

A UNITED STATES
DEPARTMENT OF
COMMERCE
PUBLICATION



NBS SPECIAL PUBLICATION **350**

**Time and Frequency:
A Bibliography of NBS
Literature Published
July 1955-December 1970**

**U.S.
DEPARTMENT
OF
COMMERCE**

National
Bureau
of
Standards

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards¹ was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of a Center for Radiation Research, an Office of Measurement Services and the following divisions:

Applied Mathematics—Electricity—Heat—Mechanics—Optical Physics—Linac Radiation²—Nuclear Radiation²—Applied Radiation²—Quantum Electronics³—Electromagnetics³—Time and Frequency³—Laboratory Astrophysics³—Cryogenics³.

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement, standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; provides advisory and research services to other Government agencies; and develops, produces, and distributes standard reference materials. The Institute consists of the Office of Standard Reference Materials and the following divisions:

Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Reactor Radiation—Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations leading to the development of technological standards (including mandatory safety standards), codes and methods of test; and provides technical advice and services to Government agencies upon request. The Institute also monitors NBS engineering standards activities and provides liaison between NBS and national and international engineering standards bodies. The Institute consists of the following technical divisions and offices:

Engineering Standards Services—Weights and Measures—Flammable Fabrics—Invention and Innovation—Vehicle Systems Research—Product Evaluation Technology—Building Research—Electronic Technology—Technical Analysis—Measurement Engineering.

THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in improving cost effectiveness in the conduct of their programs through the selection, acquisition, and effective utilization of automatic data processing equipment; and serves as the principal focus within the executive branch for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Center consists of the following offices and divisions:

Information Processing Standards—Computer Information—Computer Services—Systems Development—Information Processing Technology.

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal Government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System; provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world, and directs the public information activities of the Bureau. The Office consists of the following organizational units:

Office of Standard Reference Data—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

¹ Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

² Part of the Center for Radiation Research.

³ Located at Boulder, Colorado 80302.

UNITED STATES DEPARTMENT OF COMMERCE • Maurice H. Stans, *Secretary*

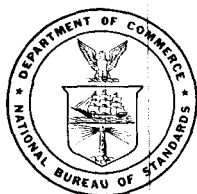
NATIONAL BUREAU OF STANDARDS • Lewis M. Branscomb, *Director*

**Time and Frequency:
A Bibliography of NBS Literature**

Published July 1955–December 1970

B. E. Blair

Time and Frequency Division
Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado 80302



National Bureau of Standards Special Publication 350

Nat. Bur. Stand. (U.S.), Spec. Publ. 350, 52 pages (June 1971)
CODEN: XNBSA

Issued June 1971

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
(Order by SD Catalog No. C 13.10:350), Price \$0.55

Stock Number 0303-0871

Library of Congress Catalog Number: 73-611327

Contents

	Page
Introduction	1
[Sections A-E are grouped by fiscal year]	
Section A—Time and Frequency Standards	3-12
Section B—Time Scales, Time	13-18
Section C—Distribution/Reception of Time and Frequency Signals	19-27
Section D—Statistics of Time and Frequency Analyses, Frequency Stability	28-31
Section E—General, Summary, and Status Reports	32-35

Page numbers by Section
Category and Fiscal Year.

Fiscal Year	Section A	Section B	Section C	Section D	Section E
July 1955-June 1956	4	15	21	--	--
July 1956-June 1957	4	15	21	--	33
July 1957-June 1958	4	--	21	--	33
July 1958-June 1959	5	--	--	--	33
July 1959-June 1960	5-6	--	21-22	29	--
July 1960-June 1961	6	15-16	22	29	33
July 1961-June 1962	6	16	23	--	--
July 1962-June 1963	6-7	16	23	29	34
July 1963-June 1964	7-8	16-17	23	29	34
July 1964-June 1965	8	17	24	29	34
July 1965-June 1966	8	17	24	29-30	34
July 1966-June 1967	9	17	24-25	30	34-35
July 1967-June 1968	9	17-18	25	30	35
July 1968-June 1969	9-10	18	25-26	30	--
July 1969-June 1970	10-11	18	26	31	35
July 1970-June 1971	11-12	--	27	31	35
Section F—NBS Author Index					36-39
Section G—NBS Time and Frequency Services—Outside Publications					40-48
Appendix I—Structure of NBS Time and Frequency Division					49
Appendix II—NBS Time/Frequency Broadcast Notices, Bulletins, HF Prediction Methods					50

**TIME AND FREQUENCY:
A BIBLIOGRAPHY OF NBS LITERATURE
PUBLISHED JULY 1955—DECEMBER 1970**

B. E. Blair

This publication gives bibliographic references to NBS time and frequency papers (principally those of the Time and Frequency Division or its predecessor sections) published over the past 15 years. The NBS material is classified under five general sections: Time and Frequency Standards; Time Scales, Time; Distribution/Reception of Time and Frequency Signals; Statistics of Time and Frequency Analyses, Frequency Stability; and General, Summary, and Status Reports. An additional section lists outside publications which describe the use of NBS time and frequency services or illustrate their varied use in seismic research, industrial practice, navigation, and propagation studies, among others. The bibliography documents past progress, will aid access to available literature, and gives an indication of the present direction, scope, and status of NBS time and frequency research.

Key words: Atomic clocks; atomic standards; clock dissemination; crystal oscillators; definition of second; flicker noise; frequency; frequency stability; lasers; length standards; measurement standards; spectral density; standard frequency broadcasts; speed of light; statistics of time/frequency measurements; time; time/frequency dissemination; time scales; timing (HF, LF, satellite, TV, VLF); wavelength standards; WWV; WWVB; WWVH; WWVL.

Introduction

This bibliography lists NBS papers and reports in the field of time and frequency under five categories and by fiscal year, published from June 1955 through December 1970. The cited work is principally that of the Time and Frequency Division; however, important related work in the time and frequency area by other NBS personnel also is listed. We include an NBS author index as well as a selected listing of non-NBS written articles about our work. This latter section gives a sampling of reports and papers which describe and illustrate, for instance, instrumentation methods for comparability to NBS time and frequency standards, the use of the NBS radio broadcasts and services, and the scope and depth of such usage.

The contents of this bibliographic listing exemplify the extent and character of work performed by the Time and Frequency Division. (The listing is in the form of an NBS Special Publication which we plan to update periodically.) The Division welcomes questions and provides consultation services on matters relating to time and frequency. Appendix I shows the section structure and responsibilities of the Division. Appendix II indicates the various time and frequency broadcast notices, bulletins, HF prediction notices, etc., available to the public on the basis of need.

To aid in the location of the source material, there has been a vigorous attempt to list complete references in consistent form, using accepted journal title abbreviations as given in the 1961 *Chemical Abstracts—Lists of Publications* or the 1966 *Revised and Enlarged Word Abbreviation List for USASI Z39.5-1963—American Standard for Periodical Title Abbreviations*. Most of the bibliographic listings can be seen at public or university libraries. NBS Technical Notes and papers with a USGPO notation are available, for the price shown, from:

Superintendent of Documents
U. S. Government Printing Office
Washington, D. C. 20402

A listing with a Libr. Congr. notation is available as follows:

The Library of Congress
Washington, D. C. 20540

Photocopying is done also by the Library for research purposes, under certain specified conditions. Any out-of-print Bureau documents can generally be obtained by such photoduplication, as well as single articles in a publication, such as proceedings of a conference. Complete information about these services are available from the Photoduplication Service Group of the Library of Congress. Papers with an AD accession number and a NTIS notation are available from the National Technical Information Service as follows:

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Va. 22151

Limited reprints of some listed research articles and reports are available from:

Secretary to the Chief
Time and Frequency Division
National Bureau of Standards
Boulder, Colo. 80302
(Telephone: 303-447-1000, ext. 3294)

NBS PUBLICATIONS—TIME AND FREQUENCY
SECTION A
TIME AND FREQUENCY STANDARDS

This section is concerned with studies on primary time and frequency standards at NBS since 1955. The studies embrace low temperature crystal oscillators; development, construction, and evaluation of atomic beam frequency standards assembled at the NBS laboratories (including ammonia masers, cesium, thallium, and hydrogen beam standards); evaluation of commercial atomic frequency standards, such as rubidium, cesium, and hydrogen standards; evaluation of errors in atomic frequency standards; development of low noise electronics; theoretical research on atomic beam resonances and hydrogen spin-exchange; stabilization of laser frequencies; and refinement of measurements of the speed of light.

Over this 15-year period, the accuracy of primary frequency standards has improved from about 1 part in 10^8 to some 5 parts in 10^{13} (1σ). The rigorous evaluation of the cesium beam standard at NBS, along with similar studies at other national laboratories, contributed to the 13th General Conference of Weights and Measures defining, in 1967, the international unit of time—the second—based on a cesium resonance frequency. For the future, studies indicate that frequency accuracies of a few parts in 10^{14} are within reach of today's research capabilities. An exciting consequence of further work envisions a single Standard for frequency, time, and length, from which other units of measurement can be derived. This approach would specify a numerical value for the speed of light (previous best experimental value) and, since length measurements could be referred back to a frequency standard, there would be no need for a separate length standard.

SECTION A
TIME AND FREQUENCY STANDARDS

July 1955 - June 1956

- [A-1] GEORGE, W. D., "A frequency standard at low temperature," PROC. 10th ANN. SYMP. ON FREQUENCY CONTROL (Signal Corps Engineering Lab., Ft. Monmouth, N. J. 07703, May 15-17, 1956), pp. 197-215 (Libr. Congr., PB-125 393, 1956).
- [A-2] NBS, "Constant temperature oven for quartz crystal oscillator," NAT. BUR. STAND. (U. S.), TECH. NEWS BULL., 40, No. 4, p. 59 (USGPO, \$0.15, April 1956).
- [A-3] NBS, "Portable secondary frequency standard," NAT. BUR. STAND. (U. S.), TECH. NEWS BULL., 39, No. 7, pp. 92-93 (USGPO, \$0.15, July 1955).
- [A-4] SULZER, P. G., "An oscillator with direct-feedback frequency correction," (Unpublished report).

July 1956 - June 1957

- [A-5] LYONS, H., "Atomic clocks," SCIENTIFIC AMERICAN, 196, No. 2, pp. 71-82 (February 1957).
- [A-6] NBS, "Portable frequency standard," NAT. BUR. STAND. (U. S.), TECH. NEWS BULL., 41, No. 4, p. 62 (USGPO, \$0.15, April 1957).
- [A-7]
(D)¹ PHELPS, F. P., "Stability of quartz resonators at very low temperatures," PROC. 11th ANN. SYMP. ON FREQUENCY CONTROL (Signal Corps Engineering Lab., Ft. Monmouth, N. J. 07703, May 7-9, 1957), pp. 256-276 (Libr. Congr., PB-134 925, 1957).

July 1957 - June 1958

- [A-8] BENDER, P. L., BEATY, E. C., and CHI, A. R., "Optical detection of the cesium hyperfine transition," PROC. 12th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Signal Research and Development Lab., Ft. Monmouth, N. J. 07703, May 6-8, 1958), pp. 593-605 (Libr. Congr., PB-142 945, 1958).
- [A-9]
(E) PHELPS, F. P., and MORGAN, A. H., "Research at NBS Boulder Laboratories on quartz crystal resonators and oscillators at low temperatures," PROC. 12th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Signal Research and Development Lab., Ft. Monmouth, N. J. 07703, May 6-8, 1958), pp. 162-171 (Libr. Congr., PB-142 945, 1958).
- [A-10] RICHARDSON, J. M., "Experimental evaluation of the oxygen microwave absorption as a possible atomic frequency standard," J. APPL. PHYS., 29, No. 2, pp. 137-145 (1958).

1. Letters in parentheses indicate applicability to additional sections.

July 1958 - June 1959

- [A-11] BEATY, E. C., BENDER, P. L., and CHI, A. R., "Hyperfine transitions in rubidium-87 vapor," PROC. 13th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Signal Research and Development Lab., Ft. Monmouth, N. J. 07703, May 12-14, 1959), pp. 669-675 (Libr. Congr., PB-146 982, 1959).
- [A-12] (D) MOCKLER, R. C., and BARNES, J. A., "Maser frequency stability," PROC. 13th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Signal Research and Development Lab., Ft. Monmouth, N. J. 07703, May 12-14, 1959), pp. 583-595 (Libr. Congr., PB-146 982, 1959).
- [A-13] MOCKLER, R. C., BARNES, J., BEEHLER, R., SALAZAR, H., and FEY, L., "The ammonia maser as an atomic frequency and time standard," IRE TRANS. INSTRUM., 1-7, Nos. 3 and 4, pp. 201-202 (December 1958).
- [A-14] SIMPSON, P. A., and MORGAN, A. H., "Quartz crystals at low temperatures," PROC. 13th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Signal Research and Development Lab., Ft. Monmouth, N. J. 07703, May 12-14, 1959), pp. 207-231 (Libr. Congr., PB-146 982, 1959).
- [A-15] SULZER, P. G., "Frequency stabilized oscillator," U. S. Patent 2,871,356 (January 27, 1959).

July 1959 - June 1960

- [A-16] BENDER, P. L., "Atomic frequency standards and clocks," Quantum Electronics--A Symposium, C. H. Townes, Ed. (Conf. on Quantum Electronics--Resonance Phenomena, Bloomingburg, N. Y. 12721, September 14-16, 1959), pp. 110-120 (Columbia University Press, New York, N. Y. 10025, 1960).
- [A-17] MOCKLER, R. C., and BEEHLER, R. E., "NBS atomic frequency standards," PROC. 14th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Signal Research and Development Lab., Ft. Monmouth, N. J. 07703, May 31-June 2, 1960), pp. 298-309 (Libr. Congr., PB-153 716, 1960).
- [A-18] (D) MOCKLER, R. C., BEEHLER, R. E., and BARNES, J. A., "An evaluation of a cesium beam frequency standard," Quantum Electronics--A Symposium, C. H. Townes, Ed. (Conf. on Quantum Electronics--Resonance Phenomena, Bloomingburg, N. Y. 12721, September 14-16, 1959), pp. 127-145 (Columbia University Press, New York, N. Y. 10025, 1960).
- [A-19] (D) MORGAN, A. H., and BARNES, J. A., "Short-time stability of a quartz-crystal oscillator as measured with an ammonia maser," PROC. IRE (Corresp.), 47, No. 10, p. 1782 (October 1959).
- [A-20] NBS, "National standards of time and frequency in the United States," PROC. IRE (Corresp.), 48, No. 1, pp. 105-106 (January 1960).
- [A-21] RICHARDSON, J. M., "Microwave spectroscopy--atomic frequency standards," Encyclopedia of Spectroscopy, G. L. Clark, Ed., pp. 647-656 (Reinhold Publishing Corp., New York, N. Y. 10001, 1960).

