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# NBS Frequency and Time Broadcast Services

U.S.
DEPARTMENT
OF
COMMERCE
National
Bureau
of
Standards

## RADIO STATIONS
## WWV, WWVH, WWVB, WWVL

UNITED STATES DEPARTMENT OF COMMERCE
MAURICE H. STANS, *Secretary*
NATIONAL BUREAU OF STANDARDS • LEWIS M. BRANSCOMB, *Director*

# NBS FREQUENCY AND TIME BROADCAST SERVICES

## RADIO STATIONS WWV, WWVH, WWVB, AND WWVL

P. P. Viezbicke, Editor

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

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## Contents

# Services Provided by NBS Standard Frequency and Time Stations

Detailed descriptions are given of the technical services provided by the National Bureau of Standards radio stations WWV, WWVH, WWVB, and WWVL. These services are: 1. Standard radio frequencies; 2. Standard audio frequencies; 3. Standard musical pitch; 4. Standard time intervals; 5. Time signals; 6. UT corrections; and 7. Official announcements. In order to provide users with the best possible services, occasional changes in broadcasting schedules are required. This publication shows the schedules in effect on July 1, 1971. Annual revisions will be made. Current data relating to standard frequencies and time signals are available monthly in the Time and Frequency Services Bulletin. Advance notices of changes occurring between revisions will be sent to users of NBS broadcast services who request such notice on the basis of need.[1]

Key words: Broadcast of standard frequencies; high frequency; low frequency; standard frequencies; time signals; very low frequency.

## Introduction

In March 1923 the National Bureau of Standards started transmitting standard radio frequencies on a regularly announced schedule from radio station WWV. The WWV transmitter, originally located at the National Bureau of Standards, Washington, D. C., has moved several times. From 1931 to 1966 the station was moved successively from Washington, D. C. to Greenbelt, Maryland, and finally to Fort Collins, Colorado, where it went on the air at 0000 hours Universal Time on December 1, 1966.

The move to Fort Collins was prompted by several considerations: the need for wider and more uniform coverage in the continental U. S. from a more central location; the advantage of more precise control from the NBS Time and Frequency Division at Boulder, Colorado; improvement in radiation patterns obtained by location in a less congested area; and reduction of interference on the West Coast between time signals from WWV and those from WWVH, Hawaii.

Original broadcasts were accurate to within a few parts in a thousand. Their transmitted accuracy today is on the order of a few parts in $10^{12}$—approaching the accuracy of the NBS frequency standard itself.

To supplement the coverage of WWV, broadcasts from WWVH were instituted in 1948. These play an increasingly important role in various types of operations in the Pacific and Far East, both military and civilian. In 1971, WWVH was moved from its former site on Maui, to its present location near Kekaha, Kauai.

WWVB began broadcasting from Boulder, Colorado in 1956, and WWVL, an experimental station, from Sunset, Colorado in 1960. Both of these stations have been in operation from Fort Collins, Colorado, since July 1963. These stations, WWVB transmitting on low frequency (LF) and WWVL transmitting on very low frequency (VLF), make possible wide-scale distribution of the NBS standard frequency; WWVB also transmits time signals. They are used to coordinate operations of the global networks of missile and satellite stations, to assist other government efforts which require accurate time and frequency, to improve the uniformity of frequency measurement on a national and international basis, and to provide a more accurate standard of frequency, one easily available to many users for electronic research and development.

Thus in the 48 years since the beginning of its radio broadcasts, NBS has expanded such services so that it is making major contributions today to the nation's space and defense programs, to world-wide transportation and communications, and to a multitude of industrial operations, as well as providing convenient time service to thousands of listeners.

[1] Inquiries concerning the Time and Frequency Services Bulletin or the NBS broadcast service policies may be addressed to Frequency-Time Broadcast Services Section, Time and Frequency Division, NBS, Boulder, Colorado 80302.

# 1. Technical Services and Related Information

The following chart summarizes the services offered by the NBS broadcast stations:

| Station | Date in Service | Radio frequencies | Audio frequencies | Musical pitch | Time intervals | Time Signals | UT corrections | Official announcements |
|---|---|---|---|---|---|---|---|---|
| WWV | 1923 | √ | √ | √ | √ | √ | √ | √ |
| WWVH | 1948 | √ | √ | √ | √ | √ | √ | √ |
| WWVB | 1956 | √ | | | √ | √ | √ | |
| WWVL | 1960 | √ | | | | | | |

The broadcasts of WWV may also be heard via telephone by dialing (303) 499-7111, Boulder, Colorado. The telephone user will hear the live broadcasts as received by radio in Boulder. Considering the instabilities and variable delays of propagation by radio and telephone combined, the listener should not expect accuracy of the telephone time signals to be better than 30 milliseconds.

The coordinates of the NBS radio stations are as follows:

| | | |
|---|---|---|
| WWV | 40° 40′ 49.0″ N | 105° 02′ 27.0″ W |
| WWVB | 40° 40′ 28.3″ N | 105° 02′ 39.5″ W |
| WWVL | 40° 40′ 51.3″ N | 105° 03′ 00.0″ W |
| WWVH | 21° 59′ 26.0″ N | 159° 46′ 00.0″ W |

Correspondence pertaining directly to station operations may be addressed to:

John Stanley, Engineer-in-Charge
NBS Radio Stations WWV/WWVB/WWVL
Route 2, Box 83-E
Fort Collins, Colorado 80521
Telephone (303) 484-2372

Charles Trembath, Engineer-in-Charge
NBS Radio Station WWVH
P. O. Box 417
Kekaha, Kauai, Hawaii 96752
Telephone (808) 337-5217

Visiting hours are observed at WWV, WWVB, and WWVL every Wednesday, except holidays, from 1:00 p.m. to 4:00 p.m. Special tours may be scheduled at other times only by prior arrangement with the Engineer-in-Charge.

## 1.1. Standard Radio Frequencies

### (a) Program

WWV, WWVH, and WWVL broadcast nominal frequencies and time consistent with the internationally agreed upon time scale, Universal Coordinated Time (UTC). The present fractional frequency offset for the UTC scale has been set at $-300 \times 10^{-10}$ with respect to the definition.

WWV broadcasts on radio carrier frequencies of 2.5, 5, 10, 15, 20, and 25 MHz. WWVH broadcasts on radio carrier frequencies of 2.5, 5, 10, 15, and 20 MHz. The broadcasts on both stations are continuous, night and day.

WWVB broadcasts the internationally agreed upon Stepped Atomic Time (SAT) scale which has no fractional frequency offset. WWVB broadcasts on the standard frequency of 60 kHz and WWVL on the nominal frequency of 20 kHz. These two stations have scheduled maintenance periods on alternate Tuesdays between 1300 UT and 2400 UT. Otherwise the service is continuous.

WWVL transmits experimental programs with multiple frequencies. Transmissions presently alternate between 20 kHz and 19.9 or 20.9 kHz, the change being made every 10 seconds. The transmission format and the frequencies used by WWVL are subject to change to meet the requirements of the particular experiment(s) being conducted.

