NATIONAL BUREAU OF STANDARDS REPORT

7027

Development, Testing, and Evaluation of Visual Landing Aids
Consolidated Progress Report for the Period July 1 to September 30, 1960

By
Photometry and Colorimetry Section
Metrology Division

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers. These papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($1.50), available from the Superintendent of Documents, Government Printing Office, Washington 25, D.C.

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Development, Testing, and Evaluation of Visual Landing Aids

Consolidated Progress Report
to
Ship Aeronautics Division
& Meteorological Division
Bureau of Naval Weapons
Department of the Navy

and to
Federal Aviation Agency
Washington 25, D. C.

For the Period
July 1 to September 30, 1960

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Development, Testing, and Evaluation of Visual Landing Aids
July 1 to September 30, 1960

I. REPORTS ISSUED

Report No.	Title
6862	Development of Visual Landing Aids for Jet Aircraft, Final Report[3]
6904	Field Tests of Runway Distance Markers Constructed By Cecil Field[1]
6940	Development, Testing, and Evaluation of Visual Landing Aids, Consolidated Progress Report for the Period January 1 to March 31, 1960[1]
6941	Development, Testing, and Evaluation of Visual Landing Aids, Consolidated Progress Report for the Period April 1 to June 30, 1960[1]
21P-12A/59 Sup.	Maintenance of Luminous Output of Type FGL-4 Flash-tubes[2]
21P-12B/59 Sup.	Maintenance of Luminous Output of Type R4336 Flash-tubes[2]
21P-12C/59 Sup.	Maintenance of Luminous Output of Type FT-36 Flash-tubes[2]
21P-12D/59 Sup.	Maintenance of Luminous Output of Type S-471 Flash-tubes[2]
21P-16/60 Sup.	Physical and Electrical Tests of Connectors for Airfield Lighting Cable[1]
21P-22/60	Photometric Tests of a Runway Floodlight[1]
21P-23/60	Photometric Tests of Six Prismatic-Type Approach and Runway Lights[1]
21P-27/60 Sup.	Tests of Mink-Dayton Inc. Runway Identification Light[1]
21P-30/60	Photometric Tests of a "Night Vision Flood Light" Type No. 328[1]
21P-38/60	Photometric Tests of a Dobson Open Grid Flush Runway Light[1]
21P-41/60	Physical and Electrical Tests of Connectors for Airport Lighting Cable[1]
Letter Report	Infrared Filter for Condenser Discharge Lights (July 18, 1960)[3]
Letter Report	Battery Powered L.S.E. Suit (July 20, 1960)[1]
Memo Report	Experimental Design for Tests of Runway Marking Materials (August 1, 1960)[3]

Report No. Title (cont.)

Letter Report Review of Specification MIL-L-26202B (August 3, 1960)(1)

(1) For Bureau of Naval Weapons
(2) For Federal Aviation Agency
(3) For Air Force

II. VISIBILITY METERS AND THEIR APPLICATION

Shipboard Visibility Meter. Construction of the mechanical parts of a feasibility model meter of the type described in NBS Report 6410 is progressing. The unit should be ready for preliminary testing next quarter.

Slant Visibility Meter. The new site for the slant visibility meter has been selected and the projector and detector units have been placed upon the foundations. Putting the slant visibility meter into operation at the new site has been delayed by preparations for the testing of the Fog-Master Corporation light for the Bureau of Ships. This installation will be completed very shortly. The installation of the transmissometer for obtaining horizontal transmission at the new site has been completed. The site for the 100-foot tower for carrying the targets and lights for observations has been selected and the foundation prepared. Slant visibility observations for use in evaluating the recorded data of the slant visibility meter will be started as soon as the installation is completed.

Transmissometer. A conference was held with representatives of the Westinghouse Electric Corporation. Performance data and test methods for the type WL-759 trigger tube were compared and specification requirements developed.

The Effect of High-Intensity Airfield Lighting on Background Luminance and Horizontal Illumination. An analysis has been made of the effects of runway lights and slopeline and centerrow approach lights on background luminance and horizontal illumination on the runway and in the approach zone. Under some conditions the runway lights raised the horizon luminance to 0.4 footlambert and the horizontal illumination to 0.03 footcandle, and in the approach zone for positions on the centerline the horizon brightness and the horizontal illumination were increased to as much as 6 footlamberts and 0.4 footcandle, respectively, for the slopeline approach light system and to 40 footlamberts and 0.6 footcandles, respectively, for the centerrow lights. When the horizon sky brightness produced by the centerrow lights was measured from a position 150 feet from the centerline, the brightness was very similar to that obtained for the slopeline lights when measured from the centerline.