- [A-22] SIMPSON, P. A., BARCLAY, C., and PHELPS, F. P., "Quartz oscillator unit for operation at low temperatures," U. S. Patent 2,931,924 (April 5, 1960).

July 1960 - June 1961

- [A-23] BARNES, J. A., and HEIM, L. E., "A high-resolution ammonia-maser-spectrum analyzer," IRE TRANS. INSTRUM., 1-10, No. 1, pp. 4-8 (June 1961).
(D)
- [A-24] BEEHLER, R. E., MOCKLER, R. C., and SNIDER, C. S., "A comparison of atomic beam frequency standards," NATURE (Letter), 187, No. 4738, pp. 681-682 (August 20, 1960).
- [A-25] BENDER, P. L., "Atomic clocks for space experiments," ASTRONAUTICS, 5, No. 7, pp. 37, 70, 71 (July 1960).
- [A-26] BOOTH, Sherman F., Ed., Precision Measurement and Calibration--Papers on Electricity and Electronics, (contains 6 selected reprints of NBS time and frequency publications 1950 - 1960), NAT. BUR. STAND. (U.S.) HANDB. 77, I, pp. 472-577 (USGPO, \$6.00, February 1961).
(B, C, D)
- [A-27] CARPENTER, R. J., BEATY, E. C., BENDER, P. L., SAITO, S., and STONE, R. O., "A prototype rubidium vapor frequency standard," IRE TRANS. INSTRUM., 1-9, No. 2, pp. 132-135 (September 1960).
- [A-28] MOCKLER, R. C., "Atomic beam frequency standards," Advances in Electronics and Electron Physics, L. Marton, Ed., 15, pp. 1-71 (Academic Press, Inc., New York, N. Y. 10003, 1961).
(D)
- [A-29] MOCKLER, R. C., BEEHLER, R. E., and SNIDER, C. S., "Atomic beam frequency standards," IRE TRANS. INSTRUM., 1-9, No. 2, pp. 120-132 (September 1960).
(D)
- [A-30] NBS, "Atomic frequency standards," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 45, No. 1, pp. 8-10 (USGPO, \$0.15, January 1961).
- [A-31] RICHARDSON, J. M., "The caesium resonators of the National Bureau of Standards," Monograph of Radioelectric Measurements and Standards (XIIIth Gen. Assem. of URSI, London, England, September 5-15, 1960), B. Deaux, Ed., pp. 26-29 (Elsevier Publishing Co., Amsterdam, Netherlands, 1961).

July 1961 - June 1962

- [A-32] BARNES, J. A., ALLAN, D. W., and WAINWRIGHT, A. E., "The ammonia beam maser as a standard of frequency," IRE TRANS. INSTRUM., 1-11, No. 1, pp. 26-30 (June 1962).

July 1962 - June 1963

- [A-33] BEEHLER, R. E., ATKINSON, W. R., HEIM, L. E., and SNIDER, C. S., "A comparison of direct and servo methods for utilizing cesium beam resonators as frequency standards," IRE TRANS. INSTRUM., 1-11, Nos. 3 and 4, pp. 231-238 (December 1962).

- [A-34] BEEHLER, R. E., and GLAZE, D. J., "Experimental evaluation of a thallium beam frequency standard," PROC. 17th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, May 27-29, 1963), pp. 392-407 (NTIS, AD 423 381, 1963).
- [A-35] SHIRLEY, J. H., "Some causes of resonant frequency shifts in atomic beam machines," J. APPL. PHYS., 34, No. 4, Part I - "Shifts due to other frequencies of excitation," pp. 783-788; Part II - "The effect of slow frequency modulation on the Ramsey line shape," pp. 789-791 (April 1963).

July 1963 - June 1964

- [A-36a] BEEHLER, R. E., and MOCKLER, R. C., "A comparison of atomic frequency standards," PROC. XIVth GEN. ASSEM. of URSI (Tokyo, Japan, September 9-20, 1963), Publication 1183, pp. 128-129 (National Academy of Sciences, Washington, D.C. 20418, December 1963);
(E)
- [A-36b] Progress in Radio Science 1960 - 1963, Radio Standards & Measurements, Proc. of Comm. 1 on Radio Measur. & Stand., - XIVth Gen. Assem. of URSI (Tokyo, Japan, September 9-20, 1963), R. W. Beatty, Ed., 1, pp. 20-26 (Elsevier Publishing Co., Amsterdam, Netherlands, 1965).
- [A-37a] BENDER, P. L., "Precise measurements of distance and the velocity of light using lasers," URSI National Committee Report, XIVth GEN. ASSEM., Tokyo, Japan, September 1963: COMM. 1, Radio Measurement Methods and Standards, Part 7, RADIO SCI. J. RES., NBS/USNC - URSI, 68D, No. 5, pp. 540-541 (May 1964);
- [A-37b] URSI - Radio Standards and Measurements - Commission 1, (XIVth Gen. Assem. of URSI, Tokyo, Japan, September 9-20, 1963), XIII-1, pp. 109-114 (URSI, Brussels 18, Belgium, 1963);
- [A-37c] (Summary), Progress in Radio Science 1960-1963, Proc. of Comm. 1 on Radio Measur. & Stand., XIVth Gen. Assem. of URSI (Tokyo, Japan, September 9-20, 1963), R. W. Beatty, Ed., 1, p. 101 (Elsevier Publishing Co., Amsterdam, Netherlands, 1965);
- [A-37d] (Summary), U.S.A. National Committee International Scientific Radio Union, (Report on the XIVth Gen. Assem. of URSI, Tokyo, Japan, September 9-20, 1963), Publication 1183, pp. 195-199 (National Academy of Sciences, Washington, D. C. 20418, 1963).
- [A-38] BENDER, P. L., "Effect of hydrogen-hydrogen exchange collisions," PHYS. REV., 132, No. 5, pp. 2154-2158 (December 1, 1963).
- [A-39] CARPENTER, R. J., "A portable rubidium-vapor frequency standard," NAT. BUR. STAND. (U.S.), TECH. NOTE 235, 25 pages (USGPO, \$0.25, April 6, 1964).
- [A-40a] MOCKLER, R. C., "Atomic frequency and time interval standards," URSI - Radio Standards and Measurements - Commission 1, (XIVth Gen. Assem. of URSI, Tokyo, Japan, September 9-20, 1963), XIII-1, pp. 66-76 (URSI, Brussels 18, Belgium, 1963);
(B, E)

[A-40b] URSI National Committee Report, XIVth GEN. ASSEM., Tokyo, Japan, September 1963: COMM. 1, Radio Measurement Methods and Standards, Part 1, RADIO SCI., J. RES., NBS/USNC - URSI, 68D, No. 5, pp. 523-527 (May 1964).

[A-41] NBS, "Standards and calibration--Precision of the U.S. frequency standard," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 48, No. 2, pp. 31-32 (USGPO, \$0.15, February 1964).

July 1964 - June 1965

[A-42] HUDSON, G. E., "Frequency and time standards," ELECTRONICS WORLD, 72,
(B) No. 2, pp. 20-23 (August 1964).

[A-43] NBS, "Frequency stability calibration of signal sources," NAT. BUR. STAND.
(D) (U.S.), TECH. NEWS BULL., 49, No. 6, p. 89 (USGPO, \$0.15, June 1965).

July 1965 - June 1966

[A-44] BARNES, J., and WAINWRIGHT, A., "A precision pulse-operated electronic
phase shifter and frequency translator," PROC. IEEE (Corresp.), 53, No.
12, pp. 2143-2144 (December 1965).

[A-45] BEEHLER, R. E., and GLAZE, D. J., "The performance and capability of
(D) cesium beam frequency standards at the National Bureau of Standards,"
IEEE TRANS. INSTRUM. AND MEAS., IM-15, Nos. 1 and 2, pp. 48-55
(March and June 1966).

[A-46] BEEHLER, R. E., and GLAZE, D. J., "Evaluation of a thallium atomic beam
(D) frequency standard at the National Bureau of Standards," IEEE TRANS.
INSTRUM. AND MEAS., IM-15, Nos. 1 and 2, pp. 55-58 (March and June
1966).

[A-47] BEEHLER, R., HALFORD, D., HARRACH, R., ALLAN, D., GLAZE, D.,
(D) SNIDER, C., BARNES, J., VESSOT, R., PETERS, H., VANIER, J.,
CUTLER, L., and BODILY, L., "An intercomparison of atomic standards,"
PROC. IEEE (Letters), 54, No. 2, pp. 301-302 (February 1966).

[A-48] BEEHLER, R. E., MOCKLER, R. C., and RICHARDSON, J. M., "Cesium beam
(D) atomic time and frequency standards," METROLOGIA, 1, No. 3, pp. 114-
131 (July 1965).

[A-49] BLAIR, B. E., and MORGAN, A. H., "The long-term performance of two com-
(D) mercial rubidium vapor frequency standards," NAT. BUR. STAND. (U.S.),
TECH. NOTE 341, 31 pages (USGPO, \$0.25, June 1966).

[A-50] HARRACH, R. J., "Some accuracy limiting effects in an atomic beam frequency
standard," PROC. 20th ANN. SYMP. ON FREQUENCY CONTROL (U.S.
Army Electronics Command, Ft. Monmouth, N. J. 07703, April 19-21,
1966), pp. 424-435 (NTIS, AD-800 523, 1966).

[A-51] RICHARDSON, J. M., "Time standards," Encyclopedic Dictionary of Physics,
(B) Suppl. 1, J. Thewlis, Ed., pp. 351-355 (Pergamon Press Ltd., Oxford,
London, 1966).

July 1966 - June 1967

- [A-52] BEEHLER, R. E., "A historical review of atomic frequency standards," PROC. (E) IEEE, 55, No. 6, pp. 792-805 (June 1967).
- [A-53] HALL, J. L., and MOREY, W. W., "Optical heterodyne measurement of neon laser's millimeter wave difference frequency," APPL. PHYS. LETT., 10, No. 5, pp. 152-155 (March 1, 1967).
- [A-54] HARRACH, R. J., "On the natural shift of a resonance frequency," NAT. BUR. STAND. (U.S.), TECH. NOTE 346, 27 pages (USGPO, \$0.25, September 1966).
- [A-55] HARRACH, R. J., "Radiation-field-dependent frequency shifts of atomic beam resonances," J. APPL. PHYS., 38, No. 4, pp. 1808-1819 (March 15, 1967).
- [A-56] RICHARDSON, J. M., and BROCKMAN, J. F., "Atomic standards of frequency (B) and time," THE PHYSICS TEACHER, 4, No. 6, pp. 247-256 (September 1966).
- [A-57] VESSOT, R., PETERS, H., VANIER, J., BEEHLER, R., HALFORD, D., (D) HARRACH, R., ALLAN, D., GLAZE, D., SNIDER, C., BARNES, J., CUTLER, L., and BODILY, L., "An intercomparison of hydrogen and cesium frequency standards," IEEE TRANS. INSTRUM. AND MEAS., IM-15, No. 4, pp. 165-176 (December 1966).

July 1967 - June 1968

- [A-58] BAY, Z., and LUTHER, G. G., "The measurement of optical frequencies and a redetermination of the velocity of light by microwave modulation of laser beams," Research on Laser Standards and Materials at the National Bureau of Standards, NAT. BUR. STAND. (U.S.), TECH. NOTE 449, K. G. Kessler, E. Passaglia, and N. N. Winogradoff, Eds., p. 30 (USGPO, \$0.30, June 1968).

July 1968 - June 1969

- [A-59] BARGER, R. L., and HALL, J. L., "Pressure shift and broadening of methane line at 3.39μ studied by laser-saturated molecular absorption," PHYS. REV. LETT., 22, No. 1, pp. 4-8 (January 6, 1969).
- [A-60] BARGER, R. L., and HALL, J. L., "Use of laser-saturated absorption of methane for laser frequency stabilization," (Summary), PROC. 23rd ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, May 6-8, 1969), p. 306 (Electron. Ind. Ass., Washington, D. C. 20006, \$6.50, 1969).
- [A-61] BAY, Z., and LUTHER, G. G., "Locking a laser frequency to the time standard," APPL. PHYS. LETT. 13, No. 9, pp. 303-304 (November 1, 1968).
- [A-62] HALL, J. L., "The laser absolute wavelength standard problem," IEEE J. QUANTUM ELECT., QE-4, No. 10, pp. 638-641 (October 1968).

- [A-63] HALL, J. L., BARGER, R. L., BENDER, P. L., BOYNE, H. S., FALLER, J. E., and WARD, J., "Precision long path interferometry and the velocity of light," Electron Technology, (Proc. URSI (Comm. 1) Conf. on Laser Meas., Warsaw, Poland, September 24-28, 1968), A. Smoliński and S. Hahn, Eds., 2, No. 2/3, pp. 53-66 (Institute of Electron. Technol., Polish Academy of Sciences, Warsaw, Poland, 1969).
- [A-64] JENNINGS, D. A., EVENSON, K. M., SIMMONS, W. R., and RASMUSSEN, A. L., "Laser energy, power, and frequency measurements," Electron Technology, (Proc. URSI (Comm. 1) Conf. on Laser Meas., Warsaw, Poland, September 24-28, 1968), A. Smoliński and S. Hahn, Eds., 2, No. 2/3, pp. 149-158 (Institute of Electron. Technol., Polish Academy of Sciences, Warsaw, Poland, 1969).
- [A-65] SHIRLEY, J. H., "Dynamics of a simple maser model," AMER. J. PHYS., 36, No. 11, Part 1, pp. 949-963 (November 1968).
- [A-66] SHIRLEY, J. H., "Validity of the semiclassical approximation in maser theory," PHYS. REV., 181, No. 2, pp. 600-609 (May 1969).