### (b) Accuracy and Stability

Since December 1, 1957, the standard radio transmissions from WWV and WWVH have been held as nearly constant as possible with respect to the atomic frequency standards maintained and operated by the National Bureau of Standards. Atomic frequency standards have been shown to realize the ideal Cs resonance frequency, $f_{Cs}$, to within a few parts in $10^{13}$. The present NBS frequency standard and time scale system realizes this resonance frequency to an uncertainty of $\pm$ 9 parts in $10^{13}$.[2]

The definitions for time and frequency are based on the same physical process: "The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium–133 atom" as was decided in October 1967 by the XIIth General Conference on the International Committee of Weights and Measures, and for frequency the hertz is one cycle per second.

On January 1, 1960, the NBS standard was brought into agreement with this definition as quoted above by increasing its assigned value by 74.5 parts in $10^{10}$.

[2] Glaze, D. J., Improvements in Atomic Beam Frequency Standards at the National Bureau of Standards, IEEE Trans. on Instr. and Meas., **IM–19**, No. 3, 156-160, August 1970.

Frequencies measured in terms of the NBS standard between December 1, 1957 and January 1, 1960 need to take the above correction into account.[3]

The frequencies transmitted by WWV and WWVH are held stable to better than $\pm$ 2 parts in $10^{11}$ at all times. Deviations at WWV are normally less than 1 part in $10^{12}$ from day to day. Incremental frequency adjustments not exceeding 1 part in $10^{11}$ are made at WWV as necessary. Frequency adjustments made at WWVH do not exceed 2 parts in $10^{11}$.

Changes in the propagation medium (causing Doppler effect, diurnal shifts, etc.) result in fluctuations in the carrier frequencies as received which may be very much greater than the uncertainties described above.

WWVB and WWVL frequencies are normally within their prescribed values to better than 2 parts in $10^{11}$. Deviations from day to day are less than 5 parts in $10^{12}$.

The effects of the propagating medium on the received frequencies are much less at LF and VLF. The full transmitted accuracy may be obtained using appropriate receiving and averaging techniques.[4,5]

#### (c) Corrections

All carrier and modulation frequencies at WWV and WWVH are derived from cesium controlled oscillators. These frequencies, in conformity with the UTC scale, are intentionally offset from the defined frequency by a small but precisely known amount to reduce departure between the time signals as broadcast and astronomical time, UT2. The fractional frequency offset for 1960 and 1961 was $-150$ parts in $10^{10}$; in 1962 and 1963, $-130$ parts in $10^{10}$; in 1964 and 1965, $-150$ parts in $10^{10}$; and in 1966 through 1971, $-300$ parts in $10^{10}$. Although UT2 is subject to unpredictable changes readily noted at this level of precision, a particular offset from standard frequency remains in effect for the entire year.

At the recommendation of the International Radio Consultative Committee (CCIR), the frequency offset of UTC will be made permanently zero effective 0000 hours GMT January 1, 1972. The time difference between the UTC scale and the International Atomic Time (IAT) scale will be constrained to be an integral number of seconds. Corrections to UTC will be made in step adjustments of exactly 1 second when the Bureau International de l'Heure (BIH) determines they are needed. These steps will normally occur on either 31 December or 30 June, and are introduced to approximate UT1.

Corrections to the transmitted frequency or phase are regularly determined with respect to the NBS time standard and are published monthly (since March 1966) in the NBS Time and Frequency Services Bulletin.

### 1.2. Standard Audio Frequencies

#### (a) Program

Standard audio frequencies of 440 Hz, 500 Hz, and 600 Hz are broadcast on each radio carrier frequency by WWV and WWVH. The duration of each transmitted standard tone is approximately 45 seconds. A 600 Hz tone is broadcast during odd minutes by WWV and during even minutes by WWVH. A 500 Hz tone is broadcast during alternate minutes unless voice announcements or silent periods are scheduled. The 440 Hz tone is broadcast beginning one minute after the hour at WWVH and two minutes after the hour at WWV. The 440 Hz tone period is omitted during the first hour of the UT day. WWVB and WWVL do not transmit standard audio frequencies.

No audio tones or special announcements are broadcast during a semi-silent period from either station. The periods are from 45 minutes to 50 minutes after the hour at WWV, and from 15 minutes to 20 minutes after the hour at WWVH.

#### (b) Accuracy

The audio frequencies are derived from the carrier and have the same basic accuracy as transmitted. Changes in the propagation medium sometimes result in fluctuations in the audio frequencies as received.

While the 100 Hz subcarrier is not considered one of the standard audio frequencies, the IRIG-H time code which is transmitted continuously from WWV and WWVH does contain this frequency and may be used as a standard with the same accuracy as the audio frequencies.

### 1.3. Standard Musical Pitch

The frequency 440 Hz, for the note A above middle C, is the standard in the music industry in many countries and has been in the United States since 1925. The radio broadcast of this standard was commenced by the National Bureau of Standards in 1937. The 440 Hz tone is broadcast for approximately 45 seconds beginning one minute after the hour at WWVH and two minutes after the hour at WWV. The tone is omitted during the zero hour of each UT day. In addition to its application as a muscial standard, the 440 Hz tone may be used to provide an hourly marker for chart recorders or other automated devices.

### 1.4. Standard Time Intervals

UTC seconds pulses at precise intervals are derived from the same frequency standard that controls the radio carrier frequencies; i.e., they commence at intervals of 5,000,000 cycles of the 5 MHz carrier. They are given by means of double-sideband amplitude-modulation on each radio carrier frequency. Each minute, except the first of the hour, begins with an

[3] National Standards of Time and Frequency in the United States, Proc. IRE, **IRE–48**, No. 105, 1960.

[4] Allan, D. W., and J. A. Barnes, Some Statistical Properties of LF and VLF Propagation, AGARD Conf. Proc. No. 33, Phase and Frequency Instabilities in Electromagnetic Wave Propagation (Proc. AGARD/EPC 13th Symp., Ankara, Turkey, Oct. 9-12, 1967). K. Davies, Ed., Chapter 15 (Technivision Services, Slough, England, in press).

[5] Guetrot, A., L. S. Higbie, J. Lavanceau, and D. W. Allan, An Application of Statistical Smoothing Techniques on VLF Signals for Comparison of Time between USNO and NBS, (Summary) Proc. 23rd Annual Symp. on Frequency Control, Fort Monmouth, N. J., May 6-8, 1969, pp. 251-262.

