.

It is essential that the particulate matter in question have a dielectric constant different than that of the suspending fluid. Pearl-chains have been observed in diluted blood.[5] This would hardly have been predicted, inasmuch as erythrocytes show nearly identical electrical properties as that of plasma[6,7] and should, therefore not align. Neither Liebesny's nor Muth's work is sufficiently quantitized to permit direct application of Eq. (1). More work must be done to check the validity of this equation. Other mechanisms than Krasny-Ergen's are suggested in light of experimental evidence.

Schwan[8] lists various field strengths necessary to align different particulates but his calculations do not agree with precision with those obtained from physical data and Eq. (1) (see Table E-I).

Irrespective of the theoretical basis for the phenomenon, the fact remains that pearl-chain formation is a reality. Profound disturbances of normal metabolism are expected if pearl-chains could be formed in living tissue. Although it has not yet been observed, the possibility must not be discarded.

Another facet of pearl-chain formation is its possible use as a microwave dosimeter. The observation of chain formation, perhaps by resistance or dielectric changes, should be usable to indicate the electric field strength at the point of observation. Carbon particles, polystyrene spheres or other particulates could be suspended in a fluid which approximates the electrical characteristics of tissue. The temperature rise of the liquid should be measured as well.

TABLE E-I[8]

Material	r (in microns)	E_o (v/cm)	Watts/cm^2 to produce E_o
Blood	3	2	0.030
Mitochondria	1	10	0.800
Proteins	0.01	10^4	8×10^5

Note: It is pointed out that experimental conditions may cause great variation in E_o from those expected by calculation from the power density.

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APPENDIX F

VARIATIONS IN ELECTROMAGNETIC FIELD PROPERTIES WITH DISTANCE FROM THE RADIATION SOURCE

The study of the biological effects of electromagnetic radiation is strongly dependent upon the observation of experimental results. Consequently, the conditions under which experiments are performed must be completely known and fully reported if the experimental results are to have any subsequent value. Since, in general, wave polarization and mode of r-f energy propagation, in addition to magnetic and electric field strength, may be different at different distances from any given source of r-f electromagnetic radiation, serious experimental discrepancies can result if care is not exercised in defining and recording experimental conditions in detail.

By the same token, evaluation of r-f radiation hazards in the field can be rendered completely worthless by careless techniques which do not take into account the variations in the character of the electromagnetic field at various distances from the source. Conditions which may constitute considerable hazards to personnel may be overlooked when measurements are based on "far-field" assumptions which are not valid in regions near the source.

As an example of the discrepancies that may result from inadequate experimental data, suppose that experimenter "A", using a transmitter capable of delivering W_A watts, irradiates a subject in a field E volts per meter, for a period of t seconds, by placing that subject at a distance r_{PA} meters from the source. Suppose, further, that "A" reports the results of his experiment along with a statement of the frequency, field strength, time of exposure, and type of antenna used, but does not include any other information. It is entirely conceivable that another experimenter, "B", whose transmitter is capable of delivering only W_B watts, may attempt to reproduce the experiment of "A" by placing his subject at a distance r_{PB} meters from the source in order to obtain the desired field strength, E volts per meter, only to obtain somewhat different results than those reported by "A". The experimental results are different because, in reality, the experimental conditions are different, even though the same frequency and the same field strength (at least according to the calculations and/or measurements of "B") were used and the times of exposure were the same.

It is not difficult to imagine a similar example relating to the evaluation of r-f radiation hazards in the field. However, in this connection the misinterpretation of r-f electromagnetic field conditions can have much more serious consequences than in the case of a laboratory experiment; the lives and welfare of personnel may be involved. Thus, in both laboratory and field investigations, an understanding of electromagnetic field properties, and of how these properties vary with distance from the source of electromagnetic waves is essential to the intelligent consideration of instrumentation and techniques to be used.

It will be our purpose here to discuss some of these field properties and to obtain some insight into their variations with distance from the source. The discussion begins with a consideration of the approximation techniques that are frequently used in electromagnetic field calculations and of the conditions under which these approximations are valid. Next, the total electromagnetic field and its variations with distance from the source will be considered. Finally, a comparison will be made between the total field and the approximate field in order to point out the care that must be taken in applying the approximations.

A. Approximation Techniques in Electromagnetic Field Calculations

All electromagnetic radiation arises ultimately from accelerated charge. Since charge in motion is equivalent to current, it follows that every source of electromagnetic waves can be represented by an appropriate distribution of time-varying current. Consequently, the infinitesimal current element can be considered as a basic building block from which all sources of electromagnetic waves can be constructed. If one knows the character of the electromagnetic field produced by such a current element, in addition to the current distribution over a given source of finite dimensions, one can (at least in theory) find the total electromagnetic field produced by that source at any point in space by summing the contributions from all differential current elements which compose the source.

In practice, the summation of these contributions for a given source configuration is sometimes difficult and more often impossible to obtain by completely rigorous analytic processes. However, in many electromagnetic radiation problems, the total field created at some point of observation very far away from the source is of primary interest. When attention is focused on this so-called "far field", certain approximations can be made which simplify the summation process but do not appreciably affect the accuracy of the result.

The first of these approximations is concerned with the physical nature of the field and is based on the fact that at great distances from the source, the "static" (or, more precisely, the "quasi-static") field, which varies inversely as the cube of distance, and the "induction" field, which varies inversely as the square of distance, are both negligible in comparison with the "radiation" field, which varies inversely with the distance from the source.[1]

The remaining approximations are concerned with the geometry involved in the calculation of the total field at a given point. At distances which are extremely large in comparison with the source dimensions, the distance from any part of the source to the point of observation is essentially equal to the distance from any other part of the source to the point of observation. In this event, the field contributions from all parts of the source can be added together with the same relative phase relationship and with the same relative amplitudes that they have at the source. This approximation corresponds to the Fraunhaufer approximation used in dealing with the analogous situation in optics.[2] If the point of observation is located somewhat nearer the source, the distances between various parts of the source and the point of observation differ by somewhat larger percentages, although these distances may be measured along lines which are still essentially parallel. These differences in distance have a more pronounced effect on the relative phases of the various contributions than on their relative amplitudes. It becomes necessary to use a more refined approximation, comparable to the Fresnel approximation in optics,[3] which takes into account the effect of distance on phase retardation, but not on amplitude variation. As the distance between source and observation point continues to decrease, the percentages by which the distances between various portions of the source and the point of observation differ become so large that their effects on both amplitude and phase of the contributions to the total field must be taken into account, and the lines along which these distances are measured can no longer be considered parallel.

Ultimately, as the distance between the point of observation and source grows smaller, the approximation concerning the nature of the field produced by each differential portion of the source, as well as the approximation concerning the geometry to be used in these differential contributions to the total electromagnetic field, become invalid. The problem of determining the total electromagnetic field at the point of observation in the "near field" must be approached through the use of exact equations with consequent complication of the mathematics involved. The problem is frequently solvable only by machine computation.

A great deal of attention has been given to the problems of geometry and integration associated with "near-field" calculations.[4,5,6,7] Although the solutions to such problems are important steps in the analysis of the total electromagnetic field produced near a given antenna of finite size, they do not fully develop the fundamental differences between wave polarization, field variations with time, and modes of energy propagation in the "near field" and the "far field". Since the differential current element represents a basic subdivision of any finite radiation source, considerable information concerning variations of these field properties can be obtained from an analysis of its total electromagnetic field, without involvement in geometrical and integration difficulties.

B. <u>The Total Electromagnetic Field of a Differential Current Element</u>

The derivation of the total electromagnetic field of a differential current element forms an appropriate introduction to the discussion of the basic properties of this field. Since this derivation is extensively treated in the literature,[8,9] it will be presented here with a minimum amount of detail, primarily for the purpose of establishing the notation to be used in the subsequent discussion.

Consider the linear, thin-wire current element of differential length dz, situated at the origin of a set of space coordinates and oriented along the Z-axis, as shown in Fig. F-1. Let this element carry a current $i(t) = I \cos \omega t$, where the reference direction is taken along the positive Z-axis and $\omega = 2\pi f$ is the "angular radian frequency" of the current time variation. At an arbitrary point of observation, P, having space coordinates r_P, θ_P, ϕ_P, this current element will produce a vector potential, $\underline{A}$, which can be defined in terms of the volume integral of a vector current density, $\underline{J}$, in the following manner:[10]

$$\underline{A} = \frac{\mu}{4\pi} \int_{\vartheta} \frac{\underline{J}\left(t - \frac{r_P}{c}\right)}{r_P} \, d\vartheta = \underline{Z} \, \frac{I dz}{4\pi r_P} \cos \omega\left(t - \frac{r_P}{c}\right) \quad . \qquad (1)$$

Here, $\underline{Z}$ is a unit vector in the Z-direction, μ is the permeability of the medium in which the current element is immersed and in which the electromagnetic waves are propagated, and the factor $\cos \omega\left(t - \frac{r_P}{c}\right)$ accounts for the finite time required for the effects of a change in element current to be propagated over the distance r_P at a velocity c. Expressed in terms of its spherical-coordinate components, (1) becomes

$$\underline{A} = \frac{\mu K}{r_P} \cos\left(\omega t - k r_P\right)\left[\underline{r} \cos \theta_P - \underline{\theta} \sin \theta_P\right] \quad , \qquad (2)$$

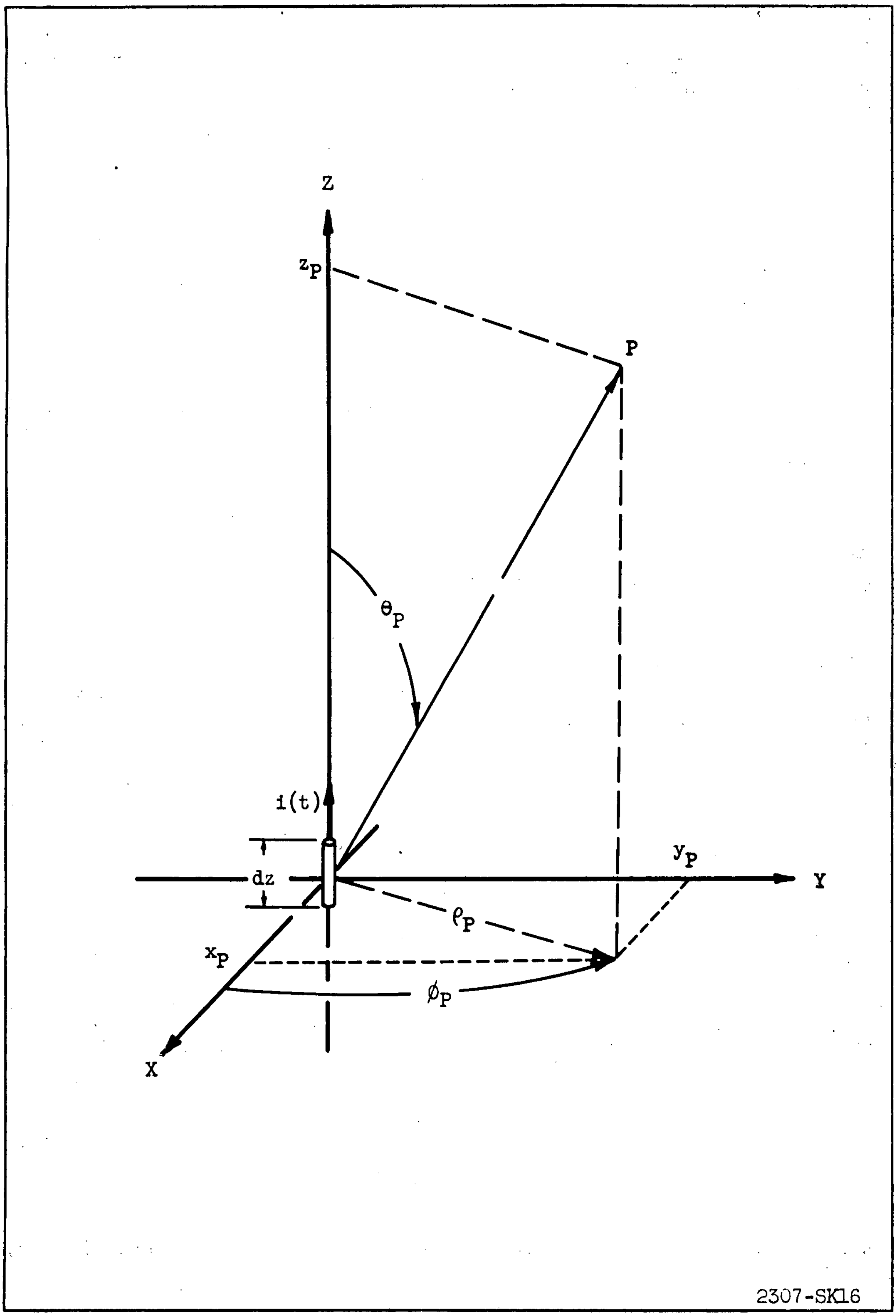


Fig. F-1 - Differential Current Element

where $\underline{r}$ and $\underline{\theta}$ are appropriate unit vectors in the r- and θ-directions, respectively, and the substitutions $K = Idz/4\pi$ and $k = \omega/c = 2\pi/\lambda$ have been made in order to simplify the notation.

1. <u>The magnetic field</u>: The vector potential is defined in such a way that the magnetic field at P is given by[11]

$$\underline{H} = \frac{1}{\mu}(\nabla_P \times \underline{A})$$

$$= \frac{K}{\sqrt{\mu\epsilon}}\left\{\underline{\phi}\sin\theta_P\left[\frac{1}{cr_P^2}\cos(\omega t - kr_P) - \frac{\omega}{c^2 r_P}\sin(\omega t - kr_P)\right]\right\}, \quad (3)$$

where $\underline{\phi}$ is a unit vector in the ϕ-direction (mutually perpendicular to $\underline{r}$ and $\underline{\theta}$), and the fundamental relation $c = 1/\sqrt{\mu\epsilon}$ has been used to put the expression into a convenient form for further manipulation.

