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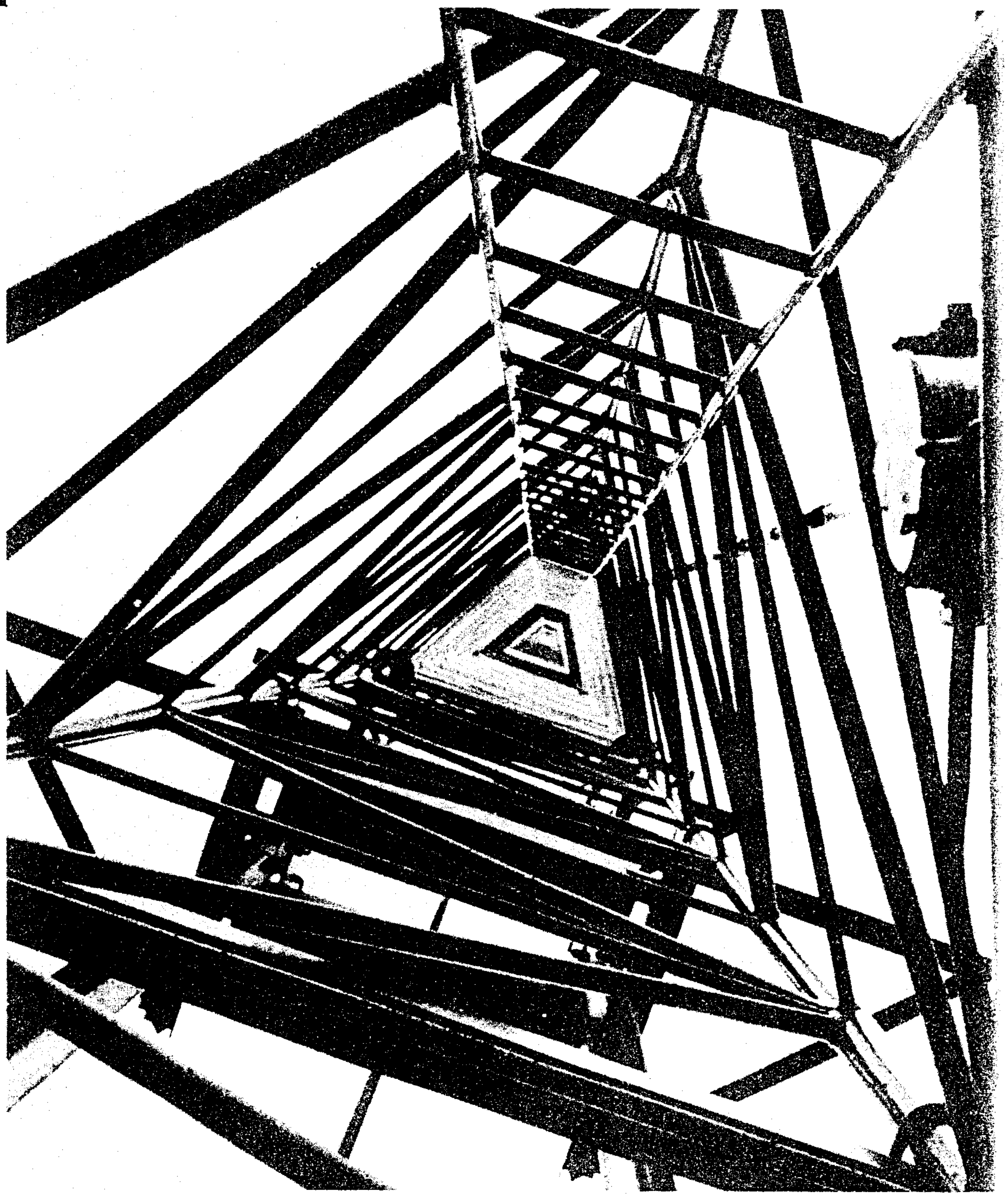
NBS FREQUENCY AND TIME BROADCAST SERVICES

RADIO STATIONS WWV, WWVH, WWVB, WWVL



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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.

UNITED STATES DEPARTMENT OF COMMERCE

PETER G. PETERSON, *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

Peter P. Viezbicke

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. UT1 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 January 1, 1972. 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), were designed to provide a 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 49 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 worldwide 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, Colo. 80302.

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, CO 80521
Telephone (303) 484-2372

Charles Trembath, Engineer-in-Charge
NBS Radio Station WWVH
P. O. Box 417
Kekaha, Kauai, HI 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. WWV and WWVH Broadcast Services

1.1. Standard Radio Frequencies

(a) Program

WWV and WWVH broadcast nominal frequencies and time consistent with the internationally agreed upon time scale, Universal Coordinated Time[2] (UTC). Changes in UTC effective January 1, 1972, are discussed in section 1.5(b).

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.

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 transmitted from the station. Considering the instabilities and variable delays of propagation by telephone, the listener should not expect accuracy of the telephone time signals to be better than 30 milliseconds. This service is automatically limited to 3 minutes per call.

[2] As noted in a resolution of Commission 31 of the International Astronomical Union, August 1970: "The terms 'GMT' and 'Z' are accepted as the general equivalents of UTC in navigation and communication."