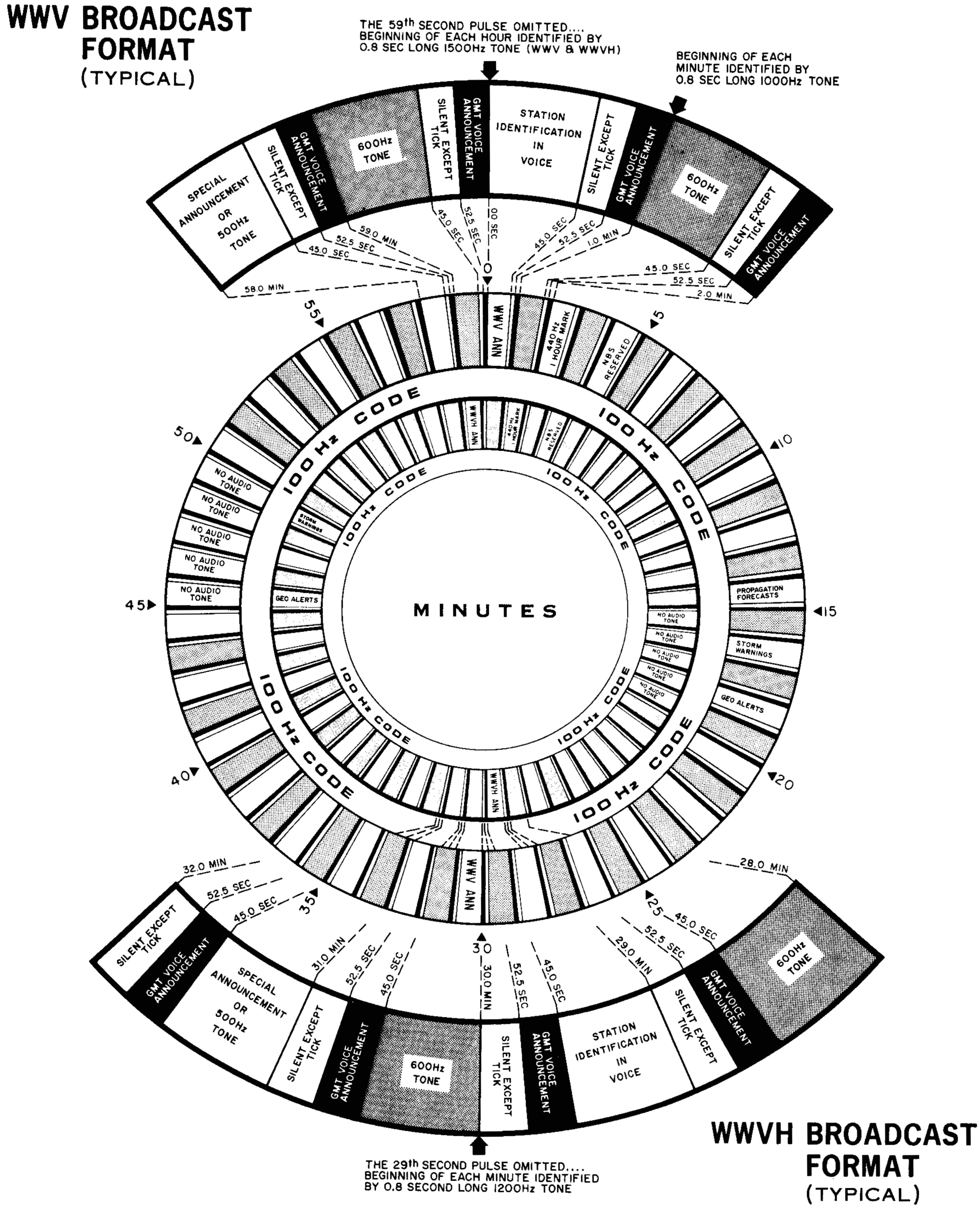


FIGURE 1. *The hourly broadcast schedules of WWV and WWVH.*

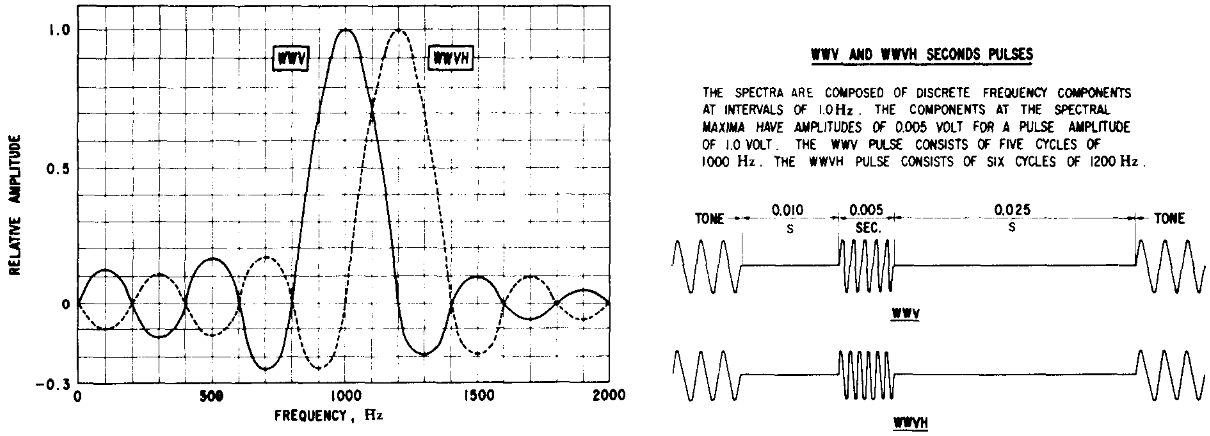


FIGURE 2. *Sample characteristics of time pulses broadcast from NBS radio stations WWV and WWVH.*

800 millisecond tone of 1000 Hz at WWV and 1200 Hz at WWVH. The first minute of every hour begins with an 800 millisecond tone of 1500 Hz at both stations.

The one-second markers are transmitted throughout all programs of WWV and WWVH except that the 29th and 59th markers of each minute are omitted. As noted above, the seconds marker which begins the minute is lengthened to 800 millisceonds. All other markers consist of a 5-millisecond pulse of 1000 Hz at WWV and 1200 Hz at WWVH, commencing at the beginning of the second (fig. 2).

The seconds pulse spectrum is composed of Fourier frequency components as shown in figure 2. Each pulse is preceded by 10 milliseconds of silence and followed by 25 milliseconds of silence. These 40-millisecond interruptions do not appreciably degrade the intelligibility of voice announcements on which the pulses are often superimposed.

WWVB transmits seconds pulses continuously using a special time code described in section 1.8. Although WWVL does not transmit seconds markers, the phase coincidence of the multi-frequencies does contain time information, and accurate time intervals may be obtained directly from the carrier using appropriate techniques.

## 1.5. Time Signals

### (a) Program

Common usage of the name Greenwich Mean Time (GMT) includes any of the astronomers Universal Time scales and rather coarse approximations to these scales. This time (GMT) is basically just the local solar time at the Greenwich Meridian (longitude zero) expressed on a 24-hour clock starting at midnight, Greenwich, England.

Because of the common usage of the name Greenwich Mean Time, the time announcements on WWV and WWVH are referred to by this name. More precisely, the actual reference time scale is the Coordinated Universal Time Scale as maintained by the National Bureau of Standards, UTC(NBS).

The 0 to 24 hour system is used starting with 0000 at midnight at longitude zero. The first two figures give the hour, and the last two figures give the number of minutes past the hour when the tone returns. The time announcement refers to the end of an announcement interval, i.e., to the time when the audio tone occurs.

At WWV a voice annoucement of Greenwich Mean Time is given during the last 7.5 seconds of every minute. At 1035 GMT, for instance, the voice announcement given in English is: "At the tone—ten hours, thirty-five minutes Greenwich Mean Time."

At WWVH a voice announcement of Greenwich Mean Time occurs during the period 45 seconds to 52.5 seconds after the minute. It should be noted that the voice announcement for WWVH precedes that of WWV by 7.5 seconds. However, the tone markers referred to in both announcements occur simultaneously, though they may not be so received due to propagation effects.