Inspection of (3) shows that the magnetic field at any point, P, produced by the differential current element at the origin is totally ϕ-directed, around the line of current flow in the same manner as dictated by the "right-hand" rule commonly applied to determine the direction of flux produced by a direct current. This ϕ-directed <u>vector</u> is written in terms of two <u>phasors</u>, one of magnitude

$$H_{\phi 1} = \frac{K\sin\theta_P}{cr_P^2\sqrt{\mu\epsilon}} = \frac{K\sin\theta_P}{r_P^2}, \quad (4)$$

which is in time phase with the vector potential at P (i.e., in phase with the element current as seen from P), and the other of magnitude

$$H_{\phi 2} = \frac{\omega K\sin\theta_P}{cr_P} = \frac{\omega r_P}{c}H_{\phi 1}, \quad (5)$$

which leads the vector potential by $\pi/2$ radians (90 electrical degrees).

These two phasors are represented graphically in Fig. F-2a. According to the results indicated there, the expression for the magnetic field can be written in the form

$$\underline{H} = \underline{\phi}\, H_\phi(r_P,\, \theta_P)\, \cos\left[\, \omega t^* + \psi_\phi(r_P)\right] \quad , \tag{6}$$

where

$$H_\phi(r_P,\theta_P) = \sqrt{H_{\phi 1}^2 + H_{\phi 2}^2} = H_{\phi 1}\sqrt{1 + \frac{\omega^2 r_P{}^2}{c^2}} = \frac{kK \sin\theta_P}{r_P}\sqrt{1 + \frac{1}{k^2 r_P{}^2}} \quad , \tag{7}$$

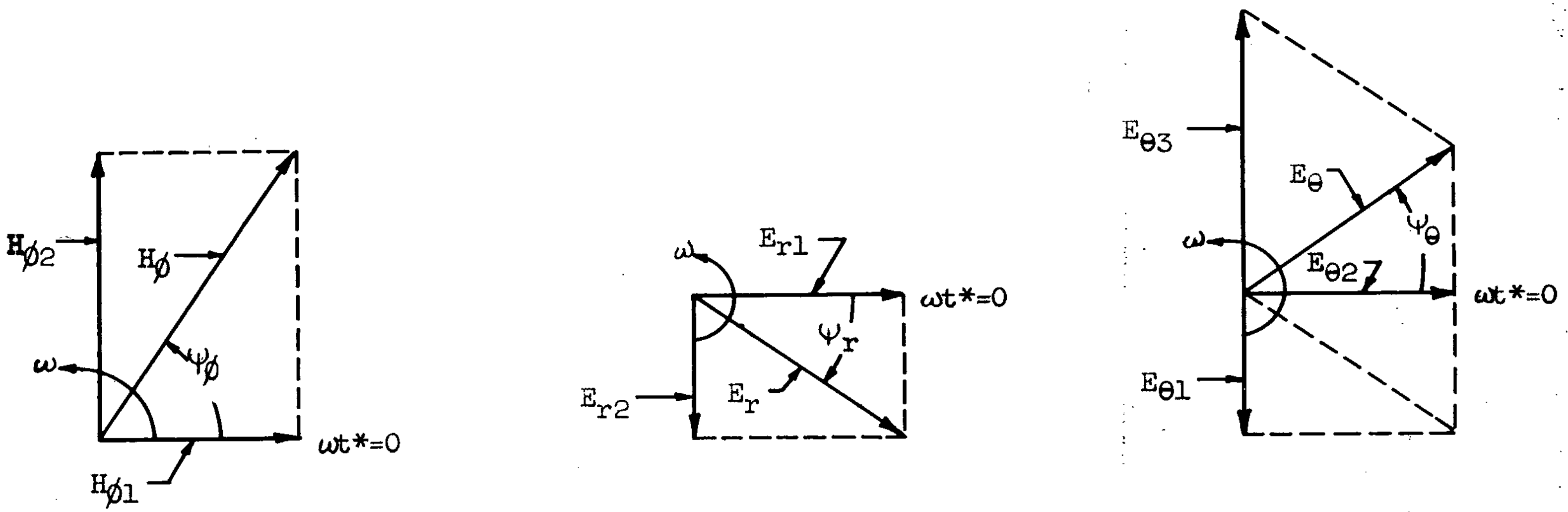
$$\psi_\phi\,(r_P) = \tan^{-1}\left(\frac{\omega r_P}{c}\right) = \tan^{-1}(kr_P) \quad , \tag{8}$$

and the "retarded time", $t^* = t - \frac{r_P}{c}$, has been used in order to further simplify notation.

Conveniently "normalized" plots of (7) and (8) are presented in Fig. F-3. These curves indicate the magnetic field is a fairly well-behaved function of r_P . Its asymptotic behavior for small values of r_P is such that $H_\phi(r_P,\theta_P) \longrightarrow \frac{1}{r_P{}^2} H_\phi(\theta_P)$ and $\psi_\phi(r_P) \longrightarrow 0$. At great distances from the differential current element, $H_\phi(r_P,\theta_P) \rightarrow \frac{1}{r_P} H_\phi(\theta_P)$ and $\psi_\phi(r_P) \longrightarrow \pi/2$.

Since there is only one vector component of $\underline{H}$, the polarization of the magnetic field is in the same direction (the ϕ-direction) at all distances from the source.

The distance $r_P = \lambda/2\pi$ is of particular interest in relation to the magnetic field. This value of r_P may be considered as somewhat of a "transition value" because when r_P has this value, the two phasor



(a) $H_{\phi 1} = \dfrac{K \sin \theta_P}{r_P^2}$

$H_{\phi 2} = \dfrac{\omega r_P}{c} H_{\phi 1}$

$\psi_\phi = \tan^{-1}\left(\dfrac{\omega r_P}{c}\right)$

$H_\phi = \dfrac{kK \sin \theta_P}{r_P} \sqrt{1 + \dfrac{1}{k^2 r_P^2}}$

(b) $E_{r1} = \dfrac{2\eta K \cos \theta_P}{r_P^2}$

$E_{r2} = \dfrac{c}{\omega r_P} E_{r1}$

$\psi_r = \tan^{-1}\left(- \dfrac{c}{\omega r_P}\right) = \tan^{-1}\left(- \dfrac{1}{k r_P}\right)$

$E_r = \dfrac{2\eta K \cos \theta_P}{r_P^2} \sqrt{1 + \dfrac{1}{k^2 r_P^2}}$

(c) $E_{\theta 1} = \dfrac{c}{\omega r_P} E_{\theta 2}$

$E_{\theta 2} = \dfrac{\eta K \sin \theta_P}{r_P^2}$

$E_{\theta 3} = \dfrac{\omega r_P}{c} E_{\theta 2}$

$\psi_\theta = \tan^{-1}\left(\dfrac{k^2 r_P^2 - 1}{k r_P}\right)$

$E_\theta = \dfrac{\eta k K \sin \theta_P}{r_P} \sqrt{1 - \dfrac{1}{k^2 r_P^2} + \dfrac{1}{k^4 r_P^4}}$

$\underline{H} = \underline{\phi}\, H_\phi \cos\left[\omega t^* + \psi_\phi\right]$

$\underline{E} = \underline{r}\, E_r \cos\left[\omega t^* + \psi_r\right] + \underline{\theta}\, E_\theta \cos\left[\omega t^* + \psi_\theta\right]$

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Fig. F-2 - Phasor Components of $\underline{E}$ and $\underline{H}$ at $t^* = 0$.

components, (4) and (5), have equal magnitudes and the phase of the magnetic field consequently leads the vector potential by $\pi/4$ radians or 45°.

2. The electric field: At the point P , the electric field is given by the expression[12]

$$\underline{E} = \frac{1}{\mu\epsilon} \nabla_P \nabla_P \circ \int \underline{A}\, dt - \frac{\partial \underline{A}}{\partial t}$$

$$= \frac{K\eta}{\sqrt{\mu\epsilon}} \left\{ \underline{r}\, 2\cos\theta_P \left[\frac{1}{\omega r_P^3} \sin(\omega t - kr_P) + \frac{1}{c r_P^2} \cos(\omega t - kr_P) \right] \right.$$

$$\left. + \underline{\theta} \sin\theta_P \left[\frac{1}{\omega r_P^3} \sin(\omega t - kr_P) + \frac{1}{c r_P^2} \cos(\omega t - kr_P) - \frac{\omega}{c^2 r_P} \sin(\omega t - kr_P) \right] \right\}, \qquad (9)$$

where $\eta = \sqrt{\mu/\epsilon}$ is the "intrinsic impedance" of the medium.

From (9) it can be seen that $\underline{E}$ comprises two vector components. The r-directed vector consists of two phasors, one of magnitude

$$E_{r1} = \frac{2K\eta \cos\theta_P}{c r_P^2 \sqrt{\mu\epsilon}} = \frac{2K\eta \cos\theta_P}{r_P^2}, \qquad (10)$$

which is in time phase with the vector potential at P , and the other of magnitude

$$E_{r2} = \frac{2K\eta \cos\theta_P}{\omega r_P^3 \sqrt{\mu\epsilon}} = \frac{c}{\omega r_P} E_{r1}, \qquad (11)$$

which lags the vector potential by $\pi/2$ radians, as indicated in Fig. F-2b. The θ-directed vector component of $\underline{E}$ comprises three phasors:

$$E_{\theta 1} = \frac{K\eta \sin\theta_P}{\omega r_P^3 \sqrt{\mu\epsilon}} = \frac{c}{\omega r_P} E_{\theta 2}, \qquad (12)$$

which lags the vector potential by $\pi/2$ radians;

$$E_{\theta 2} = \frac{K\eta \sin \theta_P}{c r_P^2 \sqrt{\mu \epsilon}} = \frac{K\eta \sin \theta_P}{r_P^2} \quad , \tag{13}$$

which is in time phase with the vector potential at P ; and

$$E_{\theta 3} = \frac{\omega K \eta \sin \theta_P}{c r_P} = \frac{\omega r_P}{c} E_{\theta 2} \quad , \tag{14}$$

which leads the vector potential by $\pi/2$ radians, as shown in Fig. F-2c. In comparison with (6) for the case of the magnetic field, Figs. F-2b and F-2c show that the total electric field at P can be expressed as

$$\underline{E} = \underline{r} E_r(r_P, \theta_P) \cos\left[\omega t^* + \psi_r(r_P)\right] + \underline{\theta}\, E_\theta(r_P, \theta_P) \cos\left[\omega t^* + \psi_\theta(r_P)\right] \tag{15}$$

where

$$E_r(r_P, \theta_P) = \sqrt{E_{r1}^2 + E_{r2}^2} = \frac{2K\eta \cos \theta_P}{r_P^2} \sqrt{1 + \frac{1}{k^2 r_P^2}} \quad , \tag{16}$$

$$\psi_r(r_P) = \tan^{-1}\left(-\frac{c}{\omega r_P}\right) = \tan^{-1}\left(-\frac{1}{k r_P}\right) \quad , \tag{17}$$

$$E_\theta(r_P, \theta_P) = \sqrt{E_{\theta 2} + (E_{\theta 3} - E_{\theta 1})^2} = \frac{kK\eta \sin \theta_P}{r_P} \sqrt{1 - \frac{1}{k^2 r_P^2} + \frac{1}{k^4 r_P^4}} \quad , \tag{18}$$

and

$$\psi_\theta(r_p) = \tan^{-1}\left(\frac{\omega^2 r_p^2 - c^2}{c\omega r_p}\right) = \tan^{-1}\left(\frac{k^2 r_p^2 - 1}{k r_p}\right) \quad . \tag{19}$$

Conveniently "normalized" plots of (16) through (19) are also given in Fig. F-3. From these curves it becomes apparent that, in comparison with the magnetic field, the electric field is an extremely complicated function of r_p, particularly at small distances from the source. Since the electric field is composed of two orthogonal vector components whose magnitudes and phases vary in different manners with r_p, its over-all magnitude, phase, and polarization all change with distance from the source. Only when $r_p \longrightarrow \infty$ does $\underline{E}$ become essentially a θ-directed field with $E_\theta(r_p,\theta_p) \longrightarrow \frac{1}{r_p} E_\theta(\theta_p)$ and $\psi_\theta(r_p) \longrightarrow \pi/2$, so that $\underline{E}$ and $\underline{H}$ form an essentially plane wave.

At the "transition" distance, $r_p = \lambda/2\pi$, the three phasor components of E_θ have the same magnitude and the two phasor components of E_r have the same magnitude. Thus, at this distance from the source, E_r lags the vector potential by $\pi/4$ radians while E_θ is in phase with the vector potential. However, the magnitudes of E_r and E_θ are still functions of position and, consequently, the magnitude, phase, and polarization of the total electric field are also.