TABLE 1.
Services and coordinates of the NBS broadcast stations

Station	Date in Service	Radio Frequencies	Audio Frequencies	Musical Pitch	Time Intervals	Time Signals	UT1 Corrections	Official Announcements
WWV	1923	√	√	√	√	√	√	√
WWVH	1948	√	√	√	√	√	√	√
WWVB	1956	√			√	√	√	
WWVL	1960	√						

The coordinates of these 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

(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 cesium 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} [1][3].

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 XIIIth General Conference of Weights and Measures. 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}. Frequencies measured in terms of the NBS standard between December 1, 1957 and January 1, 1960 need to take the above correction into account [2].

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 fluctua-

[3] Figures in brackets indicate the literature references at the end of this publication.

tions in the carrier frequencies as received which may be very much greater than the uncertainties quoted above.

(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 broadcast with no intentional offset from the nominal frequency. Previously, 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}.

At the recommendation of the International Radio Consultative Committee (CCIR), the frequency offset of UTC was made permanently zero effective 0000 hours UTC January 1, 1972.

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

The hourly broadcast format of WWV and WWVH is presented in figure 1. Standard audio frequencies of 440 Hz, 500 Hz, and 600 Hz are broadcast on each radio carrier frequency by the two stations. 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 UTC day.

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 (sec. 1.7) is not considered one of the standard audio frequencies, the modified 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 1 minute after the hour at WWVH and 2 minutes after the hour at WWV. The tone is omitted during the zero hour of each UTC day. In addition to its application as a musical 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 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 1-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 milliseconds. 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.

1.5. Time Signals

(a) Program

Because of the common usage of the name Greenwich Mean Time, the time announcements on WWV and WWVH are referred to by this name (see footnote 2). 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 for midnight at longtitude 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 0.8 second long audio tone begins.

