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# Time and Frequency: A Bibliography of NBS Literature Published July 1955–December 1970

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# Time and Frequency: A Bibliography of NBS Literature

## Published July 1955–December 1970

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Institute for Basic Standards
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# Contents

# 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:

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# 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 $10^{13}$ ($1\sigma$). 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

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## 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 1re 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

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July 1957 - June 1958

NONE

July 1958 - June 1959

NONE

July 1959 - June 1960

NONE

July 1960 - June 1961

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July 1961 - June 1962

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July 1962 - June 1963

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July 1963 - June 1964

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July 1966 - June 1967

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## 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 $\mu$ 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

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[C-3] (B) NBS, "Standard frequency and time signals WWV and WWVH," PROC. IRE (Corresp.), 44, No. 10, pp. 1470-1473 (October 1956).

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[C-4] GEORGE, W. D., and NBS STAFF, "WWV standard frequency transmissions," PROC. IRE (Corresp.), 46, No. 5, pp. 910-911 (May 1958).
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[C-5] (B) GILLILAND, T. R., "Automatic radio control for clocks," U. S. patent 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

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[C-8b] PROC. IRE, 49, No. 11, pp. 1659-1673 (November 1961).

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[C-9b] J. RES. NAT. BUR. STAND. (ENG. AND INSTRUM.), 64C, No. 2, pp. 159-165 (April-June 1960).

[C-10] (B) MORGAN, A. H., "Precise time synchronization of widely separated clocks," NAT. BUR. STAND. (U.S.), TECH. NOTE 22, 65 pages (NTIS, PB 151 381, $3.00, July 1959).

[C-11] (A) NBS, "Standards and calibration in radio and electronics," 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

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[C-18] (B) NBS, "Standard frequencies and time signals from NBS stations WWV and WWVH," 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

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[C-26] MORGAN, A. H., "Time and frequency broadcasting," ISA J., 10, No. 6, pp. 49-54 (June 1963).

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[C-41] (B) NBS, "WWVB adds time code to broadcasts," 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).

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[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).

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[C-57] GATTERER, L. E., BOTTONE, 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).

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July 1969 - June 1970

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[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. 24thANN. 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] (A, B) 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).

[C-70] (A, B, D, E) 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., I-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] (A) BARNES, J. A., "Atomic timekeeping and the statistics of precision signal generators," PROC. IEEE, 54, No. 2, pp. 207-220 (February 1966).

[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] (C) 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).

[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] (C) 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).

[D-16] (A, B, E) 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).

July 1969 - June 1970

[D-17] (A) 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°), France, 1969).

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] (A, B, C) 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] (B) McNISH, A. G., "The basis of our measuring system," PROC. IRE, 47, No. 5 (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] (A) RICHARDSON, J. M., "Report on the velocity on light," Monograph of Radioelectric 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] (A, B) McNISH, A. G., "Fundamentals of measurement," ELECTRO-TECHNOLOGY, 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] (A, B, C) 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] (A, B, C) 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] (A, B, C) RICHARDSON, J. M., Ed., "Progress in radio measurements and standards," (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] (A, B, C) RICHARDSON, J. M., MOCKLER, R. C., GERBER, E. A., SYKES, R. A., 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



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

## 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


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# 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 frequeney and time broadeasts is given monthly in the NAT. BUR. STAND. (U.S.), TECH. NEWS BULL. (USGPO, $3.00/yr.) sinee January 1967.

2. The Frequeney-Time Broadeast Services Seetion publishes a monthly bulletin which ineludes time scale information, daily phase deviations of NBS and non-NBS stations, daily television time transfer measurements, outages of NBS radio broadcasts, advanee announeements concerning phase adjustments, offsets or alterations of broadeast formats, ete. Users of NBS radio broadcasts, who require sueh information on the basis of need, should address a request to:

Chief, Frequeney-Time Broadcast
Serviees Seetion, 273.02
Time and Frequeney 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 publieations of the Atomic Frequeney and Time Standards Section is maintained. On the basis of need, make written request to:

Chief, Atomic Frequeney and Time
Standards Seetion, 273.04
Time and Frequeney 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., "Predieting long-term operational parameters and high-frequeney sky-wave teleeommunieation 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 predieting long-term performanee of HF telecommunieation systems. Measures of the system performanee are derived in terms of eireuit reliability and service probability. A complete listing of the electronic computer program is given whieh ineludes deseriptions of input and output data.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

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. Its purpose is to document past progress, aid access to available literature, and give an indication of the present direction, scope, and status of NBS time and frequency research. The listing includes some non-NBS references which show the wide spread usage of the NBS time and frequency services.

17. 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; statistics of time/frequency measurements; time; time/frequency dissemination; time scales; timing (HF, LF, satellite, TV, VLF); velocity of light; wavelength standards: WWV: WWVB: WWVH: WWVL.

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# NBS TECHNICAL PUBLICATIONS

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## 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.

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