3. Instantaneous Poynting vector - propagation of energy: We are now in a position to investigate the propagation of energy in the total field of the differential current element. The investigation is most easily carried out by considering the instantaneous Poynting vector[13] which is representative of the instantaneous power density or rate and direction of energy flow at any point in the field. Using the expressions for the total magnetic field given in (3) and the total electric field given in (9), we find the instantaneous Poynting vector to be

$$\underline{S} = \underline{E} \times \underline{H} = \underline{r} E_\theta H_\phi - \underline{\theta} E_r H_\phi$$

$$= \frac{\eta K^2}{\mu \epsilon} \sin\theta_p \left\{ \underline{r} \sin\theta_p \left[\frac{\sin\omega t^* \cos\omega t^*}{\omega c r_p^5} + \frac{\cos^2\omega t^* - \sin^2\omega t^*}{c^2 r_p^4} - \frac{2\omega \sin\omega t^* \cos\omega t^*}{c^3 r_p^3} + \frac{\omega^2 \sin^2\omega t^*}{c^4 r_p^2} \right] - \underline{\theta}\, 2\cos\theta_p \left[\frac{\sin\omega t^* \cos\omega t^*}{\omega c r_p^5} + \frac{\cos^2\omega t^* - \sin^2\omega t^*}{c^2 r_p^4} - \frac{\omega \sin\omega t^* \cos\omega t^*}{c^3 r_p^3} \right] \right\} . \tag{20}$$

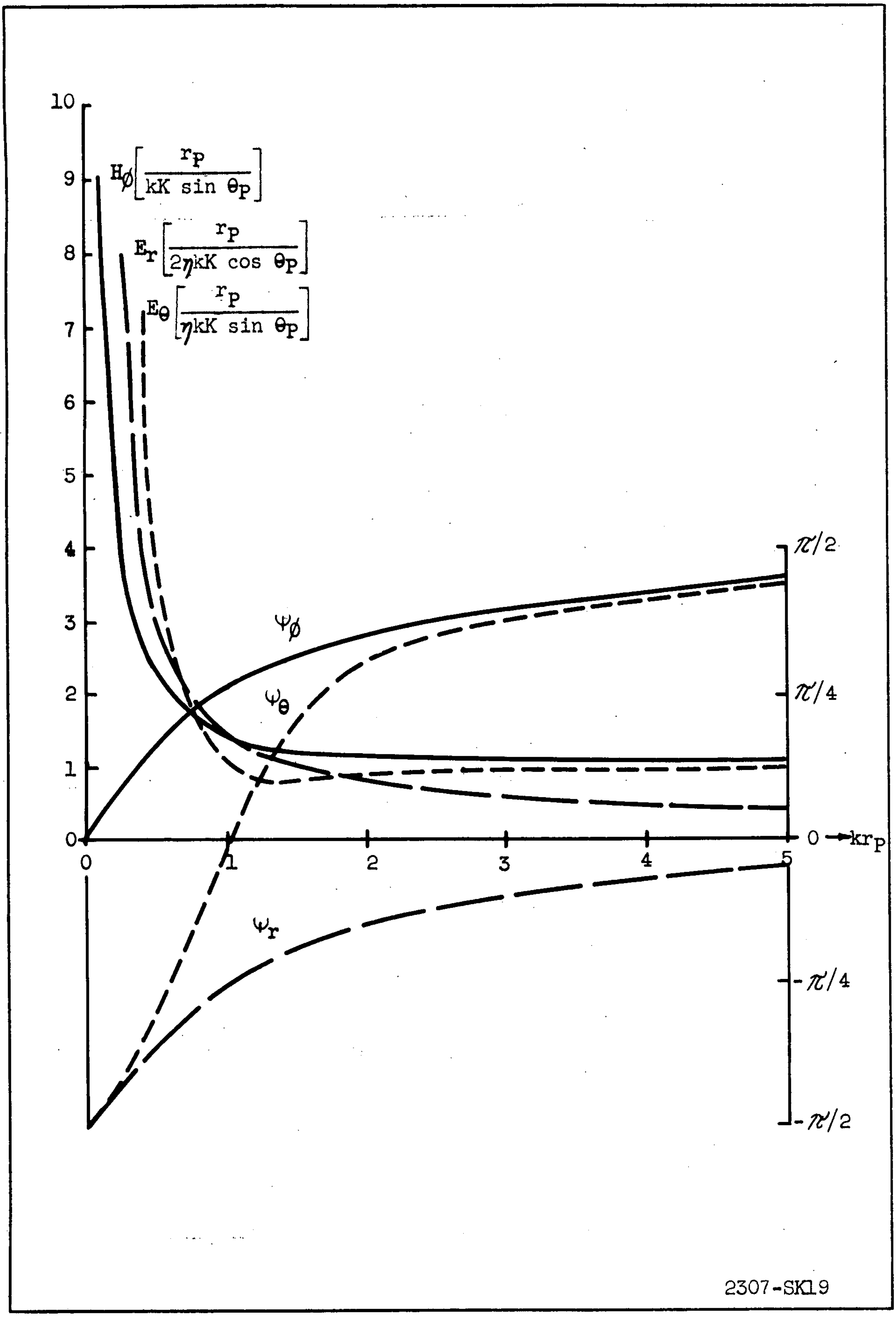

Fig. F-3 - Phase and "Normalized" Magnitude of the Various Components of E and H

By application of the appropriate trigonometric double-angle relations, and a slight amount of subsequent manipulation, (20) can be put into the form

$$\underline{S} = \frac{\eta}{2}\left[\frac{kK}{r_p}\right]^2 \left\{ \underline{r} \sin \theta_p \left[1 - \sqrt{1 + \frac{1}{k^6 r_p^6}} \cos\left(2\,\omega t^* + \tan^{-1} \frac{2k^2 r_p^2 - 1}{k^3 r_p^3 - 2kr_p}\right)\right] - \underline{\theta}\, 2 \cos\theta_p \sin\theta_p \left[\left(\frac{1}{kr_p} + \frac{1}{k^3 r_p^3}\right) \cos\left(2\,\omega t^* + \tan^{-1} \frac{1 - k^2 r_p^2}{2kr_p}\right)\right]\right\} . \quad (21)$$

From (21) it is apparent that there is, in general, a θ-directed flux of energy around the differential current element as well as a radial energy flow. Moreover, it is clear that both the θ-directed and the r-directed energy flows vary with time at twice the frequency of the current variation in the differential current element. The θ-directed flux of energy is seen to be a maximum for

$$\frac{d}{d\theta_p}\left[\sin \theta_p \cos \theta_p\right] = 1 - 2 \sin^2\theta_p = 0 \qquad \text{or} \qquad \theta_p = \left\{ \begin{matrix} \pm\pi/4 = \pm 45^\circ \\ \text{and} \\ \pm 3\pi/4 = \pm 135^\circ \end{matrix} \right\} , \quad (22)$$

and to decrease to zero at $\theta_p = 0,\ \pi/2,\ \pi$, and $3\pi/2$. Inspection of (21) also shows that the θ-directed flux of energy is a sinusoidal function of time while the radial component of this energy flux comprises the superposition of a steady (outward) term and a sinusoidally varying term. Consequently, the time-average value of the total Poynting vector is seen to be

$$\overline{\underline{S}} = \underline{r}\, \frac{\eta}{2}\left[\frac{kK \sin\theta_p}{r_p}\right]^2 \quad (23)$$

everywhere in the space around the differential current element but the magnitude and direction of the peak or maximum value of $\underline{S}$ both vary with r_p and θ_p. These facts are graphically illustrated by plotting S_r and

S_θ as functions of time for several representative values of r_P as in Fig. F-4. A summary of the information with respect to the maximum and minimum values of S_r and S_θ is presented in Fig F-5, once again in respect to a conveniently "normalized" scale.

C. The "Far-Field" Approximation

We now return to the consideration of the approximations concerning the physical nature of the total electromagnetic field of the differential current element. From (3) and (9) it is apparent that when r_P is quite large, the magnetic and electric fields at P can be represented by the approximations

$$\underline{H} = - \underline{\phi} \frac{K}{\sqrt{\mu\epsilon}} \sin \theta_P \left[\frac{\omega}{c^2 r_P} \sin \omega t^* \right] = - \underline{\phi} \frac{kK \sin \theta_P}{r_P} \sin \omega t^* \quad , \qquad (24)$$

and

$$\underline{E} = - \underline{\theta} \frac{\eta K}{\sqrt{\mu\epsilon}} \sin \theta_P \left[\frac{\omega}{c^2 r_P} \sin \omega t^* \right] = - \underline{\theta} \frac{\eta \, kK \sin \theta_P}{r_P} \sin \omega t^* = \eta \underline{H} \quad . \qquad (25)$$

Under these circumstances the instantaneous Poynting vector is found to be

$$\underline{S} = \underline{E} \times \underline{H} - \underline{r} E_\theta H_\phi = \underline{r} \eta \left[\frac{kK \sin \theta_P}{r_P} \right]^2 \sin^2 \omega t^* \quad . \qquad (26)$$

From (26) it follows that the time-average Poynting vector is

$$\overline{\underline{S}} = \underline{r} \frac{\eta}{2} \left[\frac{kK \sin \theta_P}{r_P} \right]^2 \quad . \qquad (27)$$

which is identical with the result expressed in (23). Thus, it becomes apparent that one can calculate the average rate of energy flux through any

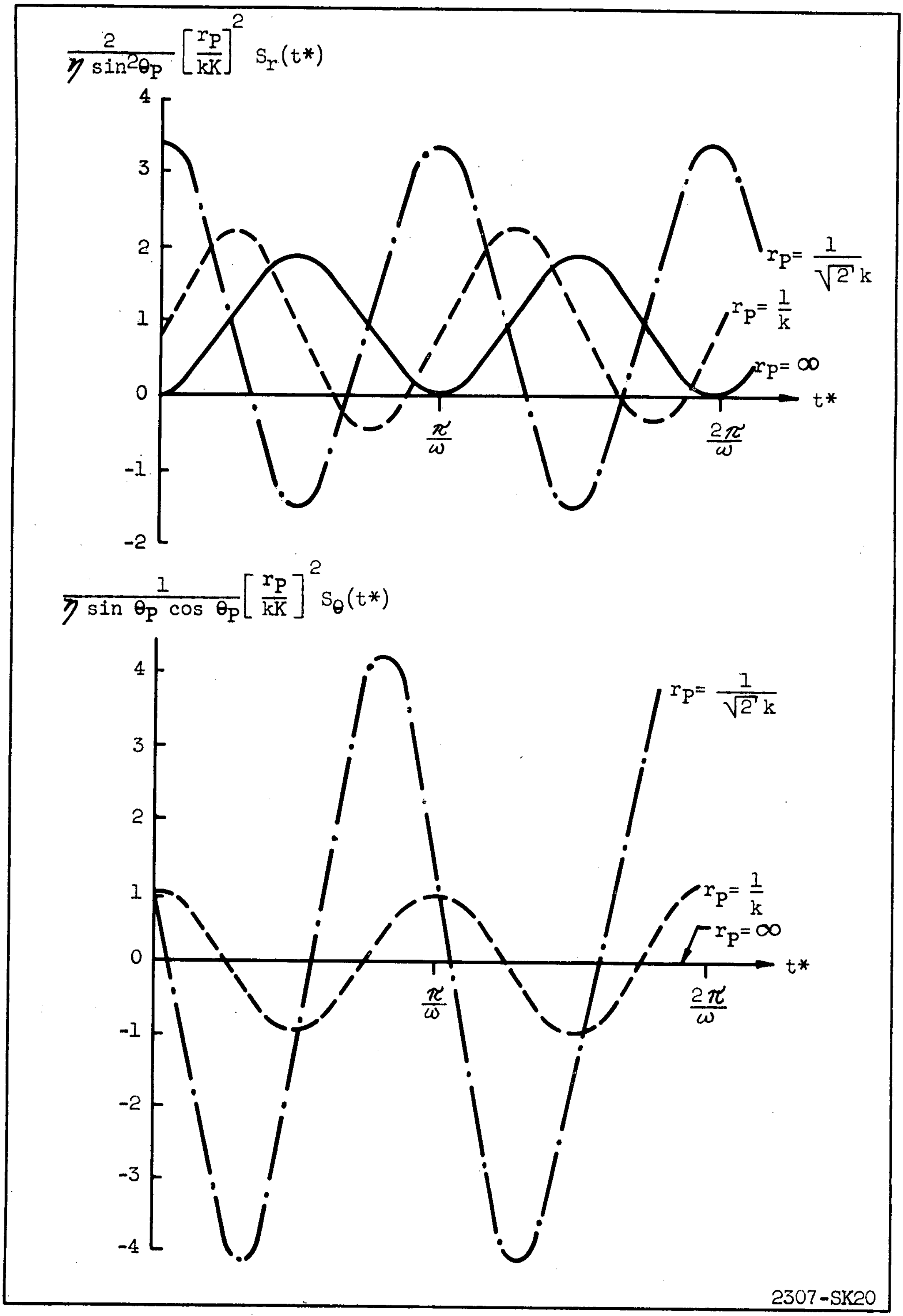

Fig. F-4 - Time Variation of Poynting Vector at Various Distances from Source

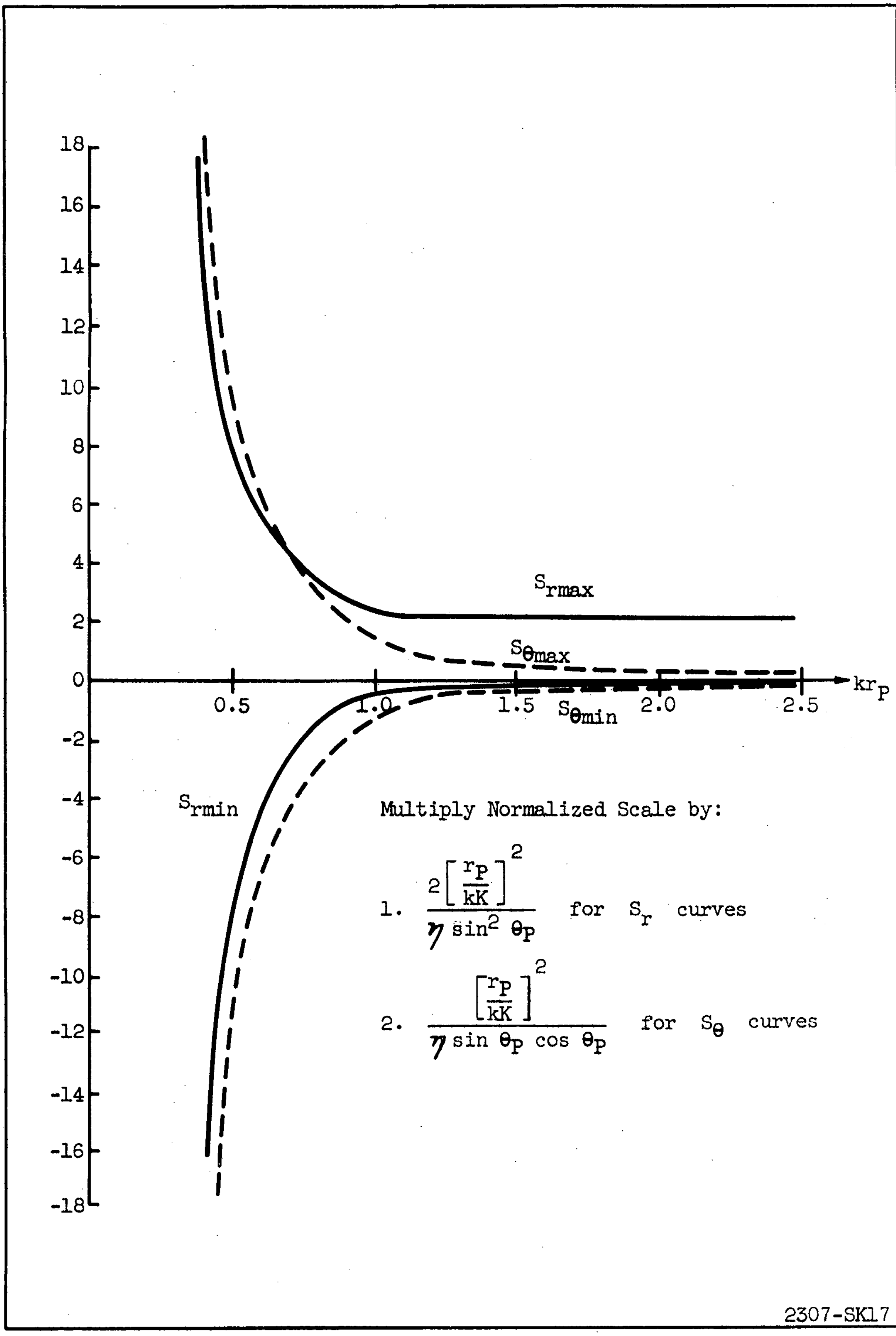

Fig. F-5 - "**Normalized**" Summary of Relative Amplitudes of Poynting Vector Components given element of surface area, having arbitrary location and orientation in space, by using either the total magnetic and electric field expressions or their "far-field" approximations; the results will be the same because the "static" and "induction" portions of the total field do not contribute to the average rate of energy flow at any point in the field. However, the peak value of the Poynting vector, i.e., the peak rate of energy flux, obtained through the use of the "far-field" approximation is just twice the average value, while the peak value of $\underline{S}$ obtained when the exact values of $\underline{E}$ and $\underline{H}$ are used depend on r_P, and (for small values of r_P) may be many times larger than the average value.