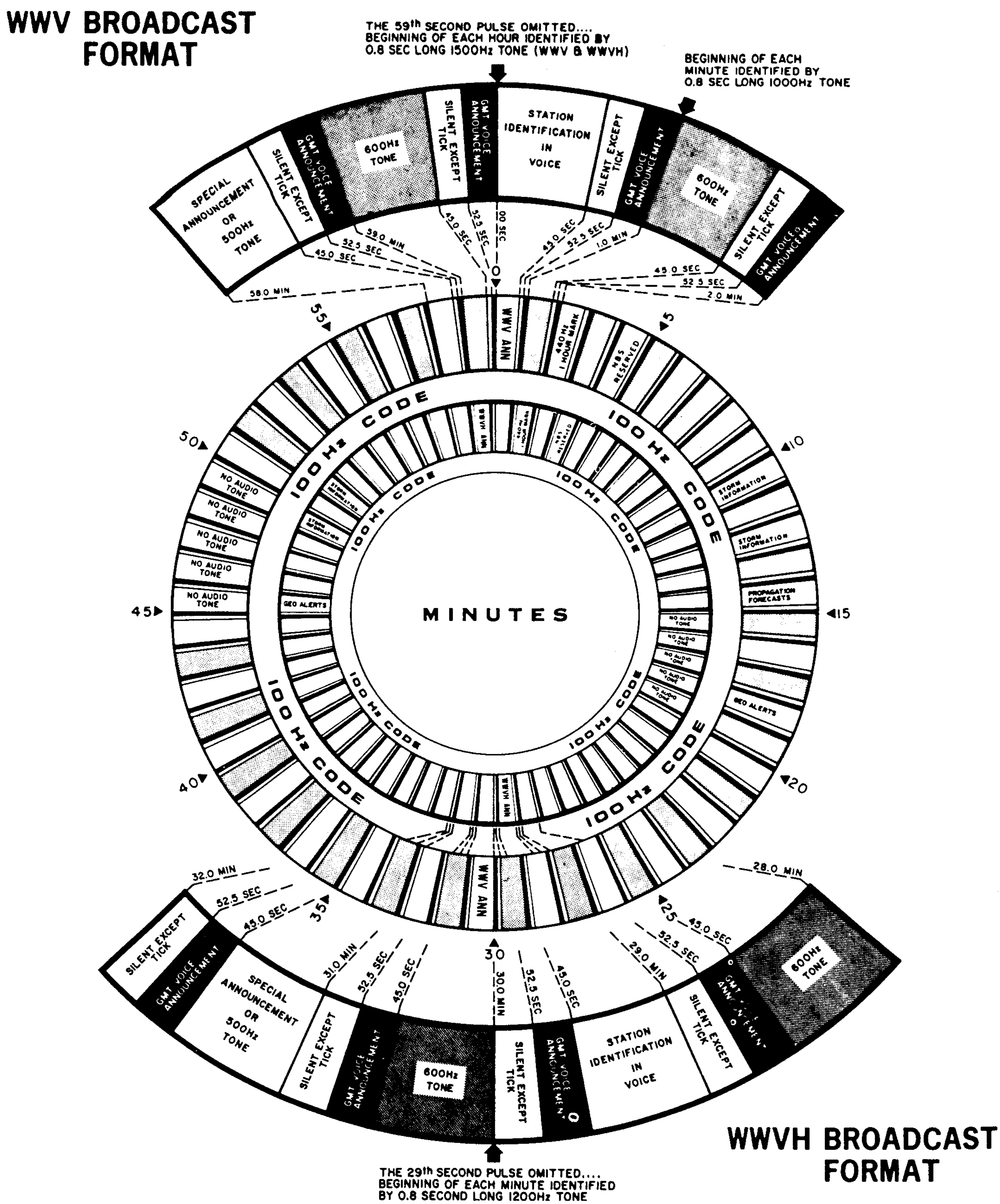

FIGURE 1. *The hourly broadcast schedules of WWV and WWVH.*

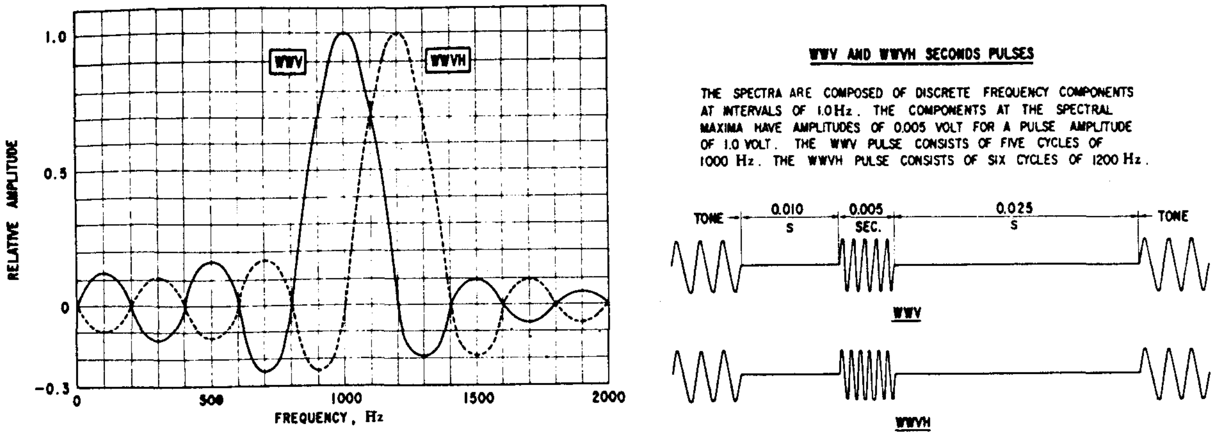

FIGURE 2. *Sample characteristics of time pulse broadcast from NBS radio stations WWV and WWVH.*

At WWV a voice announcement 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 were kept in close agreement with UT2 (astronomical time) by making step adjustments of 100 milliseconds as necessary.

On December 1, 1971 at 23h 59min 60.107600s UTC (i.e., GMT), UTC(NBS) "was retarded 0.107600 second" to give the new UTC scale an initial difference of 10 seconds late with respect to International Atomic Time (IAT) as maintained by the Bureau International de l'Heure (BIH) in Paris, France.

Corrections to UTC will be made in step adjustments of exactly 1 second when the BIH determines they are needed to keep the broadcast time signals within ± 0.7s of astronomical time, UT1. (Note: the corrections no longer relate to UT2.

(c) UTI Corrections

Since the new UTC rate (effective January 1, 1972) is no longer adjusted periodically to agree with the earth's rotation rate, the new UTC departs more rapidly than before from earth rotation time (known as UT1), gaining about 1 second per year. In order to prevent this difference from exceeding 0.7 second, step adjustments of exactly one second, to be called a leap second, will be made as necessary at the end of the UTC month, preferably on 31 December or 30 June. Thus, when required, a leap second will be inserted between the end of the 60th second of the last minute of the last day of a month, and the beginning of the next minute. This is analogous to adding an extra day (which might be called a leap day) during a leap year. Figure 3 illustrates how events will be dated in the vicinity of a leap second. The BIH will announce the occurrence of leap seconds two months in advance.

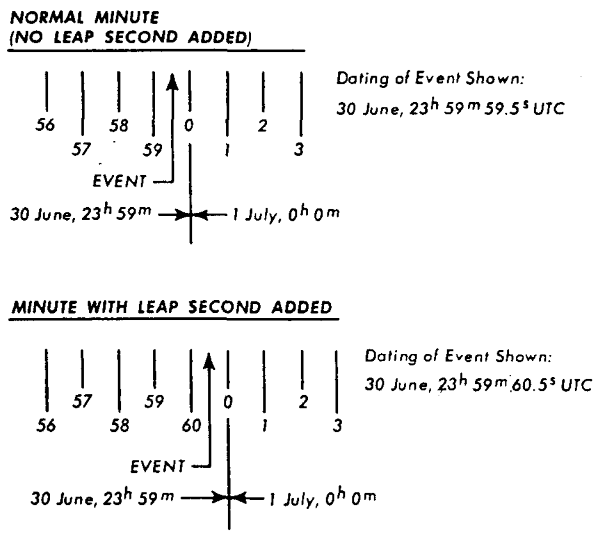

FIGURE 3. *Illustration of how events will be dated in the vicinity of a leap second.*

The method of coding the UT1 corrections 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 in units of 0.1 second 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. To obtain UT1, use the relationship

$$\text{UT1} - \text{Broadcast} = \text{Correction.}$$

That is, add the correction to the time broadcast if "plus" is transmitted, subtract if "minus" is transmitted. Thus, a clock keeping step with the time signals broadcast will be early with respect to UT1 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 UTC.

