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NBS Frequency and Time Broadcast Services

RADIO STATIONS
WWV WWVH WWVB WWVL

U.S.
DEPARTMENT
OF
COMMERCE
National
Bureau
of
Standards

UNITED STATES DEPARTMENT OF COMMERCE
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NBS FREQUENCY AND TIME BROADCAST SERVICES

RADIO STATIONS WWV, WWVH, WWVB, AND WWVL

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Frequency-Time Standards
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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. UT2 corrections; 7. Radio propagation forecasts; and 8. Geophysical alerts. 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 February 1, 1970. 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, but the original towers remain on the pioneer site. From 1931 to 1966 the station was moved successfully from Washington, D. C. to Greenbelt, Maryland and finally to Fort Collins, Colorado, where it went on the air at 0000 Universal Time (GMT) 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, Maui, Hawaii.

Original broadcasts were accurate to within a few parts in a thousand. Their transmitted accuracy today is of 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 station 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.

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 frequency and 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 47 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 standard frequency and time stations of the National Bureau of Standards broadcast these services:

Station	Date in service	Radio frequencies	Audio frequencies	Musical pitch	Time intervals	Time signals	UT2 corrections	Propagation forecasts	Geophysical alerts
WWV	1923	✓	✓	✓	✓	✓	✓	✓	✓
WWVH	1948	✓	✓	✓	✓	✓	✓		✓
WWVB	1956	✓			✓	✓	✓		
WWVL	1960	✓							

The NBS radio stations are located as follows:

WWV	40°40′ 49″N	105°02′ 27″W
WWVB	40°40′28.3″N	105°02′39.5″W
WWVL	40°40′51.3″N	105°03′00.0″W
WWVH	20°46′ 02″N	156°27′ 42″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.

Sadami Katahara, Engineer-in-charge
NBS Radio Station WWVH[2]
Box 578
Puunene, Maui, Hawaii 96784
Telephone (808) 79-4111.

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

1.1. Standard Radio Frequencies

(a) Program

Station WWV broadcasts on nominal radio frequencies of 2.5, 5, 10, 15, 20, and 25 MHz. The broadcasts are continuous, night and day, except for an interruption of 4 min. each hour. The silent period commences at 45 min 15 s after each hour (fig. 1). During the silent periods, measurements of background noise level can be made.

Station WWVH broadcasts on nominal radio frequencies of 2.5 5, 10, and 15 MHz. The broadcast is interrupted for approximately 4 min each hour. The silent period commences at 15 min (plus 0 to 15 s) after each hour.

Station WWVB broadcasts on the standard frequency of 60 kHz and station 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.

(b) Accuracy and Stability

Since December 1, 1957, the standard radio transmissions from stations WWV and WWVH have been held as nearly constant as possible with respect to the atomic frequency standards maintained and operated by the Time and Frequency Division of the National Bureau of Standards. Carefully made atomic standards have been shown to realize the ideal Cs resonance frequency, f_{Cs}, to a few parts in 10^{12}. The present NBS frequency standard realizes this resonance frequency to within 5 parts in 10^{12}.

The number f_{Cs}=9 192 631 770 Hz, originally measured[3] with an uncertainty of 2 parts in 10^9, is now defined as the exact value assigned to the atomic frequency standard to be used for the physical measure of time. This was officially decided by the International Committee of Weights and Measures at the XIIIth General Conference in October 1967.

On January 1, 1960, the NBS standard was brought into agreement with f_{Cs} as quoted above by arbitrarily 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, may be referred to the above value of f_{Cs} and to the Ephemeris second by means of this relative correction.[4]

The frequencies transmitted by WWV and WWVH are held stable to better than ±2 parts in 10^{11} at all times. Deviations at WWV are normally much less than 1 part in 10^{11} 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 4 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 stable to better than 2 parts in 10^{11}. Devi-

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[2] WWVH is being relocated to Kauai, Hawaii, and is planned to be operational at the new site in 1971.

[3] Markowitz, Hall, Essen, and Parry—Frequency of cesium in terms of ephemeris time—Phys. Rev. Letters **1**, 105 (1958).

[4] National standards of time and frequency in the United States, Proc. IRE **48**, 105 (1960).

ations from day to day are less than 1 part in 10^{11}.

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 techniques.

(c) Corrections

All carrier and modulation frequencies at WWV are derived from cesium controlled oscillators and at WWVH are derived from precision quartz oscillators. Coordinated by the Bureau International de l'Heure (BIH) in Paris, these frequencies are intentionally offset from standard frequency by a small but precisely known amount to reduce departure between the time signals as broadcast and astronomical time, UT2. The 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 1970, -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 will remain in effect for the entire calendar year.

Corrections to the transmitted frequency and 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.

The carrier frequency of WWVL is also offset from standard frequency by the same amount as noted above. Station WWVB initially transmitted with the carrier frequency offset, but since January 1, 1965 the transmissions have been without offset. Thus, one of the NBS transmissions makes available to users the standards of frequency and time interval so that atomic frequency comparisons may be made directly. The carrier frequency of station WWVB is not subject to annual offset changes as are the frequencies of the other three stations.

(d) Offset Frequencies

WWV, WWVH, and WWVL transmit reminders of the fact that all transmitted frequencies are offset from nominal by a fixed amount (for 1966, 1967, 1968, 1969, and 1970 by -300×10^{-10}). International Morse Code symbols for M300, representing minus 300, are transmitted from WWV and WWVH immediately following the "on-the-hour" voice announcement. WWVL transmits experimental programs with multiple frequencies. Transmissions presently alternate between 20.0 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. All three of the above stations are coordinated under the UTC (Universal Time Coordinated) system by the BIH.

Since WWVB transmits standard frequency without offset, no reminder is needeo. Broadcasts of this station are coordinated by the BIH under the Stepped Atomic Time (SAT) system. Step adjustments of 200 milliseconds are announced in advance for the first of a month when necessary to maintain the difference between the broadcast time and UT2 within about 100 milliseconds.

1.2. Standard Audio Frequencies

(a) Program

Standard audio frequencies of 440 Hz and 600 Hz are broadcast on each radio carrier frequency for WWV and WWVH. The audio frequencies are transmitted alternately at 5-min intervals starting with 600 Hz on the hour (fig. 1). The first tone period at WWV (600 Hz) is of 3-min duration. The remaining periods are of 2-min duration. At WWVH all tone periods are of 3-min duration. WWVB and WWVL do not transmit standard audio frequencies.

(b) Accuracy

The accuracy of the audio frequencies, as transmitted, is the same as that of the carrier. The frequency offset mentioned under 1.1 (c) applies. Changes in the propagation medium will sometimes result in fluctuations in the audio frequencies as received.

While 1000 Hz is not considered one of the standard radio frequencies, the time code which is transmitted 10 times an hour from WWV does contain this frequency and may be used as a standard with the same accuracy as the audio frequencies. The audio tones used for the Morse Code information prior to the voice announcements are not standard frequencies.

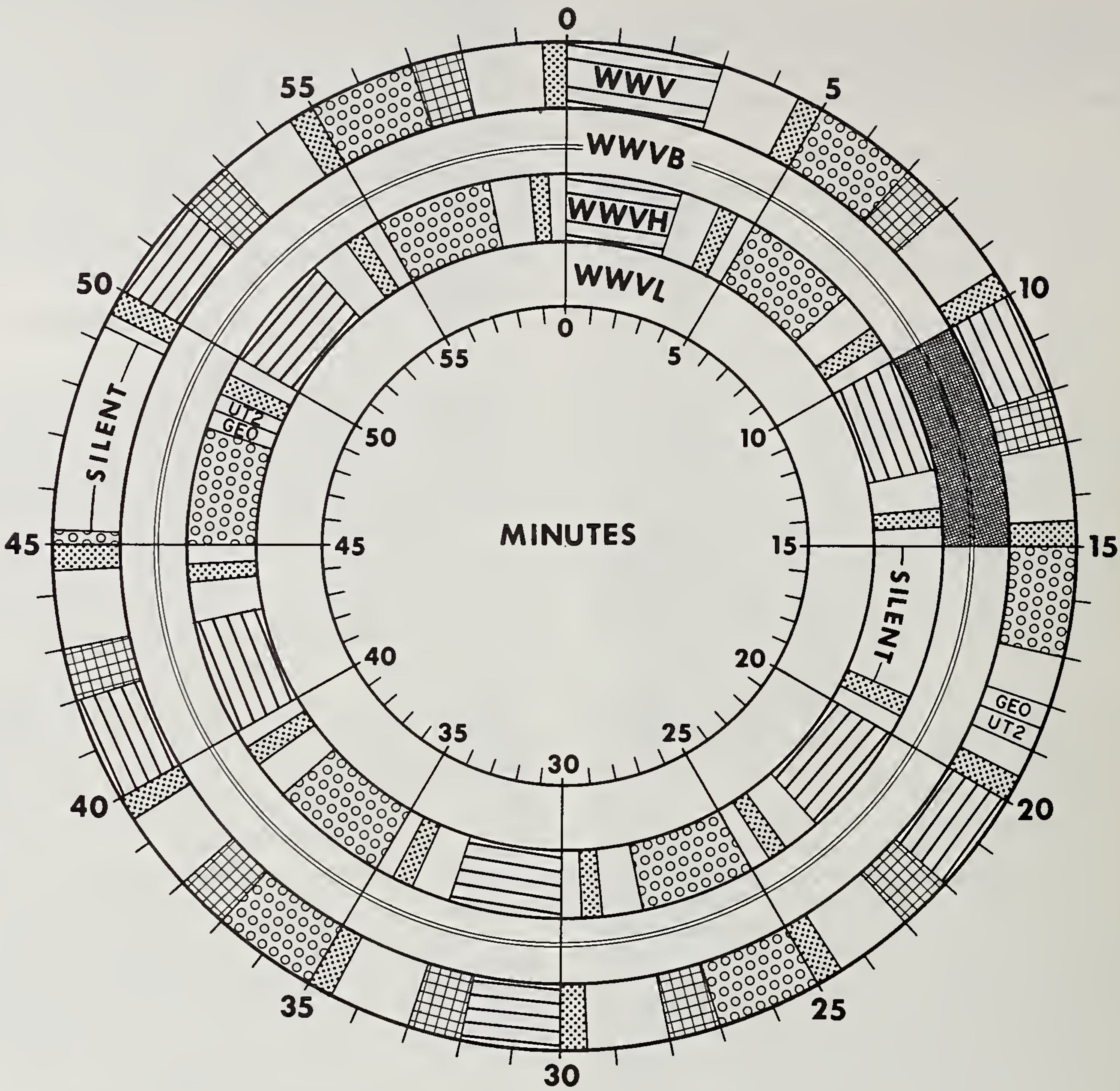
1.3. Standard Musical Pitch

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 periods of transmission of 440 Hz from WWV and WWVH are shown in figure 1. With this broadcast the standard pitch is maintained, and musical instruments are manufactured and adjusted in terms of this practical standard. The majority of musical instruments manufactured can be tuned to this frequency.

1.4. Standard Time Intervals

Seconds pulses at precise intervals are derived from the same oscillator that controls the radio carrier frequencies, i.e., they commence

HOURLY BROADCAST SCHEDULES OF WWV, WWVH, WWVB, AND WWVL



STATION ANNOUNCEMENT

WWV: Morse Code - Call letters; universal time; propagation forecast; frequency offset (on the hour only)

Voice - Greenwich mean time

WWVH: Morse Code - Call letters; universal time; frequency offset (on the hour only)

Voice - Greenwich mean time

WWVL, WWVB: - No station identification

100 pps 1000 Hz MODULATION WWV TIMING CODE

GEO GEOALERTS

UT2 UT2 TIME CORRECTION

TONE MODULATION 600 Hz

TONE MODULATION 440 Hz

IDENTIFICATION PHASE SHIFT

SPECIAL TIME CODE

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

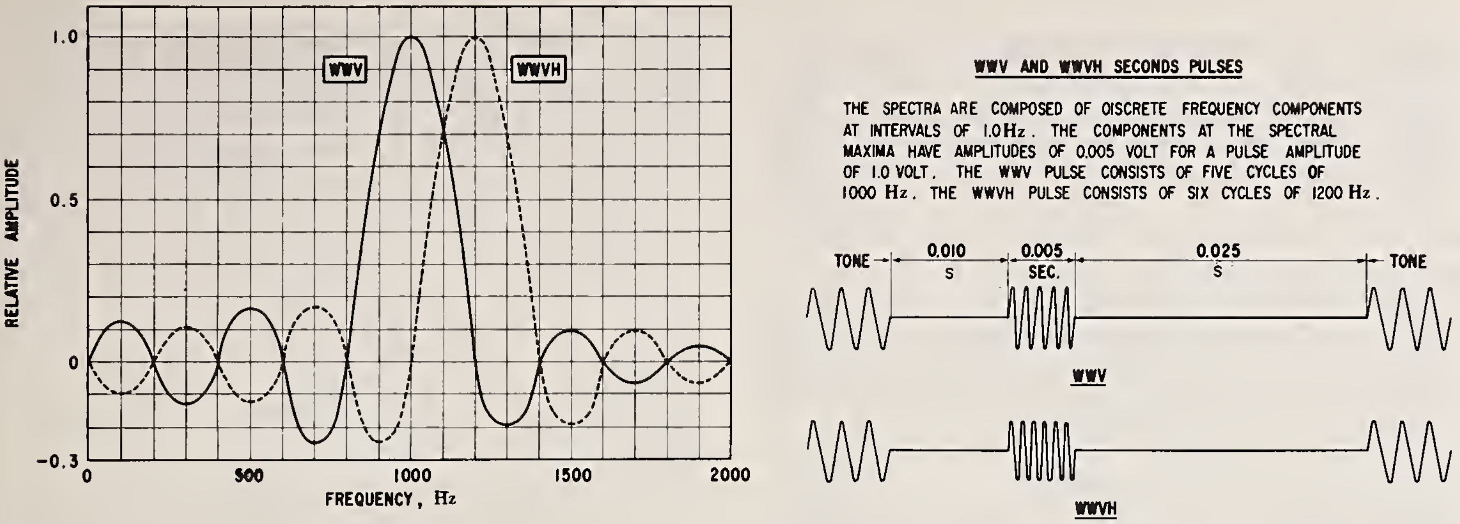


FIGURE 2. *Sample characteristics of time pulses broadcast from NBS radio stations WWV and WWVH.*

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. Intervals of 1 min are marked by the omission of the pulse at the beginning of the last second of every minute and by commencing each minute with two pulses spaced by 0.1 second.

The first pulse marks the beginning of the minute. The 2-min, 3-min, and 5-min intervals are synchronized with the seconds pulses and are marked by the beginning or ending of the periods when the audio frequencies are not transmitted. The pulse duration is 5 milliseconds. The pulse waveform is shown in figure 2. At WWV each pulse contains 5 cycles of 1000 Hz frequency. At WWVH the pulse consists of 6 cycles of 1200 Hz frequency. The pulse spectrum is composed of discrete frequency components at intervals of 1 Hz. The components have maximum amplitudes at approximately 995 Hz for WWV and 1194 Hz for WWVH pulses. The tone is interrupted 40 milliseconds for each seconds pulse. The pulse starts 10 milliseconds after commencement of the interruption.

WWVB transmits seconds pulses continuously using a special time code described in section 1.9. WWVL does not transmit seconds markers. However, accurate time intervals may be obtained directly from the carrier using appropriate techniques.

1.5. Time Signals

(a) Program

The audio frequencies are interrupted at precisely 3 min before each hour at WWV and 2 min before each hour at WWVH. They are resumed on the hour at WWV and WWVH, and at 5- and 10-min intervals throughout the hour as indicated in figure 1.

Universal Time, abbreviated UT after the given time (e.g., 1000 UT) is the time of a clock in the Coordinated Universal Time (UTC) system. This time is referenced to the Greenwich Meridian (longitude zero), and thus is also known as Greenwich Mean Time (GMT).

Time (GMT) is announced every five minutes from WWV and WWVH both in International Morse Code and by voice. The Morse Code announcements immediately precede the voice on both stations.

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. For example, at 1655 GMT, the four figures 1-6-5-5 are broadcast in code. The time announcement refers to the end of an announcement interval, i.e., to the time when the audio frequencies are resumed.

At station WWV a voice announcement of Greenwich Mean Time is given during the last half of every fifth minute during the hour. At 10:35 a.m. GMT, for instance, the voice announcement given in English is: "National Bureau of Standards, WWV, Fort Collins, Colorado; next tone begins at ten hours, thirty-five minutes Greenwich Mean Time."

At station WWVH a similar voice announcement of Greenwich Mean Time occurs during the first half of every fifth minute during the hour. It should be noted that the voice announcement for station WWVH precedes that of WWV by 30 seconds. However, the tones referred to in both announcements occur simultaneously, though they may not be so received due to propagation effects. In areas where both stations are received, sometimes the keying for WWV (which occurs prior to the WWV voice announcement) may be mistaken for the WWVH returning tone. It it were not for the WWV signal interference, the tone for WWVH would be heard 30 seconds after the WWVH voice announcement ended and there would be no misinterpretation.

Time-of-day information is given from WWVB using the time code described in section 1.9. Specialized equipment is needed for reception of this time code. WWVL does not transmit time-of-day information.

(b) Corrections

Time signals broadcast from WWV and WWVH are 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 made by an international committee. Differences between the time signals and UT2 are published periodically by the U.S. Naval Observatory.

Seconds pulses broadcast from WWVB will depart from UT2 at a different rate due to the fact that WWVB broadcasts 60 kHz with no offset (see 1.1(c)). Step time adjustments of 200 milliseconds will be 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.

(c) UT2 Corrections

Since a majority of time users do not require UT2 information to better than 100 milliseconds the systems described in 1.5(b) are quite satisfactory. An additional service is provided in cooperation with the U.S. Naval Observatory which makes available the best values of UT2 on a daily basis. Corrections to be applied to the time signals as broadcast are given in International Morse Code during the last half of the 19th min of each hour from WWV and during the last half of the 49th min of each hour from WWVH. Similar information is incorporated in the WWVB Time Code.

The symbols which are broadcast are as follows:

"UT2," then "AD" or "SU"

followed by a three-digit number. This number is the correction in milliseconds. To obtain UT2, add the correction to the time indicated by the Time Signal pulse if "AD" is broadcast. Subtract if "SU" is broadcast. Thus a clock, keeping step with the time signals being broadcast, will be early with respect to UT2 if "SU" is the symbol used. These corrections will be revised daily, 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, with a probable error of ±1 millisecond, are published in the Time Service Bulletins of the U.S. Naval Observatory.

1.6. Propagation Forecasts

A forecast of radio propagation conditions is broadcast in International Morse Code during the last half of every fifth minute of each hour on each of the standard frequencies from WWV. Propagation notices were first broadcast from WWV in 1946. The announcements each five minutes were commenced on November 15, 1963. The present type of propagation forecasts has been broadcast from WWV since July 1952. North Pacific forecasts were broadcast from WWVH from January 1954 until November 1964, but these are no longer available.

The WWV forecast announcements refer to propagation along paths in the North Atlantic Area, such as Washington, D.C. to London or New York City to Berlin. The announcements are the short term forecasts prepared by the ESSA Telecommunication Services Center, ESSA Research Laboratories, Institute for Telecommunication Sciences, Boulder, Colorado 80302. The regular times of issue of the forecasts are 0200, 0800, 1400, and 2000 UT for the period November 1 through April 30, and 0100, 0700, 1300, and 1900 UT for the period May 1 through October 31.

The forecast announcement tells users the condition of the ionosphere at the regular time of issue and the radio quality to be expected during the next six hours. The forecasts are based on data obtained from a worldwide network of geophysical and solar observatories. These data include radio soundings of the upper atomosphere, short wave reception data, observations of the geomagnetic field, solar activity, and similar information. Trained forecasters evaluate the information and formulate the forecasts using known sun-earth relationships.

WWV broadcasts the forecast as a letter and a number. The letter portion identifies the radio quality at the time the forecast is made. The letters denoting quality are "N", "U", and

"W", signifying that radio propagation conditions are either normal, unsettled, or disturbed, respectively. The number portion of the forecast announcement from WWV is the forecast of radio propagation quality on a typical North Atlantic path during the six hours after the forecast is issued. Radio quality is based on the ITS 1 to 9 scale which is defined as follows:

Grades of Propagation:
Disturbed (W)
Unsettled (U)
Normal (N)

Intelligibility Scale

1. useless	6. fair-to-good
2. very poor	7. good
3. poor	8. very good
4. poor-to-fair	9. excellent
5. fair	

If for example, propagation conditions are normal at the time the forecast is issued but are expected to become "poor-to-fair" during the next six hours, the forecast announcement would be broadcast as N4 in International Morse Code.

1.7. Geophysical Alerts

Letter symbols indicating the current geophysical alert (Geoalert) as declared by the World Warning Agency of the International Ursigram and World Days Service (IUWDS) are broadcast in very slow International Morse Code from WWV and WWVH on each of the standard radio carrier frequencies. These broadcasts are made from WWV during the first half of the 19th min of each hour and from WWVH during the first half of the 49th min of each hour. Such notices have been broadcast since the International Geophysical Year, 1957-58 and have continued by international agreement.

On January 1, 1968 a new coding system was instituted for broadcasting Geoalerts. This was necessary to make possible the dissemination of larger quantities of information resulting from improved techniques in observation and prediction of geophysical events. The coding was modified again on January 1, 1970. The symbols used indicate to experimenters and researchers in radio, geophysical, and solar sciences the content of the IUWDS Geoalert message which is issued daily at 0400 UT to identify days on which outstanding solar or geophysical events are expected or have occurred in the preceding 24-hour period.

Geoalerts for a given day are first broadcast at 0418 UT on station WWV, Fort Collins, Colorado, then at 0448 UT on station WWVH, Maui, Hawaii. These broadcasts are repeated at hourly intervals until the new alert is issued. Each message begins with the letters GEO in Morse Code followed by coded information. The new coding permits three types of information at each broadcast—each in the form of letters repeated three times in slow International Morse Code.

The first set concerns either alerts of possible solar or geophysical events or the *observation* of a stratospheric warming (STRATWARM), together with the alert of possible solar or geophysical events when appropriate. Letters which may occur in the first set and their meaning are as follows:

	EEE	(.)	No forecast (or STRATWARM observation) statement
	III	(..)	SOLALERT in effect which means one or several eruptive or active centers are present on the sun
	SSS	(...)	XRAYALERT or PROTONALERT is in effect
	TTT	(-)	MAGSTORM expected
1st letter	UUU	(..-)	SOLALERT and MAGALERT
	VVV	(...-)	PROTONALERT and MAGALERT
	HHH	(....)	STRATWARM observed
	DDD	(-..)	STRATWARM observed and SOLALERT
	BBB	(-...)	STRATWARM observed and PROTONALERT
	MMM	(--)	STRATWARM observed and MAGSTORM expected

The second and third sets of letters pertain to the occurrence of and approximate time of *observed* solar or geophysical events. The coding for the beginning time and type of event is shown in the table given below:

	Day before that of Issue (hours UT)				Day of issue	In Progress	NIL
	00-06	06-12	12-18	18-24	00-04		
2nd letter set: PROTON EVENT	MMM (- -)	TTT (-)	HHH (. . . .)	SSS (. . .)	III (. .)	GGG (- - .)	EEE (.)
3rd letter set: GEOMAGNETIC STORM	UUU (. . -)	AAA (. -)	BBB (- . . .)	DDD (- . .)	NNN (- .)	PPP (. - - .)	EEE (.)