D. Experimental Discrepancies Arising from Indiscriminant Use of "Far-Field" Approximations

In order to illustrate how discrepancies may arise from indiscriminant application of the "far-field" approximation, let us return to the example of experimenters "A" and "B" mentioned earlier. We shall simplify the problem by assuming that "A" and "B" have made a previous agreement to use short dipoles (essentially differential current elements) as radiation sources and to place their experimental subjects in the XY-plane (see Fig. F-1) where the electric field is essentially vertically polarized. Thus, according to (6), (15) and (21), the magnetic field, electric field and instantaneous Poynting vector are given, in general, by the expressions

$$\underline{H} = \underline{\phi}\,\frac{kK}{r_P}\sqrt{1 + \frac{1}{k^2 r_P^2}}\,\cos\left[\omega t^* + \tan^{-1}(kr_P)\right] , \qquad (28)$$

$$\underline{E} = \underline{\theta}\,\frac{\eta kK}{r_P}\sqrt{1 - \frac{1}{k^2 r_P^2} + \frac{1}{k^4 r_P^4}}\,\cos\left[\omega t + \tan^{-1}\left(\frac{k^2 r_P^2 - 1}{kr_P}\right)\right] , \qquad (29)$$

$$\underline{S} = \underline{r}\,\frac{\eta}{2}\left[\frac{kK}{r_P}\right]^2 \left\{1 - \sqrt{1 + \frac{1}{k^6 r_P^6}}\,\cos\left[2\omega t^* + \tan^{-1}\left(\frac{2k^2 r_P^2 - 1}{k^3 r_P^3 - 2kr_P}\right)\right]\right\} . \qquad (30)$$

We shall also assume that since the transmitter used by "B" is somewhat less powerful than the one used by "A", "B" finds that he must place his subject at a distance $r_{PB} = r_{PA}/\sqrt{2}$ from the source in order to obtain the same field strength reported by "A".

Now, if both transmitters are powerful enough that

$$r_{PB} = r_{PA}/\sqrt{2} >> 1/k \tag{31}$$

at the specified frequency, it follows that both "A" and "B" may use the "far-field" approximations for (28) through (30). Under these circumstances it is found that

$$\left.\begin{aligned} \underline{H}_A &\approx -\underline{\phi}\,\frac{kK_A}{r_{PA}}\sin\omega t^* \;; & \underline{H}_B &\approx -\underline{\phi}\,\frac{kK_B}{r_{PB}}\sin\omega t^* \\ \underline{E}_A &\approx -\underline{\theta}\,\frac{\eta kK_A}{r_{PA}}\sin\omega t^* \;; & \underline{E}_B &\approx -\underline{\theta}\,\frac{\eta kK_B}{r_{PB}}\sin\omega t^* \\ \underline{S}_A &\approx \underline{r}\,\frac{\eta}{2}\left[\frac{kK_A}{r_{PA}}\right]^2\left\{1-\cos 2\omega t^*\right\} \;; & \underline{S}_B &\approx \underline{r}\,\frac{\eta}{2}\left[\frac{kK_B}{r_{PB}}\right]^2\left\{1-\cos 2\omega t^*\right\} \end{aligned}\right\} \tag{32}$$

with the condition that

$$\frac{\eta kK_B}{r_{PB}} = \frac{\eta kK_A}{r_{PA}} \quad . \tag{33}$$

Upon substituting from (33) into the various expressions in (32) and comparing the magnitudes of the resulting quantities, without regard to relative phases, we find that

$$H_{\phi B} \approx H_{\phi A} \;;\; E_{\theta B} \approx E_{\theta A} \;;\; \overline{S}_{rB} \approx \overline{S}_{rA} \;;\; \text{and } S_{rBmax} \approx S_{rAmax} \;, \tag{34}$$

at least within the degree of approximation that has been assumed in the use of the "far-field" expressions for these quantities. However, if the transmitters used by "A" and "B" are not sufficiently powerful that the subjects can be placed in a region where the "far-field" approximations are valid, the situation is quite different. This may be readily demonstrated by taking the specific example where it is found necessary to make

$$r_{PB} = r_{PA}/\sqrt{2} = 1/\sqrt{2}\,k \quad . \tag{35}$$

The exact equations, (28) through (30), may now be used to find

$$\begin{aligned}
&\underline{H}_A = \underline{\phi}\sqrt{2}\,k^2K_A \cos\left[\omega t^* + \tan^{-1}(1)\right] \;;\quad \underline{H}_B = \underline{\phi}\sqrt{6}\,k^2K_B \cos\left[\omega t^* + \tan^{-1}\left(\frac{\sqrt{2}}{2}\right)\right] \\
&\underline{E}_A = \underline{\theta}\eta k^2K_A \cos\left[\omega t^* + \tan^{-1}(0)\right] \;;\quad \underline{E}_B = \underline{\theta}\eta\sqrt{6}\,k^2K_B \cos\left[\omega t^* + \tan^{-1}\left(\frac{\sqrt{2}}{2}\right)\right] \\
&\underline{S}_A = \underline{r}\,\frac{\eta}{2}\left[k^2K_A\right]^2 \left\{1 - \sqrt{2}\cos\left[2\omega t^* + \tan^{-1}(-1)\right]\right. \;; \\
&\qquad \underline{S}_B = \underline{r}\,\frac{\eta}{2}\left[\sqrt{2}\,k^2K_B\right]^2 \left\{1 - \sqrt{1+2\sqrt{2}}\cos\left[2t^* + \tan^{-1}(0)\right]\right\}
\end{aligned} \tag{36}$$

with the condition that

$$\eta\sqrt{6}\,k^2K_B \equiv \eta k^2K_A \quad . \tag{37}$$

Upon substituting from (37) into the various expressions in (36) and once again comparing the magnitudes of the resulting quantities without regard to their relative phases, we find

$$\left.\begin{aligned}
&H_{\phi B} = \frac{\sqrt{2}}{2} H_{\phi A} \;;\; E_{\theta B} = E_{\theta A} \;,\; \bar{S}_{rB} = \frac{1}{3}\bar{S}_{rA} \;; \\
&\text{and} \\
&S_{rBmax} = \frac{1 + \sqrt{1+2\sqrt{2}}}{3(1+\sqrt{2})} S_{rAmax} \approx 0.41\; S_{rAmax}
\end{aligned}\right\} \quad . \tag{38}$$

Thus, although "B" has faithfully reproduced all of the conditions stipulated by "A" (i.e., frequency, electric field strength, and time of exposure), he has, in reality, not reproduced the experiment performed by "A" for his subject has been exposed to only one-third the average power density of that experienced by the subject in the experiment of "A" and only 41 per cent of the peak power density experienced by the subject in the experiment of "A".

Suppose that "A" had specified average power density rather than field strength and that the condition (35) was found to be necessary for "B" to achieve this average power density. In this case, the relations in (36) remain unchanged but (37) is replaced by

$$\frac{\eta}{2} k^4 K_A^2 = \frac{\eta}{2} 2k^4 K_B^2 \quad . \tag{39}$$

A similar substitution into the expressions of (36) and comparison of resulting magnitudes show that if this had been the case, then we would have found that

$$\left.\begin{aligned} &H_{\phi B} = \frac{\sqrt{6}}{2} H_{\phi A} \; ; \; E_{\theta B} = \sqrt{3}\, E_{\theta A} \; ; \; \overline{S}_{rB} = \overline{S}_{rA} \; ; \\ &\text{and} \\ &S_{rBmax} = \frac{1 + \sqrt{1+2\sqrt{2}}}{1 + \sqrt{2}} S_{rAmax} \approx 1.22\, S_{rAmax} \end{aligned}\right\} \quad . \tag{40}$$

Once again, in following the incomplete experimental conditions stipulated by "A", the experimenter "B" has performed what might, at first sight, be an identical experiment, but upon complete analysis is found to be a far different one from the one performed by "A".

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12. Skilling, _op. cit._, Eq. (386), p. 166.

13. Stratton, _op. cit._, pp. 131-137.

APPENDIX G

COMMERCIALLY AVAILABLE MEASURING INSTRUMENTS

Instruments which are applicable in some fashion to power density or field intensity measurements and are currently available are given in the following table. The table does not include associated equipment, such as antennas, bolometer and thermistor mounts, coaxial directional couplers, attenuators.

TABLE G-I

EMR MEASURING INSTRUMENTS

Manufacturer	Model No.	Frequency Range
Stoddart Aircraft Radio Co.	NM-40A (AN/URM-41)	30 cps - 15 kc.
Stoddart Aircraft Radio Co.	NM-10A (AN/URM-6)	14 kc. - 250 kc.
Stoddart Aircraft Radio Co.	NM-20B (AN/PRM-1A)	150 kc. - 25 mc.
Stoddart Aircraft Radio Co.	NM-30A (AN/URM-47)	20 mc. - 400 mc.
Stoddart Aircraft Radio Co.	NM-50A (AN/URM-17)	375 mc. - 1000 mc.
Stoddart Aircraft Radio Co.	NM-60A (AN/URM-42)	1000 mc. - 10.7 kmc.
Empire Devices Products Corp.	NF-105	150 kc. - 1000 mc.
Empire Devices Products Corp.	NF-157	200 mc. - 10 kmc.
Empire Devices Products Corp.	NF-112	1 mc. - 10 mc.

TABLE G-I (Concluded)

Manufacturer	Model No.	Frequency Range
Polorad Electronics Corp.	FIM	1000 mc. - 10 kmc.
Polorad Electronics Corp.	P-3 Power Bridge	Depends on detecting elements
General Electric General Engineering Lab.	Field Intensity Indicator	750 mc. - 30 kmc.
Polytechnic Research and Development Co., Inc.	Type 650 B Power Bridge	Depends on detecting elements
Polytechnic Research and Development Co., Inc.	PRD Type 662 Calorimeter	DC - 40 kmc.
Sperry Microwave Electronics Co.	Microline 646 Radiation Detector	400 mc. - 1600 mc. 2700 mc. - 3300 mc. 5200 mc. - 5900 mc. 8500 mc. - 9600 mc.
FXR, Inc.	B-831A	0.01 kmc. - 40 kmc.
Radar Measurements Corporation	1200 Densitometer	200 mc. - 225 mc. 400 mc. - 450 mc. 2.6 kmc. - 3.3 kmc. 5.0 kmc. - 5.9 kmc. 8.5 kmc. - 10 kmc.
Radio Corporation of America	MI30410 (Meter indication only)	50 mc. - 500 mc.
Radio Corporation of America	MI30411 (with self-contained alarms)	Depends on antenna chosen
ITI Electronics, Inc.	(AN/PRM-21)	1.7 mc. - 4 mc.
Narda	440 Power Bridge	Depends on detecting elements
Narda	369 NF	0.7 kmc. - 12.4 kmc.
Hewlett Packard	430 C Power Bridge	Depends on detecting elements

APPENDIX H

BIO-EFFECTS

I. INTRODUCTION

There are divergent philosophies in the "Bio-Effects" area inherent in the present research effort.

A major military duty and need is the examination and alleviation of hazards arising from electromagnetic radiations. To this end the three branches of our Armed Forces have commissioned various individuals and organizations, both extra-service and inter-service, to examine exposed personnel and report these medical findings and to conduct research studies on the interaction of nonionizing radiation with biological materials.

Inasmuch as many of these projects have only been recently instituted, conclusive evidence is not readily available. Further, as was implied in the opening paragraph, the basic philosophies and immediate goals of the various investigators are not the same. Therefore, much of the progress achieved and information derived from the more basic research programs are not directly applicable to the present need of hazard evaluation.

To illustrate, it may be said that no genetic change or damage has been observed in military or civilian personnel either occupationally or accidentally exposed to electromagnetic radiation in the frequency range of 14 kc. to 40 kmc. Genetic damage has been observed, however, in growing plant cells when irradiated with 6 and 27 mc. radiation.[1/]

From the immediate viewpoint of hazard evaluation, it only can be said that, under current frequencies and powers available, genetic damage is improbable. From the broader viewpoint of "Bio-Effects", however, it can be said that genetic damage is demonstrable, at least in plant cells.

II. BIOLOGICAL EFFECTS OF ELECTROMAGNETIC FREQUENCY FROM 14 KC. TO 40 KMC.

Developing further the different philosophical viewpoints outlined in the Introduction, this section will be divided into two parts: (A) Hazards, a section limited to the biological reactions known to occur in humans who have been irradiated with r-f energy. These reactions have been tentatively explained by means of a heating or thermal action. (B) Bio-Effects, a section which comprises the effects known to MRI personnel which may cause or have been shown to cause biological reactions, changes or damage, including hazards.