The UT1 corrections are also encoded in the time code transmitted continuously 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 0.1 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 official 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 semisilent periods are available. Arrangements for use of segments at the two stations may be made through the Frequency-Time Broadcast Services Section, 273.02, National Bureau of Standards, Boulder, CO 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.[4]

The broadcast consists of the statement, "The radio propagation quality forecast at . . . (one of the following times: 0100, 0700, 1300, or 1900 UTC) is . . . (one of the following adjectives: excellent, very good, good, fair-to-good, fair, poor-to-fair, poor, very poor, or useless). Current geomagnetic activity is . . . (one of the following characteristics: quiet, unsettled, or disturbed)."

(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 UTC with provisions to provide real-time data alerts of outstanding occurring events. These are followed by a summary of selected solar and geophysical events in the past 24 hours. Information concerning these forecasts are prepared by the Space Environment Laboratory, NOAA, Boulder, Colorado.[5]

(c) Weather Information

Weather information about major storms in the Atlantic and Pacific areas is broadcast from WWV and WWVH respectively.[6] The brief messages are designed to tell mariners of storm threats in their areas. If there are no warnings in the designated areas, the broadcasts will so indicate. The ocean areas involved are those for which the U.S. has warning responsibility under international agreement. The regular times of issue by the National Weather Service are 0500, 1100, 1600, and 2300 UTC by WWV and 0000, 0600, 1200, and 1800 UTC by WWVH. These broadcasts are updated effective with the next scheduled announcement following the time of issue.

WWV broadcasts information about storms in the western North Atlantic, and WWVH lists storms in the eastern and central part of the North Pacific. These broadcasts are given in voice during the 11th and 13th minute from WWV and during the 50th and 52nd minute from WWVH.

Sample broadcasts that exemplify the type of information mariners might expect to receive from WWV, for instance, are as follows:

"North Atlantic weather, west of 35 degrees West at 1700 GMT: Hurricane Donna, intensifying, 24 North, 60 West, moving northwest, 20 knots, winds 75 knots; storm 65 North, 35 West, moving east, 10 knots, seas 15 feet."

1.7. WWV/WWVH Time Code

On July 1, 1971, WWV commenced broadcasting the time code shown in figure 4. The time code is now