### (b) Corrections

Prior to January 1, 1972, time signals broadcast from WWV and WWVH will be kept in close agreement with UT2 (astronomical time) by making step adjustments of 100 milliseconds as necessary. These adjustments are made at 0000 UT on the first day of a month. Advance notice of such adjustments is given to the public upon advice by the BIH that an adjustment is to be made. Decision to adjust the time signals is based upon observations by a network of international observatories and is announced by the BIH. Differences between the time signals and UT2 are published periodically by the U. S. Naval Observatory.

Seconds pulses broadcast from WWVB depart from

UT2 at a different rate due to the fact that WWVB broadcasts Stepped Atomic Time (SAT) with no offset. Step time adjustments of 200 milliseconds are made at 0000 UT on the first day of a month with appropriate advance notice. The BIH advises when such adjustments are to be made in order to maintain the seconds pulses within about 100 milliseconds of UT2.

Commencing January 1, 1972, all the standard frequency time signal emissions from WWV, WWVH and WWVB will contain information and corrections on the difference between UTC time signals and Astronomical Time, UT1. On the same date, WWVB will commence broadcasting UTC(NBS) time signals.

#### (c) UT Corrections

Additional corrections to those described in 1.5(b) are provided in cooperation with the U. S. Naval Observatory which makes available the current values of UT2 on a daily basis. Through December 31, 1971, corrections to be applied to the time signal are broadcast in voice four minutes after the hour on WWV and three minutes after the hour on WWVH. For example, the broadcast announcement from WWV and WWVH is: "The UT2 correction is plus (or minus) thirty-four milliseconds . . . Repeat . . . plus (or minus) three-four milliseconds." Similar information is incorporated in the WWVB time code.

To obtain UT2, add the correction to the time indicated by the time signal pulse if "plus" is announced; subtract if "minus" is announced. Thus, a clock keeping step with the time signals broadcast will be early with respect to UT2 if a "minus" is broadcast. These corrections will be revised as needed, the new value appearing for the first time during the hour after 0000 UT, and will remain unchanged for the succeeding 24-hour period.

The corrections necessary to obtain UT2 are derived from extrapolated data furnished weekly by the U. S. Naval Observatory. These indicate the variation in UT2 with respect to broadcast time. Preliminary corrections are published monthly in the Time and Frequency Services Bulletin with a probable error of ± 5 milliseconds. Final data, obtained aposteriori, with a probable error of ± 1 millisecond, are published in the Time Services Bulletins of the U. S. Naval Observatory.

After January 1, 1972, the UT2 corrections announced in voice will be discontinued. Thereafter, the corrections will apply to UT1, and will be encoded and broadcast each minute.

The method of coding the UT1 corrections after January 1, 1972 uses a system of double seconds pulses. The first through the seventh seconds pulse, when marked by a double pulse, will indicate a "plus" correction, and from the ninth through the fifteenth a "minus" correction. The eighth seconds pulse is not used. The amount of correction is determined by counting the number of seconds pulses that are doubled. For example, if the first, second, and third seconds pulses are doubled, the UT1 correction is "plus" 0.3 second. Or if the ninth, tenth, eleventh, twelfth, thirteenth, and fourteenth seconds pulses are doubled, the UT1 correction is "minus" 0.6 second. In addition to these corrections, the UT1 correction will be encoded in the control bits of the IRIG-H BCD code.

The UT1 corrections are encoded in a continuous IRIG-H BCD code transmitted on a 100 Hz subcarrier from WWV and WWVH. The value of the correction is indicated by the weight of the control bits that occur at the end of the code frame. The "plus" or "minus" indication is encoded in the first control bit, i.e., if the bit is a binary one the correction is "plus"; if it is a binary zero it is "minus." The correction is to the nearest 0.01 second.

## 1.6. Official Announcements

The 45-second announcement segments available every other minute from WWV and WWVH are offered on a subscription basis to other agencies of the Federal Government to disseminate offical and public service information. The accuracy and content of these announcements is the responsibility of the originating agency—not necessarily the National Bureau of Standards.

All segments except those reserved for NBS use and the semi-silent periods are available. Arrangements for use of segments at the two stations may be made through the Frequncy-Time Broadcast Services Section, 273.02, National Bureau of Standards, Boulder, Colorado 80302.

#### (a) Propagation Forecasts

A forecast of radio propagation conditions is broadcast in voice during part of every 15th minute of each hour from WWV. The announcements are short-term forecasts and refer to propagation along paths in the North Atlantic area, such as Washington, D. C. to London or New York to Berlin. These forecasts are also applicable to high latitudes provided the appropriate time correction is made for other latitudes. The forecasts are prepared by the Office of Telecommunications Services Center, OT, Boulder, Colorado.[6]

#### (b) Geophysical Alerts

Current geophysical alerts (Geoalerts) as declared by the World Warning Agency of the International Ursigram and World Days Service (IUWDS) are broadcast in voice during the 19th minute of each hour from WWV and during the 46th minute of each hour from WWVH. The messages are changed daily at 0400 UT with provisions to provide immediate alerts of outstanding occurring events. These are followed by summary information on selected solar and geophysical events in the past 24 hours and corresponding forecasts prepared by the Space Environment Services Center, NOAA, Boulder, Colorado.[7]

[6] For details regarding these forecasts, write John Harris, Telecommunications Service Center, OT, Boulder, Colorado 80302.

[7] For details of these announcements, write Miss J. Virginia Lincoln, Deputy Secretary IUWDS, NOAA, Boulder, Colorado 80302.

### (c) Storm Warnings

A program is being implemented to broadcast storm and hurricane warnings over WWV and WWVH soon after July 1, 1971. Initially, the areas of coverage will be the waters of the North Atlantic and North Pacific. The storm warning broadcasts will be voice announcements and will be prepared by the National Weather Bureau.[8]

## 1.7. WWV/WWVH Time Code

On July 1, 1971, WWV commenced broadcasting the time code shown in figure 3. Originally broadcast for one minute out of five, the time code is now transmitted continuously by both WWV and WWVH on a 100 Hz subcarrier. This time code provides a standardized timing base for use when scientific observations are made simultaneously at widely separated locations. It may be used, for instance, where signals telemetered from a satellite are recorded along with the time code; subsequent analysis of the data is then aided by having unambiguous time markers accurate to about 10 milliseconds.

The code format being broadcast is known as the IRIG-H BCD time code. The code is produced at a 1 pps rate and is carried on 100 Hz modulation.

The code contains time-of-year information in Coordinated Universal Time in seconds, minutes, hours, and day of year. The code is synchronous with the frequency and time signals.

The binary coded decimal (BCD) system is used. Each minute contains 7 BCD groups in this order: 2 groups for minutes, 2 groups for hours, and 3 groups for day of year. The code digit weighting is 1-2-4-8 for each BCD group multiplied by 1, 10, or 100 as the case may be.

A complete time frame is 1 minute. The binary groups follow the 1 minute reference marker. "On-time" occurs at the positive-going leading edge of all pulses.

The code contains 60/minute clocking rate, 6/minute position identification markers, and a 1/minute reference marker. The 100 Hz is synchronous with the code pulses so that 10 millisecond resolution is readily obtained.