July 1969 - June 1970

- [A-67] BENDER, P. L., and COHEN, V. W., "New information on the physics of rubidium gas cells," (Summary), PROC. 24th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N.J. 07703, April 27-29, 1970), p. 279 (Electron. Ind. Ass., Washington, D. C. 20006, \$6.50, 1970).
- [A-68] BENDER, P. L., and COHEN, V. W., "Collisional broadening of the RB⁸⁷ hyperfine transition," Book of Abstracts, (VIth Int. Conf. Phys. of the Electron. and At. Collisions, Cambridge, Mass. 02142, July 28-August 2, 1969), pp. 720-722 (Mass. Inst. Technol. Press, Cambridge, Mass. 02142, 1969).
- [A-69] BOYNE, H. S., "Laser frequency stabilization techniques and their applications," PROC. 24th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, April 27-29, 1970), pp. 233-239 (Electron. Ind. Ass., Washington, D. C. 20006, \$6.50, 1970).
- [A-70] EVENSON, K. M., WELLS, J. S., and MATARRESE, L. M., "Absolute frequency measurements of the CO₂ cw laser at 28 THz (10.6 μm)," APPL. PHYS. LETT., 16, No. 6, pp. 251-253 (March 15, 1970).
- [A-71] EVENSON, K. M., WELLS, J. S., MATARRESE, L. M., and ELWELL, L. B., "Absolute frequency measurements of the 28- and 78-μm cw water vapor laser lines," APPL. PHYS. LETT., 16, No. 4, pp. 159-161 (February 15, 1970).
- [A-72] HELLWIG, H., "Hydrogen spin exchange frequency shifts," NAT. BUR. STAND. (U.S.), TECH. NOTE 387, 13 pages (USGPO, C13.46:387, \$0.30, March 1970).

- [A-73] HELLWIG, H., "The hydrogen storage beam tube --a proposal for a new frequency standard," METROLOGIA, 6, No. 2, pp. 56-60 (April 1970).
- [A-74a] HELLWIG, H., "Areas of promise for development of future primary frequency standards," PROC. 24th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, April 27-29, 1970) pp. 246-258 (Electron. Ind. Ass., Washington, D. C. 20006, \$6.50, 1970);
- [A-74b] METROLOGIA, 6, No. 4, pp. 118-126 (October 1970).
- [A-75a] HELLWIG, H., ALLAN, D. W., GLAZE, D. J., VESSOT, R. F. C., LEVINE, M., ZITZEWITZ, P. W., and PETERS, H. E., "Measurement of the unperturbed hydrogen hyperfine transition frequency," (Summary) CPEM DIGEST (1970 Conf. on Precision Electromagnetic Meas., Boulder, Colo. 80302, June 2-5, 1970), pp. 72-73 (IEEE, Inc., New York, N. Y. 10017, \$15.00/\$10.00 member, June 1970).
- (D)
- [A-75b] HELLWIG, H., ET. AL., IEEE TRANS. INSTRUM. AND MEAS., IM-19, No. 4, pp. 200-209 (November 1970).
- [A-76] NBS, "Measurement of light frequencies," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 53, No. 9, p. 206 (USGPO, \$0.30, September 1969).
- [A-77] RISLEY, A. S., ALLAN, D. W., GRAY, J. E., SHOAF, J. H., MACHLAN, H. E., GLAZE, D. J., PETERS, H. E., JOHNSON, E. H., VESSOT, R. F. C., and LEVINE, M., "Long term frequency stability of a NASA prototype hydrogen maser," (Summary) CPEM DIGEST (1970 Conf. on Precision Electromagnetic Meas., Boulder, Colo. 80302, June 2-5, 1970), pp. 74-75 (IEEE, Inc., New York, N. Y. 10017, \$15.00/\$10.00 member, June 1970).
- (D)

July 1970 - June 1971

- [A-78] BARGER, R. L., and HALL, J. L., "Precision wavelength measurement of the methane 3.39 μ saturated absorption line by laser-controlled interferometry," (Abstract), Proceedings International Conference on Precision Measurement and Fundamental Constants (NBS - Gaithersburg, Md. 20760, August 3-7, 1970), D. N. Langenberg and B. N. Taylor, Eds., NAT. BUR. STAND. (U.S.), SPEC. PUBL. (in press).
- [A-79] BARNES, J. A., "Frequency measurement errors of passive resonators caused by frequency modulated exciting signals," IEEE TRANS. INSTRUM. AND MEAS., IM-19, No. 3, pp. 147-152 (August 1970).
- (D)
- [A-80] BAY, Z., "The use of microwave modulation of lasers for length measurements," Proceedings International Conference on Precision Measurement and Fundamental Constants (NBS - Gaithersburg, Md. 20760, August 3-7, 1970), D. N. Langenberg and B. N. Taylor, Eds., NAT. BUR. STAND. (U.S.), SPEC. PUBL. (in press).
- [A-81] BAY, Z., and LUTHER, G. G., "The measurement of optical frequencies and a redetermination of the velocity of light," Proceedings International Conference on Precision Measurement and Fundamental Constants (NBS - Gaithersburg, Md. 20760, August 3-7, 1970), D. N. Langenberg and B. N. Taylor, Eds., NAT. BUR. STAND. (U.S.), SPEC. PUBL. (in press).
- [A-82] EVENSON, K. M., WELLS, J. S., and MATARRESE, L. M., "Defining the speed of light: A combination time, frequency and length standard," Proceedings International Conference on Precision Measurement and Fundamental Constants (NBS - Gaithersburg, Md. 20760, August 3-7, 1970), D. N. Langenberg and B. N. Taylor, Eds., NAT. BUR. STAND. (U.S.), SPEC. PUBL. (in press).

- [A-83a] GLAZE, D. J., "Improvements in atomic cesium beam frequency standards at the National Bureau of Standards," IEEE TRANS. INSTRUM. AND MEAS., IM-19, No. 3, pp. 156-160 (August 1970);
- [A-83b] Progress in Radio Science 1966-1969 - Part 1, (Proc. XVIth Gen. Assem. of URSI, Comm. 1, Ottawa, Canada, August 18-28, 1969), C. E. White, Ed. (in press).
- [A-84] HALL, J. L., and BARGER, R. L., "The implication of saturated molecular absorption for the laser wavelength standard problem," (Abstract), Proceedings International Conference on Precision Measurement and Fundamental Constants (NBS - Gaithersburg, Md. 20760, August 3-7, 1970), D. N. Langenberg and B. N. Taylor, Eds., NAT. BUR. STAND. (U.S.), SPEC. PUBL. (in press).
- [A-85] HELLWIG, H., "The ion storage technique for application in frequency standards," NAT. BUR. STAND. (U.S.), TECH. NOTE 388, 23 pages (USGPO, C13.46: 388, \$0.35, November 1970).
- [A-86a] HELLWIG, H., and HALFORD, D., "Accurate frequency measurements: survey, (D) significance, and forecast," Proceedings International Conference on Precision Measurement and Fundamental Constants (NBS - Gaithersburg, Md. 20760, August 3-7, 1970), D. N. Langenberg and B. N. Taylor, Eds., NAT. BUR. STAND. (U.S.), SPEC. PUBL. (in press);
- [A-86b] Unpublished report.
- [A-87] MIELENZ, K., "Interferometry for wavelength comparisons," Proceedings International Conference on Precision Measurement and Fundamental Constants (NBS - Gaithersburg, Md. 20760, August 3-7, 1970), D. N. Langenberg and B. N. Taylor, Eds., NAT. BUR. STAND. (U.S.), SPEC. PUBL. (in press).
- [A-88] PAGE, C. H., HARRIS, F. K., FOWLER, H. A., TOOTS, J., OLSEN, P. T., EICKE, W., and WITT, T., "Referencing of the U.S. national volt against a Josephson frequency-to-voltage source," Proceedings International Conference on Precision Measurement and Fundamental Constants (NBS - Gaithersburg, Md. 20760, August 3-7, 1970), D. N. Langenberg and B. N. Taylor, Eds., NAT. BUR. STAND. (U.S.), SPEC. PUBL. (in press).

SECTION B

TIME SCALES, TIME

The reports and papers in this section span a period of time which experienced three different definitions of the basic unit of time—the second—with some four to five orders of magnitude improvement. In 1955 the International Astronomical Union approved a prototype time unit, the Ephemeris second, to supplant the less precise mean solar or UT second. The International Committee of Weights and Measures adopted this refined standard in 1956, and the General Conference of Weights and Measures gave formal approval to the Ephemeris second in 1960. Concurrently, with the advent of atomic frequency standards, it was apparent that an even more refined unit of time—an atomic second—could be defined. As a consequence, the International Committee of Weights and Measures (CIPM) established in 1956 a Consultative Committee for the Definition of the Second (CCDS) which held four meetings in Paris (1957, 1961, 1963, and 1967). Dr. F. W. Brown represented NBS at the first meeting and entered into initial discussions as recorded in Comité Consultatif Pour La Définition De La Seconde 1^{re} Session, 1957 (Minutes of the First Meeting), pages 1-32 (Gauthier-Villars, Paris, France, 1958). In 1964 the General Conference of Weights and Measures authorized the International Committee of Weights and Measures to define a provisional atomic second based on the cesium transition frequency.

The 13th General Conference of Weights and Measures, in 1967, defined the unit of time in the International System of units as follows:

“The second is the duration of
9 192 631 770
periods of the radiation
corresponding to the transition
between two hyperfine levels
of the ground state of the
atom of cesium 133.”

Since navigators, astronomers, and others require earth or UT time, studies continue for optimizing and striking a compromise between the needs of both kinds of time. There is also anticipation that future research will further refine the present definition of the second.

NBS participation in such far reaching endeavors as time unit definitions, coordination of UT and AT, development of a national and/or international time scale, and research into methods for synchronizing time scales, is shown in the scope, depth, and variety of applicable subjects listed in this section.

SECTION B

TIME SCALES, TIME

July 1955 - June 1956

- [B-1]
(C) NBS, "Improvements in standard frequencies broadcast by radio stations WWV and WWVH," NAT. BUR. STAND. (U. S.), TECH. NEWS BULL., 40, No. 3, pp. 37-38 (USGPO, \$0.15, March 1956).

July 1956 - June 1957

- [B-2]
(A) GEORGE, W. D., "Étalons et mesures de fréquence et d'intervalle de temps aux États-Unis d'Amérique de 1954 à 1957," (Standards and measures of frequency and interval of time in the United States of America from 1954 to 1957), Comité Consultatif pour la Définition de la Seconde-Procès Verbaux des Séances, (Consultative Committee for the Definition of the Second-Minutes of Meeting), (CIPM, 1^{re} Session, Paris, France, June 3-4, 1957), 26-B, Series 2, Annex S3, pp. S35-S37, (Gauthier-Villars, Paris, France, December 1958).
- [B-3]
(A) MOCKLER, R. C., "Étalons de temps atomiques et moléculaires au National Bureau of Standards," (Atomic and molecular standards of time at the National Bureau of Standards), Comité Consultatif pour la Définition de la Seconde-Procès Verbaux des Séances, (Consultative Committee for the Definition of the Second-Minutes of Meeting), (CIPM, 1^{re} Session, Paris, France, June 3-4, 1957), 26-B, Series 2, Annex S4, pp. S38-S42, (Gauthier-Villars, Paris, France, December 1958).

July 1957 - June 1958

NONE

July 1958 - June 1959

NONE

July 1959 - June 1960

NONE

July 1960 - June 1961

- [B-4]
(C) MORGAN, A. H., and ANDREWS, D. H., "Méthodes et techniques de contrôle des ondes kilométriques et myriamétriques aux Boulder Laboratories," (Methods and techniques of low and very low frequency monitoring at Boulder Laboratories), Comité Consultatif pour la Définition de la Seconde Auprès du Comité International des Poids et Mesures, (Consultative Committee for the Definition of the Second to the International Committee of Weights and Measures), (CIPM, 2^e Session, Paris, France, April 11-12, 1961), Annex 6, pp. 68-72, (Gauthier-Villars & C^{ie}, Paris, France, September 1962).

- [B-5]
(A) RICHARDSON, J. M., BEEHLER, R. E., MOCKLER, R. C., and FEY, R. L., "Les étalons atomiques de fréquence au NBS," (Atomic frequency standards at the National Bureau of Standards), Comité Consultatif pour la Définition de la Seconde Auprès du Comité International des Poids et Mesures, (Consultative Committee for the Definition of the Second to the International Committee of Weights and Measures), (CIPM, 2^e Session, Paris, France, April 11-12, 1961), Annex 5, pp. 57-67, (Gauthier-Villars & C^{ie}, Paris, France, September 1962).

July 1961 - June 1962

- [B-6]
(A) TIPSON, R. S., "Sun-time replaced by atomic clocks," CAPITAL CHEMIST, 11, No. 8, pp. 255-256 (November 1961).

July 1962 - June 1963

- [B-7]
(A) HUDSON, G. E., and ATKINSON, W. R., "The redefinition of the second and the velocity of light," PHYS. TODAY, 16, No. 5, pp. 30-32, 34, 36 (May 1963).
- [B-8]
(A) HUDSON, G. E., and ATKINSON, W., "On the redefinition of the second and the velocity of light," IEEE TRANS. INSTRUM. AND MEAS., IM-12, No. 1, pp. 44-46 (June 1963).
- [B-9] NEWMAN, J., FEY, L., and ATKINSON, W. R., "A comparison of two independent atomic time scales," PROC. IEEE (Corresp.), 51, No. 3, pp. 498-499 (March 1963).

July 1963 - June 1964

- [B-10] BARNES, J. A., and FEY, R. L., "Synchronization of two remote atomic time scales," PROC. IEEE (Corresp.), 51, No. 11, p. 1665 (November 1963).
- [B-11a] BARNES, J. A., and MOCKLER, R. C., "The NBS time scale and its relation to other time scales," (Summary), Progress in Radio Science 1960 - 1963, Radio Standards & Measurements, Proc. of Comm. 1 on Radio Measur. & Stand. - XIVth Gen. Assem. of URSI (Tokyo, Japan, September 9-20, 1963), R. W. Beatty, Ed., 1, p. 41 (Elsevier Publishing Co., Amsterdam, Netherlands, 1965);
- [B-11b] U. S. A. National Committee International Scientific Radio Union, (Report on the XIVth Gen. Assem. of URSI, Tokyo, Japan, September 9-20, 1963), Publication 1183, pp. 135-136 (National Academy of Sciences, Washington, D. C. 20418, 1963).
- [B-12] BONANOMI, J., KARTASCHOFF, P., NEWMAN, J., BARNES, J. A., and ATKINSON, W. R., "A comparison of the TA-1 and the NBS-A atomic time scales," PROC. IEEE (Corresp.), 52, No. 4, p. 439 (April 1964).
- [B-13] HUDSON, G. E., "Spacetime coordinate systems," PROC. 7^{ème} CONGRÈS INTERNATIONAL DE CHRONOMÉTRIE (International Conference on Chronometry, Lausanne, Switzerland, June 8-12, 1964), Part 1, pp. 197-221 (Société Suisse de Chronométrie, Neuchatel, Switzerland, 1964).