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

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

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

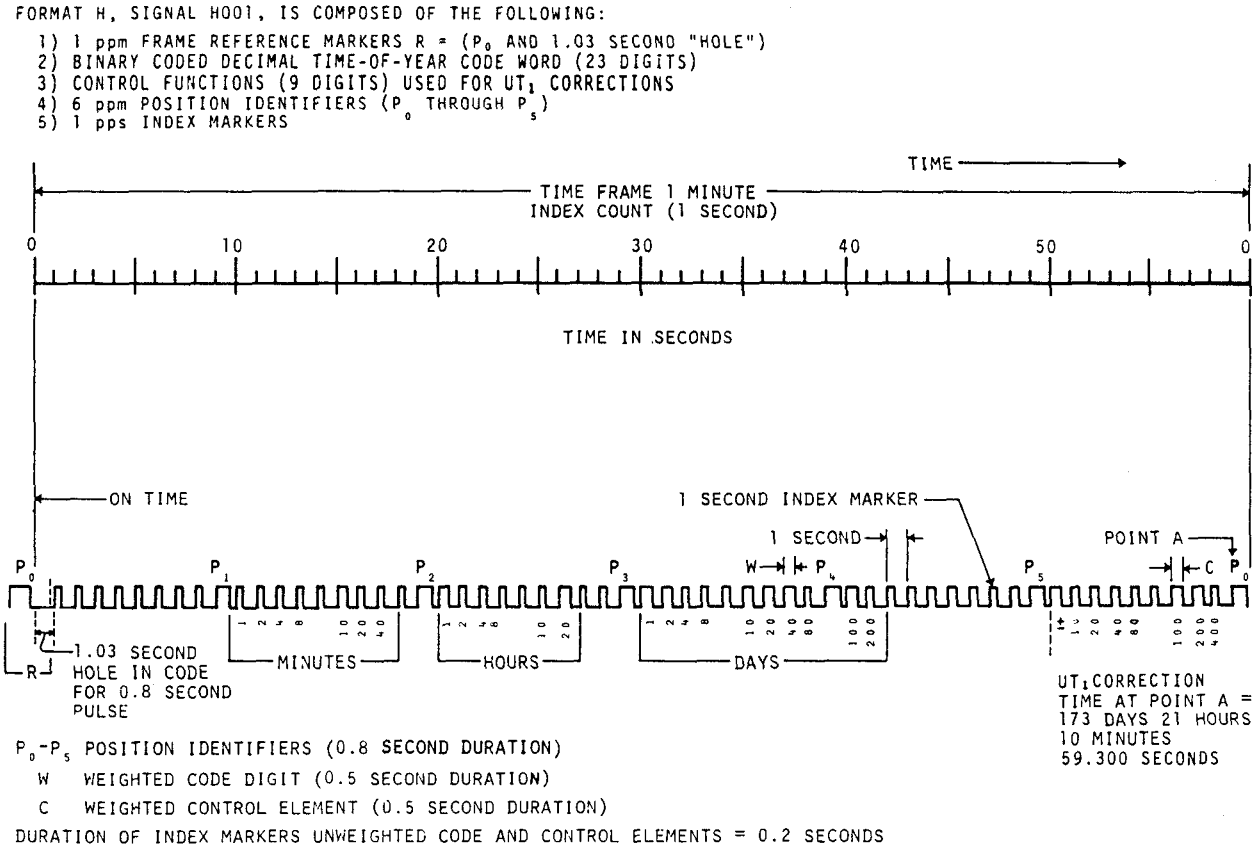

FIGURE 4. *Chart of time code transmissions from NBS radio stations WWV and WWVH.*

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 a modified IRIG-H time code. The code is produced at a 1-pps rate and is carried on 100-Hz modulation.

The code contains UTC time-of-year information in minutes, hours, and day of year. Seconds information may be obtained by counting pulses. The code is synchronous with the frequency and time signals.

The binary coded decimal (BCD) system is used. Each minute contains seven BCD groups in this order: two groups for minutes, two groups for hours, and three 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 markers per minute clocking rate, 6 per minute position identification markers, and a 1 per minute reference marker. The 100-Hz subcarrier is synchronous with the code pulses so that 10-millisecond resolution is readily obtained.

The 6 per minute position identification markers consist of 0.8 second pulses preceding each code group. The 1 per 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 with 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. Station Identification

WWV and WWVH identify by voice every 30 minutes. The station identification voice announcements are automatically synchronized recordings, not live broadcasts. The regular announcer for WWV is Mr.

Don Elliott of Atlanta, Georgia; the regular announcer for WWVH is Mrs. Jane Barbe, also of Atlanta.

1.9. Radiated Power, Antennas and Modulation

(a) Radiated Power

Frequency,	Radiated Power, kW	
MHz	WWV	WWVH
2.5	2.5	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 which radiate omnidirectional patterns.

(c) Modulation

At WWV and WWVH, double sideband amplitude modulation is employed with 50 percent modulation on the steady tones, 25 percent for the IRIG-H code, 100 percent for seconds pulses, and 75 percent for voice.

2. WWVB Broadcast Services

WWVB transmits a standard radio frequency, standard time signals, time intervals, and UT1 corrections. The station is located near WWV on the same site. The coordinates of WWVB are:

40°40′28.3″ N   105°02′39.5″ W.

Alternating its scheduled maintenance periods with those of experimental and intermittently operated station WWVL, it suspends operation for several hours between 1300 UTC and 2400 UTC every other Tuesday. Otherwise the service is continuous.

(a) Program

WWVB broadcasts a standard radio carrier frequency of 60 kHz with no offset. It also broadcasts a time code consistent with the internationally coordinated time scale UTC(NBS).

(b) Accuracy and Stability

The frequency of WWVB is normally within its prescribed value to better than 2 parts in 10^{11}. Deviations from day to day are less than 1 part in 10^{12}. Effects of the propagation medium on received signals are relatively minor at low frequencies (LF); therefore, the accuracy of the transmitted signals may be fully utilized by employing appropriate receiving and averaging techniques [3, 4].

(c) Station Identification

WWVB identifies itself by advancing its carrier phase 45° at 10 minutes after every hour and returning to normal phase at 15 minutes after the hour. WWVB can also be identified by its unique time code.

(d) Radiated Power, Antenna, and Modulation

The effective radiated power from WWVB is 13 kW. The antenna is a 122-meter, top-loaded vertical installed over a radial ground screen. The station uses 10-dB carrier-level reduction in transmitting its time code.

2.1. 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 5, 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 5. The leading edge of every negative-going pulse is on time.

(c) Marker Order and Groups

The 10-second position markers, labeled PO to P5 on the diagram, occur respectively in the 60th, 10th, 20th, 30th, 40th, and 50th seconds of each minute.[7] 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