For example, the following message (in International Morse Code)

GEO TTT EEE DDD

signifies: GEO = Solar geophysical message
TTT = Magstorm expected
EEE = No PROTON EVENT between 0000 UT yesterday and 0400 UT today
DDD = GEOMAGNETIC STORM occurred (began) between 1800-2400 UT yesterday

1.8. WWV Time Code

On January 1, 1961 WWV commenced broadcasting the time code shown in figure 3 for one minute out of each five, ten times an hour, as shown in figure 1.

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 a thousandth of a second. Astronomical observations may also benefit by the increased timing potential provided by the pulse-coded signals.

The code format being broadcast is generally known as the NASA 36-bit Time Code. The code is produced at a 100 pps rate and is carried on 1000 Hz modulation.

The code contains time-of-year information in Universal Time (GMT) 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 second contains 9 BCD groups in this order: 2 groups for seconds, 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 second. The binary groups follow the 1 second reference marker. "On time" occurs at the leading edge of all pulses.

The code contains 100/second clocking rate, 10/second index markers, and a 1/second reference marker. The 1000 Hz is synchronous with the code pulses so that millisecond resolution is readily obtained.

The 10/second index markers consist of "binary one" pulses preceding each code group except at the beginning of the second where a "binary zero" pulse is used.

The 1/second reference marker consists of five "binary one" pulses followed by a "binary zero" pulse. The second begins at the leading edge of the "binary zero" pulse.

The code is a spaced code format; that is, a binary group follows each of the 10/second index markers. The last index marker is followed by an unused 4-bit group of "binary zero" pulses just preceding the 1/second reference marker.

A "binary zero" pulse consists of 2 cycles of 1000 Hz amplitude modulation, and the "binary one" pulse consists of 6 cycles of 1000 Hz amplitude modulation. The leading edges of the time code pulses coincide with positive-going zero-axis-crossings of the 1000 Hz modulating frequency.

1.9. WWVB Time Code

(a) Code and Carrier

On July 1, 1965, Radio Station WWVB, Fort Collins, Colorado 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. The new system replaces the method whereby seconds pulses of uniform width obtained by level-shift carrier keying were broadcast. The carrier is no longer interrupted for keyed station identification.

(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

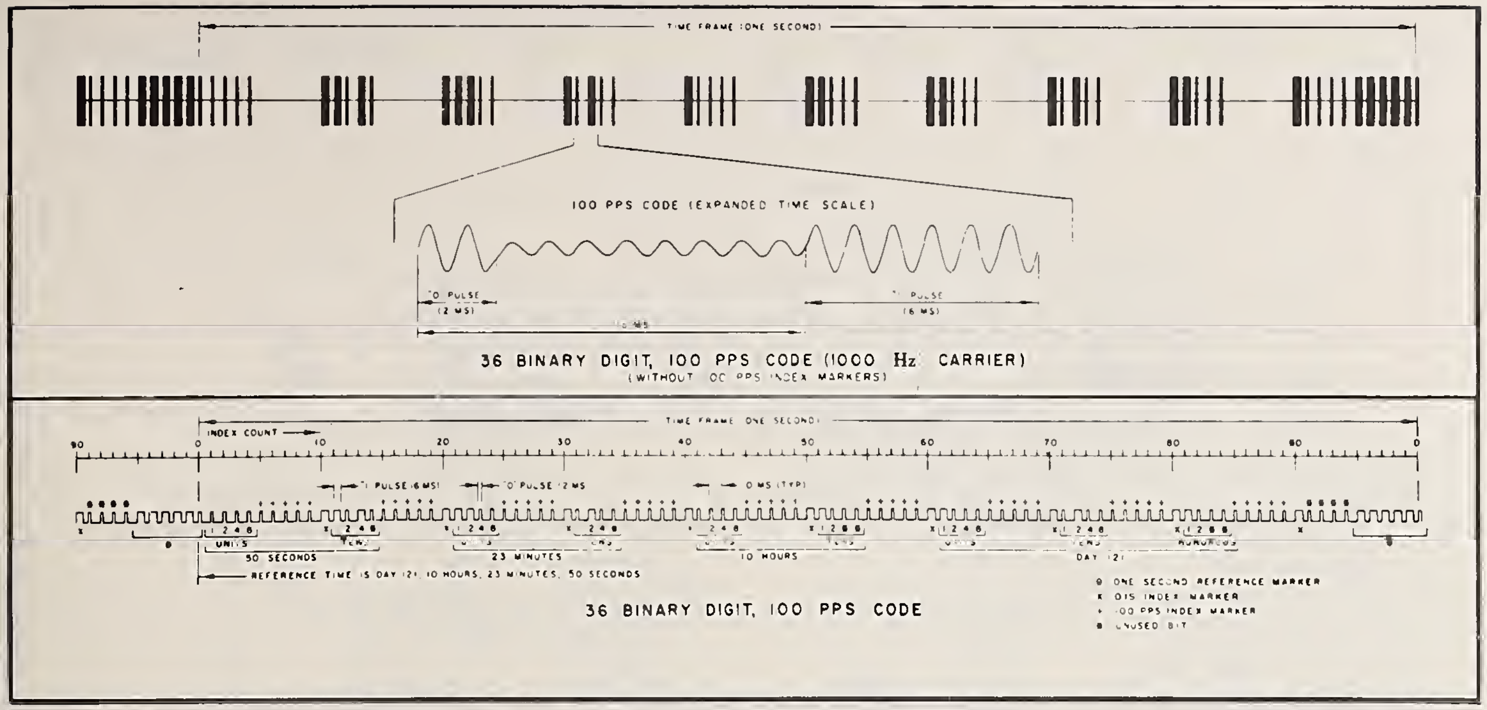


FIGURE 3. *Chart of time code transmissions from NBS radio station WWV.*

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 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. 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.

(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. 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 to 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 (subtract) 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 by the third group by 1.

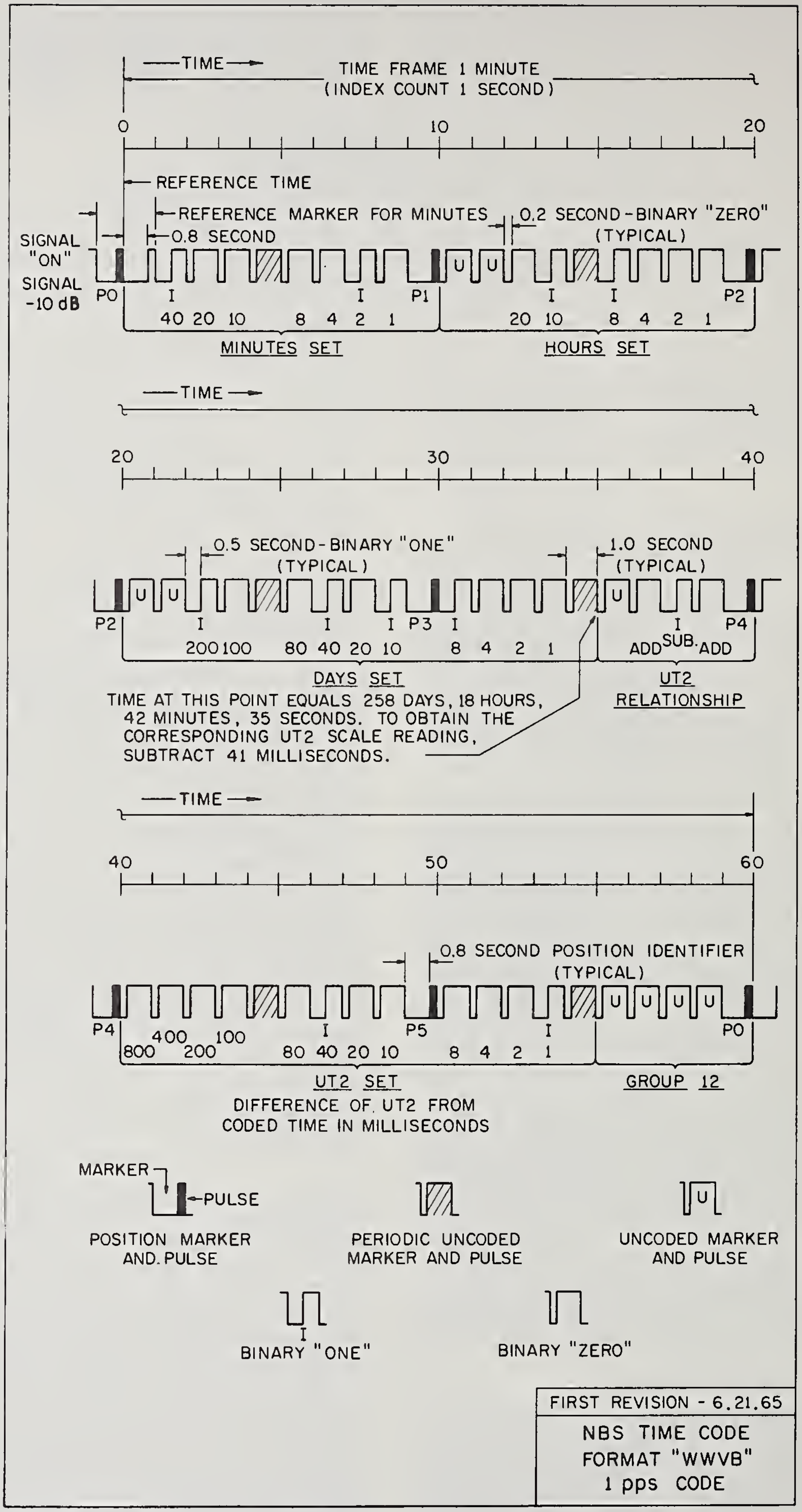


FIGURE 4. *Chart of time code transmissions from NBS radio station WWVB.*

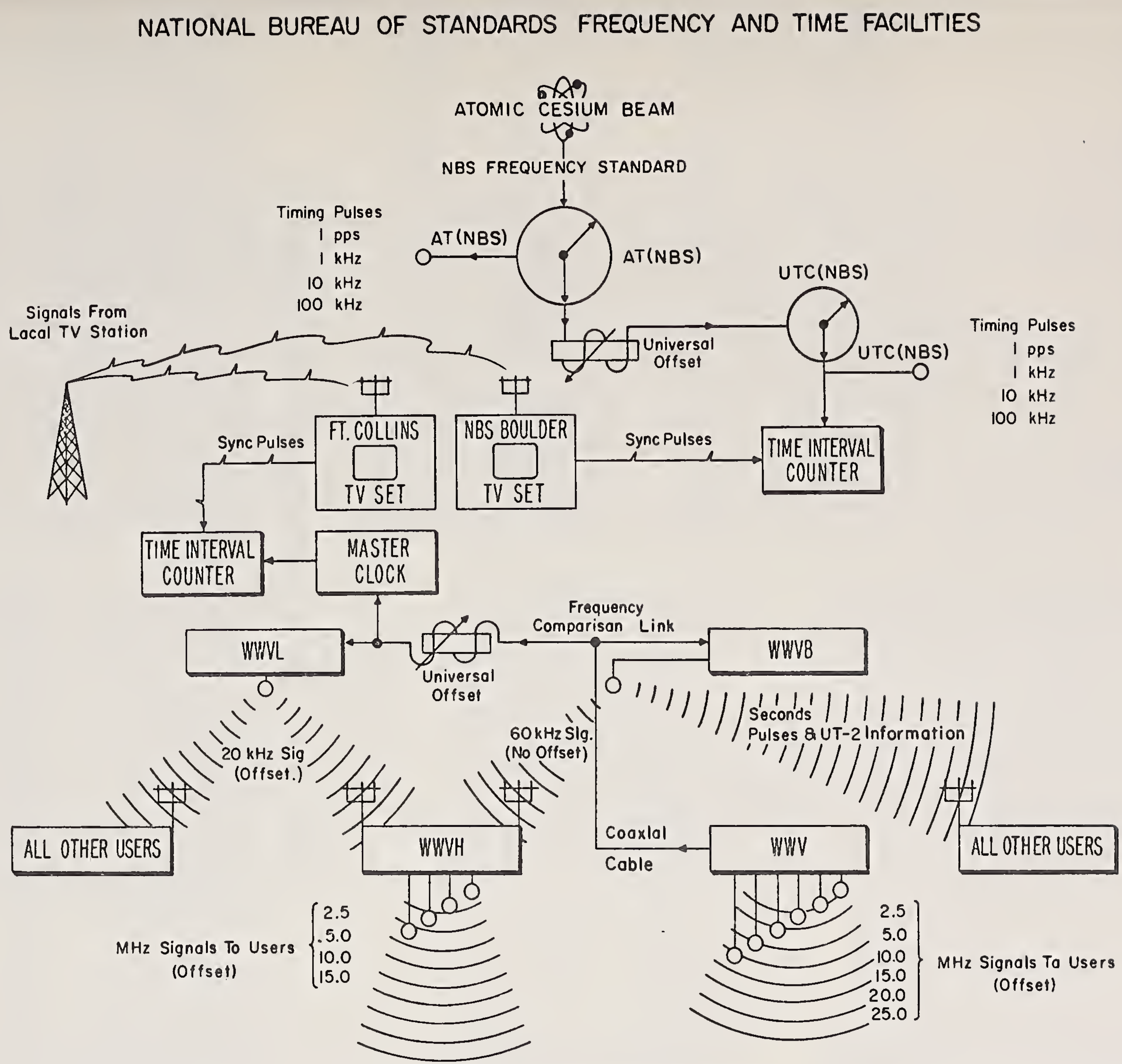


FIGURE 5. *NBS frequency control system.*

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 $35.000 - 0.041 = 34.959$.

1.10. Station Identification

WWV and WWVH identify by International Morse Code and voice (in English) every five minutes. The voice announcements are automatically synchronized magnetic-drum recordings, not live broadcasts. The announcer is Mr. Don Elliott of Atlanta, Georgia.

WWVL transmits no identification other than its unique format of alternating frequency every 10 seconds. WWVB identifies by its unique Time Code (see section 1.9) and by advancing the carrier phase 45° at 10 min after each hour and returning to normal phase at 15 min after each hour.

1.11. 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	1	—	—
5	10	2	—	—
10	10	2	—	—
15	10	2	—	—
20	2.5	—	—	—
25	2.5	—	—	—

(b) Transmitting Antennas

The broadcasts on 2.5 and 5 MHz from WWVH are from vertical quarter-wave antennas. The broadcasts on all other frequencies from WWVH and all frequencies from WWV are from vertical half-wave dipoles. WWV antennas are omnidirectional. Effective August 1, 1967 the WWVH antennas for 5, 10, and 15 MHz have directional reflectors providing additional gain in the westerly direction. The antennas used by WWVB and WWVL are 400-foot vertical antennas with capacity toploading.

(c) Modulation

At WWV and WWVH all modulation is double sideband amplitude, with 75 percent modulation on the steady tones and 100 percent modulation for seconds pulses and voice.

WWVB employs 10 dB carrier-level reduction for transmitting time information (see section 1.10).

WWVL uses no modulation. Various experimental techniques are being studied in an attempt to develop a good 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[5] 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 #8.[6] All other clocks and time-code generators at the site are then compared with this master clock. Frequency corrections of the WWVB and WWVL quartz crystal oscillators are based on their time or phase relative to the 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 oscillator controlling the transmitted frequencies and time signals is continuously compared with the received signals. Manual adjustments are then made to the controlling oscilla-

[5] J. B. Milton, Standard Time and Frequency: Its Generation Control, and Dissemination from the National Bureau of Standards Time and Frequency Division, Na. Bur. Stand. (U.S.), NBS Tech. Note 379, 30 pages (August 1969).

[6] J. Tolman, 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.

tor to compensate for the drift characteristic of quartz crystal oscillators.

To assure 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.

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards [1] was established by an act of Congress March 3, 1901. Today, in addition to serving as the Nation's central measurement laboratory, the Bureau is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To this end the Bureau conducts research and provides central national services in four broad program areas. These are: (1) basic measurements and standards, (2) materials measurements and standards, (3) technological measurements and standards, and (4) transfer of technology.

The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Radiation Research, 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 an Office of Measurement Services and the following technical divisions:

Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic and Molecular Physics—Radio Physics [2]—Radio Engineering [2]—Time and Frequency [2]—Astrophysics [2]—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; develops, produces, and distributes standard reference materials; relates the physical and chemical properties of materials to their behavior and their interaction with their environments; and provides advisory and research services to other Government agencies. The Institute consists of an Office of Standard Reference Materials and the following divisions:

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

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Office of Standard Reference Data—Clearinghouse for Federal Scientific and Technical Information [3]—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

NBS Fort Collins facility showing WWV transmitter building.

Antennas, transmitter building, and administrative buildings, WWVH, Maui, Hawaii.

WWVB/WWVL transmitter building and antennas.

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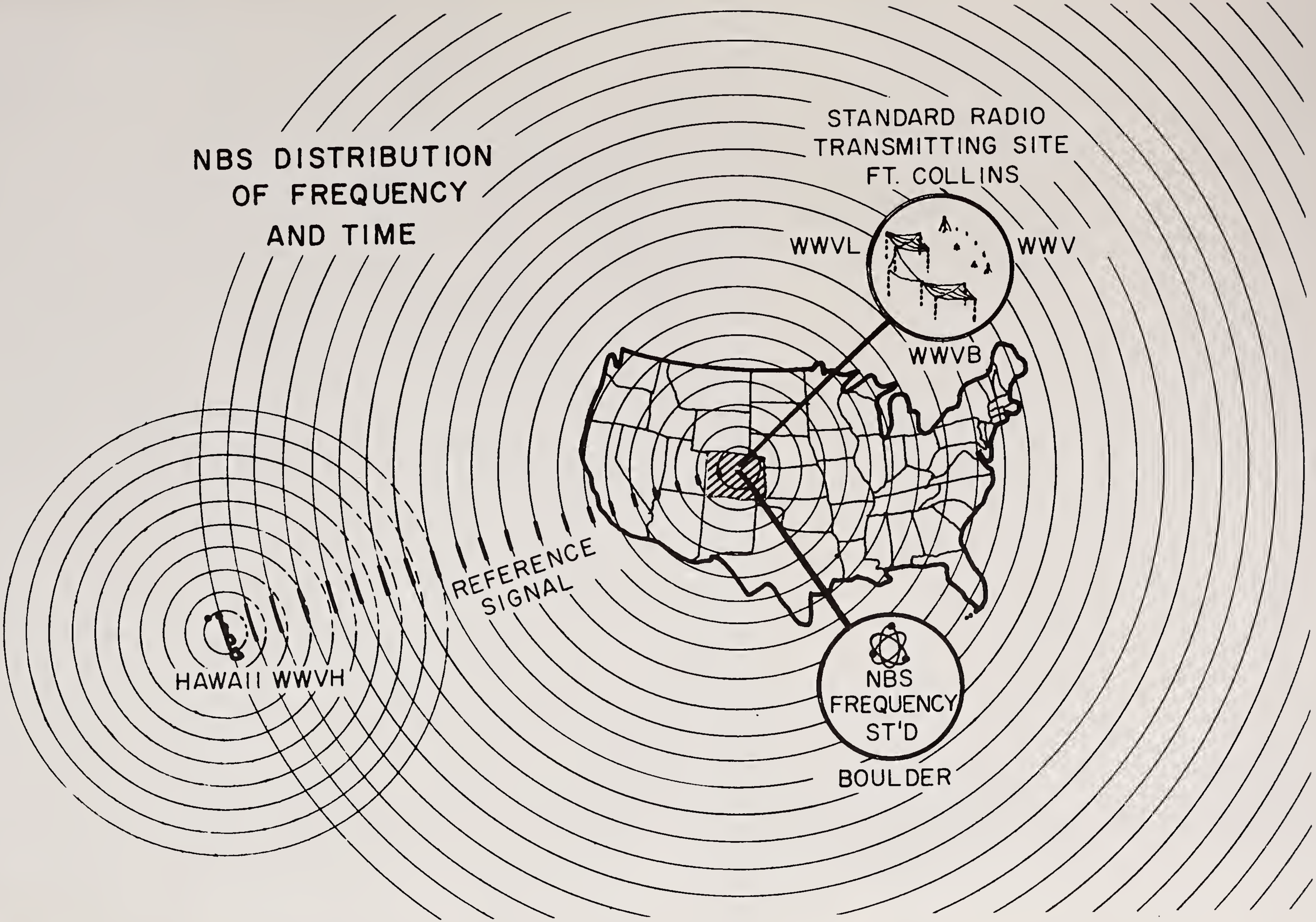
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WWV
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NBS SPECIAL PUBLICATION 236

1972 EDITION

A UNITED STATES DEPARTMENT OF COMMERCE PUBLICATION

NBS FREQUENCY AND TIME BROADCAST SERVICES

RADIO STATIONS WWV, WWVH, WWVB, WWVL

U.S. DEPARTMENT OF COMMERCE

National Bureau of Standards

Boulder Colorado

NATIONAL BUREAU OF STANDARDS

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

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[2] Part of the Center for Radiation Research.
[3] Located at Boulder, Colorado 80302.

UNITED STATES DEPARTMENT OF COMMERCE
PETER G. PETERSON, *Secretary*
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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

SPECIAL PUBLICATION 236, 1972 EDITION

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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.