As a function of transmission or visibility, the effect of each lighting system for each intensity setting was similar in shape although of a different order of magnitude. The brightness first increased rapidly as transmission decreased, then remained relatively constant over a wide range of visibility, and then decreased as visibility became less than one-fourth mile. Some additional measurements of the effect of the approach lights on the horizon brightness and horizontal illumination on the runway, and of the effect of the runway lights on the horizon brightness and horizontal illumination in the approach zone, will be made before completing this task. The first draft of a report giving the results of this study has been prepared.

Measurements of Natural Sky Brightness and Illumination Measurements. Analysis of this data has been postponed because of the shortage of personnel. Work on this task will be resumed at a later date.

Infrared Absorbing Glass for Condenser Discharge Lights. Light from condenser discharge lights of the approach light system is causing interference in the receiver of the rotating beam ceilometer. The use of infrared absorbing filters on the condenser discharge lights has been proposed as a remedy and the Air Force is developing a filter of this type. At their request measurements were made of the spectral transmittance of a cover manufactured by Polan Industries. The transmittance of the cover was approximately 0.7 throughout most of the visible part of the spectrum and dropped to 0.050 at 800 millimicrons and to 0.01 at 880 millimicrons. Thus it appears that the cover will reduce the interference to an acceptable level but will at the same time decrease the intensity of the condenser discharge lights by about 20%.

III. DEVELOPMENT OF AIRFIELD LIGHTING AND MARKING COMPONENTS

Runway Distance Markers. Tests of the runway distance markers constructed by NAS Cecil Field have been completed and reported (NBS Report 6904). Runway distance markers of this type have been recommended for adoption as the standard for Naval Air Stations.

Temperature Rise of Prismatic Head Lights. A study is being made of the feasibility of installing a 500-watt series isolating transformer in the base on which a 500-watt prismatic-head light is mounted. An airport marker light base, type MS-24526(ASG) was installed in a concrete pad. A 500-watt, 6.6/20-ampere isolating transformer was installed in the base and a bidirectional, one-half inch projection prismatic-head light, type MIL-L-26202B, class BB45, lamped with a 500-watt lamp, was mounted on the base. The temperature rise was measured at numerous points on the transformer, light, and base, as a function of the time the light was operated at rated current. After several hours of operation the temperature of the case of the transformer and of several points on the light had risen beyond the range of the potentiometer (300°F). The test was stopped and the assembly was inspected after it

had cooled. The case of the transformer had opened in two places and some of the potting compound had run out. The insulation of the cable connected to the lamp terminals and about 8 inches of the sheath of this cable had become stiff and brittle. A conversion kit to extend the range of the potentiometer has been ordered. Additional measurements will be made after the kit has been received. A study will be made of methods of reducing the heat flow to the transformer.

Runway Marking Materials. At the request of the Air Force, a design for a test to compare six types of runway marking materials was prepared. Experience in the tests conducted by the National Bureau of Standards at Washington National Airport indicated that the materials can be evaluated most satisfactorily by the comparison of pairs of adjacent materials. Therefore the arrangement of materials in the runway marking pattern was designed to facilitate this type of comparison.

Output Maintenance of Sealed-Reflector Approach and Runway Light Lamps. A comprehensive study of the output maintenance characteristics of sealed-reflector approach and runway lamps is in progress. Lamps with 6.6- and 20-ampere filaments are being burned in both vertical and horizontal positions. Measurements of the relative output are being made periodically both of the complete lamps and of selected zones of the lamps.

Intensity Distribution of Class B and Class BB Semiflush Lights. Photometric tests have been completed of one 1-inch projection and five 1/2-inch projection semiflush approach and runway lights manufactured by Multi Electric Mfg. Inc.. Intensity distribution measurements were made of each light when it was lamped with a 200-, with a 300-, and with a 500-watt lamp. The results are reported in NBS Test Report 21P-23/60. These results indicate that the intensity requirements of Specification MIL-L-26202B for 1/2-inch projection lights, Class BB, are somewhat high.