- [B-14] (A) MOCKLER, R. C., and RICHARDSON, J. M., "Quelques considérations sur une définition atomique de l'unité de temps," (Some considerations relative to an atomic definition for the unit of time), Comité Consultatif pour la Définition de la Seconde, (Consultative Committee for the Definition of the Second), (CIPM, 3^e Session, Paris, France, December 3-5, 1963), Annex 10, pp. 58-65, (Gauthier-Villars & C¹e, Paris, France, December 1964).

July 1964 - June 1965

- [B-15] NBS, "World sets atomic definition of time," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 48, No. 12, pp. 209-210 (USGPO, \$0.15, December 1964).

July 1965 - June 1966

- [B-16] BARNES, J. A., ANDREWS, D. H., and ALLAN, D. W., "The NBS-A time scale-its generation and dissemination," IEEE TRANS. INSTRUM. AND MEAS., IM-14, No. 4, pp. 228-232 (December 1965).
- [B-17] FEY, L., BARNES, J. A., and ALLAN, D. W., "An analysis of low information rate time control unit," PROC. 20th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, April 19-21, 1966), pp. 629-635 (NTIS, AD-800 523, 1966).
- [B-18] HUDSON, G. E., "Of time and the atom," PHYSICS TODAY, 18, No. 8, pp. 34-38 (August 1965 - Addendum 1968).

July 1966 - June 1967

- [B-19] BARNES, J. A., "The development of an international atomic time scale," PROC. IEEE, 55, No. 6, pp. 822-826 (June 1967).
- [B-20] HUDSON, G. E., "Some characteristics of commonly used time scales," PROC. IEEE, 55, No. 6, pp. 815-821 (June 1967).

July 1967 - June 1968

- [B-21] ALLAN, D. W., FEY, L., MACHLAN, H. E., and BARNES, J. A., "An ultra-precise time synchronization system designed by computer simulation," FREQUENCY, 6, No. 1, pp. 11-14 (January 1968).
- [B-22] BARNES, J. A., and ALLAN, D. W., "An approach to the prediction of coordinated universal time," FREQUENCY, 5, No. 6, pp. 15-20 (November - December 1967).
- [B-23] (A) CIPM, "Travaux sur les étalons atomiques de fréquence," (Works on atomic standards of frequency), December 1963-December 1966, Comité Consultatif pour la Définition de la Seconde, (Consultative Committee for the Definition of the Second), (CIPM, 4^e Session, Paris, France, July 12-13, 1967), Annex 1, pp. S16-S17 (Bur. Internat. des Poids et Mesures, Sevres, France, May 1968).
- [B-24] DAVEY, W. R., "A review of studies made on the decade fluctuations in the earth's rate of rotation," NAT. BUR. STAND. (U.S.), TECH. NOTE 358, 16 pages (USGPO, \$0.20, October 1967).

- [B-25] NBS, "Standards and calibrations - UTC clock coordination," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 51, No. 10, p. 223 (USGPO, \$0.15, October 1967).
- [B-26] NBS, "Atomic second adopted as international unit of time," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 52, No. 1, pp. 10-12 (USGPO, \$0.15, January 1968).

July 1968 - June 1969

- [B-27] HUDSON, G. E., ALLAN, D. W., BARNES, J. A., HALL, R. G., LAVANCEAU, J. D., and WINKLER, G. M. R., "A coordinate frequency and time system," PROC. 23rd ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, May 6-8, 1969), pp. 249-262 (Electron. Ind. Ass., Washington, D. C. 20006, \$6.50, 1969).
- [B-28] NBS, "Nation gets unified time system," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 53, No. 2, p. 34 (USGPO, \$0.30, February 1969).

July 1969 - June 1970

- [B-29] ALLAN, D. W., GRAY, J. E., and MACHLAN, H. E., "The NBS atomic time scale system: AT(NBS), SAT(NBS), and UTC(NBS)," (Summary), PROC. 24th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, April 27-29, 1970), p. 361 (Electron. Ind. Ass., Washington, D. C. 20006, \$6.50, 1970).

July 1970 - June 1971

- [B-30] BARNES, J. A., "A non-mathematical discussion of some basic concepts of precise time measurement," TRACOR FREQUENCY, 17 pages (in press).

SECTION C

DISTRIBUTION/RECEPTION OF TIME AND FREQUENCY SIGNALS

NBS contributions to the topic of this section were, in the middle 1950's, through the HF standard frequency broadcasts of WWV and WWVH with received precisions of some parts in 10^7 from day to day. LF broadcasts were commenced at 60 kHz (KK2XEI—later WWVB) in 1956 from a site at the Boulder Laboratories. Only radiating about a watt of power, this 60 kHz broadcast was used by Prof. Pierce at Harvard University to intercompare NBS and NPL (England) frequency standards to several parts in 10^9 . Concurrently with the LF studies, it became apparent that VLF signals also could be broadcast with precision. NBS studies, along with others, gave impetus to the adoption, in December 1959, of the 20 kHz standard frequency band by the International Radio Conference for the International Telecommunications Union (ITU). After a 3-month period of construction, NBS commenced broadcasting a 20 kHz standard frequency from WWVL at a site some 18 airline kms west of Boulder. The success of these two low frequency transmissions on an experimental basis led to the development and construction of more powerful stations at Ft. Collins, Colorado in 1963. This section of the bibliography includes papers which describe the NBS broadcasts and give their characteristics, use, special experiments, and levels of received precision. The improvement in frequency standards during this period of time contributed immensely to the precision of signals broadcast. The NBS contribution to Loran-C, although not a direct time and frequency involvement, is also listed.

As time and frequency dissemination advanced to meet more stringent goals, the use of satellites and commercial TV enabled μ second, or better, timing. The future includes providing a more powerful and effective WWVH on Kauai, Hawaii in July 1971, revising the format of the HF broadcasts for greater utility of use, and refining the satellite and TV experiments; long-range plans include WWV-type transmissions from synchronous satellites and time synchronizations through long-base interferometry (LBI) measurements.

SECTION C

DISTRIBUTION/RECEPTION OF TIME AND FREQUENCY SIGNALS

July 1955 - June 1956

- [C-1] NBS, "Standard frequencies and time signals WWV and WWVH," NAT. BUR.
(B) STAND. (U.S.), LETT. CIRC. 1023, 14 pages (June 1956), (Superseded by
MISC. PUBL. 236, December 1960).

July 1956 - June 1957

- [C-2] GEORGE, W. D., "Low frequency standard transmission," PROC. 11th ANN.
SYMP. ON FREQUENCY CONTROL (Signal Corps Engineering Lab.,
Ft. Monmouth, N. J. 07703, May 7-9, 1957), p. 574 (Libr. Congr., PB-
134 925, 1957).
- [C-3] NBS, "Standard frequency and time signals WWV and WWVH," PROC. IRE
(B) (Corresp.), 44, No. 10, pp. 1470-1473 (October 1956).

July 1957 - June 1958

- [C-4] GEORGE, W. D., and NBS STAFF, "WWV standard frequency transmissions,"
PROC. IRE (Corresp.), 46, No. 5, pp. 910-911 (May 1958).
[Note: These notices were published monthly thereafter thru October 1968--
PROC. IEEE (Letters), 56, No. 10, pp. 1759-1760 (October 1968).]
- [C-5] GILLILAND, T. R., "Automatic radio control for clocks," U. S. patent
(B) 2,824,218, 18 pages (February 18, 1958).
- [C-6] NBS, "Experimental standard frequency broadcast on 60 kilocycles," NAT. BUR.
STAND. (U.S.), TECH. NEWS BULL., 41, No. 7, pp. 99-100 (USGPO,
\$0.15, July 1957).
- [C-7] NBS, "Standard musical pitch," NAT. BUR. STAND. (U.S.), TECH. NEWS
BULL., 41, No. 8, pp. 120-121 (USGPO, \$0.15, August 1957).

July 1958 - June 1959

NONE

July 1959 - June 1960

- [C-8a] DOHERTY, R. H., HEFLEY, G., and LINFIELD, R. F., "Timing potentials
of Loran-C," PROC. 14th ANN. SYMP. ON FREQUENCY CONTROL
(U. S. Army Signal Research and Development Lab., Ft. Monmouth,
N. J. 07703, May 31-June 2, 1960), pp. 276-297 (Libr. Congr., PB-
153 716, 1960);
- [C-8b] PROC. IRE, 49, No. 11, pp. 1659-1673 (November 1961).

- [C-9a] HEFLEY, G., DOHERTY, R. H., and BERGER, E. L., "An intermittent-action camera with absolute time calibration," IRE Wescon Convention Record (PROC. WESCON, Los Angeles, Calif., August 18-21, 1959), 3, Part 6, pp. 129-135 (IRE, (IEEE) Inc., New York, N.Y. 10017, 1959).
- [C-9b] J. RES. NAT. BUR. STAND. (ENG. AND INSTRUM.), 64C, No. 2, pp. 159-165 (April-June 1960).
- [C-10] MORGAN, A. H., "Precise time synchronization of widely separated clocks," (B) NAT. BUR. STAND. (U.S.), TECH. NOTE 22, 65 pages (NTIS, PB 151 381, \$3.00, July 1959).
- [C-11] NBS, "Standards and calibration in radio and electronics," (A) NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 43, No. 12, pp. 226-230 (USGPO, \$0.15, December 1959).
- [C-12] NBS, "Standard frequency broadcast on 20 kc/s," TELECOM. J. (Notes and News-English Edition), 27, No. 5, p. 110E (May 1960).
- [C-13] WATT, A. D., and PLUSH, R. W., "Power requirements and choice of an optimum frequency for a worldwide standard-frequency broadcasting station," J. RES. NAT. BUR. STAND. (RADIO PROPAGAT.), 63D, No. 1, pp. 35-44 (July-August 1959).

July 1960 - June 1961

- [C-14] BENDER, P. L., "Synchronization of time standards for satellite tracking," (Summary), Monograph of Radioelectric Measurements and Standards (XIIIth Gen. Assem. of URSI, London, England, September 5-15, 1960), B. Decaux, Ed., pp. 48-49 (Elsevier Publishing Co., Amsterdam, Netherlands, 1961).
- [C-15a] DAVIS, T. L., and DOHERTY, R. H., "Widely separated clocks with micro-second synchronization and independent distribution systems," IRE Wescon Convention Record (Proc. WESCON, Los Angeles, Calif., August 23-26, 1960), 4, Part 5, pp. 3-17 (IRE, (IEEE) Inc., New York, N.Y. 10017, 1960).
- [C-15b] IRE TRANS. SPACE ELECT. AND TELEMETRY, SET-6, No. 3-4, pp. 138-146 (December 1960).
- [C-16] NBS, "Experimental timing code added to WWV broadcasts," (B) NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 44, No. 7, pp. 114-115 (USGPO, \$0.15, July 1960).
- [C-17] NBS, "New standard frequency broadcasts," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 44, No. 7, pp. 120-121 (USGPO, \$0.15, July 1960).
- [C-18] NBS, "Standard frequencies and time signals from NBS stations WWV and WWVH," (B) NAT. BUR. STAND. (U.S.), MISC. PUBL. 236, 6 pages (December 1960). (Reprinted with corrections July 1, 1961 - Superseded by 1965 Edition).
- [C-19] NBS, "Changes in WWV/WWVH standard broadcasts," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 45, No. 1, pp. 11-13 (USGPO, \$0.15, January 1961).
- [C-20] SAITO, S., and BRETEMPS, F. R., "For accurate timing build a WWV time signal receiver," ELECTRONIC INDUSTRIES, 19, No. 8, pp. 214, 216 (August 1960).

July 1961 - June 1962

- [C-21] FEY, R. L., MILTON, J. B., and MORGAN, A. H., "Remote phase control of radio station WWVL," NATURE, 193, No. 4820, pp. 1063-1064 (March 17, 1962).
- [C-22] NBS, "Loran-C clock timing system," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 46, No. 2, pp. 20-21 (USGPO, \$0.15, February 1962).
- [C-23] NBS, "NBS and Navy announce change in standard frequency broadcasts," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 46, No. 2, p. 24, (USGPO, \$0.15, February 1962).
- [C-24] WATT, A. D., PLUSH, R. W., BROWN, W. W., and MORGAN, A. H., "World-wide VLF standard frequency and time signal broadcasting," J. RES. NAT. BUR. STAND. (RADIO PROPAGAT.), 65D, pp. 617-627 (November-December 1961).

July 1962 - June 1963

- [C-25] MORGAN, A. H., "Frequency and time broadcast services of the National Bureau of Standards," 1962 PROC. INSTRUM. SOC. OF AMER., (17th Annu. Instrum. - Automat. Conf. and Exhib., New York City, N. Y., October 15-18, 1962), 17, Part 1, Paper 1.1.62, 9 pages (ISA, Penn Sheraton Hotel, Pittsburgh, Pa. 15219, 1962).
- [C-26] MORGAN, A. H., "Time and frequency broadcasting," ISA J., 10, No. 6, pp. 49-54 (June 1963).
- [C-27] MORGAN, A. H., "Frequency and time calibration services at the Boulder Laboratories of the National Bureau of Standards," Proceedings of the 1962 Standards Laboratory Conference (Boulder, Colo. 80302, August 8-10, 1962), NAT. BUR. STAND. (U.S.) MISC. PUBL. 248, Paper 1.6, pp. 37-43 (USGPO, \$1.75, August 1963).

July 1963 - June 1964

- [C-28] MORGAN, A. H., "Comparison of atomic standards by VLF," U. S. A. National Committee International Scientific Radio Union (Report on the XIVth Gen. Assem. of URSI, Tokyo, Japan, September 9-20, 1963), Publication 1183, pp. 134-135 (National Academy of Sciences, Washington, D. C. 20418. 1963).
- [C-29] MORGAN, A. H., BLAIR, B. E., and CROW, E. L., "International comparison of atomic frequency standards via VLF radio signals," Progress in Radio Science 1960-1963, Radio Standards & Measurements, Proc. of Comm. I on Radio Measur. & Stand. - XIVth Gen. Assem. of URSI (Tokyo, Japan, September 9-20, 1963), R. W. Beatty, Ed., 1, p. 40 (Elsevier Publishing Co., Amsterdam, Netherlands, 1963).
- [C-30] NBS, "New facilities dedicated for WWVB and WWVL," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 47, No. 10, pp. 178-179 (USGPO, \$0.15, October 1963).
- [C-31] RICHARDSON, J. M., "Establishment of new facilities for WWVL and WWVB," RADIO SCI. J. RES., NBS/USNC-URSI, 68D, No. 1, p. 135 (January 1964).