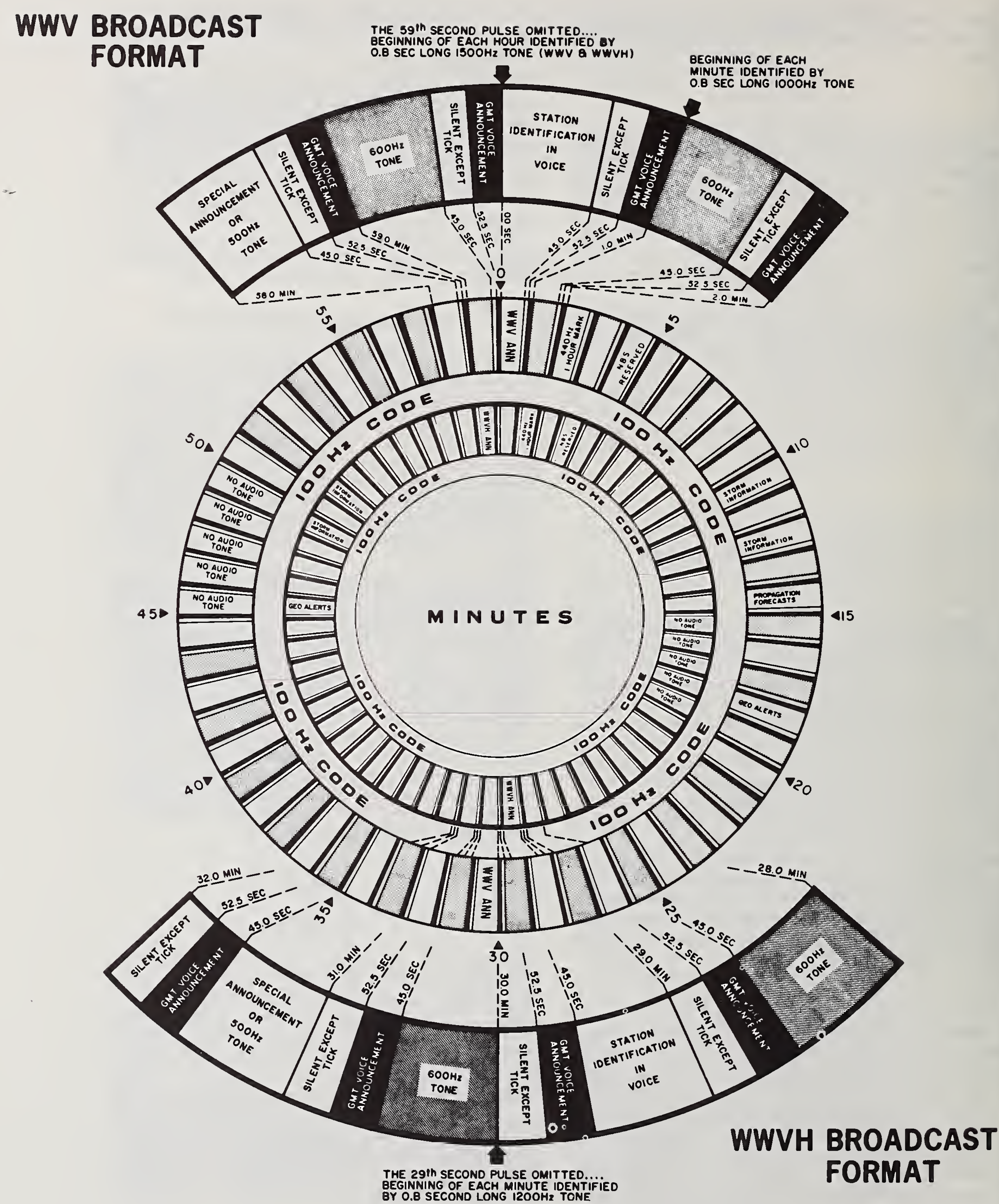


FIGURE 1. *The hourly broadcast schedules of WWV and WWVH.*

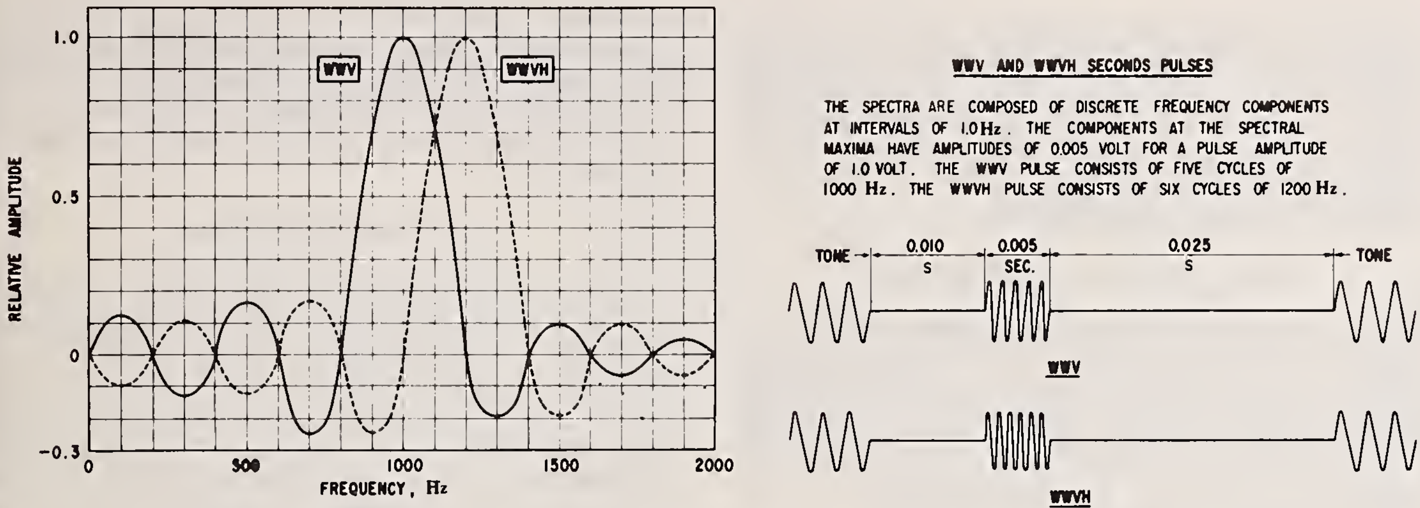


FIGURE 2. *Sample characteristics of time pulse broadcast from NBS radio stations WWV and WWVH.*

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 0.107-600 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.

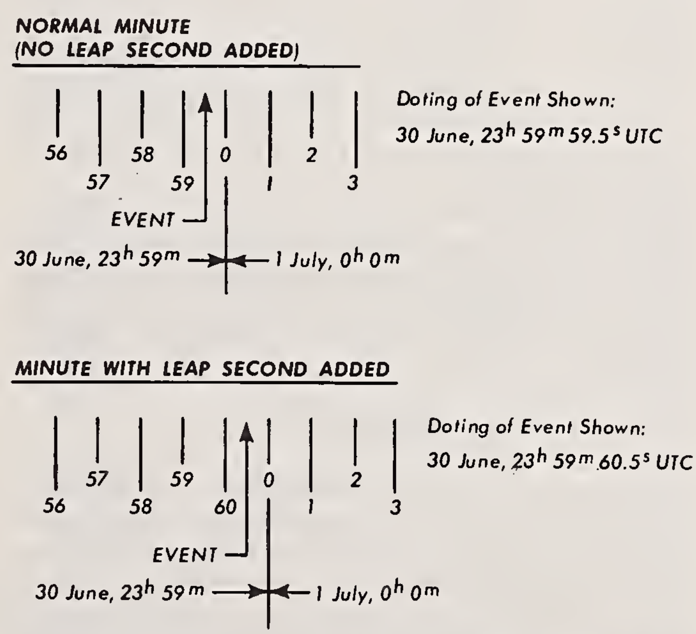


FIGURE 3. *Illustration of how events will be dated in the vicinity of a leap second.*

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.

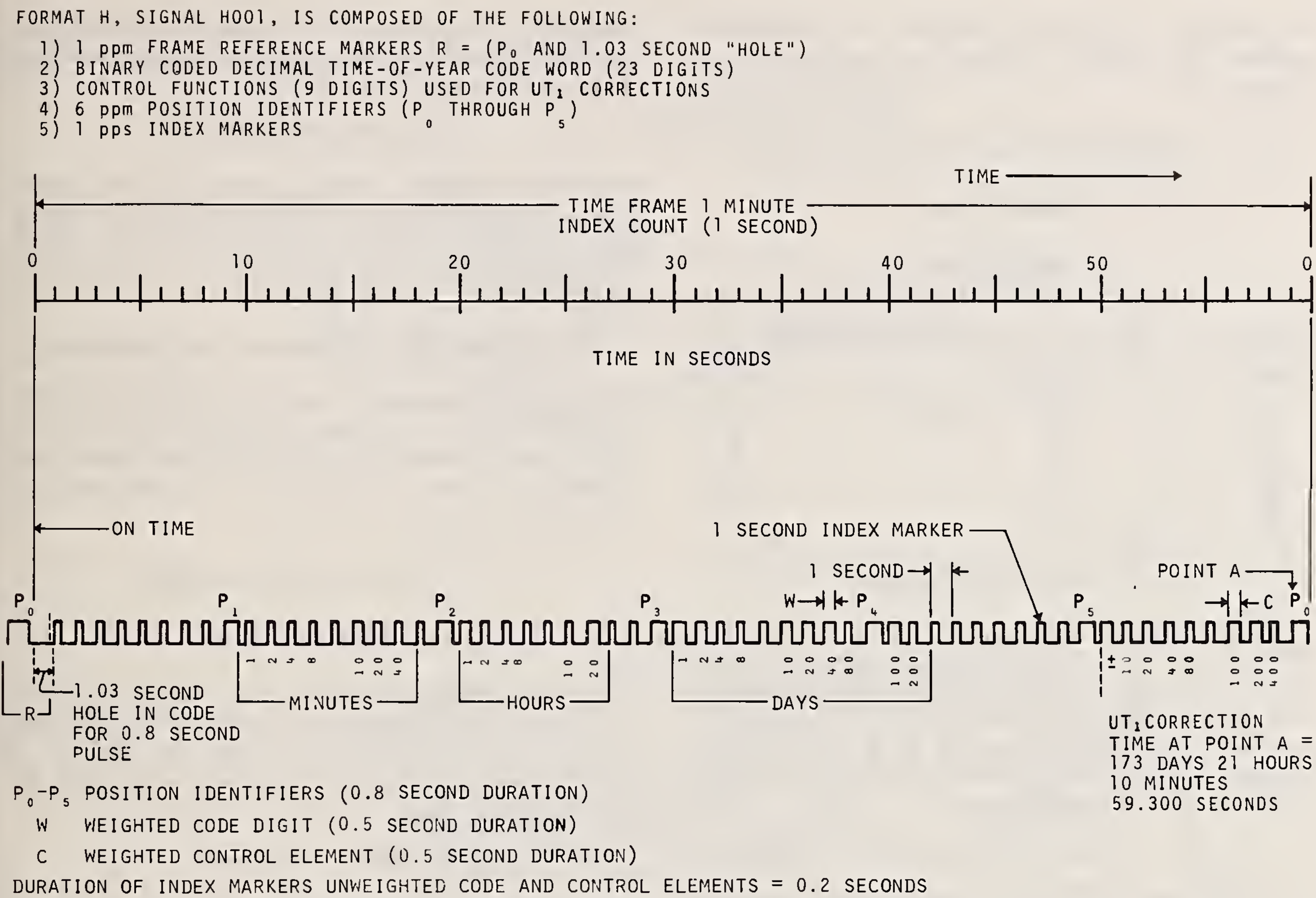


FIGURE 4. *Chart of time code transmissions from NBS radio stations WWV and WWVH.*

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, MHz	Radiated Power, kW 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.

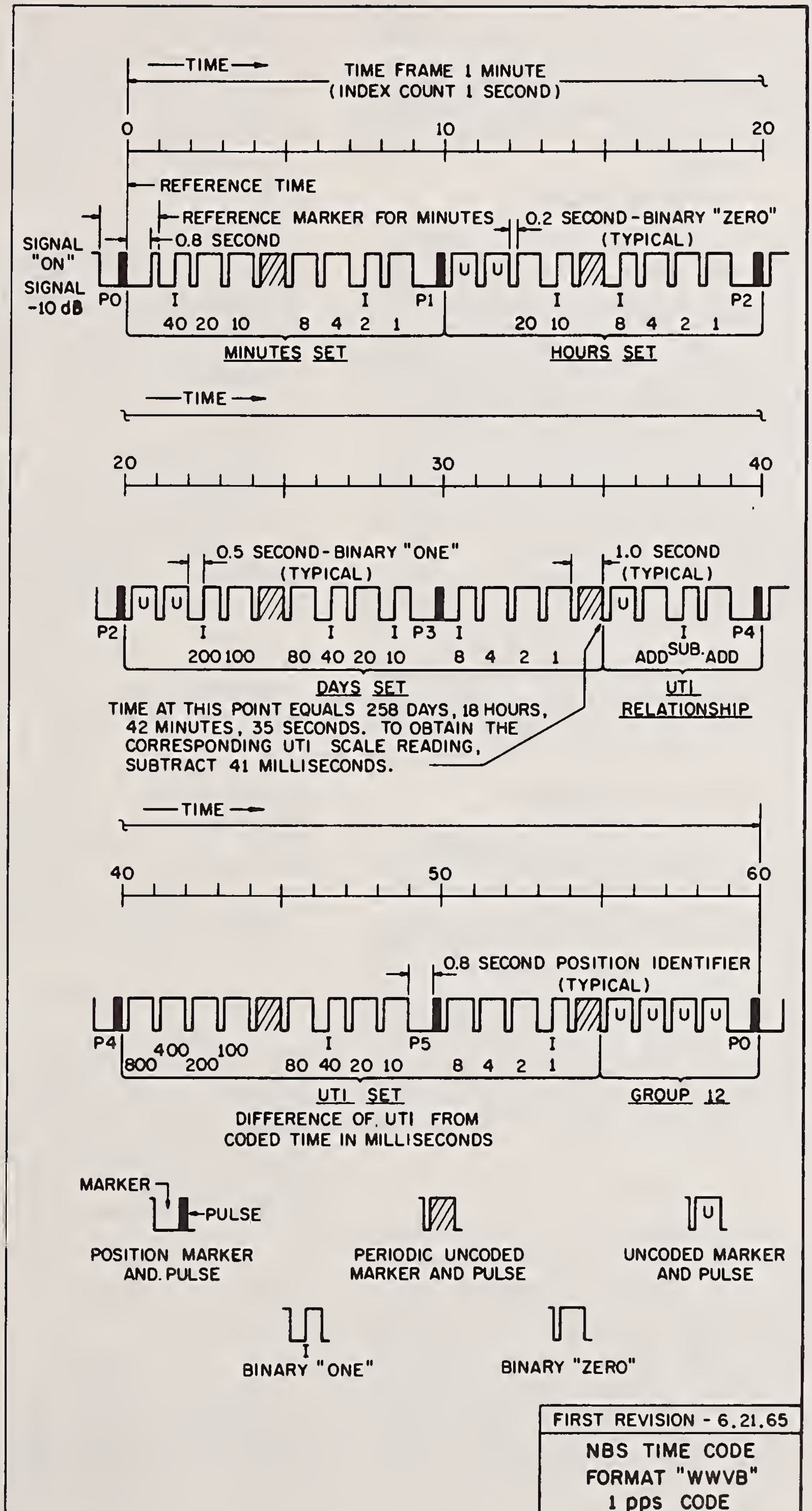


FIGURE 5. *Chart of time code transmissions from NBS radio station WWVB.*

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

[1] 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, (Aug. 1970).

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

[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.

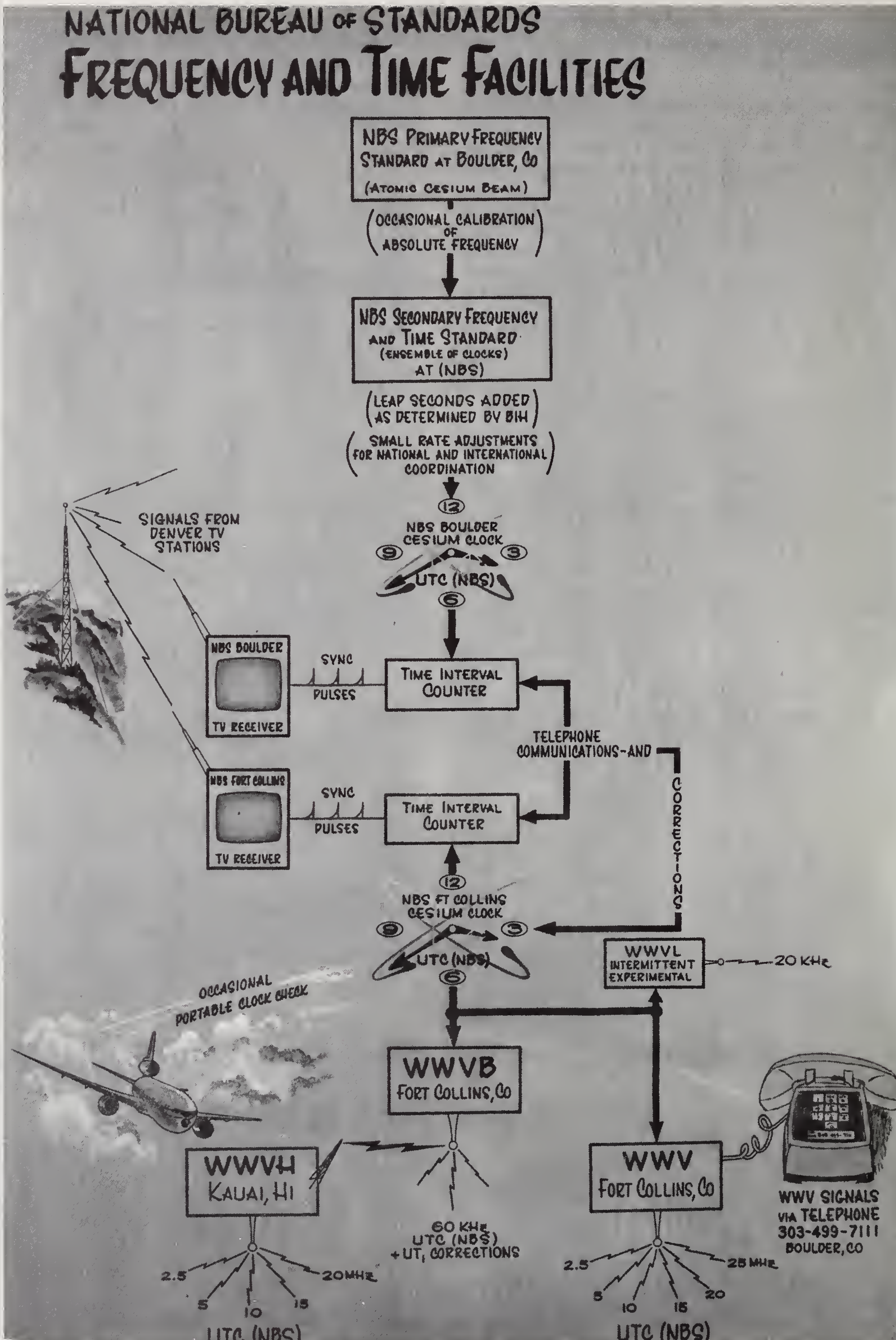
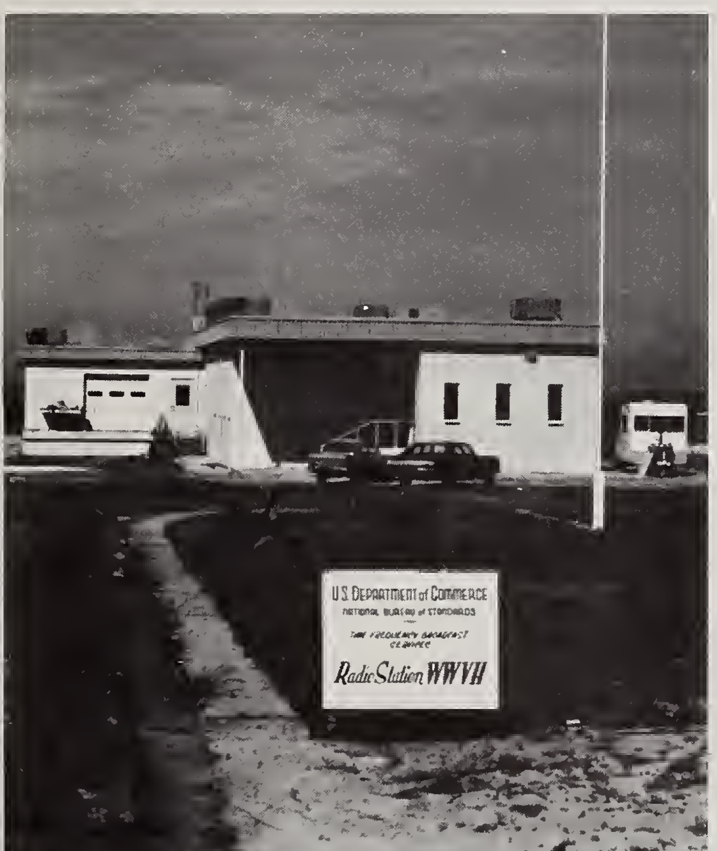


FIGURE 6. *NBS frequency control system.*

NBS Fort Collins facility showing WWV transmitter building.



WWVH transmitter building, Kekaha, Kauai, Hawaii.

WWVB/WWVL transmitter building and antennas.

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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.)

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.

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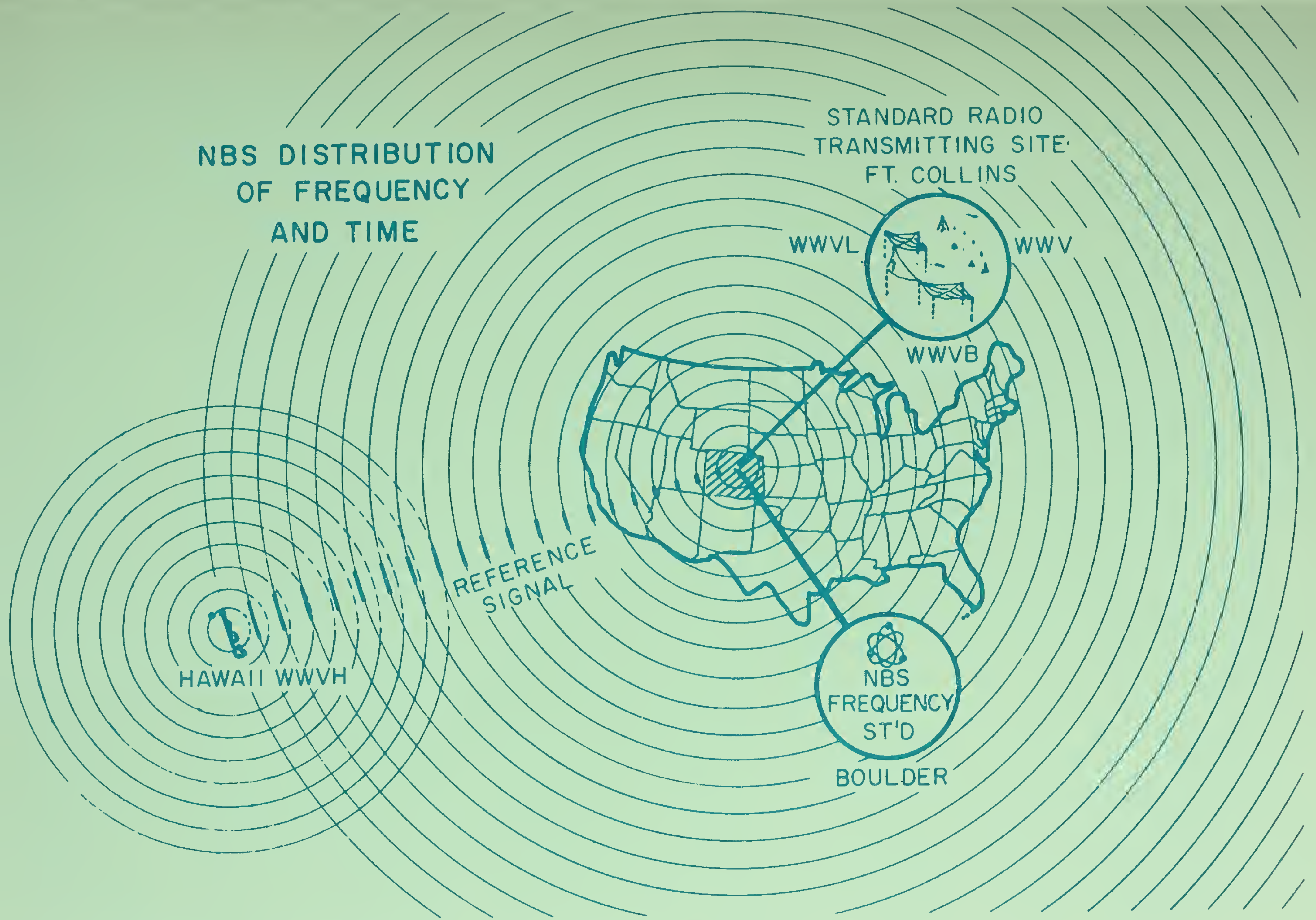