Final Report on Air Force Project. The report "Development of Visual Landing Aids for Jet Aircraft" (NBS Report 6862) was completed and released. This report is a summary of the work conducted at NBS for the Air Force during the period 1954 through 1959.

IV. DEVELOPMENT OF SEADROME LIGHTING COMPONENTS

Sealane (Runway) Identification Light. A replacement transformer of a modified design and a new "climatized" motor have been received from the contractor. The transformer was checked for output voltage under several load conditions and both the transformer and the motor were installed in the light unit and tested. The drive unit operated satisfactorily. The results of the tests were reported by letter of September 23, 1960.

V. DEVELOPMENT OF CARRIER LIGHTING AIDS (TED NBS RSSH-32001)

Feasibility Tests of Proposed Carrier Lighting Systems. A trip was made by Mr. Douglas aboard the USS Saratoga for the purpose of observing flight tests of the experimental lighting systems, and to obtain pilot reaction. The trip indicated the following points pertinent to NBS work in this field.

General acceptance of the rotating homing beacon. As a result of this, three additional beacons which were on hand at NBS have been shipped to the Fleet for use and evaluation.

Pilot reaction to the stray light of the General Electric runway floodlights was unfavorable. Consequently plans for computing the illuminance distribution on the deck from these lights have been cancelled.

Pilot reaction to deck floodlighting was generally unfavorable. However, the flight deck crews used the shielded (Doane) floodlights in preparing and placing aircraft prior to a launch. The installation and use of floodlights for this purpose appear desirable.

Additional guidance is needed, particularly at night, to assist the pilot in lining up with the landing strip at distances of several miles. The lengths of the rows of deck surface lights are not sufficient for this purpose. Designs of lights to meet the requirement are being developed.

The NBS taxi guidance wands and goggle lights were favorably received.

Present lighting of the catapult areas is unsatisfactory. The use of battery-powered portable fluorescent floodlights should be an improvement. Several lights of this type have been shipped for Saratoga evaluation.

Deck Floodlights. Intensity distribution measurements of a Type 328 deck floodlight manufactured by L. C. Doane have been completed and reported (NBS Test Report 21P-30/60). This light has a 24-inch visor and uses two 250-watt, 6.6-ampere lamps connected in series. The intensity of the peak was 18,000 candles. No light was directed above the horizontal.

Intensity distribution measurements of a General Electric runway floodlight have been completed and reported (NBS Test Report 21P-22/60). This light uses a 200-watt "quartzline" lamp. It has an auxiliary reflector to intercept direct light from the lamp but has no visor. The maximum intensity was 33,000 candles. The intensity of the stray light was of the order of 400 candles.

Battery-Powered L.S.E. Suit (TED NBS SI-5008). The two battery-powered L.S.E. suits were shipped to the USS Boxer and the USS Princeton for service evaluation in accordance with instructions received from the Bureau of Naval Weapons. A brief description of the suits was prepared and forwarded by letter of July 20, 1960.

Modified "Cut" Lights. The present cut lights on the mirror landing system are inadequate because they do not reach the required intensity fast enough when operated at low intensity setting. This is a characteristic of the heavy filament in the high intensity PAR-399 lamps now being used as "cut" lights. The approximate intensity of the PAR-399 lamps is 20,000 candles. This must be reduced to around 500 candles for night use either by decreasing applied voltage or masking the lamp area. If the intensity is reduced by lowering the applied voltage, the slow rise time due to thermal lag of the filament is increased and if the lamp is masked the source size is reduced to a very small area.

One method of correcting the problem is to use lower wattage lamps, which, because of the smaller filament mass, will reduce the time required to reach full intensity.

A service-test unit has been prepared, consisting of four PAR-38, 75-watt, 120-volt projector flood lamps spaced 12 inches from center to center mounted on a bar. This bar is to be mounted to the mirror. An aviation green plastic filter is attached to each lamp.

VI. PHOTOMETRIC AND ELECTRICAL TESTS OF AIRFIELD AND SEADROME LIGHTING COMPONENTS (TED NBS SI-5003)

Open-Grid Light. NBS Test Report 21P-38/60, giving the results of intensity distribution measurements of an open-grid type flush runway light has been prepared and released.