A. Hazards

1. Ophthalmological: Cataracts can occur in eye lenses which have been exposed to r-f radiation.[2,3,4] The energy-time relationship is such that a nearly constant energy absorption is necessary to cause cataracts after a threshold is achieved. Therefore, short exposures to high power densities can produce cataracts. Pertinent factors to be considered in the determination of the threshold value of power density and the sensitivity of the eye include: peak power, the ratio of "on time" to "off time" of the transmitter,[5] repetition rate, exposure time, species irradiated, and size of the eye. Many of these factors are interconnected in unknown and complex fashions so the usual method of hazard evaluation is by empirical experimental techniques, rather than by calculation. These cataracts occur only in the posterior lens capsule,[4] affording a clear clinical differentiation between the r-f induced cataract and other types of cataract.

2. Testicular degeneration: It has been known for some time that relatively high testicular temperatures can cause temporary or permanent sterility in man. The most common example of this is the failure of the testes to descend through the inguinal canal at the proper (prenatal) time, and therefore remain in the slightly higher temperature environment of the abdominal cavity. This condition is known as cryptorchism, and almost invariably results in sterility.

Temporary high temperatures encountered by normally descended testes are conducive to temporary sterility. Radio frequency radiation of sufficient power density is capable of causing these temperatures.[6,7] The power density requirements for this type of damage are sufficiently high so that temporary sterility caused by normal operation of transmitters is unlikely. The most hazardous frequency range is from 1,000 mc. to 3,000 mc., due to the penetration characteristics of the radiation at these frequencies.

3. Total body heating:[7,8] If the entire body is exposed to r-f radiation, the power density that can be tolerated is small because of the higher total energy absorbed. Environmental conditions play a part in determining the allowable dose.[5] The body must reject the heat which it

absorbs from the radiation, and this, as in any other heat engine, takes work. The body's capacity to do this is limited. The body's normal daily energy intake is roughly equivalent to 10 mw/cm^2 [7,8] of body surface area. It seems reasonable, but cannot be proved at this time, that the body has the ability to withstand an additional equivalent energy intake of approximately 10 mw/cm^2 from other sources. The recommended exposure limit to r-f radiation is based upon this assumed ability. Further research and experimental evidence is needed to substantiate this exposure limit for humans, but no undesirable effects have yet been noted in animal experiments conducted at the 10 mw/cm^2 level. This limit is assumed for the frequency range of 1,000-3,000 mc., because the absorption coefficients at these frequencies are high.[6,7,9]

4. Brain: Approximately 17 per cent of the blood pumped by the heart goes to the brain. Since the brain is enclosed in the skull, which has poor heat transfer properties, the temperature of the brain tends to rise more rapidly and to higher final temperatures for a given whole-body radiation intensity than does the rest of the body.

There is apparently a small difference between the acceptable power density level and levels known to do damage. At approximately 20 mw/cm^2 brain damage is observed in experimental animals. Some investigators feel that this is uncomfortably close to the recommended limit of 10 mw/cm^2. Indeed, 10 mw/cm^2 is not claimed to be safe; only that to date no damage has been recorded at this power level.[7]

5. Lung: The lungs, under conditions of whole-body irradiation, are roughly in the center of the radiation field. At power density levels near, or somewhat greater than, the acceptable level of 10 mw/cm^2, hemorrhage may occur in experimental animals. Humans can exist quite adequately with as little as one-half of the gaseous exchange surface normally present in the lung. Reduction in exchange surfaces by hemorrhage would have to be great before respiration would be impaired. This is perhaps of least concern. Infection, foreign body reactions, loss of blood, shock, and other effects are certainly of greater importance.

6. Burns: Burns, both surface and internal, have been observed to occur from r-f radiation.

Induction heating plays a very minor role in hazard evaluations with the possible exception of personnel coming into contact with inductively heated objects, such as belt buckles, coins, keys, metallic hardware, guy wires, etc.

Dielectric heating plays a more important role in hazard evaluation. External burns, particularly at areas of overlapping tissue folds, are common.[10] Internal burns, particularly in the thoracic and abdominal cavities and at tissue or organ interfaces also are seen. However, neither case has yet been demonstrated to occur at the 10 mw/cm^2 level.

B. Bio-Effects

Bio-Effects (by which is meant the deviations from normal behavior or conditions) caused by r-f radiation, either directly or indirectly, are many and varied. Since this subject properly includes hazards, there will be some repetition of the above items in the discussion which ensues. However, in most cases the duplication will be presented with different emphases.

1. Chemical reactions: Nonthermal alterations of chemical reaction rates have been observed by various investigators. Further, chemical reactions have been caused by, or initiated by, r-f radiation. The mechanisms involved are not always clearly understood but are generally ascribed to transitions between various rotational and spin levels, nuclear resonances, and physical orientation of macromolecules. Polymerization has also been both affected and effected by r-f radiation.

2. Metabolic changes: The uptake of zinc (Zn^{65}) in rats is inhibited by irradiation with 2.5 cm. microwaves.[5] The mechanism of this reaction is not known. Ion transport rates also are altered; this is thought to be caused by temperature increase.

3. Protein denaturization: Protein denaturization is easily caused by microwaves.[11] The denaturization is expected when the amount of energy absorbed in the protein is sufficient to raise its temperature to the required level. Rate and amount of denaturization has been shown to be a function of the polarization of the beam of radiation. The observation that "hot spots" occurred at the junctions of dissimilar sizes of tubing containing the protein, leads to the question of increased susceptibility of humans at similar physical structures.

4. Pearl-chain formation: Pearl-chain phenomena are not recent discoveries nor have they been demonstrated to have any clinical significance. The normal body temperature has a deleterious effect due to the relatively high k-T* product in the formation of pearl-chains. The phenomena

* Product of Boltzmann's constant and temperature denoting a measure of thermal energy.

may have more significance in lower animals and in plants since their body temperature approximates that of their environment.

5. Molecular orientations: Solutions which have the ability to change the plane of polarization of light passing through them are affected by microwaves. The rotational change seen in these solutions is a function of frequency and peak power,[12] and is known as the Faraday effect.[6]

6. Cellular orientations: Schwan and Shen's work at the University of Pennsylvania[13] may explain Heller's observation that the movement of protozoa and bacteria are influenced by r-f energy.[14] These microorganisms normally move randomly in their suspension, provided that the lighting is even. Upon application of low radio frequencies (approximately 5 mc.), the organisms move parallel to the electrodes, or perpendicular to the electric field. At higher frequencies (20 mc.), they move parallel to the electric field. At intermediate frequencies, the protozoa and bacteria either remain unaffected and move randomly, remain fixed in one position, or spin rapidly about an axis perpendicular to the plane defined by the electric field. These experiments must be performed at low power levels to insure that heating is negligible. Heller uses a 1 to 100 mc. variable generator with a variable output voltage (0 to 20 kv.). Pulse modulation is used, with pulse widths from 1 to 20 microseconds and repetition rates varying from 30 to 10,000 per second.

These phenomena are frequency and species specific. Field gradients across the cells are not known, but the gross field strengths required are quite high (300-1,200 v/cm); however, the total power requirements are quite small.

Heller is also able, apparently by selective polarization, to pull amoebas apart by using the proper frequencies and pulse rates.

Schwan and Shen's efforts have been to predict the dielectric and conductivity behavior of inhomogeneous particles as a function of frequency. They started first with spherical particles which were divided into a core and an outer layer, each with different ϵ and k (dielectric constant and conductivity). Their treatment considers the particles to be suspended in a medium of ϵ and k different from either the core or outer layer of the particle and follows the Maxwell-Wagner theory. They have progressed to three-layered elipsoids. These models can be used to closely approximate and therefore determine the behavior of blood cells, protozoa, bacteria, and tissue of varying types. The tissue cell or protozoa can be considered to be a three- or four-layered elipsoid.

7. Chromosome aberrations: The normal cell, undergoing mitotic division or reproduction passes through four phases and a resting or interphase: Prophase, when the chromosomes coalesce into visible threads; Metaphase, when they align on the equator of the cell, Anaphase, when each half of the chromosome pair splits and travels to either end of the cell; and Telophase, when the protoplasm starts to divide. At the completion of this last phase, the division is complete and two identical cells result.

Growing cells must divide. They live by transpiration through their surfaces. The energy requirements of the cell are a function of the volume of the cell. It is seen, therefore, that the volume is proportional to the cube of the radius of the cell, while the means for supporting the mass of cellular tissue is proportional to the square of the radius. The ability of a cell to absorb enough material to sustain life soon outgrows its needs and it is forced to divide.

The chromosomes are paired structures which contain the genetic material necessary to determine the characteristics of the cell. Each chromosome splits and is shared between the two resulting cells, and they are, therefore, identical.

The chromosomes are most susceptible to damage during the prophase and metaphase portions of reproduction. Any malformation of the chromosome or disruption of the process previously described will result either in a defective cell, leading to either death or malfunction, or in the inability of the cell to completely divide, again culminating in death.

R-f radiation, in the frequency range between 5 and 25 mc., has been shown by Heller[1/] to cause chromosome aberrations, chiasmas, "stickiness" and other malformations in growing garlic root tip cells. This finding is quite important, for these effects had heretofore been seen only as a result of ionizing radiation or as a result of the application of certain chemicals, notably mustard gas. The quantum energy of the radiation is so small that molecular bond disruption by direct energy absorption is highly unlikely. The effect seen, however, is not a thermal one. A new specific nonthermal effect has apparently been found. Its importance in human hazards is far from known at this time.

8. Growth and reproductive changes: Investigations at the Army Chemical Corps and by Susskind, Vogelhut,[12/] and others, primarily on plant cells; have established that growth, reproductive rates and reproductive mechanisms are affected by r-f energy.

In the microwave region, reproduction by sexual processes is inhibited. In the 1 to 20 meter band, however, growth of many organisms is enhanced. The reaction is not because of heating; rather, it appears to be a direct effect of the electric field. Further, frequency specificity is seen.

9. Neurological effects: Neurological disfunction has been reported by Bach[15,16] and the complexity of the reactions seen tends to indicate a nonthermal origin.

III. DOSE RATE AND COOLING EFFECTS

Assuming strictly thermal effects from irradiation, the methods for increasing survival probabilities and lessening the effects of radiation fall into two classes:

1. Dosage control

2. Heat removal

The following discussion of these methods is due primarily to Deichman.[5]

A. Dosage Control

Given a total exposure to r-f energy of Q watt-sec/cm^2, very different effects are seen for different rates of application, fractionation of the energy, size of the animal under study and frequencies. For the purposes of this discussion, frequency will be considered constant (Deichman used 24 kmc.) and the animal will be a rat.

One hundred milliwatt-seconds (100 millijoules), delivered at a rate of 100 mw. for 1 sec., would be expected to be a greater hazard than if it were delivered at a rate of 10 mw. for 10 sec.

What is not so clearly understood or widely known, however, is that if a given amount of energy, say 100 mw-sec, is delivered to an animal in 1 min., the effects seen are grossly dependent upon the dose rate. In the previous paragraph a dose-rate dependent situation was outlined, and the rate was a function of the total exposure time. In this paragraph the total exposure time is the same, but the rate of delivery within the exposure period is varied. An analogous situation is seen when a sailor stands a watch for 4 hr. while being exposed to radiation from a rotating antenna. If the power density is a periodic function in time, the sailor will receive the same total exposure dose whether the antenna rotates at one revolution per second, two revolutions per second, or any other speed.

Deichman has shown that if a rat receives 500 mw. per 2 sec. at a rate of 500 mw. for 1 sec., off for 1 sec., for a period of time T, its probability of survival is less than that of a rat who receives radiation at a rate of 500 mw. for 1/2 sec., off for 1/2 sec. for the same period of time T. Within a period of 2 sec., each rat receives the same exposure dose, but the rat that was exposed at the latter rate survives longer and exhibits less systemic reaction to the radiation. Survival rates can be increased many-fold by fractioning the dosage into small units.

Deichman has varied exposure times, keeping the on-off time ratios equal, from 3 sec. to 60 sec. of "on" time. The rats survived 242 per cent longer when the "on" time was 3 sec. than those exposed to "on" times of 60 sec. Over a 120 sec. period of time, the rats were exposed to the same total energy per square centimeter, yet effects seen were not equal.

The exact mechanism explaining this phenomenonis not known, but this situation is exactly equivalent to any situation in which an animal exhibits recovery from a stress. Radiologists have used this "stress-recovery" reaction for many years; when a massive dose of radiation for cancer treatment was indicated, the dose would be fractionated into small units one or more times a week to reduce the severity of radiation sickness and of erythema.

The results of Dr. Deichman's continuing efforts will be examined carefully for possible use in establishing a maximum allowable power density level for humans.

B. Heat Removal

Dr. Deichman has also studied the effect on survival time of removing induced heat from rats. He has shown that directing air blasts upon the rats can increase survival up to 400 per cent. Whether this method would be applicable to humans is not known. Rats do not sweat, have relatively thick fur, and are reported to have poor temperature-regulating abilities.

The time-constant concept in evaluating hazards is important in measuring power density and assessing hazards. The time constants of the instrumentation used must be designed in concordance with the biological and environmental time constants encountered.

Thermal orthodoxy tells us that, from the standpoint of effect, we must average the power if the period of exposure is much greater than the biological time constant, but must not average the power over longer time periods. An example is a sailor on watch, when he is 4 hr. on and 8 hr. off. Here average power is considered only during the 4-hr. period.

Where a field period is of the order of a biological time constant, an intermediate situation exists. This situation is illustrated by Deichman's work at Miami where the effects of a radiation field switched on for 3 sec. and off for 3 sec. were grossly different from those seen with an equivalent constant field. The results suggest a structure with a time constant on the order of 3 sec. or less. The low penetration of the 1.25 cm. waves used would suggest the skin, but one would not expect it to prove critical in causing acute death of the animal.

The efficacy of an air blast for cooling will depend upon the frequency of the radiation. At 24 kmc., the radiation is absorbed mainly in the skin and fat directly under the skin. As the frequency decreases, the point of maximal heating moves farther away from the area upon which the radiation impinges. The circulatory system must then carry the heat to the skin. Air blasts, therefore, may not be as efficient at lower frequencies as they are at 24 kmc.

The skin is postulated to be responsible for these effects seen at times as short as 3 sec. No other organ is small enough and close enough to the surface to account for these findings. On the other hand, it is difficult to see why irradiation of skin should result in such widespread systemic reactions. Equivalent heat loads produced by other means do not give these results.