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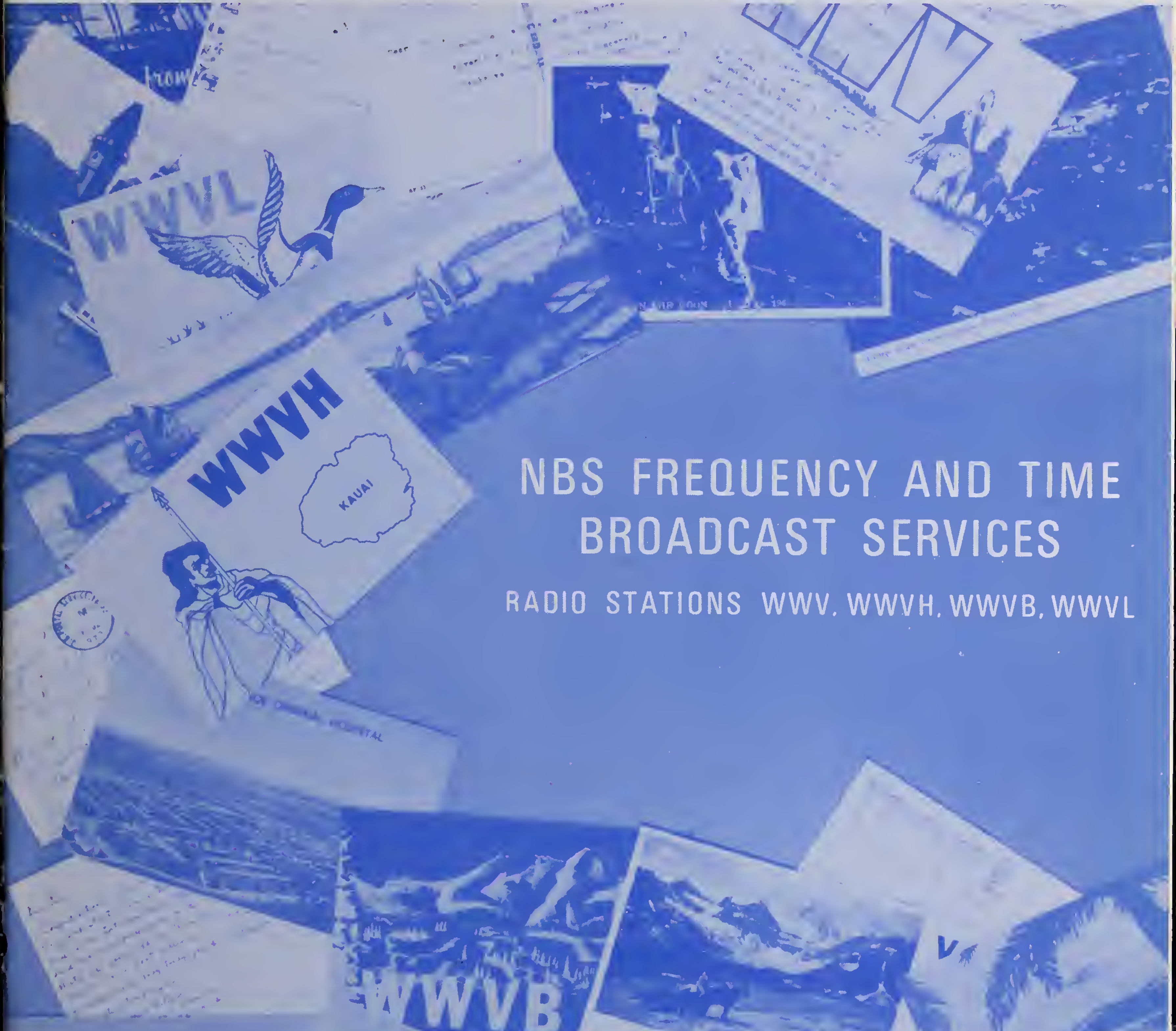

NBS FREQUENCY AND TIME BROADCAST SERVICES

RADIO STATIONS WWV, WWVH, WWVB, WWVL

U.S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

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 government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Institute for Computer Sciences and Technology, and the Office for Information Programs.

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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.
[4] Part of the Center for Building Technology.

NBS FREQUENCY AND TIME BROADCAST SERVICES

RADIO STATIONS WWV, WWVH, WWVB, and WWVL

Peter P. Viezbicke, Editor

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Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado 80302

U.S. DEPARTMENT OF COMMERCE, Frederick B. Dent, *Secretary*
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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 (NBS) 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, 1974. 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 notice 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 NBS started transmitting standard radio frequencies on a regularly announced schedule from radio station WWV. The WWV transmitter, originally located at NBS, Washington, D.C., has moved several times. Between 1931 and 1967 the station was moved successively to College Park, Beltsville, then 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; and improvement in radiation patterns obtained by location in a less congested area.

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

To supplement the coverage of WWV, broadcasts from WWVH, Hawaii, were instituted in 1948. These play an increasingly important role in various types of operations, both military and civilian, in the Pacific and Far East. 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 located at Fort Collins, Colorado, since July, 1963. Operations from WWVL were curtailed on July 1, 1972, and WWVL now broadcasts very low frequency (VLF) experimental programs only on an intermittent basis contingent upon need and funds. WWVB, transmitting on low frequency (LF), provides widespread distribution of the NBS frequency and time scale. The WWVB broadcasts are used to coordinate operations of continental networks of missile and satellite stations and to provide a highly accurate standard of frequency that is readily available to many users for electronic research and development. WWVB serves as a national time and frequency reference for many U.S. electric utilities and as a timing reference by government contractor groups for a large number of sensing stations which monitor seismological events.

Thus, in the 51 years since the beginning of its radio broadcasts, NBS has expanded these services so that they are 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 services to thousands of listeners.

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

Correspondence pertaining directly to station operations may be addressed to:

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NBS Radio Stations WWV/WWVB/WWVL
2000 East County Road 58
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) 335-4361

[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, CO 80302.

1. WWV and WWVH Broadcast Services

1.1. Standard Radio Frequencies

(a) Program

Both WWV and WWVH transmit frequencies and time coordinated through the Bureau International de l' Heure (BIH), Paris, France, in accord with international agreements. Transmissions are based upon the international time scale, Coordinated Universal Time (UTC).

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 of both stations are continuous, day and night.

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.

Similar time-of-day broadcasts from WWVH can be heard by dialing (808) 335-4363 on the Island of Kauai.

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 NBS. Relative to the primary frequency standard of NBS, there are very small intentional offsets for coordination purposes, which may be of the order of one part in 10^{12}. Up-to-date information on these small offsets can be obtained from the monthly Time and Frequency Services Bulletin.

Atomic frequency standards have been shown to provide the defined ideal cesium frequency to within a few parts in 10^{13}. For example, the present NBS frequency standard, NBS-5, and time scale system provides this frequency to an uncertainty of about 2 parts in 10^{13} [1][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 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}. Frequency measurements in terms of the NBS standard between December 1, 1957 and January 1, 1960 need to take the above correction into account [2].

All carrier and modulation frequencies at WWV and WWVH are derived from cesium-controlled oscillators and are accurate to within ± 1 part in 10^{11}. Deviations are normally less than 1 part in 10^{12} from day to day.

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

(c) Corrections

In conformity with the UTC scale, the carrier and modulation frequencies of WWV and WWVH are no longer offset significantly from nominal values. At the recommendation of the International Radio Consultative Committee (CCIR), the frequency offset of UTC was made permanently zero relative to International Atomic Time (TAI) effective 0000 hours UTC January 1, 1972. Previously, the fractional frequency offset was —150 parts in 10^{10} during 1960 and 1961; —130 parts in 10^{10} during 1962 and 1963; —150 parts in 10^{10} during 1964 and 1965; and —300 parts in 10^{10} from 1966 through 1971.

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

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 transmitted continuously from WWV and WWVH does contain this frequency and may be used as a standard with the same accuracy as the audio and radio frequencies.

1.3. Standard Musical Pitch

The frequency 440 Hz for the note A above middle C, is the standard of 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

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. Every 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

Effective 1 January 1974, WWV and WWVH began broadcasting voice announcements of Coordinated Universal Time (UTC) in lieu of Greenwich Mean Time (GMT) [3].

More precisely, the actual reference time scale is the Coordinated Universal Time Scale maintained by the National Bureau of Standards, UTC(NBS). The UTC(NBS) scale includes very small frequency offsets relative to the NBS primary frequency standard for coordination purposes as mentioned in section 1.1.(b).

The 0 to 24 hour system is used starting with 0000 for midnight at the Greenwich Meridian (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 next 800-millisecond tone begins after the announcement.

Standard time zones are established at intervals of 15° longitude east and west of the zero meridian. Local standard time differs from UTC by an integral number of hours. For example, as shown in figure 4, Eastern Standard Time (EST) is obtained by subtracting 5 hours from UTC or the time broadcast. Conversely, UTC is obtained from EST by adding 5 hours.

At WWV a voice announcement of the time is given during the 7.5 seconds immediately preceding the minute. Just before 1035 UTC, for instance, the voice announcement given is: "At the tone—ten hours, thirty-five minutes Coordinated Universal Time."

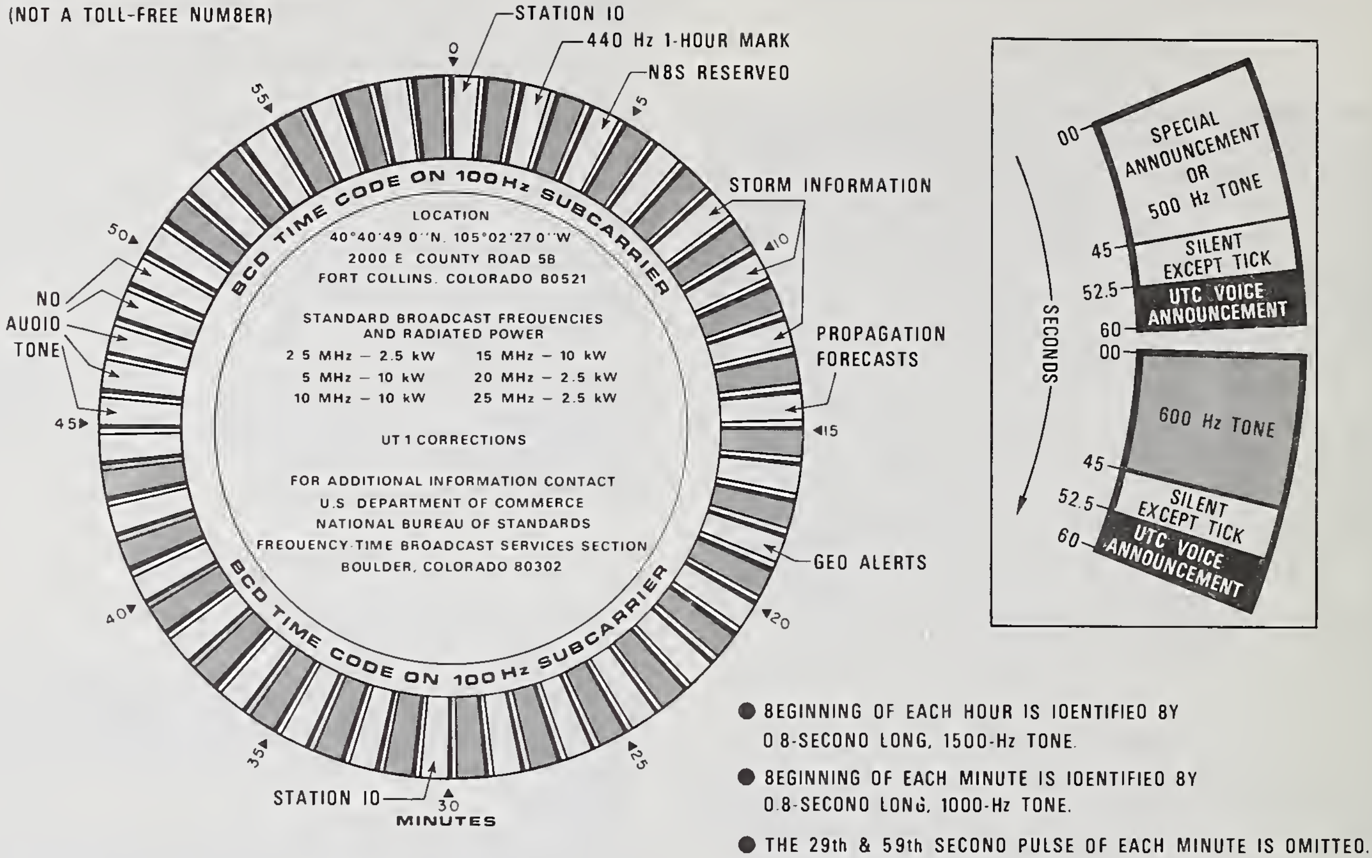
At WWVH a voice announcement of the time is given at 15 seconds preceding the minute. It should be noted that the voice announcement for WWVH precedes that of WWV by about 7.5 seconds. However, the tone markers referred to in both announcements are

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

WWV BROADCAST FORMAT

U.S DEPARTMENT OF COMMERCE
National Bureau of Standards

VIA TELEPHONE: (303) 499-7111
(NOT A TOLL-FREE NUMBER)



WWVH BROADCAST FORMAT

VIA TELEPHONE (808) 335-4363 (NOT A TOLL-FREE NUMBER)

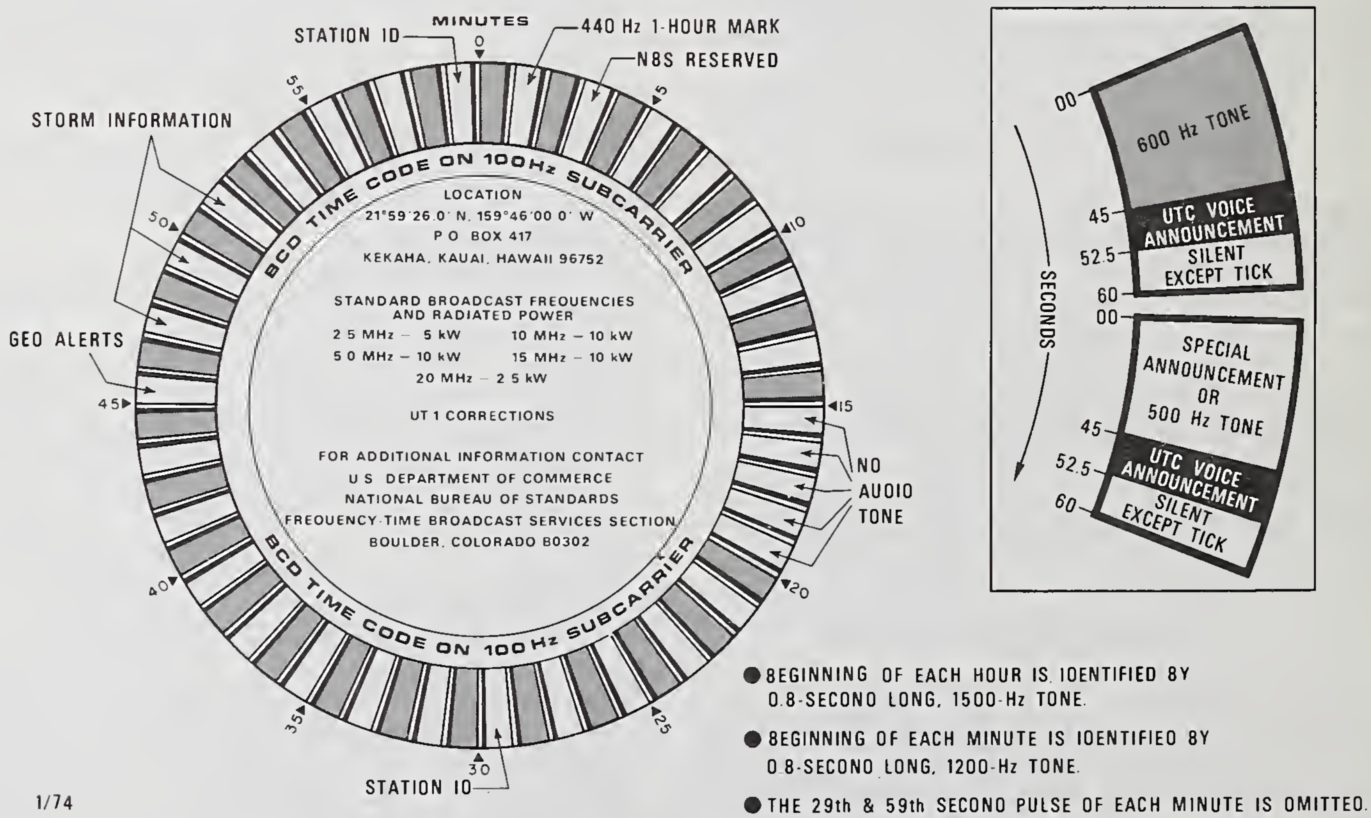


FIGURE 1. *The hourly broadcast schedules of WWV and WWVH.*

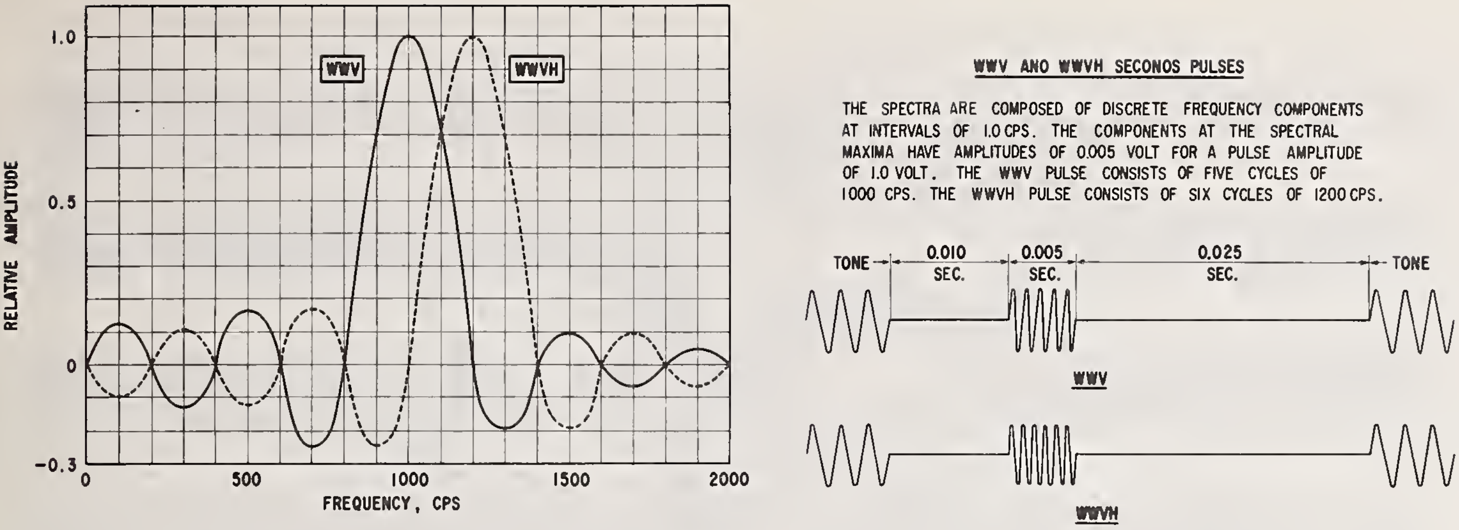


FIGURE 2. *Sample characteristics of time pulse broadcast from NBS radio stations WWV and WWVH.*

transmitted simultaneously, though they may not be received so because of 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 31, 1971 at 23 h 59m 60.107600s UTC, the UTC (NBS) scale was retarded 0.107600 second to give it an initial difference of exactly 10 seconds late with respect to the International Atomic Time (TAI) scale as maintained by BIH.

Since the new UTC rate (effective January 1, 1972) is no longer adjusted periodically to agree with the earth's rotation rate, UTC departs more rapidly than before from earth rotation time (known as UT1), gaining about 1 second per year. Corrections to UTC are now made in step adjustments of exactly 1 second (called a leap second) as directed by BIH. The leap second adjustments ensure that UTC signals as broadcast will never differ from UT1 by more than about ±0.7 second. (Note: the corrections no longer relate to UT2.) BIH announces the occurrence of a leap second two months in advance.

The leap second adjustments are made as necessary at the end of the UTC month, preferably on 31 December or 30 June. Thus, when required, a leap second is 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.[4] This is analogous to adding an extra day (which could be called a leap day) during a leap year. Figure 4 illustrates how events are dated in the vicinity of a leap second.

A positive leap second was inserted in the transmissions of all NBS broadcast stations at the end of June 1972, December 1972 and December 1973, as announced by BIH. As a result, during 1974, UTC will differ from TAI by exactly 13 seconds.

(c) Coding of UT1 Corrections

To satisfy time signal users who need to date events on the UT1 time scale to better than ± 0.7 seconds, coded corrections are provided in the broadcast formats giving UT1-UTC values to a resolution of 0.1 seconds.

The method of coding UT1 corrections uses a system of double seconds pulses. The first through the seventh seconds pulses, when doubled, indicate a "plus" correction, and from the ninth through the fifteenth a "minus" correction. The eighth seconds pulse is not

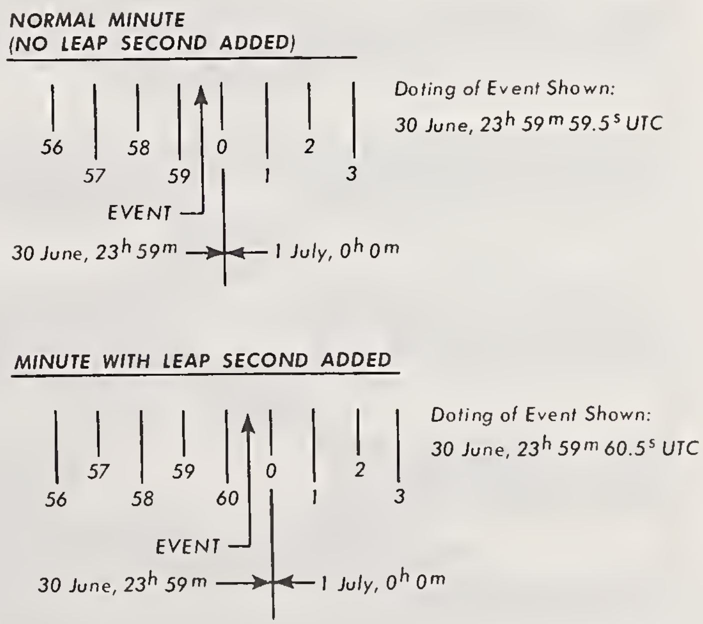


FIGURE 3. *Illustration of how events are dated in the vicinity of a leap second.*

[4] During the minute in which a one-second step correction occurs, that minute will contain either 59 or 61 seconds depending on whether the correction is negative or positive.