[8] For information regarding these broadcasts, contact George P. Cressman, Director, National Weather Service, Silver Spring, Maryland 20910.

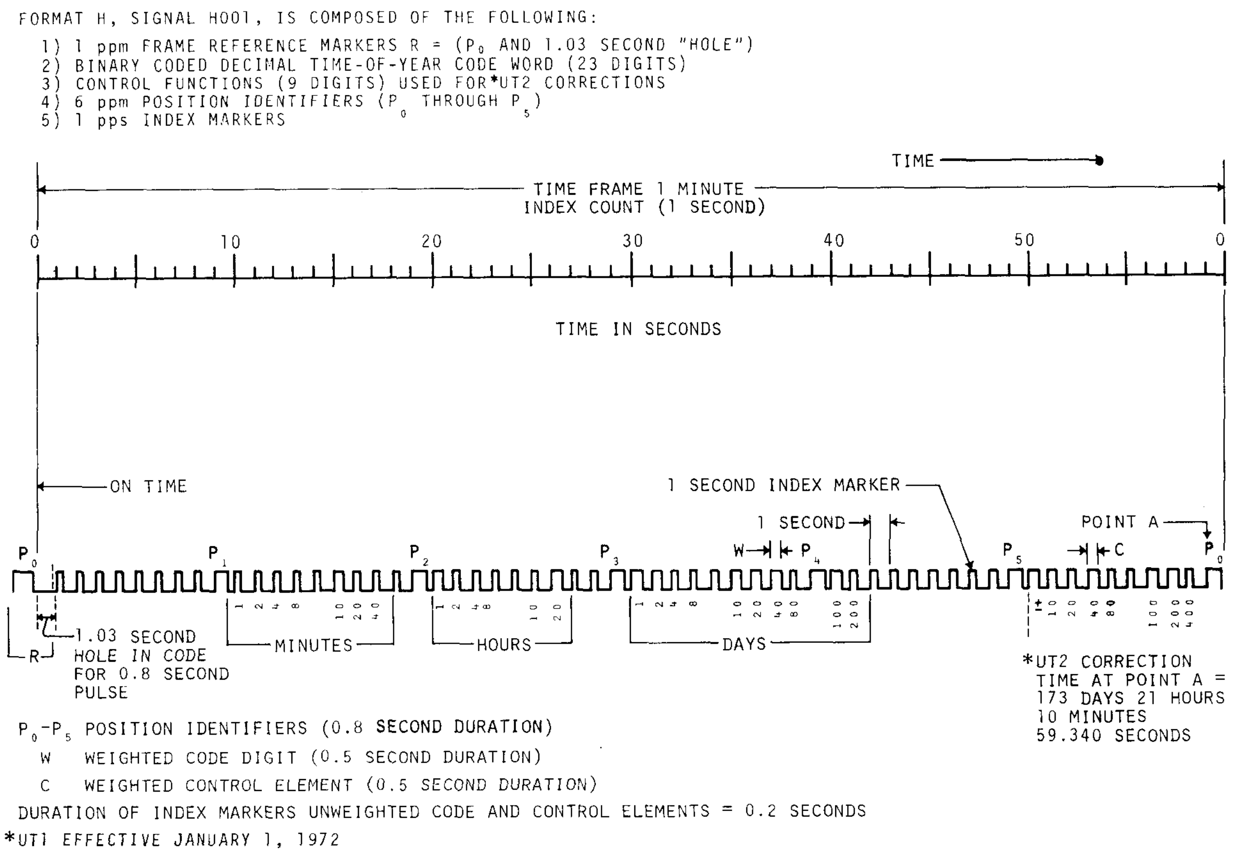


FIGURE 3. *Chart of time code transmissions from NBS radio stations WWV and WWVH.*

The 6/minute position identification markers consist of 0.8 second pulses preceding each code group.

The 1/minute reference marker consists of one 0.8 second pulse followed by a 1.03 second "hole" in the code followed by eight binary zero pulses. The minute begins at the leading edge of the 1.03 second "hole" at the beginning of the code.

A binary zero pulse consists of 20 cycles of 100 Hz amplitude modulation, and the binary one pulse consists of 50 cycles of 100 Hz amplitude modulation. The leading edges of the time code pulses coincide with positive-going zero-axis-crossings of the 100 Hz modulating frequency.

## 1.8. WWVB Time Code

### (a) Code and Carrier

On July 1, 1965, WWVB began broadcasting time information using a level-shift carrier time code. The code, which is binary coded decimal (BCD), is broadcast continuously and is synchronized with the 60 kHz carrier signal.

### (b) Marker Generation

As shown in figure 4, the signal consists of 60 markers each minute, with one marker occurring during each second. (Time progresses from left to right.) Each marker is generated by reducing the power of the carrier by 10 dB at the beginning of the corresponding second and restoring it 0.2 second later for an uncoded marker or binary zero, 0.5 second later for a binary one, and 0.8 second later for a 10-second position marker or for a minute reference marker. Several examples of binary ones are indicated by I in figure 4.

### (c) Marker Order and Groups

The 10-second position markers, labeled P0 to P5 on the diagram, occur respectively in the 60th, 10th, 20th, 30th, 40th, and 50th seconds of each minute.[9] The minute reference marker occurs in the 1st second of the minute. Uncoded markers occur periodically in the 5th, 15th, 25th, 35th, 45th, and 55th seconds of each minute, and also in the 11th, 12th 21st, 22nd, 36th, 56th, 57th, 58th, and 59th seconds. Thus, every minute contains twelve groups of five markers, each group ending either with a position marker or an uncoded marker. The signal pulses lasting for 0.2 seconds after a position marker are shown blackened in figure 4; the signal pulses lasting for 0.8 seconds after a periodically uncoded marker are shaded; other signal pulses following uncoded markers are labeled with a U.

With the exception of the uncoded and reference markers specifically mentioned above, the remaining markers in each of the groups are utilized to convey additional information.

[9] Effective January 1, 1972: During the minute in which a one-second step correction occurs, that minute will contain either 59 or 61 seconds.

### (d) Information Sets

Each minute the code presents time-of-year information in seconds, minutes, hours, and day of the year and the actual milliseconds difference between the time as broadcast and the best known estimate of UT2 (or UT1 after January 1, 1972). A set of groups, containing the first two BCD groups in the minute, specifies the minute of the hour; the third and fourth BCD groups make up a set which specifies the hour of the day; the fifth, sixth, and seventh groups form a set which specifies the day of the year; a set, made up of the ninth, tenth and eleventh BCD groups, specifies the number of milliseconds to be added or subtracted from the code time as broadcast in order to obtain UT2.

The relationship of the UT2 scale to the time as coded is indicated in the eighth group. If UT2 is late with respect to the code time, a binary one, labeled SUB (Substract) in figure 4, will be broadcast in the eighth group during the 38th second of the minute. If UT2 is early with respect to the code time, binary ones, labeled ADD, will be broadcast in the eighth group during the 37th and 39th seconds of the minute.

The twelfth group is not used to convey information.