July 1964 - June 1965

- [C-32] MORGAN, A. H., and BALTZER, O. J., "A VLF timing experiment," RADIO SCI. J. RES., NBS/USNC-URSI, 68D, No. 11, pp. 1219-1222 (November 1964).
- [C-33] NBS, "Standard frequency and time services of the National Bureau of Standards," NAT. BUR. STAND. (U.S.), MISC. PUBL. 236, 1965 Edition, 8 pages (USGPO, January 1965) (Superseded by 1966 Edition).
- [C-34] NBS, "NBS low-frequency station WWVB to broadcast international unit of time," (B) NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 49, No. 2, p. 27 (USGPO, \$0.15, February 1965).

July 1965 - June 1966

- [C-35] ANDREWS, D. H., "Standard frequency and time services of the National Bureau of Standards," FREQUENCY, 3, No. 6, pp. 30-35 (November-December 1965).
- [C-36] ANDREWS, D. H., "LF-VLF frequency and time services of the National Bureau of Standards," (B) IEEE TRANS. INSTRUM. AND MEAS., IM-14, No. 4, pp. 233-237 (December 1965).
- [C-37] BLAIR, B. E., and MORGAN, A. H., "Control of WWV and WWVH standard frequency broadcasts by VLF and LF signals," RADIO SCI. J. RES., NBS/USNC-URSI, 69D, No. 7, pp. 915-928 (July 1965).
- [C-38] MORGAN, A. H., CROW, E. L., and BLAIR, B. E., "International comparison of atomic frequency standards via VLF radio signals," (A) RADIO SCI. J. RES., NBS/USNC-URSI, 69D, No. 7, pp. 905-914 (July 1965).
- [C-39] NBS, "WWV to be relocated," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 49, No. 12, pp. 215-218 (USGPO, \$0.15, December 1965).
- [C-40] NBS, "NBS standard frequency and time services," NAT. BUR. STAND. (U.S.), MISC. PUBL. 236, 1966 Edition, 12 pages (USGPO, 1966) (Superseded by 1967 Edition).
- [C-41] NBS, "WWVB adds time code to broadcasts," (B) NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 50, No. 1, pp. 15-16 (USGPO, \$0.15, January 1966).

July 1966 - June 1967

- [C-42] ANDREWS, D. H., "Of time and frequency," How to Listen to the World, pp. 3-7 (World Publications, Hellerup, Denmark, January 1967).
- [C-43] BEERS, Y., "WWV moves to Colorado," Parts I and II, QST, LI, No. 1, pp. 11-14 (January 1967); LI, No. 2, pp. 30-36 (February 1967).
- [C-44] BLAIR, B. E., CROW, E. L., and MORGAN, A. H., "Five years of VLF world-wide comparison of atomic frequency standards," (A) RADIO SCI., 2, (New Series), No. 6, pp. 627-636 (June 1967).

- [C-45] FEY, L., and LOONEY, C. H., Jr., "A dual frequency VLF timing system," IEEE TRANS. INSTRUM. AND MEAS., IM-15, No. 4, pp. 190-195 (December 1966).
- [C-46] KAMAS, G., MORGAN, A. H., and JESPERSEN, J. L., "New measurements of phase velocity at VLF," RADIO SCI., 1, (New Series), No. 12, pp. 1409-1410 (December 1966).
- [C-47] MORGAN, A. H., "Distribution of standard frequency and time signals," PROC. IEEE, 55, No. 6, pp. 827-836 (June 1967).
- [C-48] NBS, "Construction of new WWV buildings begun," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 50, No. 9, p. 161 (USGPO, \$0.15, September 1966).
- [C-49] NBS, "NBS standard frequency and time services," NAT. BUR. STAND. (U.S.), MISC. PUBL. 236, 1967 Edition, 12 pages (USGPO, 1967) (Superseded by 1968 Edition).

July 1967 - June 1968

- [C-50] JESPERSEN, J. L., "Signal design for time dissemination: some aspects," NAT. BUR. STAND. (U.S.), TECH. NOTE 357, 38 pages (USGPO, \$0.30, November 1967).
- [C-51] JESPERSEN, J. L., KAMAS, G., and MORGAN, A. H., "VLF propagation over distances between 200 and 1500 km," PROC. CONFERENCE ON M. F., L. F. and V. L. F. RADIO PROPAGATION, (London, England, November 8-10, 1967), W. T. Blackband, Chairman, INST. ELEC. ENG. (London) CONF. PUBL. NO. 36, pp. 74-80 (Savoy Place, London, England, 1967).
- [C-52] JESPERSEN, J. L., KAMAS, G., and MORGAN, A. H., "A proposed ranging system with application to VLF timing," IEEE TRANS. INSTRUM. AND MEAS., IM-15, No. 4, pp. 282-285 (December 1967).
- [C-53] NBS, "Standards and calibrations - WWVH radiation pattern modified," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 51, No. 10, p. 223 (USGPO, \$0.15, October 1967).
- [C-54] NBS, "NBS frequency and time broadcast services," NAT. BUR. STAND. (U.S.), SPEC. PUBL. 236, 1968 Edition, 15 pages (USGPO, 1968) (Superseded by 1969 Edition).
- [C-55] VIEZBICKE, P. P., "Why WWV moved to Colorado," MARK 5 (Letter), (U.S. Power Squadron, Dist. 5 - Boating Publ.), 13, No. 3, pp. 14-16 (June 1968).

July 1968 - June 1969

- [C-56] ANDREWS, D. H., CHASLAIN, C., and DePRINS, J., "Reception of low frequency time signals," FREQUENCY, 6, No. 9, pp. 13-21 (September 1968).
- [C-57] GATTERER, L. E., BOTTONNE, P. W., and MORGAN, A. H., "Worldwide clock synchronization using a synchronous satellite," IEEE TRANS. INSTRUM. AND MEAS., IM-17, No. 4, pp. 372-378 (December 1968).

- [C-58] JESPERSEN, J. L., KAMAS, G., GATTERER, L. E., and MacDORAN, P. F., "Satellite VHF transponder time synchronization," PROC. IEEE, 56, No. 7, pp. 1201-1206 (July 1968).
- [C-59] NBS, "NBS frequency and time broadcast services," NAT. BUR. STAND. (U.S.), SPEC. PUBL. 236, 1969 Edition, 16 pages (USGPO, 1969) (Superseded by 1970 Edition).
- [C-60] NBS, "Standards and calibrations--commercial television aids NBS standard broadcasts," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 53, No. 5, p. 111 (USGPO, \$0.30, May 1969).

July 1969 - June 1970

- [C-61] ALLAN, D. W., LESCHIUTTA, S., and ROVERA, G., "TV frame pulses used for precision time synchronization and their noise distribution," ALTA FREQUENZA (Letter), 34, No. 5, (English Issue No. 2), p. 180 E (March 1970).
- [C-62] BLAIR, B. E., JESPERSEN, J. L., and KAMAS, G., "VLF precision timekeeping potential," Progress in Radio Science 1966-1969 - Part I, (Proc. XVth Gen. Assem. of URSI, Comm. 1, Ottawa, Canada, August 18-29, 1969), C. E. White, Ed. (in press).
- [C-63] DAVIS, D. D., JESPERSEN, J. L., and KAMAS, G., "The use of television signals for time and frequency dissemination," PROC. IEEE (Letters), 58, No. 6, pp. 931-933 (June 1970).
- [C-64] JESPERSEN, J. L., "A survey of time and frequency dissemination techniques," (Summary), PROC. 24th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, April 27-29, 1970), pp. 322-323 (Electron. Ind. Ass., Washington, D. C. 20006, \$6.50, 1970).
- [C-65] MILTON, J. B., "Standard time and frequency: Its generation, control, and dissemination from the National Bureau of Standards Time and Frequency Division," NAT. BUR. STAND. (U.S.), TECH. NOTE 379, 27 pages (USGPO, \$0.35, August 1969).
- [C-66] NBS, "Standards and calibrations - WWVL changes broadcast format," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 53, No. 12, p. 284 (USGPO, \$0.30, December 1969).
- [C-67] NBS, "Time dissemination and clock synchronization via television," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 54, No. 6, pp. 125-126 (USGPO, C13.13:54/6, \$0.30, June 1970).
- [C-68] NBS, "New WWVH facility," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 54, No. 6, p. 137 (USGPO, C13.13:54/6, \$0.30, June 1970).
- [C-69] VIEZBICKE, P. P. (Ed.), "NBS frequency and time broadcast services," NAT. BUR. STAND. (U.S.), SPEC. PUBL. 236, 1970 Edition, 16 pages (USGPO, C13.11:236, \$0.25, 1970).

July 1970 - June 1971

- [C-70] BLAIR, B. E. and MORGAN, A. H., (Eds.), Precision Measurement and Calibration - Selected NBS Papers on Frequency and Time, NAT. BUR. STAND. (U.S.), SPEC. PUBL. 300, vol. V (USGPO, in press).
- [C-71] DAVIS, D. D., "Transmission of time/frequency signals in the vertical interval," Synopses of Papers, (SOC. MOTION PICT. & TELE. ENG. - 108th Tech. Conf. & Equip. Exhib., New York, N.Y. 10019, October 4-9, 1970), Paper No. 43, 3 pages (October 1970).

SECTION D

STATISTICS OF TIME AND FREQUENCY ANALYSES, FREQUENCY STABILITY

This section includes NBS papers on such subjects as power spectrum, oscillator noise effects, flicker noise, stability of frequency generators, and statistics of atomic frequency standards. Specific NBS work and publications in this general subject area did not appear until the late 1950's. Impetus to the study of the definition and measurement of short-term frequency stability was given by the joint IEEE-NASA Symposium in 1964, from which evolved a Special Issue of the IEEE PROCEEDINGS in February 1966. NBS contributions to these studies are noted in this listing. Some specific characterizations or definitions of frequency stability have now been crystallized by the Subcommittee on Frequency Stability of the Frequency and Time Technical Committee (IEEE Group on Instrumentation and Measurement). The initial publication of this work is NBS TECH. NOTE 394, co-authored by 11 Subcommittee members.

SECTION D

STATISTICS OF TIME AND FREQUENCY ANALYSES; MEASUREMENTS

July 1959 - July 1960

- [D-1]
(B) ATKINSON, W., and FEY, L., "Statistical aspects of clock errors," (Unpublished report).

July 1960 - June 1961

- [D-2]
(A) BARNES, J. A., and MOCKLER, R. C., "The power spectrum and its importance in precise frequency measurements," IRE TRANS. INSTRUM., 1-9, No. 2, pp. 149-155 (September 1960).

July 1961 - June 1962

NONE

July 1962 - June 1963

- [D-3]
(A) ATKINSON, W. R., FEY, L., and NEWMAN, J., "Spectrum analysis of extremely low frequency variations of quartz oscillators," PROC. IEEE (Corresp.), 51, No. 2, p. 379 (February 1963).

July 1963 - June 1964

- [D-4] FEY, L., ATKINSON, W. R., and NEWMAN, J., "Obscurities of oscillator noise," PROC. IEEE (Corresp.), 52, No. 1, pp. 104-105 (January 1964).

July 1964 - June 1965

- [D-5]
(A) BARNES, J. A., and ALLAN, D. W., "Effects of long-term stability on the definition and measurement of short-term stability," PROC. IEEE-NASA SYMP. ON SHORT-TERM FREQUENCY STABILITY, A. R. Chi, Chairman, (Goddard Space Flight Center, Greenbelt, Md. 20771, November 23-24, 1964), NASA REP. SP-80, pp. 119-123 (USGPO, \$1.75, 1965).

July 1965 - June 1966

- [D-6]
(A) ALLAN, D. W., "Statistics of atomic frequency standards," PROC. IEEE, 54, No. 2, pp. 221-230 (February 1966).

- [D-7] BARNES, J. A., "Atomic timekeeping and the statistics of precision signal generators," PROC. IEEE, 54, No. 2, pp. 207-220 (February 1966).
(A)
- [D-8] BARNES, J. A., and ALLAN, D. W., "A statistical model of flicker noise," PROC. IEEE, 54, No. 2, pp. 176-178 (February 1966).

July 1966 - June 1967

- [D-9] BARNES, J. A., "The generation and recognition of flicker noise," (Unpublished report).

July 1967 - June 1968

- [D-10] ALLAN, D. W., and BARNES, J. A., "Some statistical properties of LF and VLF propagation," Phase and Frequency Instability in Electromagnetic Wave Propagation (AGARD/EWP XIII Symp., Ankara, Turkey, October 9-12, 1967), AGARD CONF. PROC. NO. 33, Chap. 15, K. Davies, Ed. (Technivision Services, Slough, England)(In press).
(C)
- [D-11] HALFORD, D., "A general mechanical model for $|f|^\alpha$ spectral density random noise with special reference to flicker noise $1/|f|$," PROC. IEEE, 56, No. 3, pp. 251-258 (March 1968).
- [D-12] HALFORD, D., WAINWRIGHT, A. E., and BARNES, J. A., "Flicker noise of phase in RF amplifiers and frequency multipliers: Characterization, cause, and cure," (Summary) PROC. 22nd ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, April 22-24, 1968), pp. 340-341 (NTIS, AD-844 911, 1968).
- [D-13] HUDSON, G. E., and BARNES, J. A., "Clock error statistics as a renewal process," PROC. 22nd ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, April 22-24, 1968), pp. 384-418 (NTIS, AD-844 911, 1968).