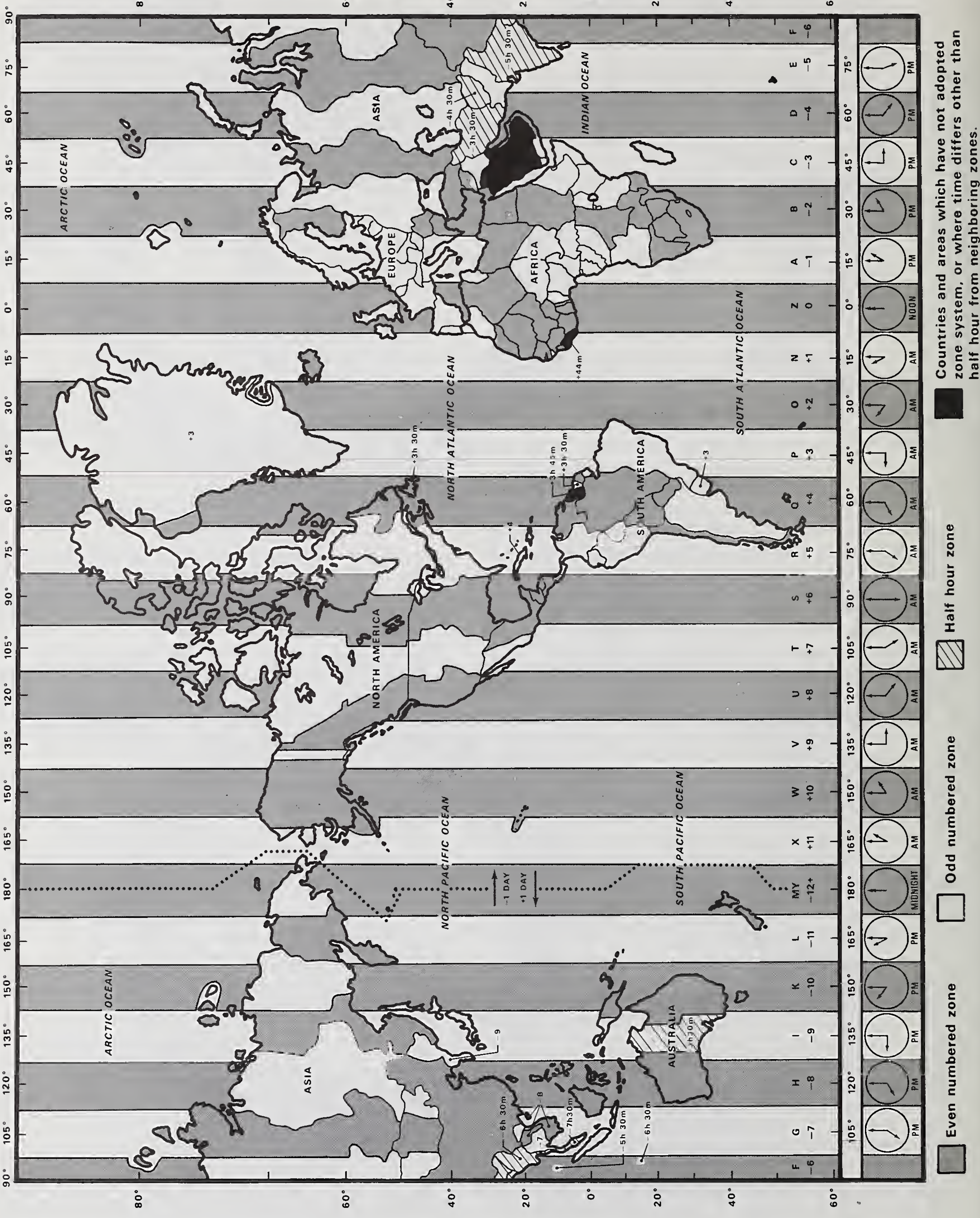


FIGURE 4. *Standard Time Zones of the World.*

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 algebraic relationship.

$$\text{UT1} = \text{Broadcast} + \text{Correction}$$

That is, add the numerical correction to the time broadcast if "plus" 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.

UT1 corrections are also encoded in the time code (sec. 1.7) transmitted continuously on a 100-Hz subcarrier from WWV and WWVH. The value of the correction is indicated by the weight of the control functions that occur at the end of the code frame. The "plus and minus" indication is encoded in the first control function. If control function #1 is a binary one, the correction is positive; if it is a binary zero, the correction is negative. The correction is expressed 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 NBS.

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 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 from WWV at 14 minutes after every hour. 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 Telecommunications Services Center, OT, Boulder, Colorado.[5]

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)."

The propogation forecast announcements are repeated in synoptic form comprised of a phonetic and a numeral. The phonetic (Whiskey, Uniform, or November) identifies the radio quality at the time the forecast is made. The numeral indicates on a scale of 1 to 9 the radio propagation quality expected during the six-hour period after the forecast is issued. The meaning of the phonetics and numerals are:

Phonetic	Meaning
Whiskey	disturbed
Uniform	unsettled
November	normal

Numeral	Meaning
One	useless
Two	very poor
Three	poor
Four	poor-to-fair
Five	fair
Six	fair-to-good
Seven	good
Eight	very good
Nine	excellent

If, for example, propagation conditions are normal and expected to be good during the next six hours, the coded forecast announcement would be "November Seven."

(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 from WWV at 18 minutes after each hour and from WWVH at 45 minutes after each hour. 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 during the previous 24 hours. Messages concerning these forecasts are prepared by the Space Environment Laboratory, NOAA, Boulder, Colorado.[6]

(c) Weather Information

Weather information about major storms in the Atlantic and Pacific areas is broadcast from WWV and

[5] For details regarding these forecasts, write J. P. Murray OT/ITS, Boulder, CO 80302.

[6] For details of these announcements, write R. B. Doeker, Chief, Space Environment Services Center, NOAA, Boulder, CO 80302.

WWVH respectively.[7] 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, 1700, and 2300 UTC for WWV and 0000, 0600, 1200, and 1800 UTC for 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 eastern North Pacific, whereas WWVH lists storms in the eastern and central parts of the North Pacific. These broadcasts are given in voice from WWV at 8, 10, and 12 minutes after each hour and from WWVH at 47, 49 and 51 minutes after each hour.

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 West at 1700 UTC: Hurricane Donna, intensifying, 24 North, 60 West, moving northwest, 20 knots, winds 75 knots; storm, 65 North, 35 West, moving east, 10 knots, winds 50 knots, seas 15 feet."

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

1.7. WWV/WWVH Time Code

On July 1, 1971, WWV commenced broadcasting the time code shown in figure 5. 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 a modified IRIG-H time code. The code is produced at a 1-pps rate and is carried on 100-Hz modulation. The 100-Hz subcarrier is synchronous with the code pulses so that 10-millisecond resolution is readily obtained.

The code contains UTC time-of-year information in minutes, hours, and day of year. Coded time-of-day information refers to time at the beginning of the frame. Seconds information may be obtained by counting pulses.

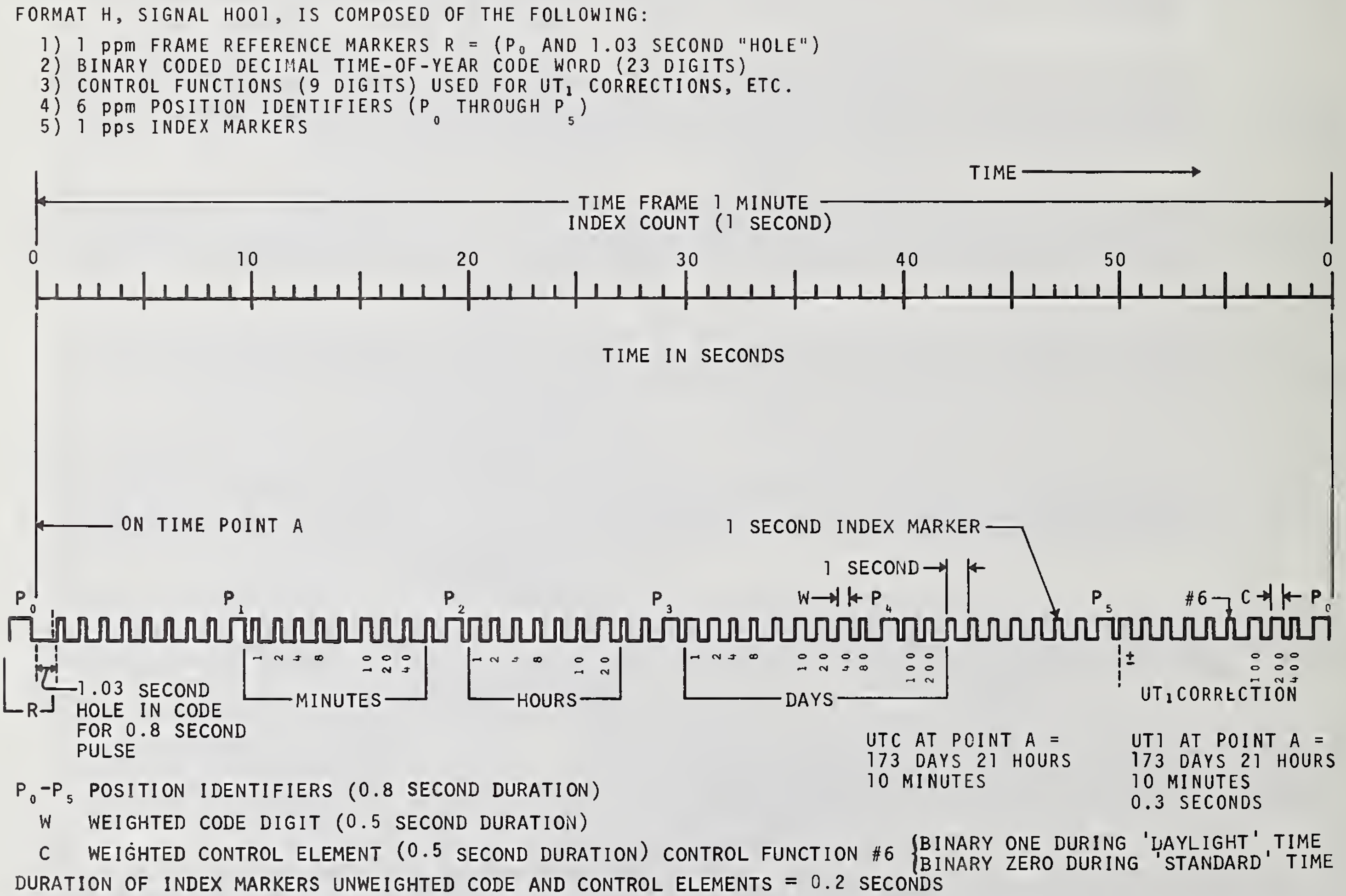


FIGURE 5. *Chart of time code transmissions from NBS radio stations WWV and WWVH.*

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.

In the standard IRIG-H format, "on-time" occurs at the leading edge of all pulses. A binary zero pulse comprises 20 cycles of 100-Hz amplitude modulation: a binary one pulse comprises 50 cycles of 100-Hz amplitude modulation. Because of the 10-millisecond hole that accompanies each seconds marker in the WWV/WWVH format, however, the leading 30-millisecond portion of each marker in the WWV/WWVH time code is deleted. The leading edge of each pulse coincides with a positive-going zero-axis crossing of the 100 Hz modulating frequency.

Based upon a clocking rate of 60 markers per minute, the code contains six position identification markers per minute and a minute reference marker. Each 6-per-minute position identification marker consists of an 0.8-second pulse preceding a code group. The 1-per-minute reference marker consists of a 0.8-second pulse followed by a 1.03-second hole in the code and eight binary zero pulses in succession. The minute begins with the 1.03-second hole preceding the first binary zero.

UT1 corrections to the nearest 0.1 second are encoded via control function pulses during the final ten seconds of the frame. Control function #1, which occurs as the 50th second pulse, discloses the sense of the correction. Control function #1 is a binary zero when the UT1 correction is negative and a binary one when the corrections is positive. Control function #7, #8, and #9, which occur as the 56th, 57th, and 58th second pulses, identify the magnitude of the UT1 correction.

Control function #6, which occurs as the 55th second pulse, is programmed as a binary one throughout those weeks when Daylight Saving Time is in effect and as binary zero when Standard Time is in effect. The setting of this function is changed at 0000 UTC on the date of change as specified by Congress. Throughout the U.S. mainland this schedule allows several hours for the function to be received before the change becomes effective locally, i.e., at 2:00 AM. Thus control function #6 provides a feature through which clocks or digital recorders operating on local time can be programmed to make an automatic one-hour adjustment in changing from Daylight Saving Time to Standard Time and vice versa.

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, Geogia; 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 continuously 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

(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 1 part in 10^{11}. Deviations from day to day are less than 5 parts 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 Coverage

The effective radiated power from WWVB is 13 kW. The antenna is a 122-meter, top-loaded vertical installed over a radial ground screen. Some measured field intensity contours are shown in figure 6.

2.1. WWVB Time Code

(a) Code and Carrier

On July 1, 1965. WWVB began broadcasting time information using a carrier-level-shift time code. The code. which is binary coded decimal (BCD), is broadcast continuously and is synchronized with the 60-kHz carrier signal. Features of the WWVB time code are shown in figure 7.

(b) Marker Generation

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 a 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. The leading edge of every negative-going pulse is on time.

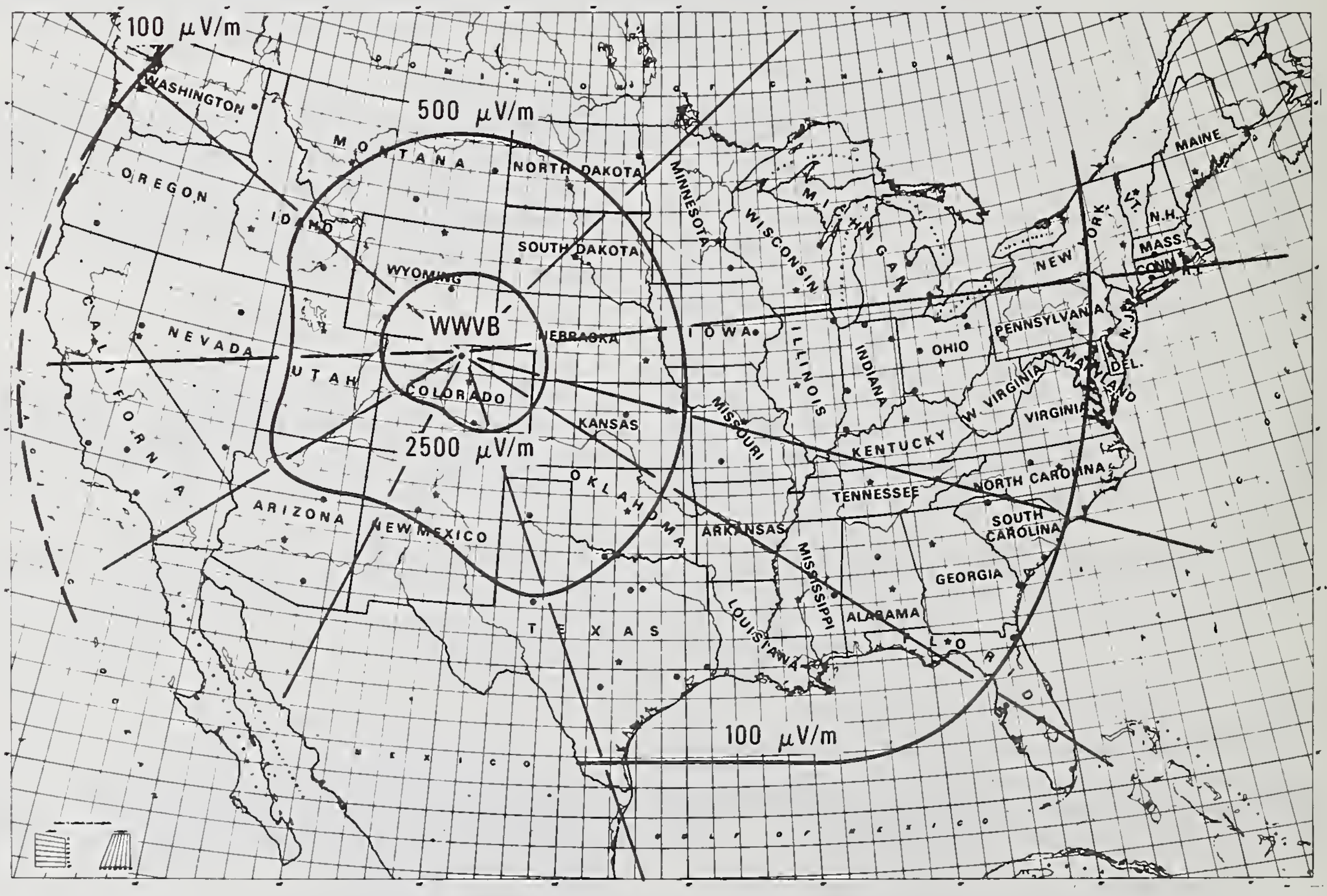


FIGURE 6. *Measured Field Intensity Contours: WWVB @ 13 kW ERP.*

(c) Marker Order and Groups

The 10-second position markers, labeled P_0 through P_5 in figure 7, occur respectively as the 59th, 9th, 19th, 29th, 39th, and 49th second pulses of each minute. The minute reference marker begins at zero seconds. Uncoded markers occur periodically as the 4th, 14th, 24th, 34th, 44th, and 54th seconds pulses and also as the 10th, 11th, 20th, 21st, 35th, 55th, 56th, 57th, and 58th seconds pulses of each minute. Thus every minute contains twelve groups of five markers, each group ending either with a position marker or an uncoded marker.

(d) Information Sets

Once every minute the code presents complete UTC (NBS) time-of-year information in minutes, hours, and day of the year as well as the estimated difference between UTC and UT1. Coded time-of-day information refers to time at the beginning of the frame. Seconds information can be obtained by counting pulses.

The first two groups in the frame specify the minute of the hour. The third and fourth groups comprise 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 groups specifies the number of milliseconds that must be added to or subtracted from the time as broadcast in order to obtain UT1. The twelfth group is not used.

The positive or negative relationship of the UT1 scale with respect to UTC is indicated by the eighth group. If UT1 is late with respect to UTC, a binary one (labeled SUB in fig. 7) will be broadcast in the eighth group as the 37th second pulse of the minute. If UT1 is early with respect to the code time, binary ones (labeled ADD) will be broadcast in the eighth group as the 36th and 38th second pulses 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 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 7. The occurrence of two binary ones in the "minutes set" indicates that the minute contemplated is the $10 + 2 =$ 12nd minute. Similarly, the two binary ones in the "hours set" indicate the $10 + 8 =$ 18th hour of the day, while the four binary ones in the "days set" indicate the $200 + 40 + 10 + 8 =$ 258th day of the

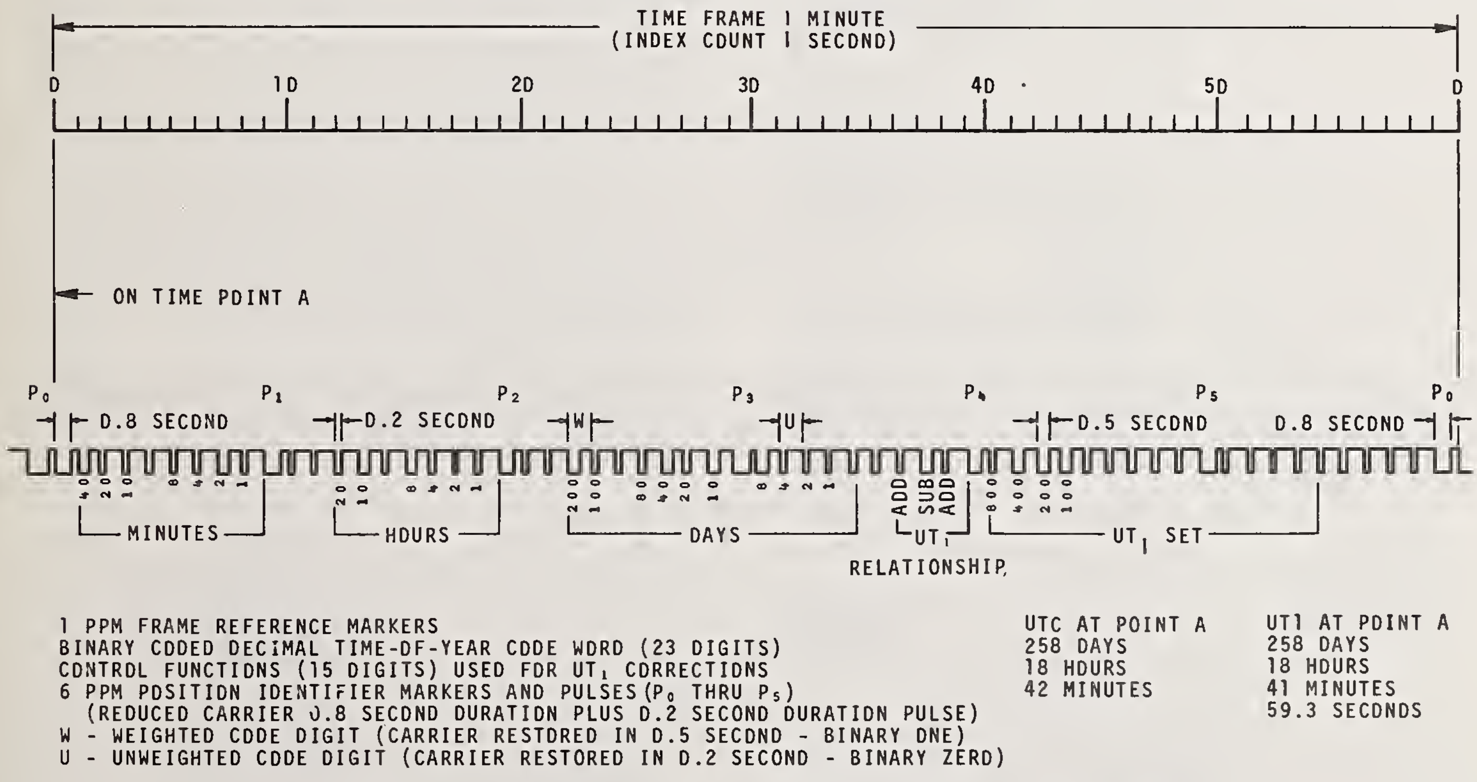


FIGURE 7. *Chart of time code transmissions from NBS radio stations WWVB.*

year. It is seen from the "UT1 Relationship" group and the "UT1 Set" that one should *subtract*, from any second in this minute, 400 + 200 + 100 = 700 milliseconds to get an estimate of UT1.

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.

Effective 0h UTC, 1 July 1972, regularly scheduled transmissions for WWVL were discontinued. Contingent upon need and availability of funds this station now broadcasts experimental programs on an intermittent basis only. Transmissions can be made available on a subscription basis to civil organizations as well as agencies of the Federal government. Arrangements for use of WWVL should be made through the Frequency-Time Broadcasts Services Section, 273.02, National Bureau of Standards, Boulder, CO 80302.

4. How NBS Controls the Transmitted Frequencies

A simplified diagram of the NBS frequency control system [5] is shown in figure 8. The entire system depends upon the basic frequency reference shown in this diagram as the NBS Primary Frequency Standard. This standard, a laboratory cesium beam device, 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 atomic time scale system, which provides the UTC (NBS) time scale [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 UTC(NBS) time scale.

The transmissions from WWV and WWVH are controlled by three commercial 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 occasionally compared with the transmitting station clocks by the use of a very precise portable clock.

References

[1] Glaze, D. J., Hellwig, H., Jarvis, S., Jr., Wainwright, A. E., and Allan, D. W., Recent Progress on the NBS Primary Frequency Standard, 27th Annual Frequency Symp., Ft. Monmouth, NJ, (June 12-14, 1973), pp. 347-356.

[2] National Standards of Time and Frequency in the United States, Proc. IRE, IRE-48, No. 105 (1960).