Maintenance of Luminous Output of Flashtubes. Measurements have been made of the luminous output of the flashtubes manufactured by four manufacturers after the flashtubes had been operated approximately 500 hours in the sequence flashing lights of an FAA approach light system. The results indicate that there are significant differences in the life and in the maintenance factor of the four groups of lamps and that the lamps having the highest maintenance factor also had the lowest rate of failure. The results of these tests were reported in NBS Test Reports 21P-12A, B, C, and D/59, Supplementary.

Tests of Airfield Lighting Connectors.

Qualification Tests. Tests of a second group of preproduction samples of airfield lighting connectors submitted by the Woodside Screw

Machine Co. Inc. have been completed and reported (NBS Test Report 21P-16/60 Supplementary). These connectors are of the same type as those previously reported but have been redesigned to obtain conformance to those specification requirements that the first group failed to meet. There were no significant deviations from the specification requirements in this group of connectors.

Connector Kits. A report giving the results of tests of nine Joy Cable Connector Kits has been completed and issued (NBS Test Report 21P-41/60). The insulation resistance of these connectors was very high (average 83,000 megohms) and the voltage drop across the contacts was low (average 0.9 mv). The connectors failed to meet some of the requirements of ASTM D-752 covering the physical properties of the insulating material. A study of the pertinence of these requirements to airfield lighting cable connectors is recommended.

VII. MISCELLANEOUS TECHNICAL AND CONSULTIVE SERVICES

The technical sections of the following specifications and drawings have been reviewed. Comments have been forwarded by letter or informally.

Draft Specification: General Requirements for Flush Approach Lights (MIL-L-26202B).

Drawings for Buoy-Mounted, Photoelectric Controlled, Fluorescent, Channel Marker Light Specification.

Draft of Purchase Order Requirements of Carrier Deck Guide Lights.

Drawings for Wheels-Up Lighting Installation.

Draft Specification: Transformer: Brightness Control, Optical Landing System (MIL-T-1958A).

Draft Specification: Light: Marker, Emergency, Airfield (MIL-L-19661A).

Lamp Tabulation. A tabulation has been completed of the lamps used in Navy airfield lighting service, their characteristics, the type of service, and the type of lights in which the lamps are used. The tabulation has been forwarded to the Bureau of Naval Weapons for checking and for the addition of stock numbers. When the tabulation is returned it will be reproduced in a form suitable for circulation to the field.

Test of Light Developed by Fog-Master Corporation. Assistance was given the Bureau of Ships in testing a fog light developed by Fog-Masters Corporation. This light was tested primarily for its performance as a spot or floodlight for shipboard use. However, observations were also made to evaluate the feasibility of its use as a signal light. The Arcata laboratory prepared the test installation and assisted in making the observations. Tests were under the direction of Mr. Amos David of

the Bureau of Ships who will evaluate and report the results. The light was represented as having unusual fog penetrating qualities. However, the greater range was obtained with an aircraft landing light operating at reduced voltage.

VIII. MISCELLANEOUS

Improvement of 1000-foot Photometric Range. The photometric and calibration system of the 1000-foot range is being modified so that calibration checks may be accomplished by remote control from the goniometer end of the range.

Photometry of Flashing Lights. In determining the effective intensity distribution of lights in which the lamp is flashed by the opening and closing of the lamp circuit, it is often convenient to determine a relative effective intensity factor and to apply this factor to intensity distribution measurements made with the lamp burning steadily. The relative effective intensity factor is the ratio of the computed effective intensity in a given direction of view to the intensity in the same direction with the lamp burning steadily at a fixed, known voltage. The computation of the effective intensity requires measurement of the instantaneous intensity of the light as a function of time. A check was made to determine the error which would be introduced by the use of a non color-corrected phototube with a type S-4 (blue-sensitive) spectral response instead of a phototube and filter combination corrected to approximate the CIE standard observer luminosity function. No significant errors were found when incandescent lamps were used as sources and the flash duration was longer than the times for incandescence and nigrescence.

Guide to Procedures in Projection Photometry. Preparation of a comprehensive report describing in detail the procedures and equipment used at NBS in projection photometry has been started. This report will serve as a guide to the personnel making the measurements. It will eliminate the need of including a detailed description of the procedures in each of the photometric test reports.