### (e) Digital Information

When used to convey numerical information, the four coded markers used as digits in a BCD group are indexed 8-4-2-1 in that order. Sometimes only the last two or three of the coded markers in a group are needed, as in the first groups in the minutes, hours, and days sets. In these cases, the markers are indexed 2-1, or 4-2-1, accordingly. The indices of the first group in each set which contains two groups are multiplied by 10, those of the second group of such a set are multiplied by 1. The indices of the first group in each set which contains three groups are multiplied by 100, those of the second group by 10, and those of the third group by 1.

### Example

A specific example is indicated in figure 4. The occurrence of two binary ones in the "minutes set" indicates that the minute contemplated is the $40 + 2 = 42$nd minute. Similarly, the two binary ones in the "hours set" indicate the $10 + 8 = 18$th hour of the day, while the four binary ones in the "days set" indicate the $200 + 40 + 10 + 8 = 258$th day of the year. It is seen from the "UT2 Relationship" group and the "UT2 set" that one should *subtract*, from any second in this minute, $40 + 1 = 41$ milliseconds to get the best estimate of UT2. For example, the 35th UT2 interval would end 41 milliseconds *later* than the end of the 35th second; or, in other words, the UT2 scale reading for the end of the 35th second would be $18^h42^m34.^s959$ since $35.000 - 0.041 = 34.959$.

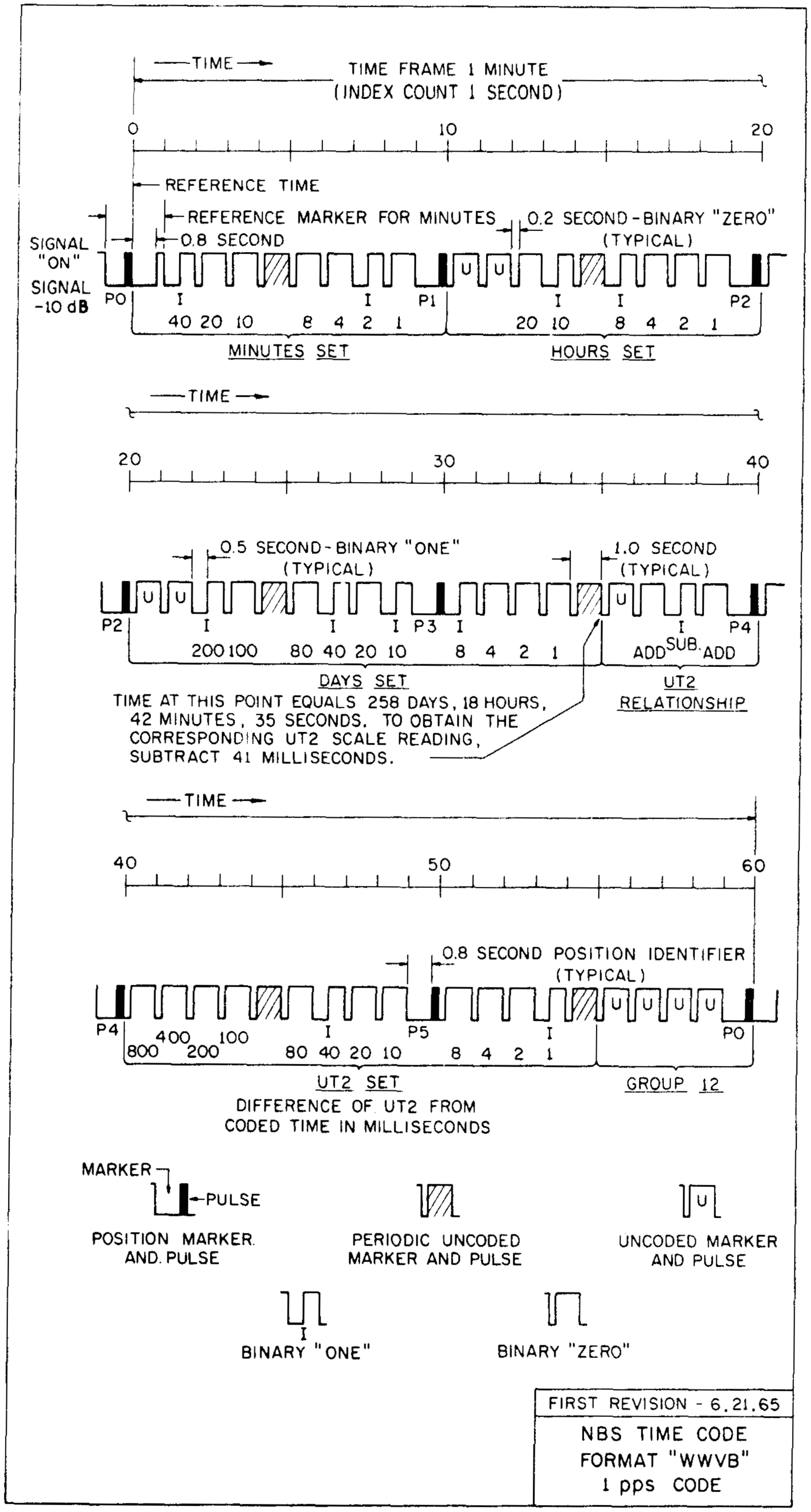


FIGURE 4. *Chart of time code transmissions from NBS radio station WWVB.*

### 1.9. Station Identification

WWV and WWVH identify by voice (in English) every 30 minutes. The voice announcements are automatically synchronized recordings, not live broadcasts. The announcer for WWV is Mr. Don Elliott of Atlanta, Georgia; the announcer for WWVH is Mrs. Jane Barbe, also of Atlanta.

WWVL transmits no identification other than its unique format of alternating frequency every 10 UTC seconds. WWVB identifies by its unique time code and by advancing the carrier phase 45° at 10 minutes after each hour and returning to normal phase at 15 minutes after each hour.

### 1.10. Radiated Power, Antennas and Modulation

**(a) Radiated Power**

| Frequency, MHz | Radiated Power, kw | | | |
|---|---|---|---|---|
| | WWV | WWVH | WWVB | WWVL |
| 0.020 | — | — | — | 2 |
| 0.060 | — | — | 16 | — |
| 2.5 | 2.5 | 2.5 | — | — |
| 5 | 10 | 10 | — | — |
| 10 | 10 | 10 | — | — |
| 15 | 10 | 10 | — | — |
| 20 | 2.5 | 2.5 | — | — |
| 25 | 2.5 | — | — | — |

**(b) Transmitting Antennas**

The broadcasts on 5, 10, 15, and 20 MHz from WWVH are from phased vertical half-wave dipole arrays. They are designed and oriented to radiate a cardioid pattern directing maximum gain in a westerly direction. The 2.5 MHz antenna at WWVH and all antennas at WWV are half-wave vertical dipoles and radiate omnidirectional patterns. The antennas used at WWVB and WWVL are 400-foot vertical antennas with capacity toploading.

**(c) Modulation**

At WWV and WWVH, double sideband amplitude modulation is employed with 50 percent modulation on the steady tones, twenty-five percent for the IRIG-H code, 100 percent for seconds pulses, and seventy-five percent for voice.

WWVB employs 10 dB carrier-level reduction for transmitting time information.

WWVL uses no modulation. Various experimental techniques are being studied to develop a better timing system at very low frequencies.