[3] Allan, D. W., and Barnes, J. A., Some Statistical Properties of LF and VLF Propagation AGARD Conf. Proc. No. 33, Phase and Frequency Instabilities in Electromagnetic Wave Propagation (Proc. AGARD/EWP 13th Symp., Ankara, Turkey, Oct. 9-12, 1967). K. Davies Ed., Chapter 15 (Technivision Services, Slough, England, 1970).

[4] Guetrot, 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 Annual Symp. on Frequency Control, Forth Monmouth, NJ, (May 6-8, 1969). p. 248.

[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, (Aug. 1969).

[6] Tolman, J., Ptacek, V., Soucek, A., and Stecher, R., Microsecond Clock Comparisons by Means of TV Synchronizing Pulses IEEE Trans. on Instr. and Meas. IM-16, No. 3, (Sept. 1967), pp. 247-254.

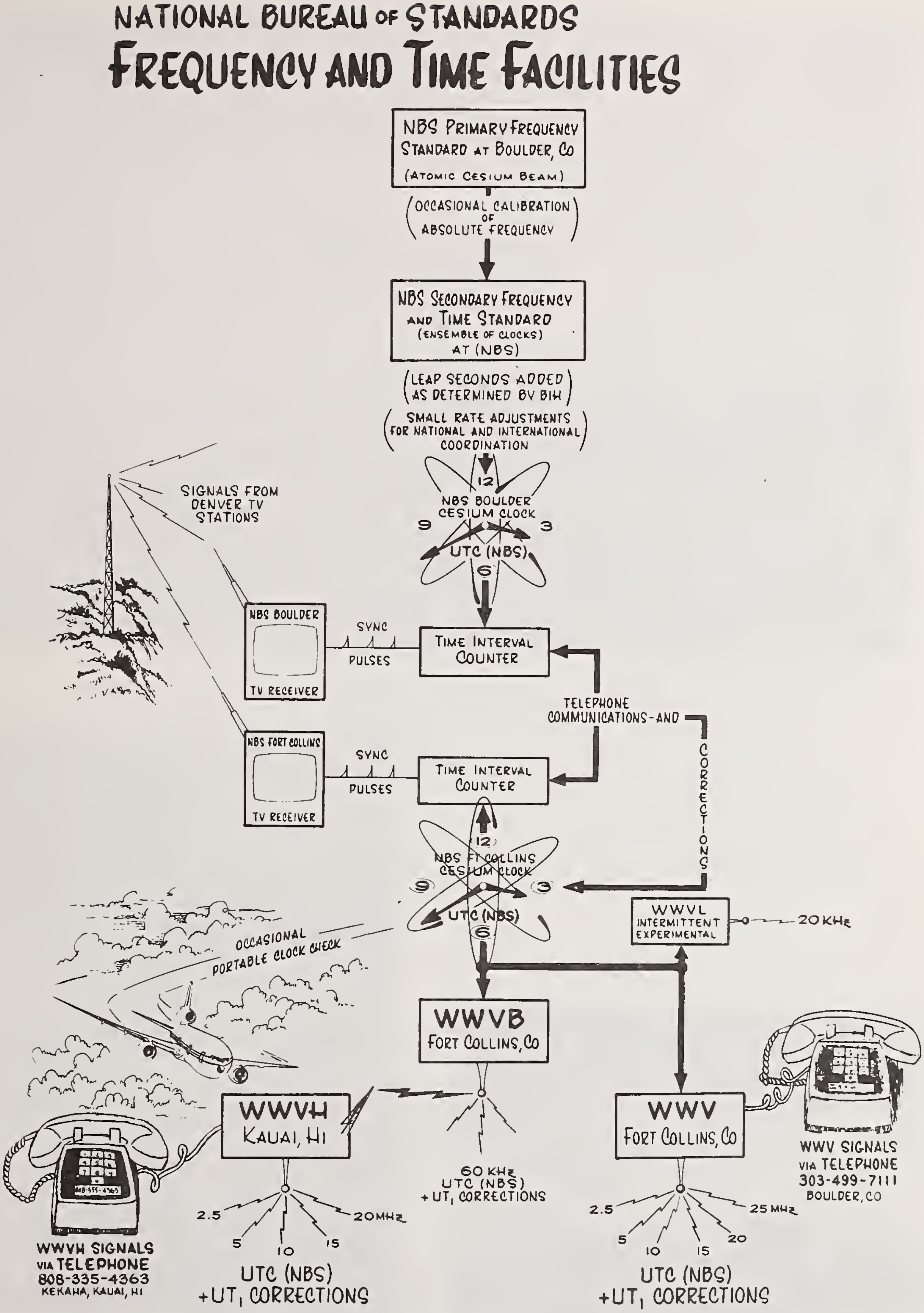


FIGURE 8. *NBS frequency control system.*

NBS Fort Collins facility showing WWV transmitter building.

WWVH transmitter building, Kekaha, Kauai, Hawaii.

WWVB/WWVL transmitter building and antennas.

NBS-114A (REV. 7-73)

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15. SUPPLEMENTARY NOTES

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.*)

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, 1974. 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.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

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

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Electromagnetic Metrology Current Awareness Service (Abstracts of Selected Articles on Measurement Techniques and Standards of Electromagnetic Quantities from D-C to Millimeter-Wave Frequencies). Issued monthly. Annual subscription: $100.00 (Special rates for multi-subscriptions). Send subscription order and remittance to the Electromagnetic Metrology Information Center, Electromagnetics Division, National Bureau of Standards, Boulder, Colo. 80302.

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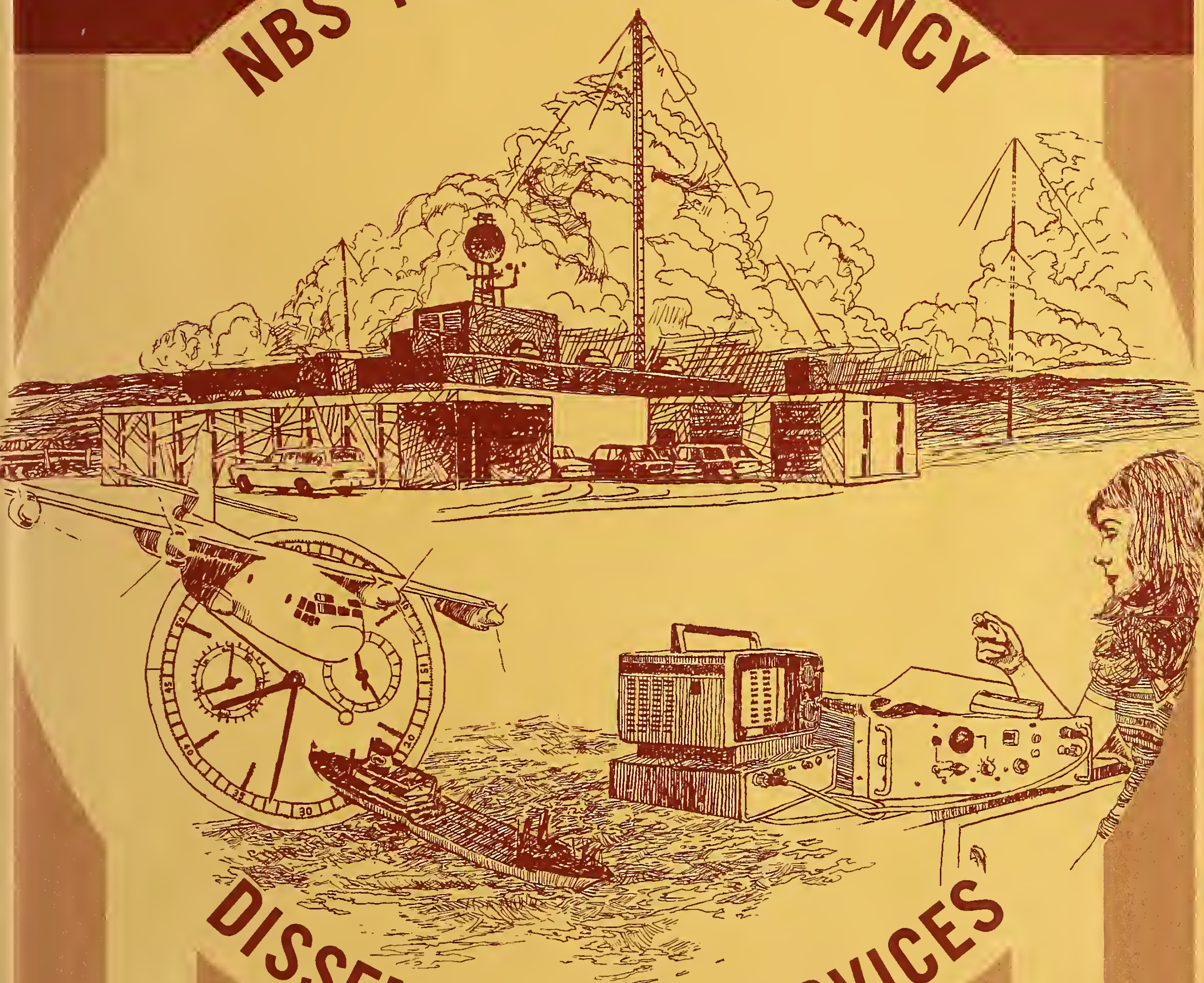
NBS SPECIAL PUBLICATION 432

U.S. DEPARTMENT OF COMMERCE • NATIONAL BUREAU OF STANDARDS

NBS TIME & FREQUENCY



DISSEMINATION SERVICES

A History of the NBS Time and Frequency Dissemination Services

Mar. 1923 First scheduled broadcasts of WWV, Washington, DC

Apr. 1933 WWV gets first 20 kW transmitter, Beltsville, MD

Jan. 1943 WWV relocated to Greenbelt, MD

Nov. 1948 WWVH commenced broadcasts, Maui, HI

Jan. 1950 WWV added voice announcements

Jul. 1956 WWVB (KK2XEI) began 60 kHz broadcasts, Boulder, CO

Apr. 1960 WWVL began 20 kHz experimental broadcasts, Sunset, CO

Jul. 1963 WWVB began high power broadcasts, Ft. Collins, CO

Aug. 1963 WWVL began high power broadcasts, Ft. Collins, CO

Jul. 1964 WWVH added voice announcements

Dec. 1966 WWV relocated to Ft. Collins, CO

Jul. 1971 WWVH relocated to Kauai, HI

Jun. 1972 First "leap second" in history added to UTC time scale

Jul. 1972 WWVL transmissions curtailed

Jan. 1974 Voice announcements changed from Greenwich Mean Time to Coordinated Universal Time (WWV and WWVH)

Mar. 1975 Frequency calibration using network color TV became a nationwide service

Aug. 1975 Line-10 time comparisons using TV synchronization pulses became a nationwide service

NBS
TIME AND FREQUENCY
DISSEMINATION SERVICES

Special publication, no. 432,

Sandra L. Howe, Editor

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

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James A. Baker, III, Under Secretary
Dr. Betsy Ancker-Johnson, Assistant Secretary for Science and Technology
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FOREWORD

This publication presents a description of the time and frequency dissemination services of the National Bureau of Standards. Those interested in information on the NBS atomic clock system, transmitting antennas, or discussion of technological applications of the dissemination services should refer to Section 8, *Other Publications*.

This SPECIAL PUBLICATION 432 replaces former Special Publication 236. It will be revised and reissued only as necessary to update information.

Contents

NBS Time and Frequency Dissemination Services

Sandra L. Howe

Detailed descriptions are given of the time and frequency dissemination services of the National Bureau of Standards (NBS.) These services include the broadcasts from radio stations WWV, WWVH, WWVB, and WWVL (on an intermittent basis), and new time and frequency calibration services using television. This publication shows the services available on January 1, 1976. It will be updated only when the services are revised or when new services are added. A list of other publications available from the Time and Frequency Division of NBS is also included.

Key words: Broadcast of standard frequencies; frequency calibration; high frequency; low frequency; standard frequencies; television color subcarrier; time calibration; time signals.

Introduction

The time and frequency community is a small community, generally unknown to the world at large, yet vitally important to many of the basic activities of everyday living. Electric power companies, radio and television stations, telephone companies, and navigators of ships and planes all depend heavily on precise frequency and time information. They must have a constantly available source—a reliable, nationally and internationally recognized *standard*—with which to compare and regulate their own timing equipment. For over 50 years, the National Bureau of Standards (NBS) has been providing this standard for most users in the United States.*

Since the inception of the broadcast services from radio station WWV in 1923, NBS has continually improved and expanded its time and frequency dissemination services to meet the ever growing needs of an ever widening community of users. Today, still striving for better ways to serve its public, NBS is making major contributions 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, highly accurate time service to many thousands of users throughout the world. Services are presently available from stations WWV and WWVB in Fort Collins, Colorado, and from WWVH in Kauai, Hawaii. In addition, new calibration services using network television are also available. This booklet is offered as a guide to these services.

1. WWV and WWVH

NBS broadcasts continuous signals from its high-frequency radio stations WWV and WWVH. The radio frequencies used are 2.5, 5, 10, 15, and 20 MHz. WWV also broadcasts on an additional frequency of 25 MHz. All frequencies carry the same program, but because of changes in ionospheric conditions, which sometimes adversely affect the signal transmissions, most receivers are not able to pick up the signal on all frequencies at all times in all locations. Except during times of severe magnetic disturbances, however—which make all radio transmissions almost impossible—listeners should be able to receive the signal on at least one of the broadcast frequencies. As a general rule, frequencies above 10 MHz provide the best daytime reception while the lower frequencies are best for nighttime reception.

Services provided by these stations include:

Time announcements
Standard time intervals
Standard frequencies
Propagation forecasts
Geophysical alerts
Marine storm warnings
UT1 time corrections
BCD time code

Figure 1 gives the hourly broadcast schedules of these services along with station location, radiated power, and details of the modulation.

1a. Accuracy and Stability

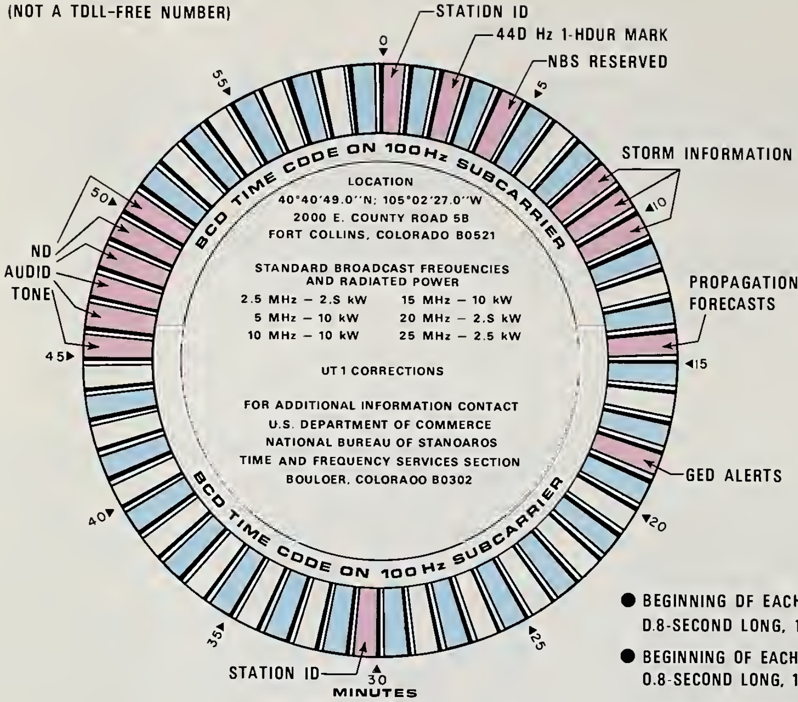
The time and frequency broadcasts are controlled by the primary NBS Frequency Standard in Boulder, Colorado. The frequencies as transmitted are accurate to within one part in 100 billion at all times. Deviations are normally less than one part in 1,000 billion from day to day. However, changes in the propagation medium (causing Doppler effect, diurnal shifts, etc.) result in fluctuations in the carrier frequencies *as received* by the user that may be very much greater than the uncertainty described above.

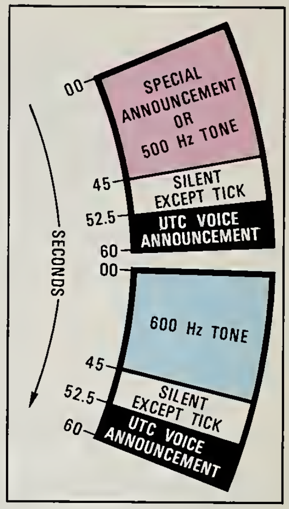
*The U.S. Naval Observatory provides time standards for the Department of Defense and other interested users.

WWV BROADCAST FORMAT

VIA TELEPHONE: (303) 499–7111
(NOT A TOLL-FREE NUMBER)

U.S DEPARTMENT OF COMMERCE
National Bureau of Standards

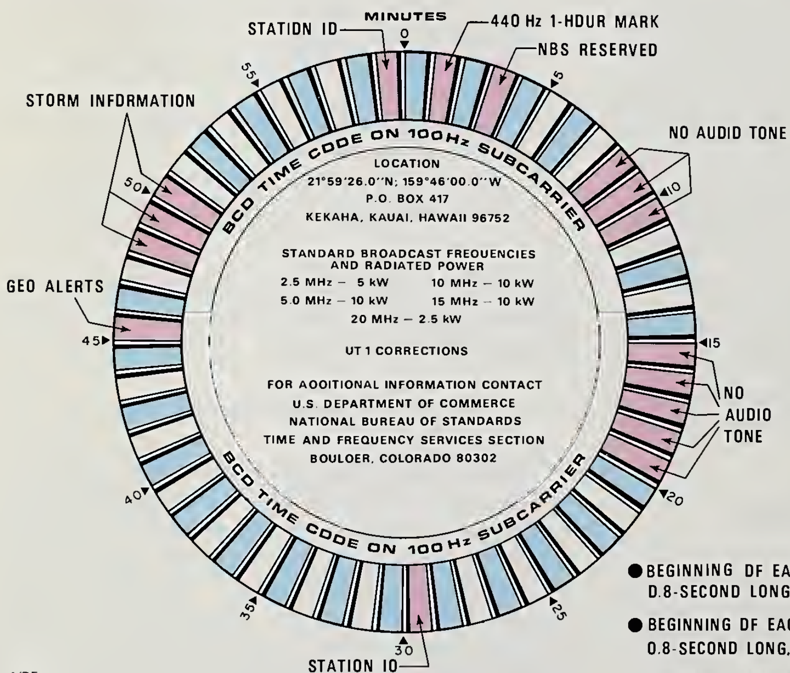


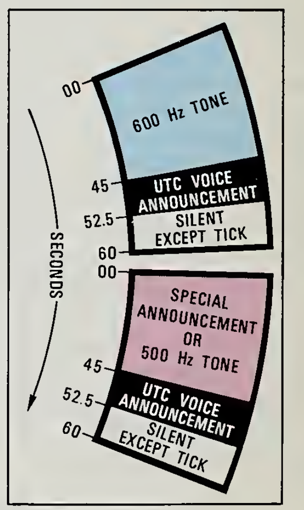


- BEGINNING OF EACH HOUR IS IDENTIFIED BY 0.8-SECOND LONG, 1500-Hz TONE.
- BEGINNING OF EACH MINUTE IS IDENTIFIED BY 0.8-SECOND LONG, 1000-Hz TONE.
- THE 29th & 59th SECOND PULSE OF EACH MINUTE IS OMITTED

WWVH BROADCAST FORMAT

VIA TELEPHONE: (808) 335–4363 (NOT A TOLL-FREE NUMBER)





- BEGINNING OF EACH HOUR IS IDENTIFIED BY 0.8-SECOND LONG, 1500-Hz TONE.
- BEGINNING OF EACH MINUTE IS IDENTIFIED BY 0.8-SECOND LONG, 1200-Hz TONE.
- THE 29th & 59th SECOND PULSE OF EACH MINUTE IS OMITTED.

1/75

Figure 1. The hourly broadcast schedules of WWV and WWVH.

1b. Radiated Power, Antennas and Modulation

Frequency, MHz	Radiated Power, kW	
	WWV	WWVH
2.5	2.5	5.0
5.0	10.0	10.0
10.0	10.0	10.0
15.0	10.0	10.0
20.0	2.5	2.5
25.0	2.5	—

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 dipoles that radiate omnidirectional patterns.

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

1c. Time Announcements

Voice announcements are made from WWV and WWVH once every minute. To avoid confusion, a man's voice is used on WWV and a woman's voice on WWVH. The WWVH announcement occurs first—at 15 seconds before the minute—while the WWV announcement occurs at 7½ seconds before the minute. Though the announcements occur at different times, the tone markers referred to are transmitted simultaneously from both stations. However, they may not be received at the same time due to propagation effects.

The time referred to in the announcements is "Coordinated Universal Time" (UTC). It is coordinated through international agreements by the International Time Bureau (BIH) so that time signals broadcast from the many stations such as WWV throughout the world will be in close agreement.

The specific hour and minute mentioned is actually the time at the time zone centered around Greenwich, England, and may be considered generally equivalent to the more well-known "Greenwich Mean Time" (GMT). UTC time differs from your local time only by an integral number of hours. By knowing your own local time zone and using the chart of world time zones in figure 3, the appropriate number of hours to add or subtract from UTC to obtain local time can be determined. The UTC time announcements are expressed in the 24-hour clock system —i.e., the hours are numbered beginning with 00 hours at midnight through 12 hours at noon to 23 hours, 59 minutes just before the next midnight.

1d. Standard Time Intervals

The most frequent sounds heard on WWV and WWVH are the pulses that mark the seconds of each minute, except for the 29th and 59th seconds pulses which are omitted completely. The first pulse of every *hour* is an 800-millisecond pulse of 1500 Hz. The first pulse of every *minute* is an 800-millisecond pulse of 1000 Hz at WWV and 1200 Hz at WWVH. The remaining seconds pulses are brief audio bursts (5-millisecond pulses of 1000 Hz at WWV and 1200 Hz at WWVH) that resemble the ticking of a clock. All pulses commence at the *beginning* of each second. They are given by means of double-sideband amplitude modulation.

Each seconds pulse is preceded by 10 milliseconds of silence and followed by 25 milliseconds of silence to avoid interference which might make it difficult or impossible to pick out the seconds pulses. This total 40-millisecond protected zone around each seconds pulse is illustrated in figure 2.

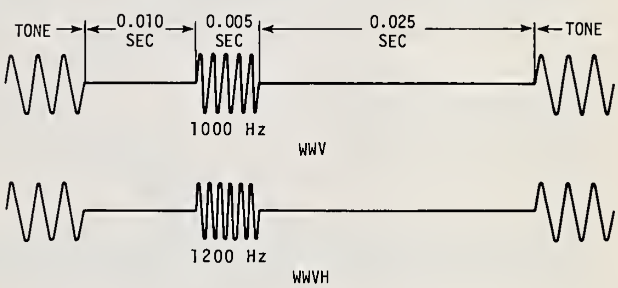


Figure 2. Format of WWV and WWVH seconds pulses.

1e. Standard Audio Frequencies

In alternate minutes during most of each hour, 500 or 600 Hz audio tones are broadcast. A 440 Hz tone, the musical note A above middle C, is broadcast once each hour. In addition to being a musical standard, the 440 Hz tone can be used to provide an hourly marker for chart recorders or other automated devices.

1f. Official Announcements

Forty-five-second announcement segments (see fig. 1) are available on a subscription basis to other Federal agencies to disseminate official and public service information. The accuracy and content of these announcements are the responsibility of the originating agency, not necessarily NBS.