July 1968 - June 1969

- [D-14] BARNES, J. A., "Tables of bias functions, B_1 and B_2 , for variances based on finite samples of processes with power law spectral densities," NAT. BUR. STAND. (U. S.), TECH. NOTE 375, 37 pages (USGPO, \$0.50, January 1969).
- [D-15] GUÉTROT, A., HIGBIE, L. S., LAVANCEAU, J., and ALLAN, D. W., "An application of statistical smoothing techniques on VLF signals for comparison of time between USNO and NBS," (Summary) PROC. 23rd ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N. J. 07703, May 6-8, 1969), p. 248 (Electron. Ind. Ass., Washington, D. C. 20006, \$6.50, 1969).
(C)
- [D-16] POWERS, R. S., and SNYDER, W. F. (Eds.), "Radio-frequency measurements in the NBS Institute for Basic Standards" (Time and Frequency Sections only), NAT. BUR. STAND. (U. S.), TECH. NOTE 373, pp. 1 to 12-1 (USGPO, \$1.00, June 1969).
(A, B, E)

July 1969 - June 1970

- [D-17] HALFORD, D., "Frequency stability of quality quartz crystal oscillators: Performance and some critical applications," (Abstract) PROC. COLLOQUE INTERNATIONAL DE CHRONOMETRIE (International Horological Symp., Paris, France, September 16-20, 1969), Paper A11, 3 pages (Nouvelle Faculte des Sciences, 11, Quai St., Paris, (5^o), France, 1969).
(A)

July 1970 - June 1971

- [D-18a] BARNES, J. A., CHI, A. R., CUTLER, L. S., HEALEY, D. J., LEESON, D. B., McGUNIGAL, T. E., MULLEN, J. A., SMITH, W. L., SYDNOR, R., VESSOT, R. F. C., and WINKLER, G. M. R., "Characterization of frequency stability," NAT. BUR. STAND. (U. S.), TECH. NOTE 394, 50 pages (USGPO, C13.46:394, \$0.60, October 1970);
- [D-18b] IEEE TRANS. INSTRUM. AND MEAS., IM-20, No. 2 (May 1971).

SECTION E

GENERAL, SUMMARY, AND STATUS REPORTS

This section includes (1) reviews of progress, developments, etc., in the general area of time and frequency for given time periods, prepared for the International Body of URSI—Commission 1; (2) conference or summary reports showing the progress of time and frequency projects; (3) status reports of time and frequency activities at a given time; and (4) reports or papers which show how time and frequency functions fit into the overall NBS mission of providing a central basis for the National Measurement System.

SECTION E
GENERAL, SUMMARY AND STATUS REPORTS

July 1956 - June 1957

- [E-1] McNISH, A. G., "Dimensions, units and standards," PHYSICS TODAY, 10, No. 4, pp. 19-25 (April 1957).

July 1957 - June 1958

- [E-2] GEORGE, W. D., and LYONS, H., "Review of developments on radio measurement methods and standards 1954-1957," - Section I - Frequency and Time Interval Measurements and Standards, Proc. XIIth Gen. Assem. of URSI - Comm. 1 - (Boulder, Colo. 80302, U.S.A., August 22 - September 5, 1957), XI, Part 1, U. S. A., Report No. 242, pp. 41-45 (URSI, Brussels 18, Belgium, 1957).

July 1958 - June 1959

- [E-3] McNISH, A. G., "The basis of our measuring system," PROC. IRE, 47, No. 5 (B) (Part 1), pp. 636-643 (May 1959).
- [E-4] NBS, "Conference on Electronic Standards and Measurements," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 42, No. 11, pp. 209-212 (USGPO, \$0.15, November 1958).

July 1959 - June 1960

NONE

July 1960 - June 1961

- [E-5] McNISH, A. G., "Time standards," INSTRUM. AND CONTROL SYSTEMS, 33, No. 8, pp. 1340-1341 (August 1960).
- [E-6] NBS, "1960 Conference on Standards and Electronic Measurements," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 44, No. 9, pp. 145-154 (USGPO, \$0.15, September 1960).
- [E-7] RICHARDSON, J. M., "Report on the velocity on light," Monograph of Radio-electric Measurements and Standards, (XIIIth Gen. Assem. of URSI, London, England, September 5-15, 1960), B. Decaux, Ed., pp. 91-98 (Elsevier Publishing Co., Amsterdam, Netherlands, 1961).

July 1961 - June 1962

NONE

July 1962 - June 1963

- [E-8] GEORGE, W. D., "Third International Conference on Precision Electromagnetic Measurements," NATURE, 196, No. 4858, pp. 921-929 (December 8, 1962).
- [E-9] McNISH, A. G., "Fundamentals of measurement," ELECTRO-TECHNOLOGY, (A, B) 71, No. 5, pp. 113-128 (May 1963).
- [E-10] NBS, "1962 International Conference on Precision Electromagnetic Measurements," NAT. BUR. STAND. (U.S.), TECH. NEWS BULL., 46, No. 12, pp. 184-186 (USGPO, \$0.15, December 1962).
- [E-11] WILDHACK, W. A., "Standards for the 70s," INDUSTRIAL RESEARCH, 5, No. 3, pp. 15-20 (March 1963).

July 1963 - June 1964

- [E-12] GEORGE, W. D., "Status of frequency and time control," FREQUENCY, 1, No. 7, pp. 27-29 (November-December 1963).
- [E-13] RICHARDSON, J. M., and BROCKMAN, J. F., "The U.S. basis of electromagnetic measurements," IEEE SPECTRUM, 1, No. 1, pp. 129-138 (January 1964).

July 1964 - June 1965

- [E-14] HUNTOON, R. D., and WILDHACK, W. A., "The role of NBS's Institute for Basic Standards in planning for better measurement accuracy," ISA J., 12, No. 1, pp. 57-60 (January 1965).

July 1965 - June 1966

- [E-15] HUNTOON, R. D., "Status of the national standards for physical measurement," SCIENCE, 150, No. 3693, pp. 169-178 (October 1965).
- [E-16] HUNTOON, R. D., "The measurement system of the United States," Proceedings of the 1966 Standards Laboratory Conference (NCSL/NBS, Session 6, Gaithersburg, Md. 20760, May 9-12, 1966), NAT. BUR. STAND. (U.S.) MISC. PUBL. 291, pp. 89-98 (USGPO, \$1.00, July 1967).
- [E-17] McNISH, A. G., "Measurement standards," INT. SCIENCE AND TECHNOL., No. 47, pp. 58-62, 64, 66 (November 1965).

July 1966 - June 1967

- [E-18] COCHRANE, R. C., Measures for Progress, (A History of the National Bureau of Standards), NAT. BUR. STAND. (U.S.), MISC. PUBL. 275, 703 pages (USGPO, C13.10:275, \$5.25, 1966).

- [E-19a] RICHARDSON, J. M., "Progress in the distribution of standard time and frequency," (Summary), Progress in Scientific Radio, (XVth Gen. Assem. of URSI, Munich, Germany, September 5-15, 1966), Report of U. S. A. National Committee of URSI, Publication 1468, pp. 55-56 (National Academy of Sciences, Washington, D. C. 20418, October 1966);
- [E-19b] Progress in Radio Science 1963-1966 - Part I, (Proc. XVth Gen. Assem. of URSI, Munich, Germany, September 5-15, 1966), R. W. Beatty, Ed., pp. 40-62 (URSI, Brussels 18, Belgium, 1967).
- [E-20] RICHARDSON, J. M., Ed., "Progress in radio measurements and standards," (A, B, C) (U. S. A. National Committee Report, Comm. 1, (XVth Gen. Assem. of URSI, Munich, Germany, September 5-15, 1966), RADIO SCI., 1 (New Series), No. 11, pp. 1333-1341 (November 1966).
- [E-21] RICHARDSON, J. M., "The functions of Commission 1 of the International Scientific Radio Union," PROC. IEEE, 55, No. 6, pp. 743-745 (June 1967).
- [E-22] RICHARDSON, J. M., MOCKLER, R. C., GERBER, E. A., SYKES, R. A., (A, B, C) and HUDSON, G. E., "Review of progress within the United States during the triennium 1963 through 1965," Proc. of the XVth Gen. Assem. of URSI, - Comm. 1 - Radio Standards and Meas., (Munich, Germany, September 5-15, 1966), XIV-1, pp. 64-68 (URSI, Brussels 18, Belgium, 1967).
- July 1967 - June 1968
- [E-23] ASTIN, A. V., "Standards of measurement," SCIENTIFIC AMERICAN, 218, No. 6, pp. 50-62 (June 1968).
- July 1968 - June 1969
- NONE
- July 1969 - June 1970
- [E-24] BARNES, J. A., "Time and frequency--progress in radio measurement methods and standards," COMM. 1 - URSI (1966-1969), R. W. Beatty, Ed., RADIO SCI., 4, No. 7, p. 579 (July 1969).
- July 1970 - June 1971
- [E-25] BRANSCOMB, L., "Measurement standards, language of discovery," Proceedings International Conference on Precision Measurement and Fundamental Constants, (Keynote address, NBS, Gaithersburg, Md. 20760, August 3-7, 1970), D. N. Langenberg and B. N. Taylor, Eds., NAT. BUR. STAND. (U.S.) SPEC. PUBL. (in press).

SECTION F
NBS AUTHOR INDEX

Name	Page
<u>A</u>	
Allan, D. W.	6, 8, 9, 11(3)*, 17(4), 18(2), 26, 29(2), 30(3)
Andrews, D. H.	15, 17, 24(3), 25
Astin, A. V.	35
Atkinson, W. R.	6, 16(4), 29(3)
<u>B</u>	
Barclay, C.	6
Barger, R. L.	9(2), 10, 11, 12
Barnes, J. A.	5(4), 6(2), 8(2), 9, 11, 16(4), 17(5), 18(2), 29(2), 30(7), 31(2), 35
Bay, Z.	9(2), 11(2)
Beaty, E. C.	4, 5, 6
Beatty, R. W.	7(2), 16, 23, 35
Beehler, R. E.	5(3), 6(3), 7(3), 8(4), 9(2), 16
Beers, Y.	24
Bender, P. L.	4, 5(2), 6(2), 7(5), 10(3), 22
Berger, E. L.	22
Blair, B. E.	8, 23, 24(3), 26, 27
Booth, Sherman F.	6
Bottone, P. W.	25
Boyne, H. S.	10(2)
Branscomb, L.	35
Bretemps, F. R.	22
Brockman, J. F.	9, 34
Brown, W. W.	23
<u>C</u>	
Carpenter, R. J.	6, 7
Crow, E. L.	23, 24(2)
<u>D</u>	
Davey, W. R.	17
Davis, D. D.	26, 27
Davis, T. L.	22(2)
Doherty, R. H.	21(2), 22(4)

* Number in parenthesis () denotes number of publications listed on given page written by author.

E

Eike, W. 12
Elwell, L. B. 10
Evenson, K. M. 10(3), 11

F

Fey, R. L. 5, 16(3), 17(2), 23, 25, 29(3)
Fowler, H. A. 12

G

Gatterer, L. E. 25, 26
George, W. D. 4, 15, 21(2), 33, 34(2)
Gilliland, T. R. 21
Glaze, D. J. 7, 8(3), 9, 11(3), 12
Gray, J. E. 11, 18

H

Halford, D. 8, 9, 12, 30(2), 31
Hall, J. L. 9(4), 10, 11, 12
Harrach, R. J. 8(2), 9(3)
Harris, F. K. 12
Hefley, G. 21(2), 22(2)
Heim, L. E. 6(2)
Hellwig, H. 10, 11(4), 12(3)
Higbie, L. S. 30
Hudson, G. E. 8, 16(3), 17(2), 18, 30, 35
Huntoon, R. D. 34(3)

I-J

Jennings, D. A. 10
Jespersen, J. L. 25(4), 26(4)

K

Kamas, G. 25(3), 26(3)
Kessler, K. G. 9

L

Linfield, R. F. 21(2)
Luther, G. G. 9(2), 11
Lyons, H. 4, 33

M

Machlan, H. E.	11, 17, 18
Matarrese, L. M.	10(2), 11
McNish, A. G.	33(3), 34(2)
Mielenz, K.	12
Milton, J. B.	23, 26
Mockler, R. C.	5(4), 6(3), 7, 8(2), 15, 16(3), 17, 29, 35
Morey, W. W.	9
Morgan, A. H.	4, 5(2), 8, 15, 22, 23(7), 24(4), 25(5), 27

N

Newman, J.	16(2), 29(2)
--------------------	--------------

O

Olsen, P. T.	12
----------------------	----

P-Q

Page, C. H.	12
Passaglia, E.	9
Phelps, F. P.	4(2), 6
Plush, R. W.	22, 23
Powers, R. S.	30

R

Rasmussen, A. L.	10
Richardson, J. M.	4, 5, 6, 8(2), 9, 16, 17, 23, 33, 34, 35(5)
Risley, A. S.	11

S

Saito, S.	6, 22
Salazar, H.	5
Shirley, J. H.	7, 10(2)
Shoaf, J. H.	11
Simmons, W. R.	10
Simpson, P. A.	5, 6
Snider, C. S.	6(3), 8, 9
Snyder, W. F.	30
Stone, R. O.	6
Sulzer, P. G.	4, 5

T

Taylor, B. N.	11(4), 12(4), 35
Tipson, R. S.	16
Toots, J.	12

U-V

Viezbicke, P. P.	25, 26
--------------------------	--------

W

Wainwright, A. E.	6, 8, 30
Watt, A. D.	22, 23
Wells, J. S.	10(2), 11
Wildhank, W. A.	34(2)
Winogradoff, N. N.	9
Witt, T.	12

X-Y-Z

SECTION G

NBS TIME AND FREQUENCY SERVICES OUTSIDE PUBLICATIONS

In this section appear some important articles which are non-NBS affiliated, yet are related to NBS services. These papers describe the NBS standards and facilities, show methods and techniques for using the NBS time and frequency services, and document some of the many ways in which the NBS outputs in time and frequency are used. These NBS services impact on a range of activities which includes the timing of seismic events; providing a time reference for both telemetering data from "clusters" of seismic stations throughout the western U. S. and automatically processing earthquake data on an electronic computer; accurate timing for telephone distribution in many of our major cities; frequency synchronization of electric power utilities throughout the U.S. and Canada; frequency and time synchronization of standards laboratories; contributions to an international time scale as determined by the B.I.H.; time service station for USNO clock reference; and specialized research and propagation studies. Such a varied range of activities provides a cross section of the NBS time and frequency user. The aggregate body of users includes government agencies (U. S. Geological Survey, U. S. Coast & Geodetic Survey, NASA, U. S. Navy, U. S. Air Force, U. S. Army), diverse university research units, Woods Hole Oceanographic group, Jet Propulsion Laboratory, Douglas Aircraft Co., Canadian Pacific Railway, Bell Telephone Co., power utilities in the U. S. and Canada, time and frequency equipment manufacturers, amateur radio operators, and scientific and technical industries.