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APPENDIX I

NOTES ON INSTRUMENTATION

The material given in this appendix has been compiled by personnel from the Welex Electronics Corporation, consultants to Midwest Research Institute. The discussions that ensue are notes on the work Welex has been doing toward the development of a field strength meter.

I. POWER DENSITY INSTRUMENTATION

At most radio frequencies it is ordinarily easier and more convenient to measure voltage, current, and impedance than it is to measure power. Under these conditions the direct determination of power is of only limited importance. On the other hand, at microwave frequencies, voltage, current and impedance are difficult to determine, may differ greatly at slightly different points in a circuit, and are appreciably affected by small changes in geometry. Accordingly, at the highest radio frequencies the most significant quantity then is power.

Power measurements are customarily made through the use of a bolometer which operates as a power sensitive element in an audio bridge circuit and changes r-f energy into heat energy.

A. Bolometers

Bolometers used for microwave measurements are of two general types. One, a metallic wire or film in which the temperature coefficient of resistance is positive, and thermistors in which it is negative. Both barretters and instrument fuses are used as positive temperature coefficient bolometers. Barretters consist of a short length of very fine platinum wire suitably encapsulated. Negative temperature coefficient bolometers (thermistors) consist of a small bit of semiconductive material suspended between two fine wires.

Barretters are delicate, and are readily burned out by absorbing too much power. Even if the overload is insufficient to burn out a barretter, it may increase its cold resistance to the point where a self-balancing bridge meter cannot be zero set. Thermistors, on the other hand, are much more rugged. Burn-out power is rated at 25 mw. maximum; they generally burn out at about 400 mw. or more, and their characteristics change only slightly, if at all, upon overload.

The frequency range of a thermistor depends upon its construction. There is a thermistor in existence which operates over the frequency range of 10 mc. to 10 kmc. with a fair amount of accuracy.

In general, square wave or pulse modulated power can be measured accurately with either a barretter, fuse or thermistor, subject to certain limitations which depend upon the characteristics of the bolometer elements in conjunction with the bridge oscillator. However, in many power meters, these limitations are not serious.

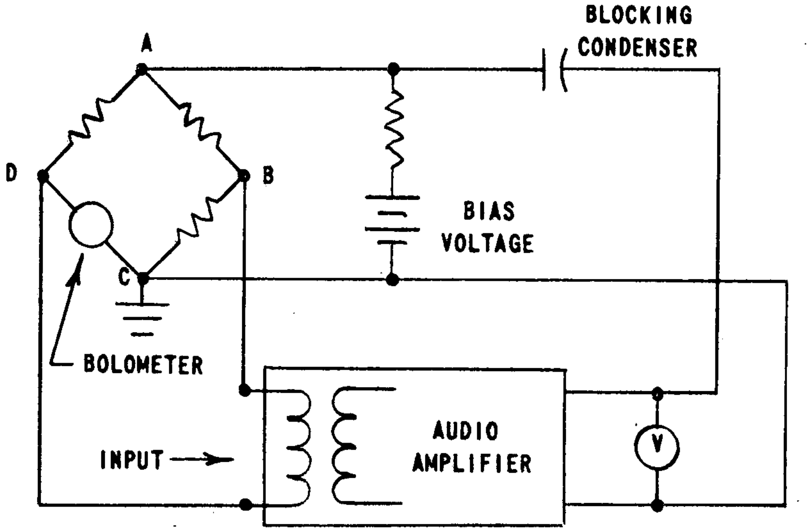
When using barretters or fuses, precautions should be taken if the modulation frequency is below about 200 cps. For sine and square wave modulated power, the meter reading will tend to increase at such low modulated frequencies. With a thermistor, precautions should be taken below 100 cps.

Thermistors seem to be preferable for our purposes in instrumentation.

B. <u>The Self-Balancing Bridge</u>

This type of bridge is the type most commonly incorporated in commercially available bolometer arrangements for measuring power. A schematic of the bridge will look something like Fig. I-1.

It consists of an amplifier the output of which is coupled back to the input through the bridge. With the bolometer at room temperature the bridge is unbalanced, permitting transmission to take place from AC to BD, and resulting in the system breaking into oscillation. Now, as the oscillations increase in amplitude, the resistance of the bolometer element changes in such a manner so as to bring the bridge more nearly in balance. By making the amplification large, the amplitude of oscillations will assume whatever value is required to make the bridge almost but not quite exactly balanced. A smaller amplitude than this will cause the bridge to be considerably unbalanced, resulting in a large input voltage to the amplifier and hence increased output. Now at the same time, a slightly larger amplitude will bring the bridge into exact balance, giving no transmission between amplifier input and output, and no oscillations. Now, if radio frequency power is dissipated in the bolometer element, this will reduce the amount of power that the oscillations must supply the bolometer to make the bridge reach a balanced condition. The r-f power is indicated on the meter V that measures



2307-SK-4

Fig. I-1 - Self-Balancing Bridge

the amplitude of the oscillations. A large amount of r-f power corresponds to a small amplitude of oscillations. The initial amplitude of oscillations in absence of r-f power is adjusted to a predetermined value corresponding to full scale deflection of the meter V by applying a DC biasing voltage to the bridge.

The method of pick-up of r-f energy is by means of a probe antenna (usually a horn of known characteristics or a resonant dipole) and delivered to the bolometer by means of coaxial cable. Coaxial cable is used since it is more flexible than waveguide systems. Generally, if the energy is of a high nature, a directional coupler is placed between the antenna and the bolometer to add additional attenuation into the measuring system. The directional coupler and coaxial cable are calibrated and their attenuation is considered in the final reading of the meter.

II. FIELD STRENGTH MEASURING INSTRUMENTS

Figure I-2 shows the circuit of a field strength meter which combines a zero-adjusted, amplifier-type DC microammeter and a tuned diode detector. The instrument is adaptable to many frequencies by means of suitable additional plug-in coils.

Use of the instrument is simple: (1) Switch on the DC supply. Plug in the coil required for the frequency of interest. (2) Set the meter to zero by adjustment of control R_1. (3) Attach an antenna to the antenna terminal.

Under signal pick-up, the diode rectifies the r-f energy and delivers a positive DC voltage to the base of the transistor. The resulting base current is amplified in the transistor and deflects the milliammeter.

Disadvantages: (1) Too sensitive. A signal of 100 to 200 mv. r-f will deflect the meter to full scale. (2) Measures only "E" component of r-f field.

Advantages: (1) Extremely portable. (2) May be used to check for interference.

If high accuracy and direct meter readings are desired, an individual calibration of the field intensity meter must be made with a calibrated r-f signal generator. This is necessary, since response of the diode is square law, but not necessarily exactly so, at high signal levels involved.

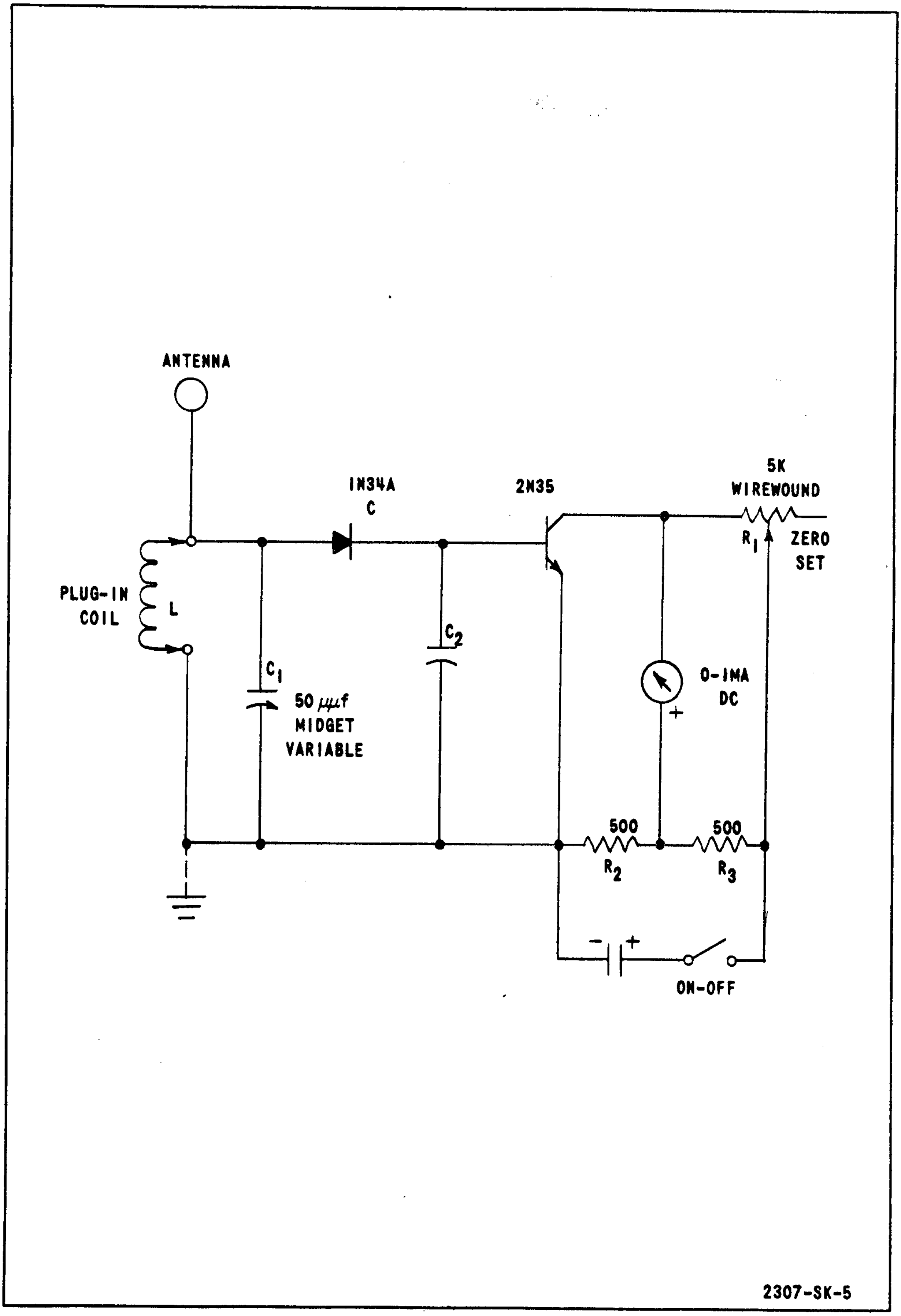


Fig. I-2 - Field Strength Meter

A. Welex Field Strength Meter

Figure I-3 shows a field strength meter under development by Welex Electronics Corporation for NObsr 77142.

The antenna may be either a rod or a loop. A rod antenna, 7 inches in length when fully extended, has been used for several tests.

The induced r-f voltage is detected by a diode (1N65G) and the resultant is applied to the base of a transistor (2N335) across a bypassed 10K resistor.

The 90K and 900K resistors with the three position switch determine the dynamic range of the meter.

The emitter circuit of the transistor contains the meter and a shorting-type phone jack.

The two parallel diodes (1N54) rectify the transistor output and the associated capacitors provide filtering.

Bias is provided by the network made up of the 25K potentiometer and two 10K resistors.

The diode (1N65G) connected between the antenna and common provides a DC return.

The transistor is powered by a 1.5 volt battery through an off-on switch.

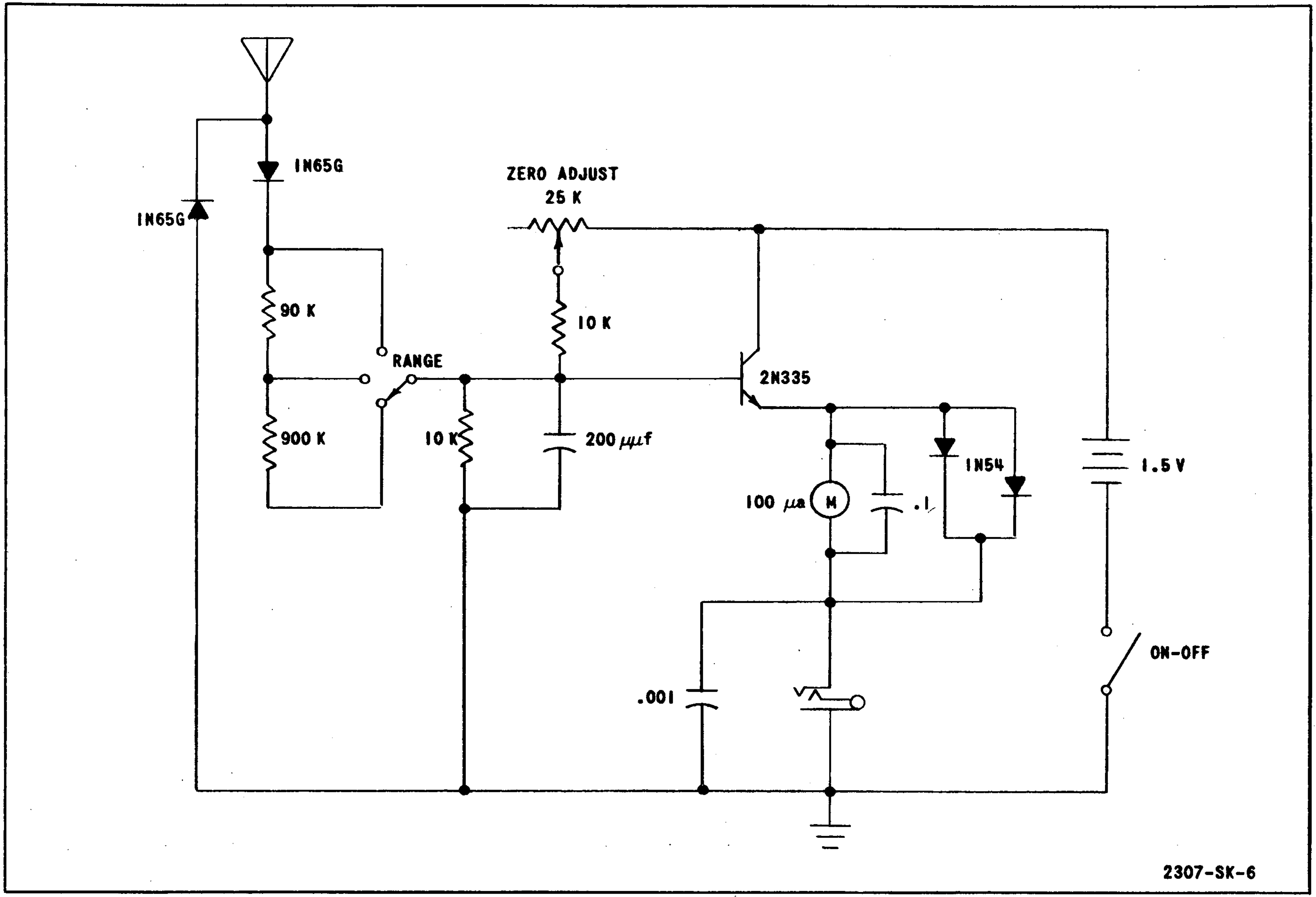


Fig. I-3 - Field Strength Meter under Development by Welex Electronics Corp. for NObsr 77142

APPENDIX J

RADIO FREQUENCY BAND NOMENCLATURE

It has been found that various bands of frequencies, such as the L band, W band, etc., are almost uniquely defined by each company or organization concerned. For example, one company may break the r-f spectrum involved into as many as 13 sub-bands, while another organization fits its classification to certain customer's desires.