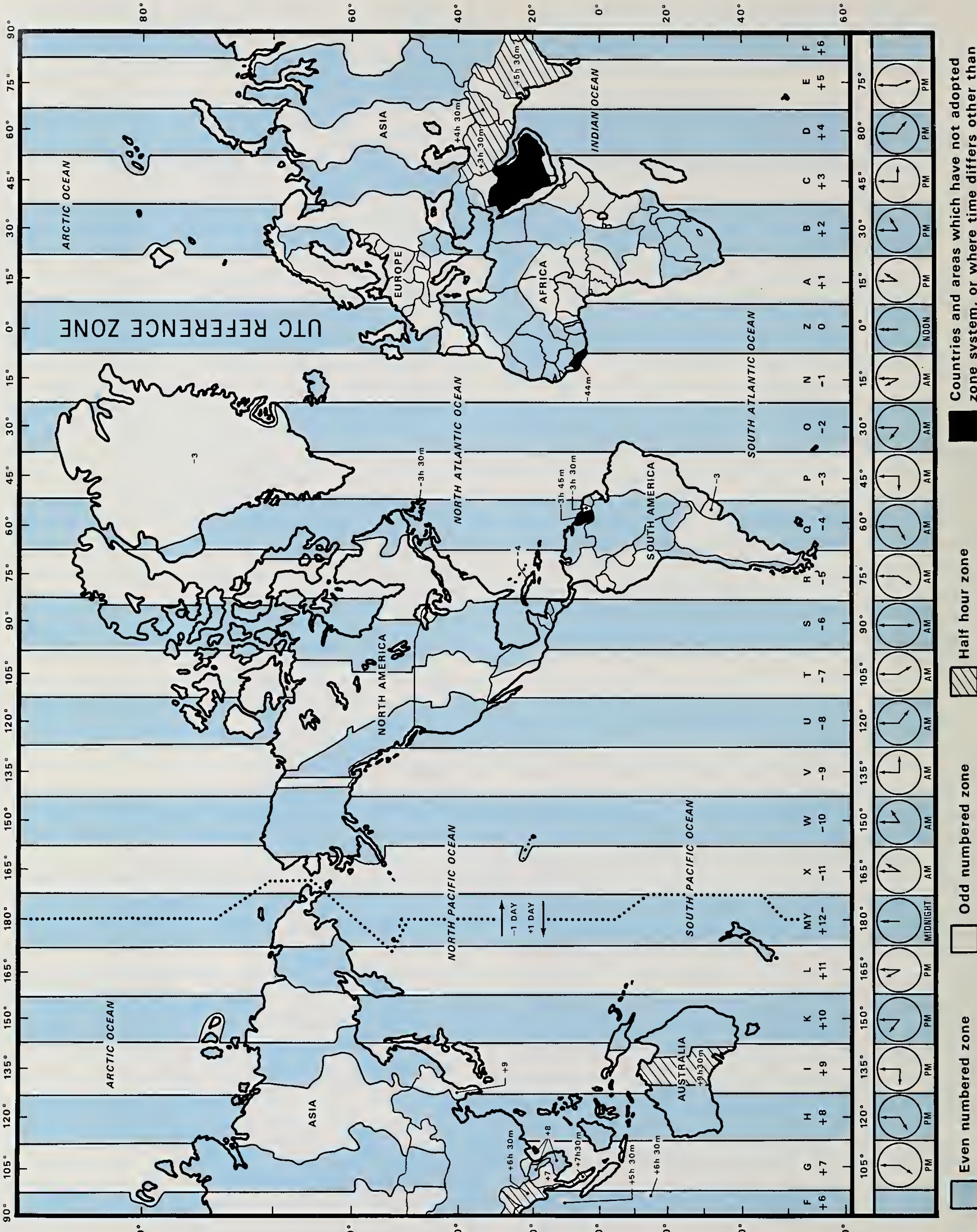


Figure 3. Standard time zones of the world and their relationship to UTC.

Most segments except those reserved for NBS use and the semi-silent periods (see section 1g) are available. Arrangements for use of segments may be made through the *Time and Frequency Services Section, 277.06, National Bureau of Standards, Boulder, CO 80302.*

Propagation Forecasts

The propagation forecasts are given in voice at 14 minutes after each hour from WWV only. They are short-term forecasts of propagation conditions along North Atlantic paths (such as Washington, D.C. to London or New York to Berlin) along with descriptions of current geomagnetic activity, K-index values (a measure of the earth's magnetic field) and solar flux data (a measure of the overall level of solar activity). These forecasts are also applicable to high latitudes provided the appropriate time correction is made.

The propagation forecast announcements are given as a phonetic and a numeral. The phonetic identifies the radio propagation quality at the time the forecast is issued (0100, 0700, 1300, or 1900 UTC). The numeral indicates the quality expected during the six-hour period after the forecast is issued. The meanings of the phonetics and numerals are:

Phonetic	**Meaning**
Whiskey	Disturbed
Uniform	Unsettled
November	Normal

Numeral	**Meaning**
One	Useless
Two	Very poor
Three	Poor
Four	Poor-to-fair
Five	Fair
Six	Fair-to-good
Seven	Good
Eight	Very good
Nine	Excellent

If, for example, propagation conditions are normal and expected to be good during the next six hours, the coded forecast announcement would be "November Seven."

The K-index is a measure of variation, or disturbance, in the earth's magnetic field during the three-hour period ending about one hour prior to issue of the forecast. The K-figures range from 0 (very quiet) to 9 (extremely disturbed). The solar flux measurements are taken at 2800 MHz three times daily. The flux value is closely associated with the well-known daily sunspot number and is coming to be preferred to sunspot number as a measure of solar activity.

A typical announcement might be:

> "The radio propagation quality forecast at 0100 is good. Current geomagnetic activity is normal. The coded forecast is November Seven" (and then repeated). "The K-index at 0100 UTC is 2" (repeated), "tending to increase. The 2800 Megahertz solar flux index is 70 units" (repeated), "tending to remain constant."

The forecasts are prepared by the *Telecommunications Services Center, Office of Telecommunications, Boulder, CO 80302.* Information regarding these forecasts may be obtained by writing to this address.

Geophysical Alerts

Current geophysical alerts (Geoalerts) are broadcast in voice from WWV at 18 minutes after each hour, and from WWVH at 45 minutes after each hour. 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 during the previous 24 hours. Inquiries regarding these messages should be addressed to the *Space Environment Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO 80302.*

Marine Storm Warnings

Weather information about major storms in the Atlantic and eastern North Pacific are broadcast in voice from WWV at 8, 9, and 10 minutes after each hour. Similar storm warnings covering the eastern and central North Pacific are given from WWVH at 48, 49, and 50 minutes after each hour. An additional segment (at 11 minutes after the hour on WWV and at 51 minutes on WWVH) may be used when there are unusually widespread storm conditions. 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, 1700, and 2300 UTC for WWV and 0000, 0600, 1200, and 1800 UTC for WWVH. These broadcasts are updated effective with the next scheduled announcement following the time of issue.

Mariners might expect to receive a broadcast similar to the following:

> "North Atlantic weather West of 35 West at 1700 UTC: Hurricane Donna, intensifying, 24 North, 60 West, moving northwest, 20 knots, winds 75 knots; storm, 65 North, 35 West, moving east, 10 knots; winds 50 knots, seas 15 feet."

Information regarding these announcements may be obtained from the *Director, National Weather Service, Silver Spring, MD 20910.*

1g. "Silent" Periods

These are periods with no tone modulation. However, the carrier frequency, seconds pulses, time announcements, and 100-Hz BCD time code continue. The main silent periods extend from 45 to 51 minutes after the hour on WWV and from 15 to 20 minutes after the hour on WWVH. An additional 3-minute period from 8 to 11 minutes after the hour is silent on WWVH.

1h. BCD Time Code

A binary coded decimal (BCD) time code is transmitted continuously by WWV and WWVH on a 100-Hz subcarrier. The 100-Hz subcarrier is synchronous with the code pulses so that 10-millisecond resolution is attained. The time code provides a standard timing base for scientific observations made simultaneously at different locations. It has application, for example, where signals telemetered from a satellite are recorded along with the time code pulses. Data analysis is then aided by having accurate, unambiguous time markers superimposed directly on the recording.

The WWV/WWVH time code format presents UTC information in serial fashion at a rate of one pulse per second. Groups of pulses can be decoded to ascertain the current minute, hour, and day of year. While the 100-Hz subcarrier is not considered one of the standard audio frequencies, the code does contain the 100-Hz frequency and may be used as a standard with the same accuracy as the audio frequencies. A description of the time code is contained in the Appendix.

1i. UT1 Time Corrections

The UTC time scale broadcast by WWV and WWVH runs at a rate that is almost perfectly constant because it is based on ultra-stable atomic clocks. This time scale meets the needs of most users. Somewhat surprisingly, however, some users of time signals need time which is not this stable. In applications such as very precise navigation and satellite tracking, which must be referenced to the rotating earth, a time scale that speeds up and slows down with the earth's rotation rate must be used. The particular time scale needed is known as UT1 and is inferred from astronomical observations.

To be responsive to these users, information needed to obtain UT1 time is included in the UTC broadcasts. This occurs at two different levels of accuracy. First, for those users needing to know UT1 only to within about one second (this includes nearly all boaters/navigators), occasional corrections of exactly one second—called "leap" seconds—are inserted into the UTC time scale whenever needed to keep the UTC time signals within ± 0.9 second of UT1 at all times. These leap seconds may be either positive or negative and are coordinated under international agreement by the International Time Bureau (BIH) in Paris. Ordinarily, a positive leap second must be added about once per year (usually on June 30 or December 31), depending on how the earth's rotation rate is behaving in each particular year. Information on how to assign dates to events that occur near the time of a leap second insertion is given in the Appendix.

The second level of correction is included in the UTC broadcasts for the very small number of users who need UT1 time to better than one second. These corrections, in units of 0.1 second, are encoded into the broadcasts by using double ticks or pulses after the start of each minute. The amount of correction is determined by counting the number of successive double ticks heard each minute. The 1st through the 8th seconds ticks indicate a "plus" correction, and the 9th through the 16th, a "minus" correction. For example, if the 1st, 2nd, and 3rd ticks are doubled, the correction is "plus" 0.3 second: UT1 = UTC + 0.3 second, or if UTC is 8:45:17, then UT1 is 8:45:17.3. If the 9th, 10th, 11th, and 12th ticks are doubled, the correction is "minus" 0.4 second, or as in the above example, UT1 = 8:45:16.6.

2. WWVB

WWVB transmits continuously on a standard radio carrier frequency of 60 kHz. Standard time signals, time intervals, and UT1 corrections are provided by means of a BCD time code. The station is located on the same site as WWV. Effective coverage area is the continental U.S.

2a. Accuracy and Stability

The frequency of WWVB is normally within its prescribed value to better than 1 part in 100 billion. Deviations from day to day are less than 5 parts in 1,000 billion. Effects of the propagation medium on received signals are relatively minor at low frequencies; therefore, frequency comparisons to better than 1 part in 100 billion are possible using appropriate receiving and averaging techniques.

2b. 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.

2c. Radiated Power, Antenna, and Coverage

The effective radiated power from WWVB is 13 kW. The antenna is a 122-meter, top-loaded vertical installed over a radial ground screen. Some measured field intensity contours are shown in figure 4.

2d. BCD Time Code

WWVB broadcasts time information in the form of a

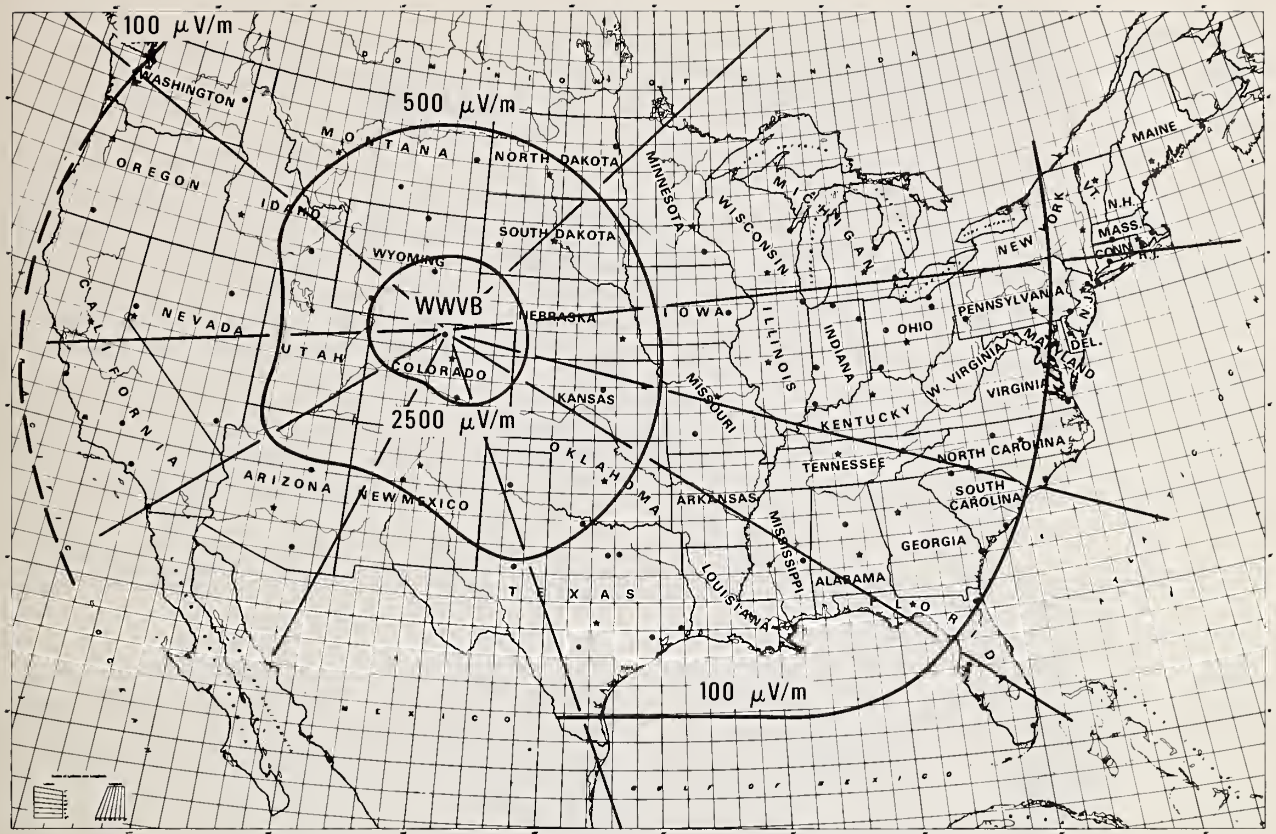


Figure 4. Measured field intensity countours of WWVB at 13 kW ERP.

BCD time code. The time code is synchronized with the 60-kHz carrier and is broadcast continuously at a rate of one pulse per second. Each pulse is generated by reducing the carrier power 10 dB at the beginning of the second, so the leading edge of every negative-going pulse is on time. Details of the WWVB time code are presented in the Appendix.

3. WWVL

WWVL is an experimental station. Regular operations were curtailed on July 1, 1972, and it now broadcasts experimental programs only on an intermittent basis, depending upon need and availability of funds. Transmissions can be made available on a subscription basis to public organizations and other Federal agencies. Arrangements for use should be made through the *Time and Frequency Services Section, National Bureau of Standards, Boulder, CO 80302.*

4. Summary of Broadcast Services

The services provided by the NBS radio stations are summarized in the following chart. Coordinates for the stations are also listed.

STATION	DATE SERVICE BEGAN	RADIO FREQUENCIES	AUDIO FREQUENCIES	MUSICAL PITCH	TIME INTERVALS	TIME SIGNALS	UT1 CORRECTIONS	OFFICIAL ANNOUNCEMENTS
WWV	1923	X	X	X	X	X	X	X
WWVH	1948	X	X	X	X	X	X	X
WWVB	1956	X			X	X	X	
WWVL	1960	X						

COORDINATES:

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

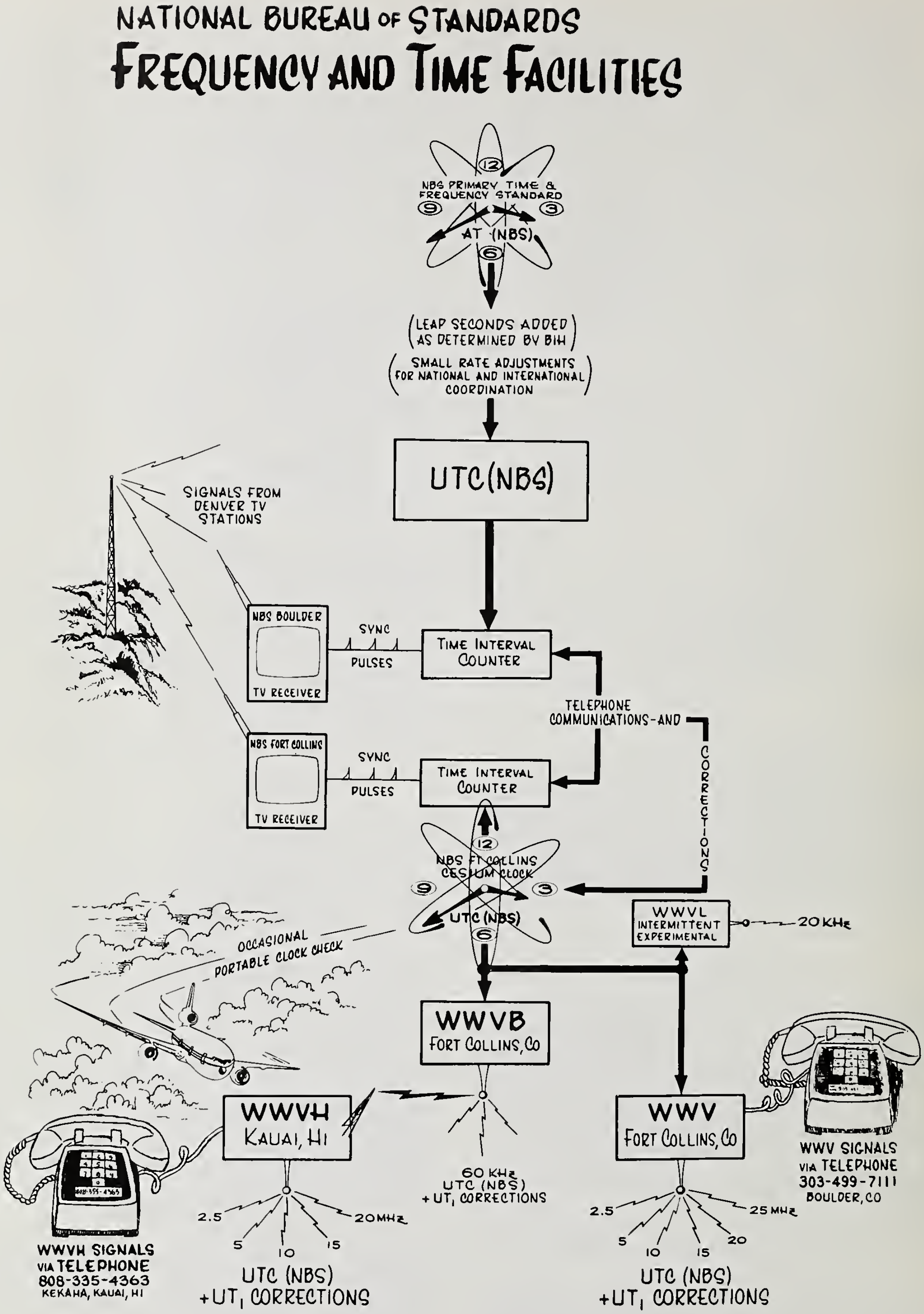


Figure 5. The NBS frequency control system.

5. How NBS Controls the Transmitted Frequencies

A simplified diagram of the NBS frequency control system is shown in figure 5. The entire system depends upon the reference shown in this diagram as the NBS Primary Time and Frequency Standard. This standard is comprised of a number of commercial cesium beam clocks, up to two primary cesium beam frequency and time standards, and computer-aided measurement and computation methods which combine all of the clock data to generate an accurate and uniform time scale, AT (NBS). Another scale, UTC (NBS), is also generated by adding leap seconds and small corrections to AT (NBS) as needed to keep UTC (NBS) synchronized with the internationally coordinated time scale, UTC, which is maintained by the BIH.

Utilizing the line-10 horizontal synchronizing pulses from a local television station, the Fort Collins master clock is compared on a regular basis with the UTC (NBS) time scale. 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 UTC (NBS) time scale.

The transmissions from WWV and WWVH are controlled by three commercial cesium standards located at each site. To insure accurate time transmission from each station, the time-code generators are compared with the stations' 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 insure that systematic errors do not enter into the system, the UTC (NBS) time scale is occasionally compared with the transmitting station clocks by the use of a very precise portable atomic clock.

6. Frequency Calibration Service Using Network Television

For those users who require only frequency calibrations, an alternative to the radio broadcasts is available. This new service provides a means of calibrating oscillators traceable to NBS. It gives the user the option of calibrating his oscillator quickly at very low cost with modest accuracy or of expending more time and money for higher accuracy.

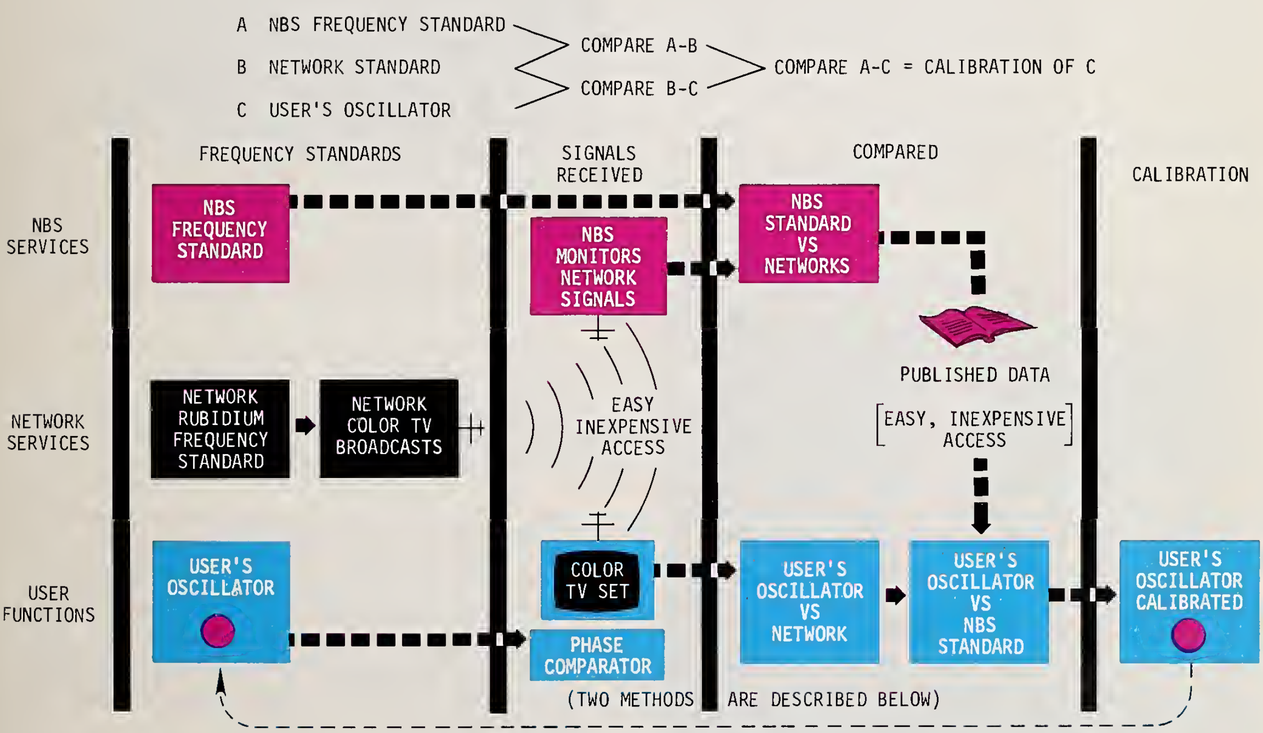


Figure 6. How the frequency calibration service using color television works.