This listing is a sample of outside publications which attempts to show the scope and depth of NBS time and frequency involvement in science and technology. It cannot be all-inclusive; however, we welcome recommendations for noteworthy accessions, as well as documentation of additional uses of our time and frequency services. The references include some manufacturers' literature; their inclusion, though, is to show overall techniques and methods of time and frequency measurement and in no way is an NBS endorsement of commercial equipment. The outline structure of this section is as follows:

- G I. Description of NBS frequency standards, broadcasts, and receiving systems.
- G II. How to use NBS time and frequency broadcasts.
- G III. Varied uses of NBS time and frequency services.
 - a. Commercial-radio frequency stabilization
 - b. Geophysical event timing
 - c. Intercomparison of frequency standards, time scales
 - d. Local laboratory synchronization
 - (1) General synchronization
 - (2) Within laboratory distribution
 - e. Navigation
 - f. Portable clock comparisons
 - g. Power industry frequency synchronization
 - h. Propagation studies
 - i. Research experiments
 - j. Timing
 - (1) Local
 - (2) Telephone company

SECTION G

NBS TIME AND FREQUENCY SERVICES--OUTSIDE PUBLICATIONS

G-1 - Description of NBS Frequency Standards, Broadcasts and Receiving Systems

- [G-1] BROADCASTING STAFF, "TV generates a new form of piggyback," BROADCASTING, 78, No. 20, p. 68 (May 18, 1970).
- [G-2] DE MAW, D., Ed., "Standard frequency and time signals," Radio Amateur's Handbook, 47th Edition, p. 534 (American Radio Relay League, Newington, Conn. 06111, 1970).
- [G-3] ELECTRONICS WORLD STAFF, "New facilities for WWVH to be activated in 1971," ELECTRONICS WORLD, 84, No. 5, p. 68 (November 1970).
- [G-4] ENGINEERING OPPORTUNITIES STAFF, "Measurement accuracy," ENGINEERING OPPORTUNITIES, 6, No. 4, pp. 44-46, 51-53 (April 1968).
- [G-5] EVANS, J., "Time and time measurement," ELECTRONICS WORLD, 76, No. 1, pp. 25-29, 84 (July 1966).
- [G-6] FROST, J. M., "Standard frequency and time signal stations," World Radio TV Handbook, 24th Edition, pp. 37-39 (Billboard Publications, Inc., New York, N. Y. 10036, 1970).
- [G-7] GARDNER, R. K., "Time and coordinate system studies," MITRE TECH. DOCUMENTARY REPT. NO. ESD-TDR-64-627, 98 pages (NTIS, AD-615 034, March 1965).
- [G-8] HAWAII BUSINESS AND INDUSTRY STAFF, "Maui is home of a $\frac{1}{2}$ -million clock," HAWAII BUSINESS AND INDUSTRY, pp. 79-80 (August 1966).
- [G-9] LAVEAU, B. J., "A new time standard," LEEDS AND NORTHRUP TECH. J., Fall Issue, No. 7, pp. 12-17 (Fall 1969).
- [G-10] LEWIS, F. D., "Frequency and time standards," PROC. IRE, 43, No. 9, pp. 1046-1068 (September 1955).
- [G-11] LINCOLN, M., "The WWV story," ELECTRONICS ILLUSTRATED, 7, No. 4, pp. 53-55, 106 (July 1964).
- [G-12] MOUNT, R. L., "Metrology beyond normal limits," QUALITY ASSURANCE, 9, No. 5, pp. 34-37 (May 1970).
- [G-13] TECHNICAL ENGINEERING STAFF, "TV becomes nation's timekeeper," TECHNICIAN ENGINEER, 19, No. 5, pp. 12-13 (May 1970).
- [G-14] WESTMAN, H. P., Ed., "Standard frequencies and time signals," Reference Data for Radio Engineers, (ITT) 5th Edition, pp. 1-27 to 1-36, (Howard W. Sams and Co., Inc., Indianapolis, Ind. 46206, 1969).
- [G-15] WIRE AND RADIO COMMUNICATION STAFF, "WWV--the frequency standard," WIRE AND RADIO COMMUNICATION, 12, pp. 38-40 (December 1959).

G-2 - How to Use NBS Time and Frequency Services

- [G-16a] BALTZER, O. J., "Microsecond timekeeping by means of multiple frequency VLF reception," PROC. 3rd ANN. PMA METROLOGY CONF. (NBS, Gaithersburg, Md. 20760, June 17, 18, 1970), A. K. Edgerton, Ed., 1, pp. 1-9 (Precision Meas. Ass., Burbank, Calif. 91505, September 1970)(\$25/\$30 nonmembers).
- [G-16b] ELECTRONIC INSTRUM. DIGEST (EID), 6, No. 12, pp. 75-79 (December 1970).
- [G-17] BURGESS, H. F. and JONES, M. C., "Using low frequency standard broadcasts," ELECTRONICS, 32, No. 44, pp. 48-49 (October 30, 1959).
- [G-18] CARINGELLA, C., "Build a three-channel time receiver," POPULAR ELECTRONICS, 33, No. 6, pp. 33-43 (December 1970).
- [G-19] ECHOLS, J. D., "Calibrating frequency standards with VLF transmissions," ELECTRONICS, 35, No. 17, pp. 60-63 (April 27, 1962).
- [G-20] FEISTEL, C. H., "Calibrating standards with VLF/LF signals," COMMUN. NEWS, 1, No. 1, pp. 30-33 (February 1970).
- [G-21] GENAILLE, R. A., "VLF loop antenna," ELECTRONICS WORLD, 69, No. 1 pp. 49-50 (January 1963).
- [G-22] HARTKE, D., "Simplified local comparisons with USFS," FREQUENCY, 2, No. 2, pp. 32-33 (March-April 1964).
- [G-23] HEWLETT-PACKARD STAFF, Frequency and Time Standards, HEWLETT-PACKARD CO. APPL. NOTE 52, 91 pages (Hewlett-Packard Co., Palo Alto, Calif. 94304, November 1965).
- [G-24] HEWLETT-PACKARD STAFF, "Making VLF frequency comparison measurements with HP laboratory equipment," HEWLETT-PACKARD CO. APPL. NOTE 50, 4 pages (Hewlett-Packard Co., Palo Alto, Calif. 94304, March 1, 1961).
- [G-25] JAENSCH, K., "Calibrating frequency standards," ELECTRONIC DESIGN, 7, No. 23, pp. 50-53 (November 11, 1959).
- [G-26] JOHNSON, J. R., "Precise measurement of radio frequencies," ELECTRONICS WORLD, 72, No. 2, pp. 47-56 (August 1964).
- [G-27] KINCAID, W. B., "Single frequency receiver," ELECTRONICS WORLD, 71, No. 4, pp. 44-45, 82-83 (April 1964).
- [G-28] LAPANNE, L., "Using wave analyzers to maintain frequency standards," FREQUENCY, 2, No. 5, pp. 20-22 (September-October 1964).
- [G-29] LENK, J. D., "Selecting and using pulse generators," ELECTRONICS WORLD, 79, No. 5, pp. 43-45, 76 (May 1967).
- [G-30] LEWIS, F. D., "VLF standard frequency calibration," GEN. RADIO EXP., 36, No. 6, pp. 1-7 (June 1962).
- [G-31] LOONEY, C. H., Jr., "A very-low-frequency (VLF) synchronizing system," PROC. IRE, 49, No. 2, pp. 448-452 (February 1961).
- [G-32] MERRELL, R., "Keeping accurate time with WWV," BROADCAST ENG., 10, No. 9, pp. 14-17 (September 1968).
- [G-33] RIVKIN, D., "VLF transmissions aid in calibrating frequency standards," ELECTRONIC INDUSTRIES, 21, No. 6, pp. G15-G19 (June 1962).

- [G-34] SEYBOLD, A. M., "An all-electronic method for tuning organs and pianos," AUDIO, 48, No. 3, pp. 22-24, 72-73 (March 1964).
- [G-35] SPERRY STAFF, "Study of methods for synchronizing remotely-located clocks," SPERRY GYROSCOPE REPT. NASA CR-738, 206 pages (NTIS, N67-19896, March 1967).
- [G-36] STILES, C. A., Jr., "A 10-Mc WWV receiver and crystal calibrator in one box," QST, 53, No. 1, pp. 23-25 (January 1969).
- [G-37] SUEKER, K. H., "One-tube low frequency converter," ELECTRONICS WORLD, 78, No. 1, pp. 28-29 (July 1967).
- [G-38] SYSTRON DONNER APPL. ENG. STAFF, Handbook of Precision Timekeeping and Tape Search, 138 pages (Systron Donner Corp., Concord, Calif. 84520, \$3.00, January 1970).
- [G-39] TOOKER, F., "Build a gated 100 kHz calibrator," POPULAR ELECTRONICS, 33, No. 3, pp. 53-59 (September 1970).
- [G-40] TOOKER, F. H., "Portable dual-range IC frequency standard," ELECTRONICS WORLD, 83, No. 2, pp. 76-77 (February 1970).
- [G-41] VANGROOS, J. C. and SHAPIRO, L. D., "Time and frequency standards," MEAS. AND DATA, 3, No. 1, pp. 90-95 (January-February 1969).
- [G-42] WALKER, L., "Build multipurpose IC digital clock," RADIO ELECTRONICS, pt. I, 41, No. 8, pp. 46-51 (August 1970); pt. II, 41, No. 9, pp. 97-99, (September 1970).
- [G-43] WALLACE, G. S., "Establishing accuracy for a local frequency standard," ELECTRONIC PRODUCTS, 7, No. 12, pp. 25, 88, 90-92 (May 1965).
- [G-44] WARD, S. C., "A time-synchronized VLF phase-tracking receiver," JET PROPULSION LAB. SPACE PROGRAMS SUMMARY 37-63, II, pp. 108-112, (Jet Propulsion Lab., Calif. Inst. of Technol., Pasadena, Calif. 91103, May 1970).
- [G-45] WATT, A. D., VLF Radio Engineering, 701 pages (Pergamon Press, Inc., Long Island City, N.Y. 11101, 1967).
- [G-46] WILLRODT, M. J., "Frequency and frequency measurement," ELECTRONICS WORLD, 76, No. 4, pp. 25-28, 60 (October 1966).
- [G-47] WINCHELL, J. A. and FLORANT, L. E., "Frequency calibration via telephone," ISA J., 8, No. 3, pp. 68-69 (March 1961).
- [G-48] WITT, S. N., "Frequency standards and calibration techniques," ELECTRONIC INSTRUM. DIGEST (EID), 5, No. 3, pp. 10-18 (March 1969).

G-3 - Varied Uses of NBS Time and Frequency Services

(a) Commercial-radio frequency stabilization

- [G-49a] MONTGOMERY, L. H., "Frequency standarization on broadcast carriers," (Summary), CPEM DIGEST (1970 Conf. on Precision Electromagnetic Meas., Boulder, Colo. 80302, June 2-5, 1970), p. 79 (IEEE, Inc., New York, N. Y. 10017, \$15.00/\$10.00 member, June 1970).
- [G-49b] (Abstract), IEEE TRANS. ON INSTRUM. AND MEAS., IM-19, No. 4, p. 428 (November 1970).

(b) Geophysical event timing

- [G-50] BURKE, M. D., KANASEWICH, E. R., MALINSKY, J. D., and MONTALBETTI, J. F., "A wide-band digital seismograph system," BULL. SEISMOL. SOC. OF AMERICA, 60, No. 5, pp. 1417-1426 (October 1970).
- [G-51] EATON, J. P., O'NEIL, M. E., and MURDOCK, J. N., "Aftershocks of the 1966 Parkfield-Cholame, Calif. earthquake: a detailed study," BULL. SEISMOL. SOC. OF AMERICA, 60, No. 4, pp. 1151-1197 (August 1970).
- [G-52] MEREU, R. F. and KOVACH, R. J., "A portable inexpensive seismic system for crustal studies," BULL. SEISMOL. SOC. OF AMERICA, 60, No. 5, pp. 1607-1613 (October 1970).
- [G-53] WARRICK, R. E., HOOVER, D. B., JACKSON, W. H., PAKISER, L. C. and ROLLER, J. C., "The specification and testing of a seismic refraction system for crustal studies," GEOPHYSICS, 26, No. 6, pp. 820-824 (December 1961).

(c) Intercomparison of frequency standards, time scales

- [G-54] ESSEN, L. and McA. STEELE, "The international comparison of atomic standards of time and frequency," PROC. INST. ELEC. ENG. (London) 109, Pt. B (Electronic and Communication Engineering) Paper No. 3752M, pp. 41-47 (January 1962).
- [G-55] GERARD, V. B., "Comparisons of frequency by long path very low frequency transmissions," NATURE, 211, No. 5055, p. 1284 (September 17, 1966).
- [G-56] GUINOT, B., FEISSEL, M., and LACLARE, F., B.I.H. Rapport Annuel pour 1969 (B.I.H. Annual Rept. of 1969), 140 pages (Bureau International de l'Heure, Paris Observatory, Paris 14^e, France, 1970).
Note: This publication describes: 1.) the B.I.H. system of time measurement, 2.) formation of atomic time (B.I.H) including weight factors of international laboratories, 3.) coordinated universal time and time signals from worldwide standard frequency and time broadcasts and 4.) history of polar motion from 1964.00 to 1969.95.
- [G-57] LOUTFY eLSAYED, A., "Comparison of WWVL and the local standard," PROC. MATH. AND PHYSICAL SOC. (Cairo, U.A.R. Egypt, 1969), 13 pages (1969).
- [G-58] MITCHELL, A. M. J., "Frequency comparison of atomic standards by radio links," NATURE, 198, No. 4886, pp. 1155-1158 (June 23, 1963).
- [G-59] MUNGALL, A. G., DAAMS, H. and BAILEY, R., "Note on atomic timekeeping at the National Research Council," METROLOGIA, 5, No. 3, pp. 73-76 (July 1969).
- [G-60] OHL, G., "International frequency comparison of high precision at very long waves," NTZ-COMMUN. J., 5, No. 3, pp. 105-108 (1966).
- [G-61] PIERCE, J. A., "Recent long-distance frequency comparisons," IRE TRANS. INSTRUM., I-7, Nos. 3 and 4, pp. 207-210 (December 1958).

- [G-62] REDER, R. H., ÅBOM, C. J. and WINKLER, G. M. R., "Precise phase and amplitude measurements on VLF signals propagated through the arctic zone," RADIO SCI., J. RES., NBS/USNC-URSI, 68D, No. 3, pp. 275-281 (March 1964).