## 2. How NBS Controls the Transmitted Frequencies

In figure 5 a simplified diagram of the NBS frequency control system[10] is shown. The entire system depends upon the basic frequency reference shown in this diagram as the Cesium (Cs) beam. This standard is used to calibrate the oscillators, dividers and clocks which generate the controlled frequency and the NBS time scales.

Utilizing the line-10 horizontal synchronizing pulses from a local television station, the Fort Collins master clock is compared on a daily basis with the NBS master clock.[11] All other clocks and time-code generators at the Fort Collins site are then compared with the Fort Collins master clock. Frequency corrections of the WWVB and WWVL quartz crystal oscillators are based on their phase relative to the NBS master clock.

The transmissions from WWV are controlled by three cesium standards located at the site. To ensure accurate time transmission from WWV, the time-code generators are compared with the Fort Collins Master Clock several times each day.

Control of the signals transmitted from WWVH is based upon signals from WWVB and WWVL as received by phase-lock receivers. The cesium standards controlling the transmitted frequencies and time signals are continuously compared with the received signals.

To ensure that systematic errors do not enter into the system, the NBS time scale is compared with the transmitting station clocks by the use of a very precise portable clock.

[10] Milton, J. B., Standard Time and Frequency: Its Generation, Control, and Dissemination from the National Bureau of Standards Time and Frequency Division, NBS Technical Note 379, August 1969.

[11] Tolman, J., V. Ptacek, A. Soucek, and R. Stecher, Microsecond clock comparisons by means of TV synchronizing pulses, IEEE Trans.—Instr. and Meas., IM–16, No. 3, September 1967, pp. 247-254.

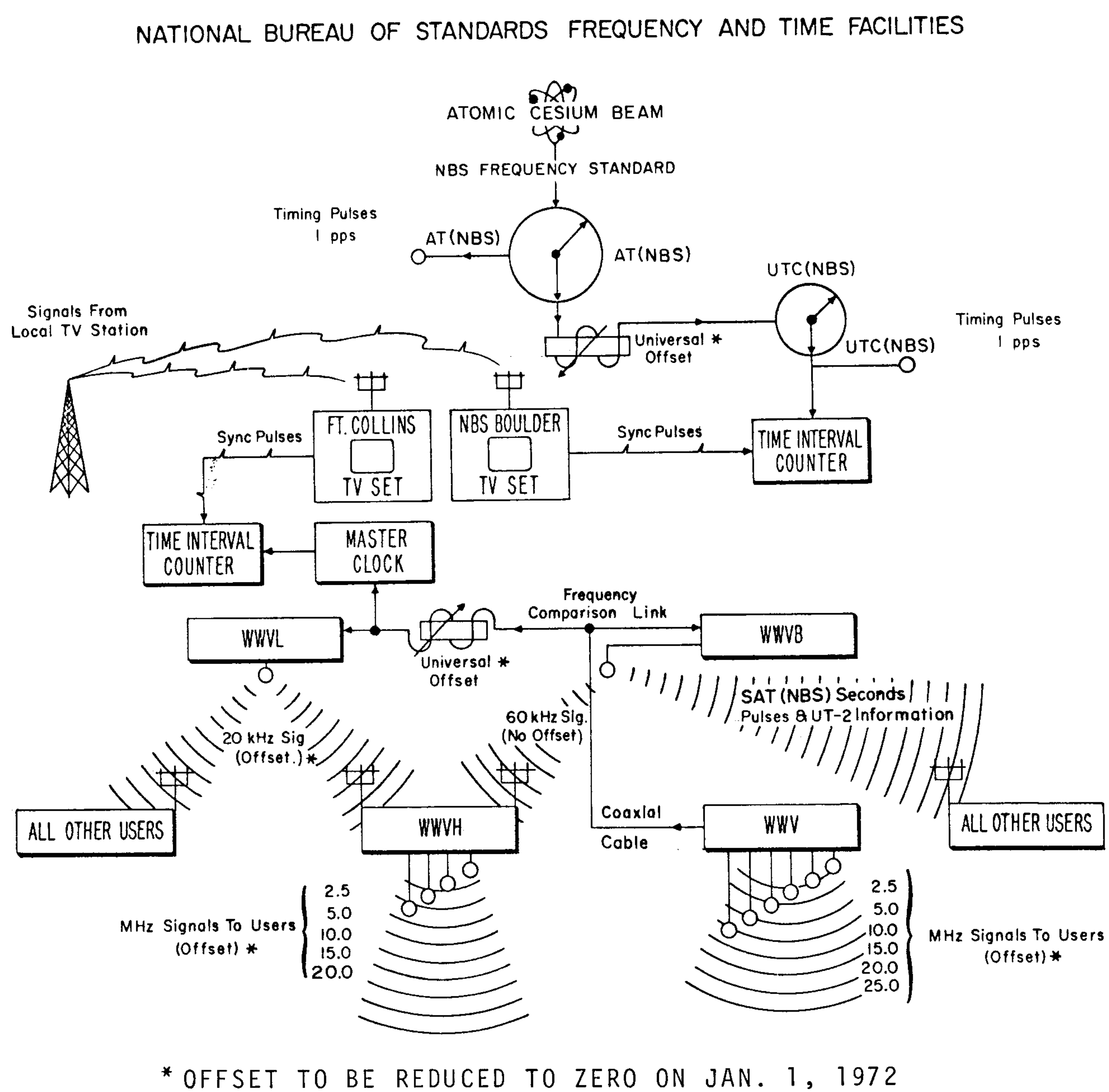


FIGURE 5. *NBS frequency control system.*

# NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards [1] 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 governments, (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 Radiation [2]—Nuclear Radiation [2]—Applied Radiation [2]—Quantum Electronics [3]—Electromagnetics [3]—Time and Frequency[2]—Laboratory Astrophysics [3]—Cryogenics [2].

**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 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 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.