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

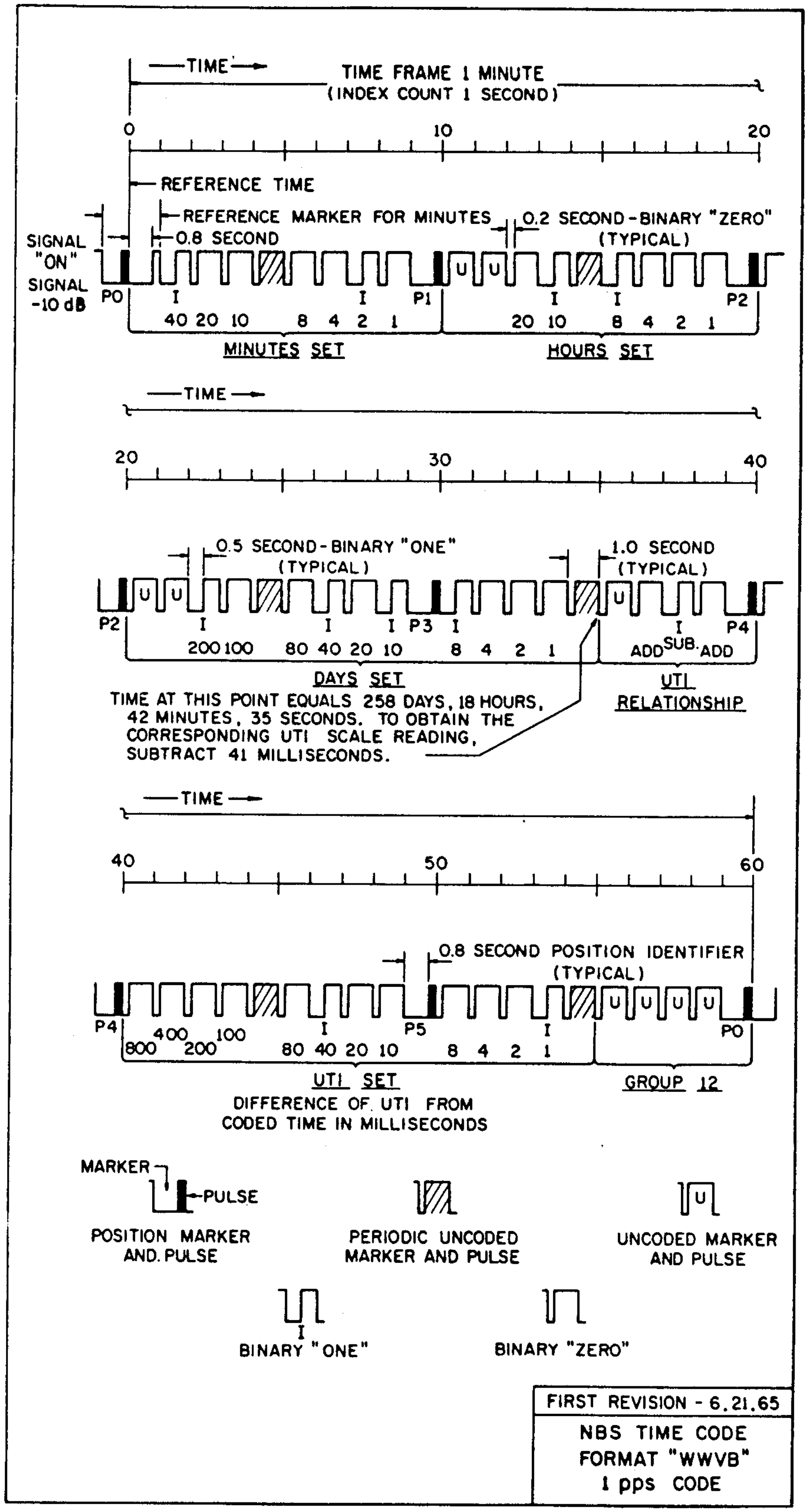

FIGURE 5. *Chart of time code transmissions from NBS radio station WWVB.*

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.

(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 UT1. The first two BCD groups in the frame specify 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 UT1. The twelfth group is not used.

The relationship of the UT1 scale to the time as coded is indicated in the eighth group. If UT1 is late with respect to the code time, a binary one, labeled SUB in figure 5, will be broadcast in the eighth group during the 38th second of the minute. If UT1 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.

(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 of the minutes, hours, and days sets. In these cases, the markers are indexed 2-1, or 4-2-1, accordingly. The indexes 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 indexes 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 5. 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 "UT1 Relationship" group and the "UT1 Set" that one should subtract, from any second in this minute, $40 + 1 = 41$ milliseconds to get the best estimate of UT1. For example, the 35th UT1 interval would end 41 milliseconds *later* than the end of the 35th second; or, in other words, the UT1 scale reading for the end of the 35th second would be 18h 42min 34.959s since $35.000 - 0.041 = 34.959$.

3. WWVL Experimental Broadcasts

WWVL broadcasts experimental programs, usually involving multiple frequencies. The station is located in the same building with WWVB and on the same site with WWV. The coordinates of WWVL are:

40°40′51.3″ N 105°03′00.0″ W.

Alternating its scheduled maintenance periods with those of WWVB, it suspends operation for several hours between 1300 UTC and 2400 UTC every other Tuesday. Otherwise the programs are continuous.

Effective 0000 hours UTC, 1 January 1972, all transmissions from WWVL will be on an intermittent and experimental basis only. These broadcasts are planned to be curtailed within a few months thereafter. Users of this service are urged to explore alternative solutions to their needs.

(a) Program Format

WWVL transmits only carrier frequencies with no modulation. In accordance with the new UTC system the frequency offset used prior to January 1, 1972, was reduced to zero on that date. The transmissions presently alternate between 20.0 kHz and 19.9 kHz on a 50 percent duty cycle with each frequency being broadcast for 10 seconds. The 20.0 kHz transmissions commence on the minute. The format and frequencies used by WWVL are subject to change to meet the requirements of the particular experiment being conducted.

(b) Accuracy and Stability

The transmitted frequencies from WWVL are normally within their prescribed values to better than 2 parts in 10^{11}. Deviations from day to day are less than 1 part in 10^{12}. Because of the excellent coverage and phase stability in the very low frequency (VLF) region, this mode of transmission permits the frequencies to be received with an accuracy approaching that of signals at the transmitter itself.