Letters have been sent to over one hundred interested companies to determine (a) the r-f band nomenclature they use, and (b) if they would be interested in adopting a standard nomenclature. Out of the replies (around 35) that have been received to date, there were only two dissenting votes to (b). In response to (a), there was a considerable diversity from company to company. The variances in r-f band nomenclature can be readily seen by the information given in Tables J-I and J-II which are comprised of some of the information received in response to the letter inquiries. Several companies desire a finer breakdown and use the nomenclature which is given in Table J-II.

The nomenclature of the frequency and wavelength bands for use in radio communications recommended by the International Radio Consultative Committee (C.C.I.R)1/ are given in Table J-III. Several U. S. companies have adopted the same nomenclature.

TABLE J-I

FREQUENCY BAND NOMENCLATURES

Company	Frequency Range (kmc/sec)	Alphabetical Designation
	1.12 - 1.70	L
	2.6 - 3.95	S
	3.95 - 5.85	C
I	5.85 - 8.2	x_B
	7.05 - 10.0	x_L
	8.2 - 12.4	x_S
	12.4 - 18.0	Ku
	18.0 - 26.5	K
	26.5 - 40.0	Ka
	0.5 - 1	U
	1 - 2	L
	2 - 4	S
	4 - 5.8	G
	4 - 8	C
	5.3 - 8.2	J
	7 - 10	H
	8 - 12	X
II	10 - 15	M
	12 - 18	P
	15 - 22	N
	18 - 26	K
	22 - 33	Q
	26 - 40	R
	33 - 50	T
	50 - 75	V
	60 - 90	Y
	90 - above	W
	0.225 - 0.390	P
	0.390 - 1.55	L
III	1.55 - 5.2	S
	5.2 - 10.9	X
	10.9 - 36.0	K
	0.5 - 2	L
	2 - 4	S
IV	4 - 8	C
	8 - 12.4	X
	7 - 9	lower x
	9 - 12.4	upper x

TABLE J-I (Concluded)

Company	Frequency Range (kmc/sec)	Alphabetical Designation
	0.15 - 0.18	A
	0.18 - 0.225	G
	0.225 - 0.390	P
V	0.390 - 1.55	L
	1.55 - 5.2	S
	5.2 - 8.2	C
	8.2 - 12.4	X
	12.4 - 36.0	K
	2.6 - 3.95	S
VI	3.95 - 5.85	C
	8.2 - 12.4	X
	18.0 - 26.5	K
	0.9 - 2.0	L
	2.0 - 5.0	S
VII	5.0 - 8.0	C
	8.0 - 12.0	X
	12.0 - 18.0	Ku
	18.0 - 30.0	K
	8.2 - 12.4	X
VIII	12.4 - 18.0	Ku
	18.0 - 26.5	K
	26.5 - 40.0	Ka
	1.12 - 1.70	L
	1.7 - 2.31	M
	2.6 - 3.95	S
IX	3.95 - 5.85	C
	5.85 - 8.20	A
	7.05 - 10.0	B
	8.2 - 12.4	X
	12.4 - 18.0	G
	18 - 26.5	K
	26.5 - 40	T
	33 - 50	V
	50 - 75	W
	60 - 90	Z

TABLE J-II

REFERENCE TABLE OF BAND CODE LETTERS
VS. FREQUENCY*

Band	Identifying Subletter	Freq. Range (kmc/sec)	Band	Identifying Subletter	Freq. Range (kmc/sec)
P	-	0.225-0.390	K	P	10.90-12.25
				S	12.35-13.25
L	P	0.390-0.465		E	13.25-14.25
	C	0.465-0.510		C	14.25-15.35
	L	0.510-0.725		U	15.35-17.25
	Y	0.725-0.780		T	17.25-20.50
	T	0.780-0.900		Q	20.50-24.50
	S	0.900-0.950		R	24.50-26.50
	X	0.950-1.150		M	26.50-28.50
	K	1.150-1.350		N	28.50-30.70
	F	1.350-1.450		L	30.70-33.00
	Z	1.450-1.550		A	33.00-36.00
S	E	1.55-1.65	Q	A	36.00-38.00
	F	1.65-1.85		B	38.00-40.00
	T	1.85-2.00		C	40.00-42.00
	C	2.00-2.40		D	42.00-44.00
	Q	2.40-2.60		E	44.00-46.00
	Y	2.60-2.70			
	G	2.70-2.90			
	S	2.90-3.10	V	A	46.00-48.00
	A	3.10-3.40		B	48.00-50.00
	W	3.40-3.70		C	50.00-52.00
	H	3.70-3.90		D	52.00-54.00
	Z	3.90-4.20		E	54.00-56.00
	D	4.20-5.20			
			K1	Includes K_U through K_Q 15.35 to 24.5 kmc/sec	
X	A	5.20-5.50			
	Q	5.50-5.75			
	Y	5.75-6.20			
	D	6.20-6.25			
	B	6.25-6.90			
	R	6.90-7.00			
	C	7.00-8.50			
	L	8.50-9.00			
	S	9.00-9.60			
	X	9.60-10.00			
	F	10.00-10.25			
	K	10.25-10.90			

*Taken from a publication by the Hallicrafters Company.

TABLE J-III

NOMENCLATURE OF FREQUENCY BANDS RECOMMENDED BY THE C.C.I.R.

Band Number	Frequency Range (Lower Limit Exclusive, Upper Limit Inclusive)	Metric Subdivision
4	3 to 30 kc/s	Myriametric waves
5	30 to 300 kc/s	Kilometric waves
6	300 to 3,000 kc/s	Hectometric waves
7	3 to 30 Mc/s	Decametric waves
8	30 to 300 Mc/s	Metric waves
9	300 to 3,000 Mc/s	Decimetric waves
10	3 to 30 Gc/s	Centimetric waves
11	30 to 300 Gc/s	Millimetric waves
12	300 to 3,000 Gc/s (or 3 Tc/s)	Decimillimetric waves

Note 1: "Band N" extends from 0.3×10^N to 3×10^N c/s.

Note 2: When a service adopts a reference number or letter to designate a specific frequency band allocated to it and situated, wholly or for the most part, in "Band N" of the above nomenclature, the prefix N should normally precede the reference in question. For example, for the 41 to 48 Mc/s band, to which broadcast users give the reference "I", the appropriate designation is "broadcast band 8-I", since it refers to a part of "Band 8".

Note 3: Abbreviations:

k = kilo (10^3)

M = Mega (10^6)

G = Giga (10^9)

T = Tera (10^{12})

Note 4: Abbreviations for adjectival band designations:

Band 4 = VLF (very low frequency)

Band 5 = LF (low frequency)

Band 6 = MF (medium frequency)

Band 7 = HF (high frequency)

Band 8 = VHF (very high frequency)

Band 9 = UHF (ultra high frequency)

Band 10 = SHF (super high frequency)

Band 11 = EHF (extremely high frequency)

REFERENCES

1. Documents of the IXth Plenary Assembly, Los Angeles, 1959, Vol I (Recommendations, published by the International Telecommunications Union, Geneva, 1959).

APPENDIX K

TENTATIVE DEFINITIONS OF RADIATION HAZARDS TERMS

The formula adopted in setting forth the subsequent definitions of terms is shown below. All of the items listed in this formula are not present in each definition; items are included only when they are necessary for complete understanding.

FORMULA FOR DEFINITIONS OF TERMS

INTRODUCTION:	Word or phrase: (symbol) (abbreviation).
DEFINITION: (Explanation)	A word picture, insofar as possible, expressing the meaning which is generally associated with the term or phrase; to be specifically understood by the various disciplines involved in RAD-HAZ.
DEMONSTRATION: (Comparison, numerical evaluation, etc.)	Note 1: A common specification for ________ is ____________________.
	Note 2: The analytical expression is ________________________.
	Note 3:
	.
	.
	.

Absorbed Dose:

Total absorbed energy.

Absorption Dose Rate:

Rate at which energy is absorbed.

Note: See also dose rate.

Absorption, Electromagnetic Energy:

Transfer of energy from an electromagnetic wave to the medium through which the wave propagates.

Antenna:

A structure used to effect the transition from a guided to an unguided electromagnetic wave, or vice versa.

Antenna Directivity: (D)

The ratio of the maximum radiation intensity to the average radiation intensity produced at a given distance from a given transmitting antenna.

Note: By the principle of reciprocity, the directivity of an antenna is the same when that antenna is used as a receiving antenna as when it is used as a transmitting antenna.

Antenna Driving-Point Impedance:

See Antenna Terminal Impedance.

Antenna Effective Aperture: (A_e)

The ratio of the power in the terminating impedance of a receiving antenna to the power density in the incident wave.

Note: By the principle of reciprocity, the effective aperture of an antenna is the same when that antenna is used as a transmitting antenna as when it is used as a receiving antenna, provided that the internal impedance of the generator driving the antenna in transmission is the same as the terminating impedance in reception.

Note: See also, Maximum Effective Aperture, Effective Area.

Antenna Effective Area: (A_{em})

Antenna maximum effective aperture.

Antenna Gain: (G)

The ratio of the maximum radiation intensity produced at a given distance from a given antenna with a given power input to the maximum radiation intensity produced at the same distance from a reference antenna with the same power input.

Note: Antenna gain must always be specified in relation to some reference antenna. A subscript may be added to the symbol G to form an appropriate indication of the reference antenna. For example, when the reference antenna is a lossless, isotropic radiator, the symbol G_o is usually used. In general, then:

$$G_{ref} = \frac{V_m}{V_{m\ ref}} = \frac{\text{max. radiation intensity of antenna under consideration}}{\text{max. radiation intensity of reference antenna}}$$

Antenna Effective Height: (h_e)

The ratio of the voltage developed across the terminating impedance of a receiving antenna to the electric field strength in the incident wave.

Note: By the principle of reciprocity, the effective height of an antenna is the same when that antenna is used as a transmitting antenna as when it is used as a receiving antenna, provided that the internal impedance of the generator driving the antenna in transmission is the terminating impedance in reception.

Note: The term "effective length" more appropriately describes the quantity under consideration here. However, the term "effective height", which came into use early when antennas were almost always vertical dipoles operating against a ground plane, is retained by convention.

Antenna Lens:

A structure, transparent to radio waves, having an effective dielectric constant different from unity, and designed in such a manner as to produce a desired radiation pattern when placed in front of a radiator.

Note: Such structure may employ dielectric or metallic configurations.

Antenna Maximum Effective Aperture: (A_{em})

The effective aperture of an antenna when the terminating impedance is the complex conjugate of the antenna impedance (i.e., matched for maximum power transfer).

Anterior:

Toward the head (except in man, toward the belly; equivalent to ventral).

Anterior Chamber:

That part of the eye between the cornea and the iris.

Aqueous Humor:

Fluid in the eye in front of the lens.

Arc:

An electrical discharge of relatively long duration which may be brought about by separating current-carrying electrodes or may result from a spark discharge between initially separated electrodes, provided that the energy source is sufficient to maintain the arc.

Athermal Effect (Nonthermal Effect):

Any initial effect of electromagnetic radiation absorption, exclusive of the production of heat.

Attenuation:

A general term used to denote a decrease in magnitude of a quantity associated with a wave, such as displacement, power density, field strength, etc., in the propagation of the wave from one point to another.

Average Power: ($\bar{W}$)

The time-average rate of energy transfer; $\bar{W} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} W(t)dt$

Note: See Power.

Bio-Effects:

U. S. Navy Code name pertaining to hazards of electromagnetic radiation to personnel.

Bolometer:

A device capable of absorbing radiant energy, using the heat so developed to change its electrical resistance, thus serving as an indication of the magnitude of radiant power.

Bridge Wire:

A metal wire, heated by the passage of electric current, which causes an initiating detonating charge surrounding the wire to be ignited.

Cataract:

An opacity of the eye lens or its enveloping membrane (capsule).

Cataractous:

Containing or afflicted with cataracts.

Ciliary Body:

Tissue of the eye composed of ciliary processes, ciliary muscles and other minor parts, to which the iris is attached.

Ciliary Muscles:

Muscles forming one side of the ciliary body and which affect visual accommodation.

Ciliary Processes:

Circularly arranged folds of tissue attached to the ciliary body and to which are attached the fibers which support the eye lens.

Combustion:

Burning; consumption by fire.

Cornea:

The outermost, transparent covering of the eye in front of the anterior chamber.

Cortex:

The outer layer of any organ.

Cortical:

Pertaining to the outside or outer layers of an organ.

Cylindrical Wave:

A wave in which the equiphase surfaces constitute a family of concentric cylinders.

dbm:

Decibels referred to one milliwatt.

Decibel: (db)

A dimensionless unit which is a measure of the ratio of two powers. The number of decibels, $\underline{n}$, corresponding to the ratio of powers $\underline{P}_1$ and $\underline{P}_2$ is

$$n = 10 \log_{10} \frac{P_1}{P_2} \text{ db}$$

Note: If conditions are such that the ratio of currents I_1/I_2 or voltages V_1/V_2 (or analogous quantities) is the square root of the corresponding power ratio, then

$$n = 10 \log_{10} \frac{P_1}{P_2} = 20 \log_{10} \frac{I_1}{I_2} \qquad \text{or}$$

$$n = 10 \log_{10} \frac{P_1}{P_2} = 20 \log_{10} \frac{V_1}{V_2} \quad .$$

Deflagration:

Combustion proceeding at a very rapid, but subsonic, rate in a material.