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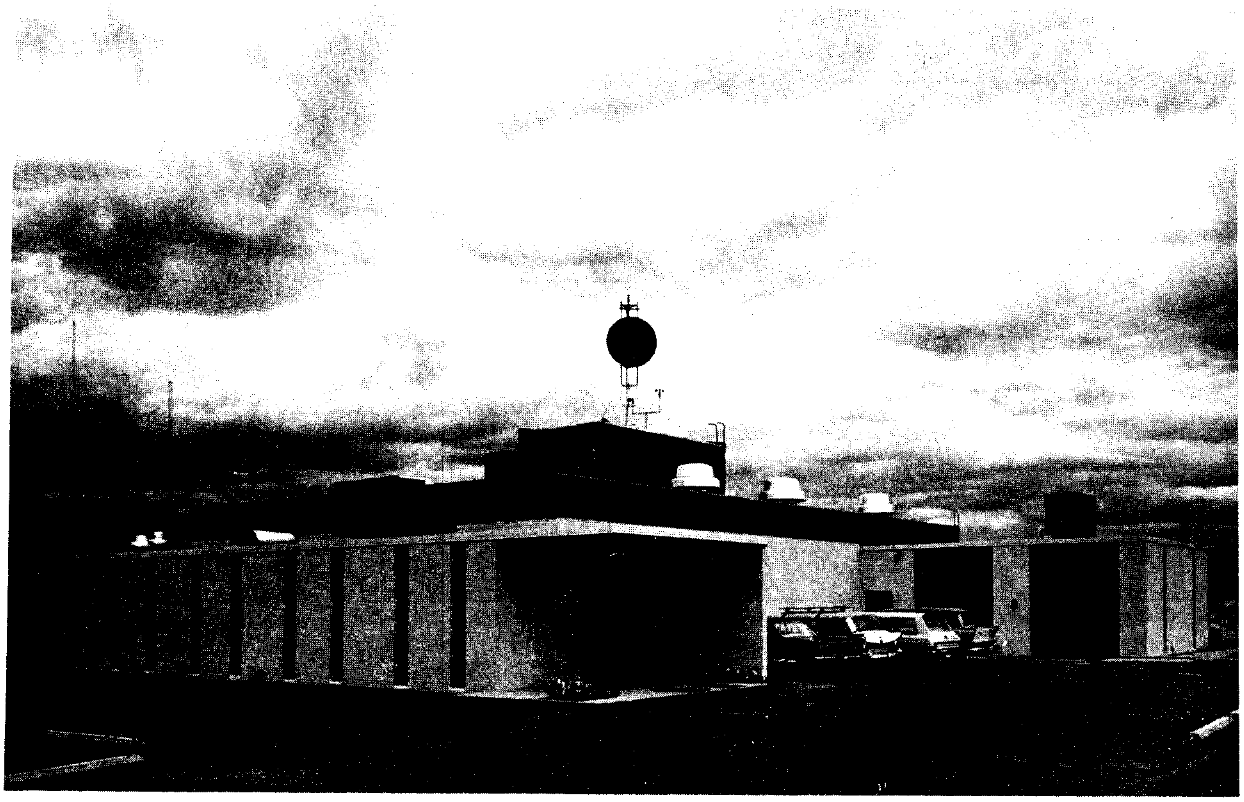
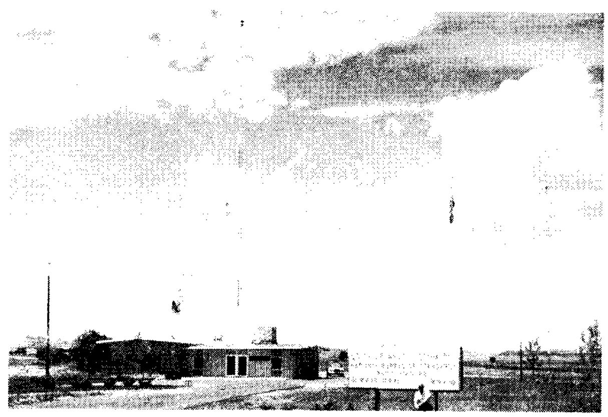
[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Part of the Center for Radiation Research.
[3] Located at Boulder, Colorado 80302.

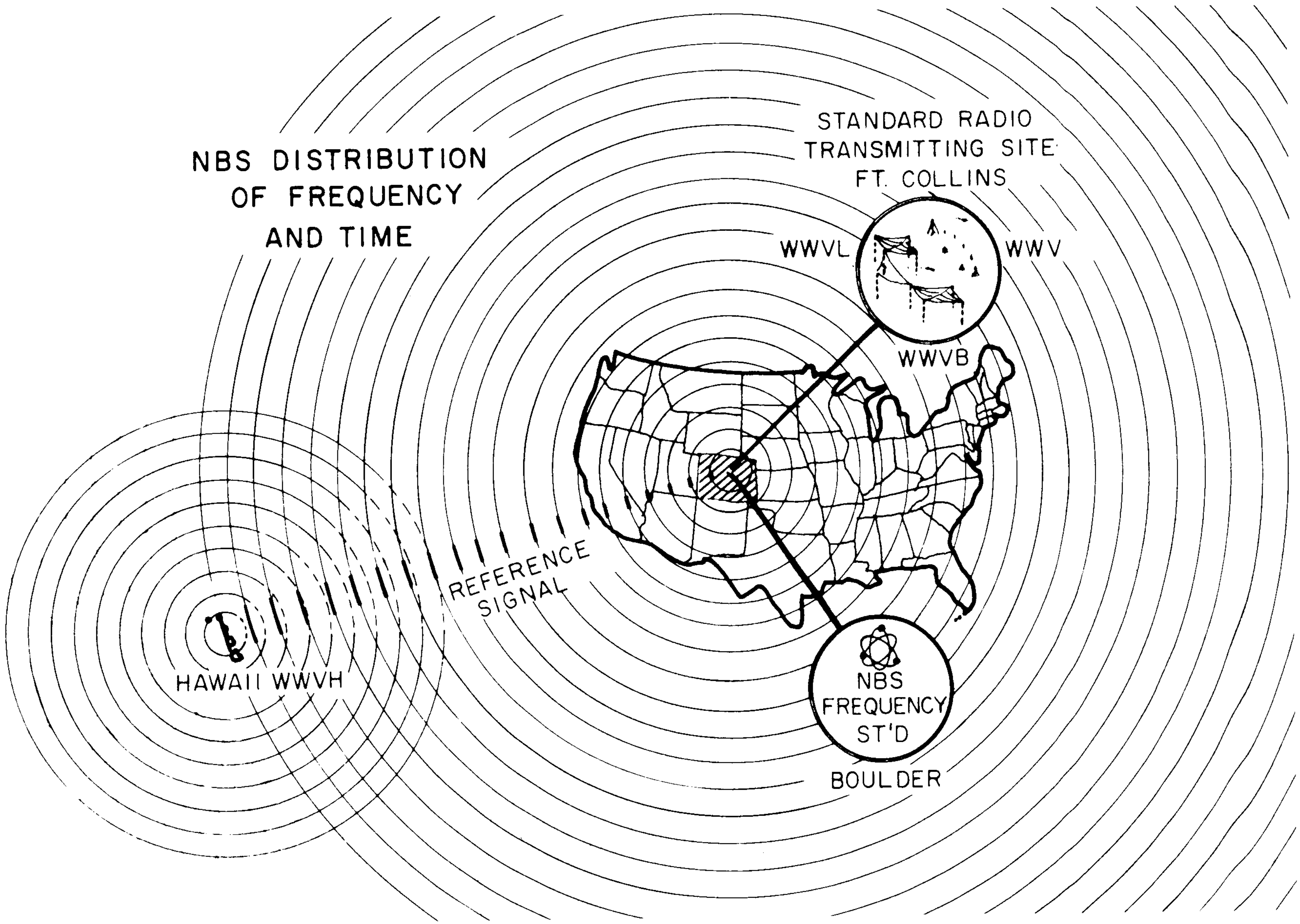


NBS Fort Collins facility showing WWV transmitter building.

WWVH transmitter building, Kekaha, Kauai, Hawaii.



WWVB/WWVL transmitter building and antennas.


NBS DISTRIBUTION
OF FREQUENCY
AND TIME
STANDARD RADIO
TRANSMITTING SITE
FT. COLLINS
WWVL
WWV
WWVB
REFERENCE
SIGNAL
HAWAII WWVH
NBS
FREQUENCY
ST'D
BOULDER