(d) Local laboratory synchronization

1) General synchronization

- [G-63] ABLOWICH, D., Jr., "Frequency and time standardization," MEAS. AND DATA, 1, No. 1, pp. 30-47 (January-February 1967).
- [G-64] BORNCAMP, W. M. and BRUMMER, E., "A method for precision measurement of synchronization errors in tracking station clocks," Advanced Navigation Techniques, (Papers of 14th AGARD/AVIONICS Panel Meet., Milan, Italy, September 12-15, 1967), AGARD CONF. PROC. NO. 28, W. T. Blackband, Ed., pp. 163-184 (Technivision Services, Slough, England, January 1970).
- [G-65] FUZIE, R. E., "DSIF network maintenance facility: reference standards frequency and timing laboratory," JET PROPULSION LAB. SPACE PROGRAMS SUMMARY 37-63, II, pp. 101-107 (Jet Propulsion Lab., Calif. Inst. of Technol., Pasadena, Calif. 91103, May 1970).
- [G-66] LOONEY, C. H., Jr., "VLF utilization at NASA satellite stations," RADIO SCI. J. RES., NBS/USNC-URSI, 68D, No. 1, pp. 43-45 (January 1964).
- [G-67] SMITH, R. M., "DSIF measurement standards and traceability," JET PROPULSION LAB. SPACE PROGRAMS SUMMARY 37-59, II, pp. 157-162 (Jet Propulsion Lab., Calif. Instit. of Technol., Pasadena, Calif. 91103, September 1969).

2) Within laboratory distribution

- [G-68] ALPERT, A. and MURPHY, D. J., "Establishing, synchronizing and maintaining a standard clock for the USAF calibration program," FREQUENCY, 6, No. 5, pp. 17-21 (May 1968).
- [G-69] KOIDE, F. K., "Frequency and time distribution," MEAS. AND DATA, 1, No. 3, pp. 98-108 (May-June 1967).
- [G-70] MEUSE, R. A., "An economical standard frequency distribution system," PROC. 21th ANN. ISA CONF. AND EXHIBIT, (New York, N. Y., October 24-27, 1966), Preprint No. 12.9-6-66, 6 pages (ISA, Penn Sheraton Hotel, Pittsburgh, Pa. 15219, 1966).
- [G-71] WITT, S. N., Jr., "Design guidelines for frequency standard and distribution systems," FREQUENCY, 2, No. 1, pp. 32-33 (January-February 1964).

(e) Navigation

- [G-72] CLAGGETT, B. D., "Study of precision position fixing requirements in special purpose marine operations," GEONAUTICS, INC. TECH. REPT. DOT-CG-83291A, 144 pages (NTIS, AD-690 929, July 1969).
- [G-73] STANBROUGH, J. H., Jr., "A VLF radio relative navigation system," J. INST. OF NAVIG., 11, No. 4, pp. 417-428 (January 1965).

(f) Portable clock comparisons

- [G-74] BODILY, L. N. and HYATT, L. C., "'Flying clock' comparisons extended to East Europe, Africa, and Australia," HEWLETT-PACKARD J., 19, No. 4, pp. 12-20 (Hewlett-Packard Co., Palo Alto, Calif. 94304 December 1967).
- [G-75] McDOWELL, J. M., "U. S. Naval Observatory time reference stations," USNO TIME SERVICE ANNOUNCEMENT SERIES 14, No. 1, 2 pages (U. S. Naval Observatory, Washington, D. C. 20390, 17 April 1968).

Note: This announcement denotes NBS, Boulder, Colo. among other laboratories, as a USNO time reference station at which precise time measurements can be made and related to the USNO master clock to about ± 2.5 microseconds.

- [G-76] WERTH, J. M., "Coordination of clock time scales," USNO TIME SERVICE ANNOUNCEMENT SERIES 14, No. 3, 1 page (U. S. Naval Observatory, Washington, D. C. 20390, 8 October 1968).
- [G-77] WINKLER, G. M. R., "Convention used for reporting clock difference; the algebraic method," USNO TIME SERVICE ANNOUNCEMENT SERIES 14, No. 2, 3 pages (U. S. Naval Observatory, Washington, D. C. 20390, 30 September 1968).

(g) Power industry frequency synchronization

- [G-78] COHN, N., "Power systems--time and frequency," LEEDS AND NORTHRUP TECH. J., Fall Issue, No. 7, pp. 3-11 (Fall, 1969).
- [G-79] TURRELL, D. W., "Digital methods for the measurement of power system frequency and time error," PROC. AMER. POWER CONF., (Chicago, Ill. 60616, April 1966), pp. 1068-1073 (1966).

(h) Propagation studies

- [G-80] CHI, A. R., "Diurnal phase construction of VLF signals near antipode of a transmitter," PROC. 24th ANN. SYMP. ON FREQUENCY CONTROL (U. S. Army Electronics Command, Ft. Monmouth, N.J. 07703, April 27-29, 1970), pp. 332-338 (Electron. Ind. Ass., Washington, D.C. 20006, \$6.50, 1970).
- [G-81] ISHII, T., YAMADA, K., TSUCHIYA, K., TGRAJIMA, Y., and YANAGIYA, T., "Diurnal phase variations in signals from NBA, WWVL, and NPG over the trans-pacific routes," RADIO RESEARCH LAB. REVIEW, 12, No. 62, pp. 283-290 (September 1966).
- [G-82] KAISER, A. B., "VLF propagation over long paths," J. ATMOS. AND TERR. PHYS., 29, No. 1, pp. 73-85 (January 1967).
- [G-83] REDER, F. H., "VLF propagation phenomena observed during low and high solar activity," Progress in Radio Science 1966-1969, Part 1, (Proc. XVth Gen. Assem. of URSI, Ottawa, Canada, August 18-28, 1969), C. E. White, Ed.(in press).
- [G-84] SAKURAZAWA, A., "VLF time disturbances-time and frequency," RADIO RESEARCH LAB. REVIEW, 16, No. 84, pp. 175-196 (in Japanese)(May 1970).
- [G-85] TOMAN, K., "Frequency variations of an oblique 5 MHz ionospheric transmission," Phase and Frequency Instability in Electromagnetic Wave Propagation, (AGARD-EWP XIII Symp., Ankara, Turkey, October 9-12, 1967), AGARD CONF. PROC. NO. 33, K. Davies, Ed. (Technivision Services, Slough, England)(In press).

(i) Research experiments

- [G-86] CHI, A. R., and WITT, S. N., "Time synchronization of remote clocks using dual VLF transmissions," PROC. 20th ANN. SYMP. ON FREQUENCY CONTROL (U.S. Army Electronics Command, Ft. Monmouth, N.J. 07703, April 19-21, 1966), pp. 588-611 (NTIS, AD-800 523, 1966).
- [G-87] KRAUS, J. D., "Sputnik I's last days in orbit," PROC. IRE, 46, No. 9, pp. 1580-1587 (September 1958).
- [G-88] ROEDER, J. H., and SHAW, M. E., "Dual VLF timing capability observed at some intermediate ranges," GODDARD SPACE FLIGHT CENTER REPT. NO. X-521-69-346, 28 pages (NASA -GSFC, Greenbelt, Md. 20771, June 1969).
- [G-89] SARGENT, H. H., and KLEMPERER, W. K., "A decametric long baseline interferometer system," RADIO SCI., 5, No. 10, pp. 1283-1286 (October 1970).
- [G-90] WESTERLUND, S., REDER, F., and ÅBOM, C., "Effects of polar cap absorption events on VLF transmissions," PLANET. SPACE SCIENCE, 17, No. 7, pp. 1329-1374 (July 1969).

(j) Timing

1) Local

- [G-91] IVES, R. L., "Time-signal broadcast sets electric clock," ELECTRONICS, 30, No. 7, pp. 174-176 (July 1, 1957).
- [G-92] RADIO ELECTRONICS STAFF, "New portable time standard," RADIO ELECTRONICS, 31, No. 7, p. 55 (July 1960).
- [G-93] RIDDLE, L. G., "Digital clock update," RADIO ELECTRONICS, 41, No. 8, pp. 54-55, 68 (August 1970).

2) Telephone Company

- [G-94] LUICHINGER, M. J., "More about time and the telephone industry," TELEPHONY, 174, No. 20, pp. 33, 36, 38, 40, 72, 74, 76 (May 18, 1968).

APPENDIX I

STRUCTURE OF NBS TIME AND FREQUENCY DIVISION

The Time and Frequency Division, one of eleven technical divisions in the NBS Institute for Basic Standards, is located at Boulder, Colorado, 80302, and consists of three Sections as follows:

Section 273.01 Frequency-Time Dissemination Research

Pursues research on new and improved methods for dissemination of frequency and time standards, including radio (HF, MF, LF, and VLF signals), satellites, television timing, portable clocks, and other advanced techniques.

Section 273.02 Frequency-Time Broadcast Services

Operates four NBS standard frequency radio stations—three located at Ft. Collins, Colorado, and one HF station, WWVH, located at Maui, Hawaii. (WWVH will relocate to Kauai, Hawaii on or about July 1, 1971.) The three Ft. Collins stations include (1) WWV, which transmits in 6 HF bands, (2) WWVB, which transmits a 60 kHz signal, and (3) WWVL, an experimental VLF broadcast, nominally at 20 kHz. Evaluates, modifies, and develops new or better techniques for improving the accuracy and/or coverage of the NBS standard frequency and time broadcasts.

Section 273.04 Atomic Frequency and Time Standards

Operates, maintains, and improves the primary NBS Frequency and Time Standards. Performs research and development on cesium beams, hydrogen beams, and other potential quantum electronic frequency standards, low noise electronics, and statistical analyses and model techniques for evaluating time and frequency data. Also provides frequency and time calibrations to users requiring traceability to the NBS standards.

APPENDIX II

NBS TIME/FREQUENCY BROADCAST NOTICES, BULLETINS, HF PREDICTION METHODS

1. Information on the NBS standard frequency and time broadcasts is given monthly in the NAT. BUR. STAND. (U.S.), TECH. NEWS BULL. (USGPO, \$3.00/yr.) since January 1967.

2. The Frequency-Time Broadcast Services Section publishes a monthly bulletin which includes time scale information, daily phase deviations of NBS and non-NBS stations, daily television time transfer measurements, outages of NBS radio broadcasts, advance announcements concerning phase adjustments, offsets or alterations of broadcast formats, etc. Users of NBS radio broadcasts, who require such information on the basis of need, should address a request to:

Chief, Frequency-Time Broadcast
Services Section, 273.02
Time and Frequency Division
National Bureau of Standards
Boulder, Colorado 80302

Telephone: (303) 447-1000, extension 3453

3. The NBS SPEC. PUBL. 236—NBS Frequency and Time Broadcast Services is revised annually. Copies are available from the USGPO.

4. A mailing list for current scientific and technical publications of the Atomic Frequency and Time Standards Section is maintained. On the basis of need, make written request to:

Chief, Atomic Frequency and Time
Standards Section, 273.04
Time and Frequency Division
National Bureau of Standards
Boulder, Colorado 80302

Telephone: (303) 447-1000, extension 3755

5. BARGHAUSEN, A. F., FINNEY, J. W., PROCTOR, L. L., AND SCHULTZ, L. D., "Predicting long-term operational parameters and high-frequency sky-wave telecommunication systems," ESSA TECH REP. ERL 110-ITS 78, 290 pages (USGPO, \$2.25, May 1969).

Note: This is a comprehensive treatment of methods and techniques for predicting long-term performance of HF telecommunication systems. Measures of the system performance are derived in terms of circuit reliability and service probability. A complete listing of the electronic computer program is given which includes descriptions of input and output data.

Many people helped in the compilation of this bibliography. Don Halford and Roger Beehler gave much encouragement to this work. Grateful appreciation is expressed to the NBS Library personnel, the Electromagnetic Metrology Center, and the Boulder Program Information Office. We thank Mrs. Louise Gaskill and Mrs. Carol Wright for patience and skill in typing this manuscript. Thanks are also due Mrs. Glynnetta Perrymore, Mrs. Darlene Noble, and Mrs. Sandra Gainsforth for assistance in checking and documenting references

NBS TECHNICAL PUBLICATIONS

PERIODICALS

JOURNAL OF RESEARCH reports National Bureau of Standards research and development in physics, mathematics, chemistry, and engineering. Comprehensive scientific papers give complete details of the work, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Illustrated with photographs, drawings, and charts.

Published in three sections, available separately:

● Physics and Chemistry

Papers of interest primarily to scientists working in these fields. This section covers a broad range of physical and chemical research, with major emphasis on standards of physical measurement, fundamental constants, and properties of matter. Issued six times a year. Annual subscription: Domestic, \$9.50; foreign, \$11.75*.

● Mathematical Sciences

Studies and compilations designed mainly for the mathematician and theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemistry, logical design and programming of computers and computer systems. Short numerical tables. Issued quarterly. Annual subscription: Domestic, \$5.00; foreign, \$6.25*.

● Engineering and Instrumentation

Reporting results of interest chiefly to the engineer and the applied scientist. This section includes many of the new developments in instrumentation resulting from the Bureau's work in physical measurement, data processing, and development of test methods. It will also cover some of the work in acoustics, applied mechanics, building research, and cryogenic engineering. Issued quarterly. Annual subscription: Domestic, \$5.00; foreign, \$6.25*.

TECHNICAL NEWS BULLETIN

The best single source of information concerning the Bureau's research, developmental, cooperative and publication activities, this monthly publication is designed for the industry-oriented individual whose daily work involves intimate contact with science and technology—for engineers, chemists, physicists, research managers, product-development managers, and company executives. Annual subscription: Domestic, \$3.00; foreign, \$4.00*.

* Difference in price is due to extra cost of foreign mailing.

Order NBS publications from:

Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

NONPERIODICALS

Applied Mathematics Series. Mathematical tables, manuals, and studies.

Building Science Series. Research results, test methods, and performance criteria of building materials, components, systems, and structures.

Handbooks. Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

Special Publications. Proceedings of NBS conferences, bibliographies, annual reports, wall charts, pamphlets, etc.

Monographs. Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

National Standard Reference Data Series. NSRDS provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated.

Product Standards. Provide requirements for sizes, types, quality and methods for testing various industrial products. These standards are developed cooperatively with interested Government and industry groups and provide the basis for common understanding of product characteristics for both buyers and sellers. Their use is voluntary.

Technical Notes. This series consists of communications and reports (covering both other agency and NBS-sponsored work) of limited or transitory interest.

Federal Information Processing Standards Publications. This series is the official publication within the Federal Government for information on standards adopted and promulgated under the Public Law 89-306, and Bureau of the Budget Circular A-86 entitled, Standardization of Data Elements and Codes in Data Systems.

Consumer Information Series. Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

NBS Special Publication 305, Supplement 1, Publications of the NBS, 1968-1969. When ordering, include Catalog No. C13.10:305. Price \$4.50; foreign, \$5.75.