(c) Station Identification

WWVL is identified only by its unique program format.

(d) Radiated Power, Antenna

The effective radiated power from WWVL is 2 kW. The antenna is a 122-meter, top-loaded vertical installed over a radial ground screen.

4. How NBS Controls the Transmitted Frequencies

In figure 6 a simplified diagram of the NBS frequency control system [5] is shown. The entire system depends upon the basic frequency reference shown in this diagram as the Atomic 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 [6]. 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 and WWVH are controlled by three cesium standards located at each site. To ensure accurate time transmission from each station, the time-code generators are compared with the station's master clock several times each day.

Control of the signals transmitted from WWVH is based not only upon the cesium standards, but upon signals from WWVB 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.

5. References

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[3] 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).

[4] 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, NJ, May 6-8, 1969, pp. 251-262.

[5] 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.

[6] 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, (Sept. 1967), pp. 247-254.

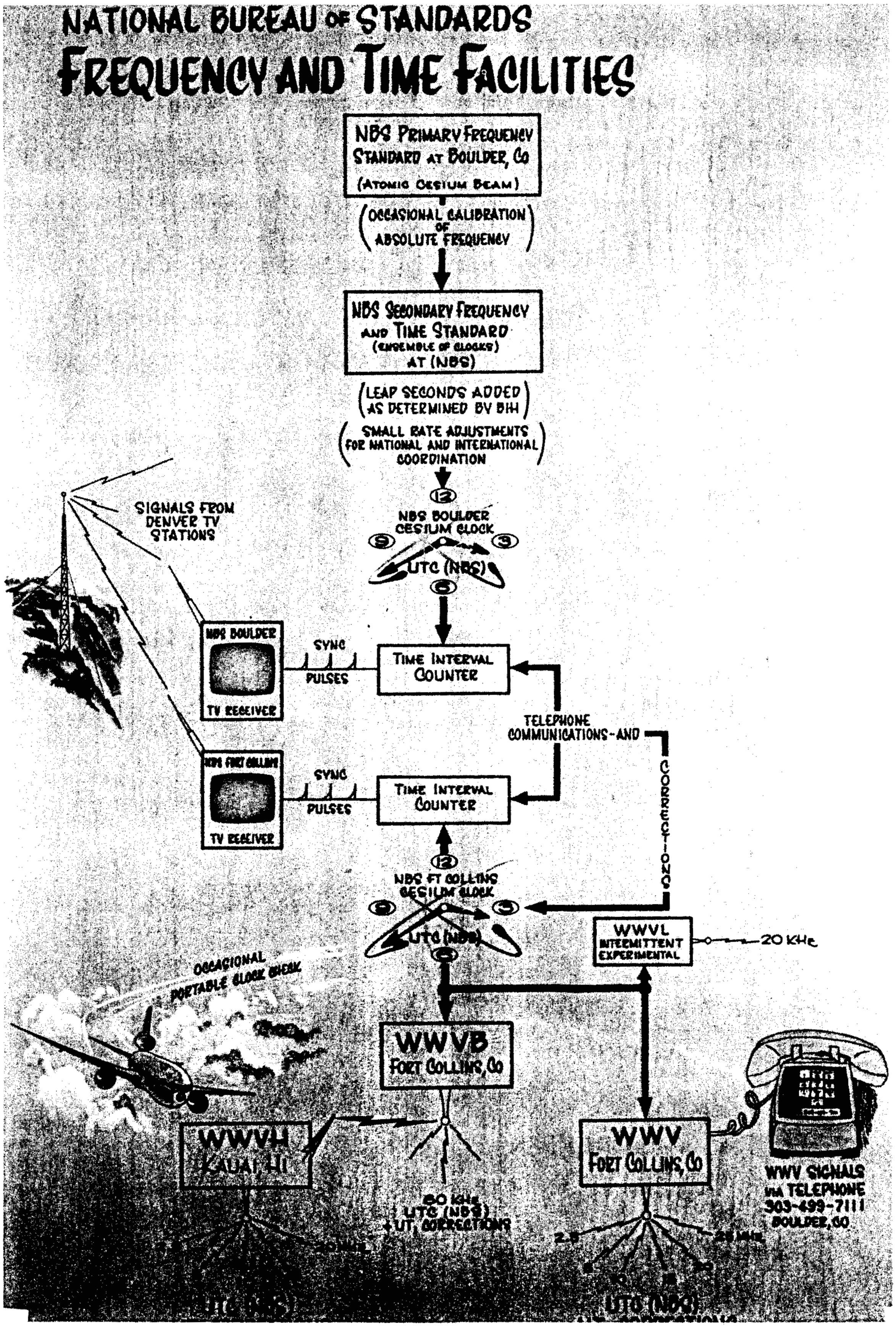
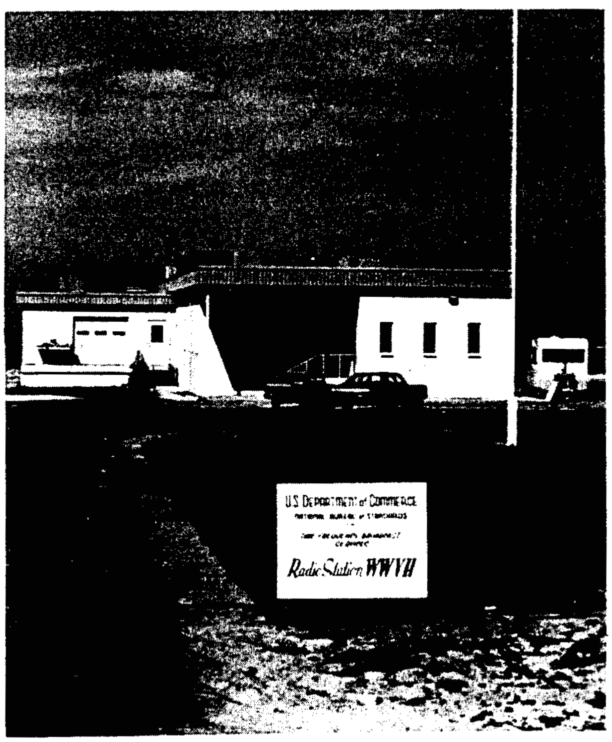