Discussion of Paper. A discussion of the paper "Design and Performance of an Inset Runway Light" by C. H. Loch was presented by Mr. Douglas at the National Technical Conference of the Illuminating Engineering Society and is given in Appendix A. An abstract of the paper was published in the September 1960 issue of Illuminating Engineering. Preprints of the complete paper are available.

Operation "Pea Soup". Assistance was given the Air Force contractor in installing a transmissometer, primary and secondary power cable, and distribution transformers.

International Lighthouse Conference. Mr. Douglas attended the Fifth International Lighthouse Conference as an observer. Many of the papers presented were pertinent to aviation lighting problems.

APPENDIX A

Discussion of the Paper "Design and Performance of an Inset Runway Light" by C. H. Loch

C. A. Douglas

Mr. Loch is to be commended both for the design of an inset runway light and for his discussion of factors to be considered in the design of lights of this type. His comments regarding the very small angles of elevation at which the more distant lights are viewed when the aircraft is on the runway and the ineffectiveness of the light which is directed at angles of elevation larger than 15 degrees are particularly pertinent. However, he understates the requirement for light at low angles when he states that part of the beam must emerge at angles of one-half degree and less. For maximum effectiveness, the intensity at these angles should be equal or very nearly equal to the peak intensity.

In computing the visual range of a 350-candlepower light as 1/8 mile when the runway visual range is 1/8 mile the author has, quite understandably, confused the terms "runway visual range" and "runway visibility." Runway visual range is the distance the average pilot is expected to see high intensity runway lights. It is computed from transmissometer measurements assuming an intensity of 10,000 candles for the runway lights. If the intensity of a light is less than 10,000 candles, the light will, of course, be visible for a distance which is less than the runway visual range.

Runway visibility is also determined from transmissometer measurements, but is the distance a meteorological observer is expected to see black objects by day and low intensity lights, of the order of 25 candles, by night. Because of the differences between pilots' thresholds and observers' thresholds, runway lights must have an intensity in the range 300 to 500 candles for the visual range of the runway light to be 1/8 mile when the runway visibility is 1/8 mile. The intensity of the light developed by Mr. Loch is within this range when the angle of view is between 4 and 6 degrees above the horizontal. However, when the pilot eye height is 9 feet, a light 1/8 mile ahead is viewed at an angle of less than 0.8 degree above the horizontal. At this angle of view the intensity of the light is about 40 candles. Hence the distance the light can be seen is considerably less than the 1/8 mile runway visibility when the light is viewed from a fighter aircraft which is on the ground.

The intensity required to meet the requirements of the proposed National Standard 400-foot visibility distance when the runway visual range is 700 feet is of the order of 250 candles by day and 15 candles by night. If a pilot eye height of 9 feet is assumed, the angle of view is 1.3 degrees above the horizontal. At this angle of view the present

light has an intensity of about 70 candles. Thus it meets the requirements by night but not by day.

Despite the results of my computations, I consider the design of this light a long step forward. The failure to meet the requirements of the proposed National Standard by day is primarily the result of the restriction of the projection of the light to 1/8 inch above the runway surface, not to deficiencies in design.

In closing I would like to emphasize two points brought out by this discussion:

1. Computations of the visual range of a light must be based upon the intensity in the direction at which the light is viewed when at maximum range, not necessarily on the peak intensity.

2. Those concerned with airport operations and design must be made aware of the penalties in performance which result from restricting inset runway lights to very low heights and of the increases in performance and effectiveness which result from very small increases in height.

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colo., is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

ELECTRICITY. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

METROLOGY. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

HEAT. Temperature Physics. Heat Measurements. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research. Equation of State. Statistical Physics. Molecular Spectroscopy.

RADIATION PHYSICS. X-Ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

CHEMISTRY. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

MECHANICS. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Combustion Controls.

ORGANIC AND FIBROUS MATERIALS. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

METALLURGY. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

MINERAL PRODUCTS. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

BUILDING RESEARCH. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

APPLIED MATHEMATICS. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

DATA PROCESSING SYSTEMS. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

ATOMIC PHYSICS. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics.

INSTRUMENTATION. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

IONOSPHERE RESEARCH AND PROPAGATION. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

RADIO PROPAGATION ENGINEERING. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

RADIO STANDARDS. High frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

RADIO SYSTEMS. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

UPPER ATMOSPHERE AND SPACE PHYSICS. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.


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