Depth of Penetration:

The distance from the surface of a material, measured in the direction of propagation, within that material, at which the field intensity is reduced to 1/e times its value at the surface.

Note: See also, Effective Depth of Penetration.

Detonation:

Combustion proceeding at sonic velocity in a material. The flame front and the shock front are contiguous.

Distal:

Away from the center, origin or head.

Dorsal:

Toward the back (opposite to ventral).

Dose Rate:

Rate of application of energy.

Note: See also, Absorption Dose Rate.

Duty Factor:

The product of the on-time interval of a recurring phenomenon and the repetition frequency of the phenomenon.

Note: In some cases where the use of the term "duty factor" is common, the phenomenon may not be stated; for example, the phenomenon implied in pulsed radar work is the duty factor of the emitted power pulse.

Note: The term "duty cycle" is deprecated in ASA C42.65.

Effective Depth of Penetration:

The distance from the surface of a material, measured in the direction of the interior normal, at which the field intensity is reduced to 1/e times its value at the surface.

Note: Effective depth of penetration depends on the angle of incidence of the impinging radiation as well as on the material upon which that radiation impinges - see also, Depth of Penetration.

Electrical Discharge:

The release of electrical energy through a dielectric material. The discharge may result from leakage through the dielectric or breakdown of the dielectric insulating strength.

Electrical Length: (l_c)

Length expressed in wavelengths, radians or degrees at the frequency under consideration.

Electromagnetic Wave: (EMW)

A wave characterized by variations of electric and magnetic fields.

Note: See Wave.

Note: Electromagnetic waves are known as radio waves, heat rays, light rays, etc., depending on the frequency at which the fields vary.

EMW:

Electromagnetic wave.

Energy: (U)

The capacity for doing work.

Note: Energy may appear in many forms such as: Kinetic energy, T (the energy of motion); Potential energy, V (the energy of position); Heat energy; Nuclear or Atomic energy; chemical energy; etc.

Energy Flux:

Power through a surface; dose rate.

Energy Flux Density:

Power density; dose rate per unit area.

Erythema:

Redness of the skin due to congestion of underlying capillaries.

Explosion:

A "lay" term describing any process accompanied by the sudden release of gases, noise, and perhaps light.

Note: See also, Detonation, Deflagration.

Fuel:

Material which may be burned or oxidized to liberate energy.

HERO, Hero:

U. S. Navy code name pertaining to "Hazards of Electromagnetic Radiation to Ordnance".

Horn Antenna:

An antenna having the shape of a tube whose cross-sectional area increases toward the open end.

Hyperpyrexia:

A high degree of fever; hyperthermic condition.

Hyperthermia:

Abnormally high body temperature.

Hypothermia:

Abnormally low body temperature.

Impedance: (Z)

The ratio of a complex, force-like quantity to a related complex, velocity-like quantity.

Note: Some examples are:

In mechanics, $Z = \frac{\text{force}}{\text{velocity}}$

In acoustics, $Z = \frac{\text{pressure}}{\text{volume velocity}}$

In electricity, $Z = \frac{\text{voltage}}{\text{current}}$

In thermodynamics, $Z = \frac{\text{temperature}}{\text{heat flow}}$

In electromagnetic propagation, $Z = \frac{\text{electric field strength}}{\text{magnetic field strength}}$

Incident Wave:

A wave propagating in one medium which impinges on another medium which has different propagation characteristics.

Initiator:

A device used to start or cause a detonation or deflagration.

Insertion Loss:

1. The loss in load power due to the insertion of apparatus at some point in a transmission system. It is measured as the difference between the power received at the load before insertion of the apparatus and the power received at the load after insertion.

Insertion Loss: (Concluded)

2. The ratio, expressed in decibels, of the power received at the load before insertion of the apparatus, to the power received at the load after insertion. (Verbatim 53 IRE 2.51)

Iris:

The annular, pigmented membrane behind the cornea; the colored part of the eye.

Isotropic Radiator:

A hypothetical source of electromagnetic waves which radiates equally in all directions.

LD50, LD_{50}:

The "lethal dose" at which 50% of the subjects die.

Lens:

The transparent lenticular organ behind the pupil which focuses light on the retina.

Nonthermal Effect:

See Athermal Effect.

Posterior:

Toward the rear or tail (except in man, toward the back; equivalent to dorsal).

Posterior Chamber:

Chamber between the iris and the lens containing aqueous humor.

Power: (W)

The time rate of change of energy; $W = \frac{dU}{dt}$.

Plane Wave:

A wave in which the equiphase surfaces constitute a family of parallel planes.

Primary Depth of Penetration:

See Depth of Penetration.

Primary Heat of Radiation:

Heat produced directly by absorption of electromagnetic radiation.

Proximal:

Towards the center, origin or head.

Pupil:

Aperture in the center of the iris for the transmission of light.

Radar:

A device which radiates electromagnetic waves and utilizes the reflection of such waves from distant objects to determine the existence, position, or velocity. The word radar is derived from the initial letters of the expression RAdio Direction And Ranging.

Reflected Wave:

The wave which occurs, in addition to the incident wave, in a medium when an incident wave in that medium impinges upon another medium with different propagation characteristics.

Repetition Frequency:

The number of times a repetitive phenomenon occurs per unit time.

Example: Pulse Repetition Frequency = number of pulses generated or emitted per unit time.

Retina:

The light sensitive structure of the eye.

Note: The retina is located at the inner posterior surface of the eye.

Secondary Heat of Radiation:

Heat produced indirectly by the absorption of electromagnetic radiation.

Spark:

An electrical discharge of relatively short duration between initially separated electrodes; the discharge may be repetitive.

SPARKS, Sparks:

U. S. Navy code name pertaining to hazards of electromagnetic radiation to volatile liquids.

Spherical Wave:

A wave in which the equiphase surfaces constitute a family of concentric spheres.

<u>Ventral</u>:

Toward the belly.

<u>Vesicule</u>:

Blister.

<u>Vitreous Humor</u>:

Viscous fluid in the eye behind the lens.

<u>Work</u>: (U)

The line integral of force;

$$U = \int_a^b F \cdot dl \quad .$$

Note: For a straight path, work is equal to the component of force in the direction of motion multiplied by the distance through which that force acts.

<u>Wave</u>:

A disturbance which is propagated in a medium in such a manner that at any point in the medium, the displacement is a function of time, while at any instant, the displacement at a point is a function of position.

Note: Displacement is used in a general sense, indicating not only mechanical displacement, but also electrical displacement or any analogous quantity.

APPENDIX L

EXISTING STANDARDS

The following standards were consulted while preparing the tentative definitions given in Appendix K.

A. American Standards Approved by the American Standards Association, 10 East 40th Street, New York City, New York

C2 - National Electrical Safety Code

C2.5 - 1940 R 1947 Radio Installations, Safety Rules for

C5 - Protection against Lightning, Code for

C5.1 - 1959 Part I, Protection of Persons
C5.2 - 1959 Part II, Protection of Buildings and Miscellaneous Property
C5.3 - 1959 Part III, Protection of Structures Containing Flammable Liquids and Gases

C16 - Radio

C16.11 - 1949 Antennas, Method of Testing
C16.21 - 1954 Terms on Antennas and Waveguides, Definitions of
C16.26 - 1955 Terms on Radio Aids to Navigation, Definitions of
C16.28 - 1956 Pulse Quantities, Methods of Measurement of
C16.29 - 1957 Gain, Amplification, Loss, Attenuation, and Amplitude - Frequency - Response, Methods of Measurement of

C42 - Definitions of Electrical Terms

C42.30 - 1957 Instruments, Meters and Meter Testing
C42.65 - 1957 Communication
C42.70 - 1957 Electron Devices
C42.80 - 1957 Electrobiology including Electrotherapeutics
C42.95 - 1957 Miscellaneous

C63

C63.2 - November 1957 - Draft of American Standard Specifications for Radio Noise and Field Strength Meters, 0.015 to 30 Megacycles per Second

C63.2 - Radio Noise Meter, 0.015 to 25 Megacycles per Second, Specifications for (Proposed American Standard; published for trial and criticism, out of print), 1950

Y32 - Graphical Symbols

Y32.2 - 1954 Graphical Symbols for Electrical Diagrams

B. Institute of Radio Engineers Standards

48IRE2., 11., 15., S1 Standards on Antennas, Modulation Systems, Transmitters

55IRE2.S1 Standards on Antennas and Waveguides: Definitions for Waveguide Components

53IRE2.S1 Standards on Antennas and Waveguides: Definitions of Terms (replaced by 54IRE2.S1?)

52IRE7.S1 Standards on Magnetrons: Definitions of Terms

56IRE7.S1 Standards on Electron Devices: Definitions of Terms Related to Microwave Tubes (Klystrons, Magnetrons, and Traveling Wave Tubes)

51IRE17.S1 Standards on Radio Receivers: Open Field Method of Measurement of Spurious Radiation from Frequency Modulation and Television Broadcast Receivers

51IRE20.S1 Standards on Pulses: Definitions of Terms - Part I

52IRE20.S1 Standards on Pulses: Definitions of Terms - Part II

57IRE21.S1 Standards on Letter Symbols and Mathematical Signs

51IRE21.S1 Standards on Abbreviations of Radio - Electronic Terms

50IRE24.S1 Standards on Wave Propagation: Definitions of Terms

(no number) Definitions of Terms Related to Guided Waves (continued from Standards on Radio Wave Propagation - definition of terms - 1942) 1945.

C. Military Standards

MIL-STD-15A, 1 April 1954, Electrical and Electronic Symbols

MIL-STD-188A, 25 April 1958, Military Communication System Technical Standards

D. Underwriters' Laboratories, Inc.

UL467, Third Ed., Standards for Safety

APPENDIX M

DICTIONARIES, GLOSSARIES, HANDBOOKS, MANUALS, ETC.

The following references were consulted while preparing the tentative definitions given in Appendix K.

1. "Radio Frequency Radiation Hazards", Handbook, T.O. 31-1-80, 15 April 1958, revised 2 January 1959, 56 pp.

2. "Communications - Electronics Terminology", Air Force Manual No. 100-39, 1 April 1959, 857 pp.

3. "Liquid Propellant Safety Manual", October 1958, Liquid Propellant Information Agency.

4. "Glossary of Terms in Nuclear Science and Technology", ASME, 1955, 189 pp.

5. "The International Dictionary of Physics and Electronics", Van Nostrand Co., Inc., 1956, 1,004 pp.

6. "The United States Air Force Dictionary", Air University Press, 1956 (with addenda, 1957), 578 pp.

7. "Encyclopedic Dictionary of Electronics and Nuclear Engineering", R. I. Sarbacher, Prentice Hall, Inc., 1959, 1,417 pp.

8. "Handbook of Microwave Measurements" (two volumes), M. Wind and H. Rapaport, prepared for Signal Corps Engineering Laboratories by Polytechnic Institute of Brooklyn.

9. "The American Illustrated Medical Dictionary", W. A. N. Dorland, W. B. Saunders Company., 1,668 pp.

10. "Handbook of Electronic Measurements" (two volumes), M. Wind, Polytechnic Institute of Brooklyn, Microwave Research Institute, 1956.

11. Quarterly Progress Report, 15 August to 15 November 1959, Contract NObsr 77142, Welex Report No. 59-07, Welex Electronics Corporation.

APPENDIX N

INDICES TO STANDARDS

The following indices were consulted while preparing the tentative definitions given in Appendix K.

1. Index of Specifications and Standards (used by) Department of the Army, Cumulative Supplement to Military Index Vol. II dated 1 April 1959, 1 September 1959.

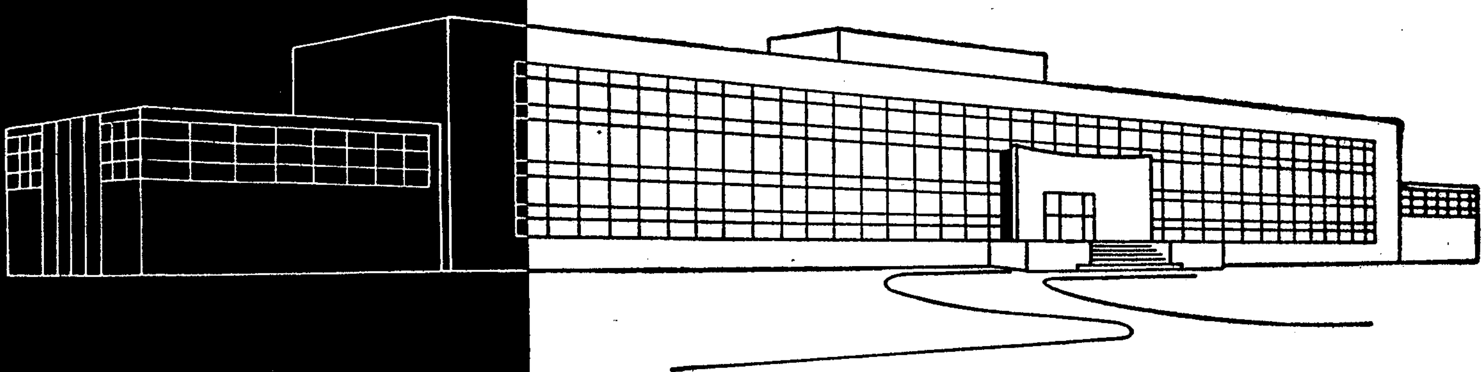
2. American Standards Price List and Index, American Standards Association, 70 East 45th Street, New York 17, New York.

3. Index of Specifications and Standards (used by) Department of the Navy, Military Index (Volume III), 1 April 1960, revised to 24 February 1960.

4. Current IRE Standards, June 1958.

5. Index of Specifications and Related Publications (used by) U. S. Air Force, Military Index, Vol. IV, 1 October 1959 and Cumulative Supplement 1, 1 February 1960.

6. Index to IRE Standards on Definitions of Terms, 1942-1957, Proc. of IRE, Vol. 46, pp. 449-476. (Contains approximately 3,500 technical terms and indicates the Proceedings of IRE where the definition may be found.)



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