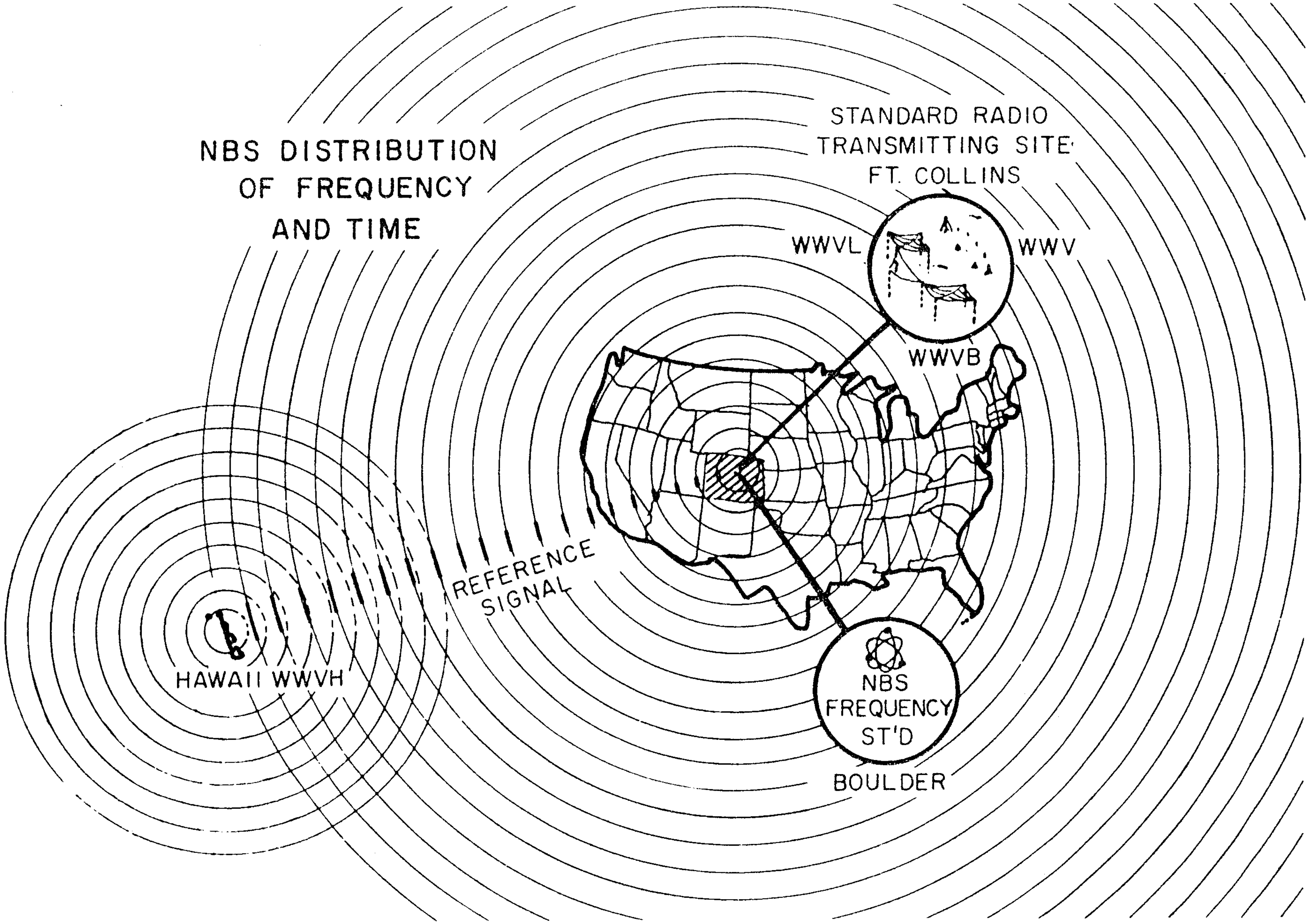
FIGURE 6. *NBS frequency control system.*

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