The service is very reliable because the networks use extremely stable rubidium oscillators to generate the 3.58 MHz color subcarrier frequency which is transmitted with all color programs. The color signal is then used as a transfer standard. Any oscillator that has a frequency of 10/N MHz, where N is any integer from 1 to 100, can be calibrated.

If a user wants to make a calibration, he compares the color signal coming from the network centers in New York City (or Los Angeles for those on the West Coast) with his local oscillator. NBS monitors the same network signals and publishes the difference between the network oscillators and the NBS Frequency Standard in the monthly *NBS Time and Frequency Services Bulletin.* A user then knows two things: (1) the difference between his oscillator and the network oscillators (by measurement) and (2) the difference between the networks and NBS (by publication). With this information, he can easily compute the difference between his oscillator and NBS (see fig. 6). Thus, his calibration is traceable to the NBS Frequency Standard.

NBS has developed two methods for making these frequency calibrations. Equipment is commercially available for both methods.

6a. Color Bar Comparator Method

The color bar comparator is a simple circuit that connects to a standard color television set (fig.7). It produces a colored bar on the screen that changes color or moves across the screen at a rate that depends on the frequency difference between the user's oscillator and the TV network signal. By timing these changes with a stopwatch and referring to the data published by NBS, an oscillator can be rapidly calibrated to an accuracy of 1 part in 1 billion.

Figure 7. Prototype of a color bar comparator.

6b. Digital Offset Computer Method

The second method, using a digital offset computer, provides an automatic means of calibrating high-quality crystal or atomic oscillators. It compares a signal from the user's oscillator with the TV color signal and displays the frequency difference on the TV screen (fig.8) as parts in 100 billion. If the measurements are averaged over about 15 minutes, a calibration accuracy of one part in 100 billion can usually be achieved.

More information on this service, including circuit details and lists of equipment manufacturers, is available upon request from the *Time and Frequency Services Section, NBS, Boulder, CO 80302.*

Figure 8. Prototype of a digital offset computer.

7. Time Comparisons Using Television Synchronization Pulses

In the previous section, methods were described for using the *frequency* of a network television signal as a transfer standard to link the user to the NBS Frequency Standard. In a similar way, it is also possible to use a particular synchronization pulse present in the normal television picture signal as a *time* transfer standard to allow clock comparisons to be made with the UTC (NBS) atomic time scale.

To use this technique, a user first makes a simple time difference measurement at a specified time during the day between his local clock and a particular television signal pulse (line-10 (odd) horizontal synchronization pulse) obtained from a normal television receiver. Commercial equipment is available which can be used for this purpose. NBS also measures, at the same specified time, the time difference between the TV synchronization pulse as received in Boulder, Colorado and the UTC (NBS) time scale and publishes the data in the monthly *NBS Time and Frequency Services Bulletin*. The difference between the local measurement and the published NBS measurement then represents the time difference between the user's clock and UTC (NBS) plus a propagation delay.

If the propagation delay can be determined—for example, by a portable clock measurement, then this part of the measurement can be subtracted out, leaving only the actual time difference between the local and NBS clocks. Although the propagation delay of the TV signals through the nationwide TV network distribution system has been shown to be relatively constant to within a few microseconds for long periods extending over weeks or months, occasional large changes of many milliseconds do occur due to network rerouting of TV signals. These large changes are usually easy to recognize, especially if a user regularly monitors more than one of the major TV networks.

Even if the propagation delays are not measured or otherwise determined, the line-10 technique can still provide useful information about the *stability* performance of a user's time scale or clock relative to NBS. As long as the delay remains constant, daily line-10 comparisons will show whether a user's clock is gaining or losing time relative to NBS, even though the exact time difference cannot be determined without knowing the value for the propagation delay.

NBS publishes daily line-10 measurements for all three major television networks and for both East Coast and West Coast-originated transmissions. The West Coast data are suppied by the Hewlett-Packard Co. in Santa Clara, California and are referenced to UTC (NBS) with an accuracy of about 0.5 microsecond. West Coast data is for use only by those users in the Pacific Time Zone. For current specific times during the day when each network is measured, potential users of the line-10 time transfer technique should either consult a current issue of the *NBS Time and Frequency Services Bulletin* or contact the *Time and Frequency Services Section, NBS, Boulder, CO 80302*.

8. Other Publications

The Time and Frequency Division offers a variety of publications about the NBS atomic time and frequency standards, the associated dissemination services and how to use them. These publications are available upon request.

For information about the atomic clock, primary time and frequency standard, as well as special time and frequency calibration, test, and measurement services, write to the *Frequency and Time Standards Section, NBS, Boulder, CO 80302* or call (303) 499-1000, x 3276. The following are available:

General Information

Frequency Standards and Clocks: A Tutorial Introduction, Helmut Hellwig, Nat. Bur. Stand. (U.S.), Tech. Note 616, 69 pages, Revised (March 1974).

Technical Publications

Accuracy Evaluation and Stability of the NBS Primary Frequency Standards, D. J. Glaze, H. Hellwig, et al, IEEE Trans. on Instr. & Meas., Vol. IM-23, No. 4 (Dec. 1974).

Atomic Frequency Standards: A Survey, H. Hellwig, Proc. IEEE, Vol. 63, No. 2 (Feb. 1975).

Time and Frequency, H. Hellwig, D.W. Allan, F.L. Walls, Proc. 5th Intl. Conf. on Atomic Masses and Fundamental Constants (AMCO-5), Paris, France (June 2-6, 1975).

An Accurate Algorithm for an Atomic Time Scale, D. W. Allan, H. Hellwig, D. J. Glaze, Metrologia, Vol. 11, (1975).

For more detailed technical information on how to use the time and frequency dissemination services, the following publications are available from the *Time & Frequency Services Section, NBS, Boulder, CO 80302* (Phone (303) 499-1000, x3212):

Frequency Standard Hides in Every Color TV Set, D. Davis, Electronics (May 10, 1971).

Calibrating Crystal Oscillators with TV Color-reference Signals, D. Davis, Electronics (March 20, 1975).

The Use of NBS High Frequency Broadcasts for Time & Frequency Calibrations, N. Hironaka and C. Trembath, Nat. Bur. Stand. (U.S.), Tech. Note 668 (May 1975).

Characterization and Concepts of Time-Frequency Dissemination, J. L. Jespersen, B.E.Blair, and L.E. Gatterer, Proc. IEEE, Vol. 60, No. 5, May 1972.

Appendix

1A. Dating of Events in the Vicinity of Leap Seconds

2A. WWV/WWVH Time Code

3A. WWVB Time Code

1A Dating of Events in the Vicinity of Leap Seconds

When leap second adjustments are necessary to keep the broadcast time signals (UTC) within ± 0.9 second of the earth-related UT1 time scale, the addition or deletion of exactly 1 second occurs at the end of the UTC month. By international agreement, first preference is given to December 31 or June 30, second preference to March 31 or September 30, and third preference to any other month.

When a positive leap second is required—that is, when UT1 is slow relative to UTC—an additional second is inserted beginning at 23h 59m 60s of the last day of the month and ending at Øh Øm Øs of the first day of the following month. In this case, the last minute of the month in which there is a leap second contains 61 seconds. To assign dates to events which occur around this extra second, refer to figure 1A.

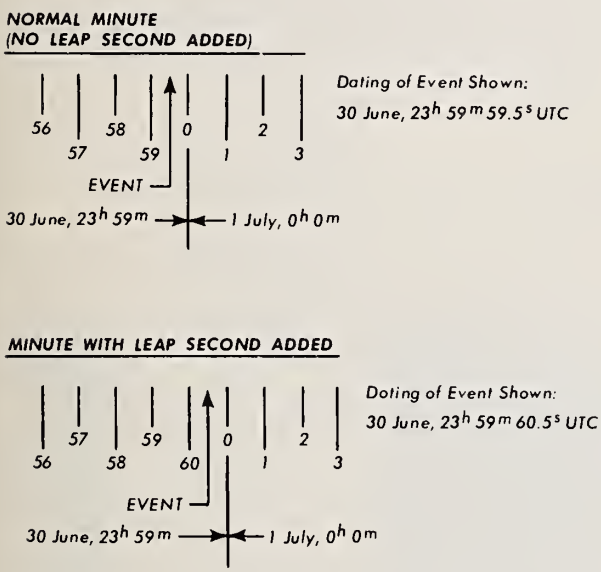


Figure 1A. Dating of events in the vicinity of a leap second.

Assuming that unexpected large changes do not occur in the earth's rotation rate in the future, it is likely that positive leap seconds will continue to be needed about once per year. If, however, the earth should speed up significantly at some future time, so that UT1 runs at a *faster* rate than UTC, then provision is also made for negative leap seconds in the UTC time scale. In this case, exactly one second would be *deleted* at the end of some UTC month, and the last minute would contain only 59 seconds.

Positive leap seconds were inserted in all NBS broadcasts at the end of June 1972, December 1972, December 1973, December 1974, and December 1975.

2A. WWV/WWVH Time Code

The WWV/WWVH time code is a modified version of the IRIG-H format. Data is broadcast on a 100-Hz subcarrier at a rate of one pulse per second. Certain pulses in succession comprise binary-coded groups representing decimal numbers. The binary-to-decimal weighting scheme is 1-2-4-8 with the least significant binary digit always transmitted first. The binary groups and their basic decimal equivalents are shown in the following table:

	BINARY GROUP	DECIMAL
Weight:	1 2 4 8	EQUIVALENT
	0 0 0 0	0
	1 0 0 0	1
	0 1 0 0	2
	1 1 0 0	3
	0 0 1 0	4
	1 0 1 0	5
	0 1 1 0	6
	1 1 1 0	7
	0 0 0 1	8
	1 0 0 1	9

In every case, the decimal equivalent of a BCD group is derived by multiplying each binary digit times the weight factor of its respective column and then adding the four products together. For instance, the binary sequence 1010 in the 1-2-4-8 scheme means $(1 \times 1) + (0 \times 2) + (1 \times 4) + (0 \times 8) = 1 + 0 + 4 + 0 = 5$, as shown in the table. If fewer than nine decimal digits are needed, one or more of the binary columns may be omitted.

In the standard IRIG-H code, a binary 0 pulse consists of exactly 20 cycles of 100-Hz amplitude modulation (200 milliseconds duration), whereas a binary 1 consists of 50 cycles of 100 Hz (500 milliseconds duration). In the WWV/WWVH broadcast format, however, all tones are suppressed briefly while the seconds pulses are transmitted (see sec. 1c).

Because the tone suppression applies also to the 100-Hz subcarrier frequency, it has the effect of deleting the first 30-millisecond portion of each binary pulse in the time code. Thus, a binary 0 contains only 17 cycles of 100-Hz amplitude modulation (170 milliseconds duration) and a binary 1 contains 47 cycles of 100 Hz (470 milliseconds duration). The leading edge of every pulse coincides with a positive-going zero crossing of the 100-Hz subcarrier, but it occurs 30 milliseconds after the beginning of the second.

Within a time frame of one minute, enough pulses are transmitted to convey in BCD language the current minute, hour, and day of year. Two BCD groups are needed to express the hour (00 through 23); and three groups are needed to express the day of year (001 through 366). When representing units, tens, or hundreds, the basic 1-2-4-8 weights are simply multiplied by 1, 10, or 100 as appropriate. The coded information always refers to time at the beginning of the one-minute frame. Seconds may be determined by counting pulses within the frame.

Each frame commences with a unique spacing of pulses to mark the beginning of a new minute. No pulse is transmitted during the first second of the minute. Instead, a one-second space or hole occurs in the pulse train at that time. Because all pulses in the time code are 30 milliseconds late with respect to UTC, each minute actually begins 1030 milliseconds (or 1.03 seconds) prior to the leading edge of the first pulse in the new frame.

For synchronization purposes, every ten seconds a so-called position identifier pulse is transmitted. Unlike the BCD data pulses, the position identifiers consist of 77 cycles of 100 Hz (770 milliseconds duration).

UT1 corrections to the nearest 0.1 second are broadcast via BCD pulses during the final ten seconds of each frame. The coded pulses which occur between the 50th and 59th seconds of each frame are called control functions. Control function #1, which occurs at 50 seconds, tells whether the UT1 correction is negative or positive. If control function #1 is a binary 0, the correction is negative; if it is a binary 1, the correction is positive. Control functions #7, #8, and #9, which occur respectively at 56, 57, and 58 seconds, specify the amount of UT1 correction. Because the UT1 corrections are expressed in tenths of a second, the basic binary-to-decimal weights are multiplied by 0.1 when applied to these control functions.

Control function #6, which occurs at 55 seconds, is programmed as a binary 1 throughout those weeks when Daylight Saving Time is in effect and as a binary 0 when Standard Time is in effect. The setting of this function is changed at 0000 UTC on the date of change. Throughout the U.S. mainland, this schedule allows several hours for the function to be received before the change becomes effective locally—i.e., at 2:00 a.m. local time. Thus, control function #6 allows clocks or digital recorders operating on local time to be programmed to make an automatic one-hour adjustment in changing from Daylight Saving Time to Standard Time and vice versa.

Figure 2A depicts one frame of the time code as it might appear after being rectified, filtered, and recorded. In this example, the leading edge of each pulse is considered to be the positive-going excursion. The pulse train in the figure is annotated to show the characteristic features of

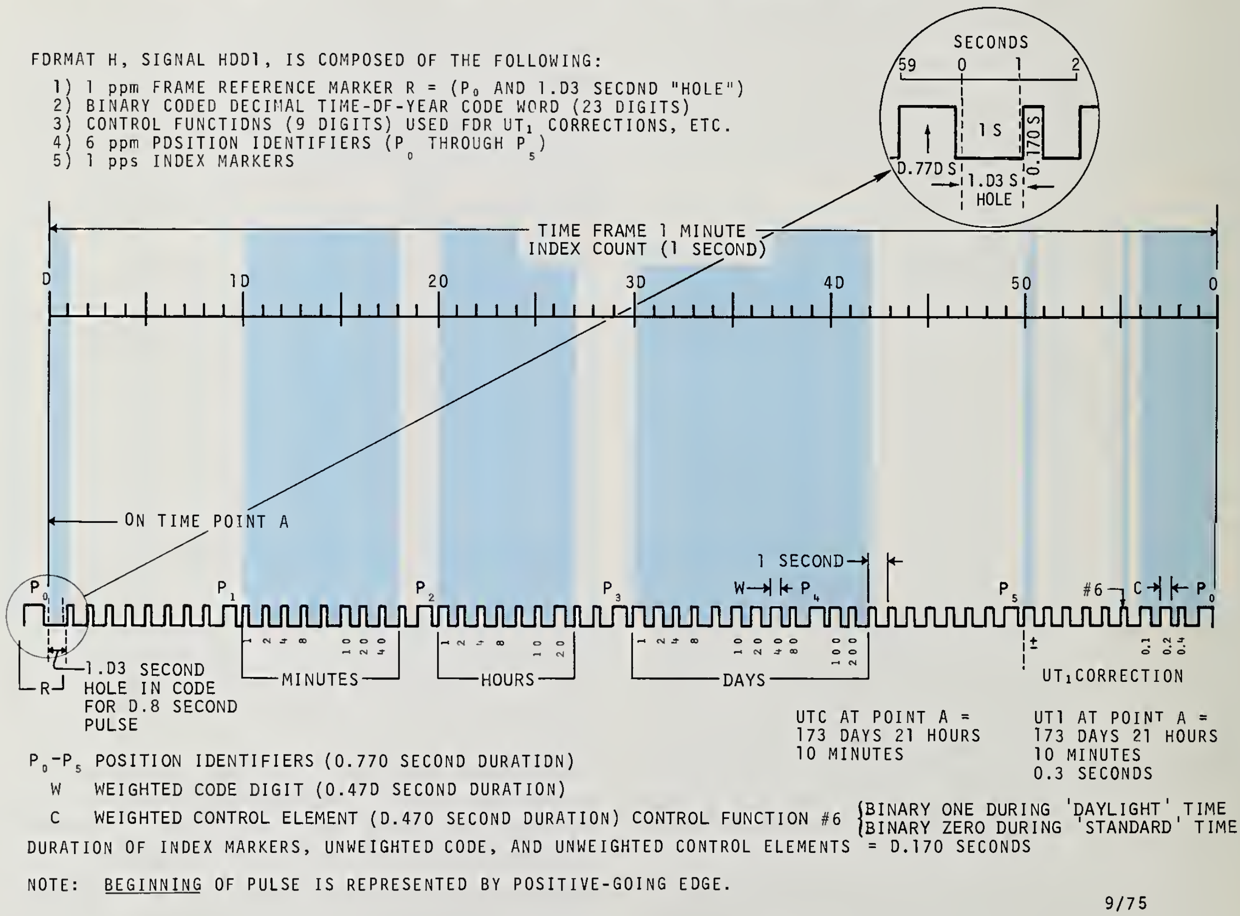


Figure 2A. WWV and WWVH time code format.

the time code format. The six position identifiers are denoted by symbols P_1, P_2, P_3, P_4, P_5, and P_0. The minutes, hours, days, and UT1 sets are marked by brackets, and the applicable weighting factors are printed beneath the coded pulses in each BCD group. With the exception of the position identifiers, all uncoded pulses are set permanently to binary 0.

The first ten seconds of every frame always include the 1.03-second hole followed by eight uncoded pulses and the position identifier P_1. The minutes set follows P_1 and consists of two BCD groups separated by an uncoded pulse. Similarly, the hours set follows P_2. The days set follows P_3 and extends for two pulses beyond P_4 to allow enough elements to represent three decimal digits. The UT1 set follows P_5, and the last pulse in the frame is always P_0.

In figure 2A, the least significant digit of the minutes set is $(0 \times 1) + (0 \times 2) + (0 \times 4) + (0 \times 8) = 0$; the most significant digit of that set is $(1 \times 10) + (0 \times 20) + (0 \times 40) = 10$. Hence, at the beginning of the 1.03-second hole in that frame, the time was exactly 10 minutes past the hour. By decoding the hours set and the days set, it is seen that the time of day is in the 21st hour on the 173rd day of the year. The UT1 correction is +0.3 second. Therefore, at point A, the correct time on the UT1 scale is 173 days, 21 hours, 10 minutes, 0.3 second.

3A. WWVB Time Code

The WWVB time code is generated by shifting the power of the 60-kHz carrier. The carrier power is reduced 10 db at the beginning of each second and restored to full power 200 milliseconds later for a binary zero, 500 milliseconds later for a binary one, and 800 milliseconds later for a reference marker or position identifier. Certain groups of pulses are encoded to represent decimal numbers which identify the minute, hour, and day of year. The binary-to-decimal weighting scheme is 8-4-2-1 with the most significant binary digit transmitted first. Note that this weighting sequence is the reverse of the WWV/WWVH code. The BCD groups and their basic decimal equivalents are tabulated below:

	BINARY GROUP	DECIMAL
Weight:	8 4 2 1	EQUIVALENT
	0 0 0 0	0
	0 0 0 1	1
	0 0 1 0	2
	0 0 1 1	3
	0 1 0 0	4
	0 1 0 1	5
	0 1 1 0	6
	0 1 1 1	7
	1 0 0 0	8
	1 0 0 1	9

The decimal equivalent of each group is derived by multiplying the individual binary digits by the weight factor of their respective columns and then adding the four products together. For example, the binary sequence 1001 in 8-4-2-1 code is equivalent to $(1 \times 8) + (0 \times 4) + (0 \times 2) + (1 \times 1) = 8 + 0 + 0 + 1 = 9$, as shown in the table. If fewer than nine decimal digits are required, one or more of the high-order binary digits may be dispensed with.

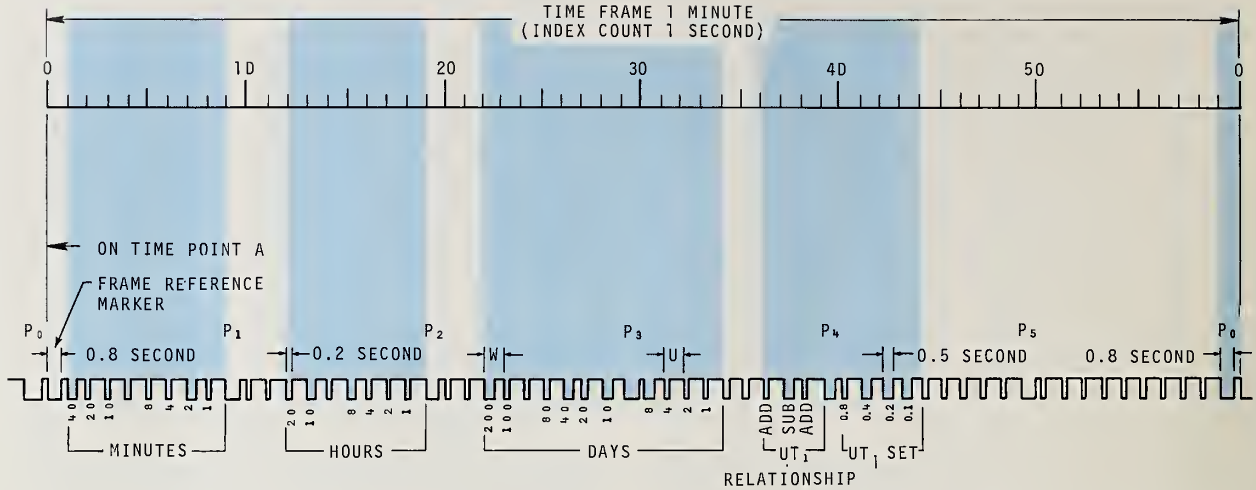
Once every minute, in serial fashion, the code format presents BCD numbers corresponding to the current minute, hour, and day on the UTC scale. Two BCD groups identify the minute (00 through 59); two groups identify the hour (00 through 23); and three groups identify the day of year (001 through 366). When representing units, tens, or hundreds, the basic 8-4-2-1 weights are multiplied by 1, 10, or 100 respectively. The coded information refers to the time at the beginning of the one-minute frame. Within each frame, the seconds may be determined by counting pulses.

Every new minute commences with a frame reference pulse which lasts for 0.8 second. Also, every ten-second interval within the minute is marked by a position identifier pulse of 0.8-second duration.

UT1 corrections to the nearest 0.1 second are transmitted at seconds 36 through 44 of each frame. Coded pulses at 36, 37, and 38 seconds indicate the positive or negative relationship of UT1 with respect to UTC. Pulses at 36 and 38 seconds are transmitted as binary ones only if UT1 is *early* with respect to UTC, in which case a correction must be *added* to the UTC signals to obtain UT1. The pulse transmitted at 37 seconds is a binary one if UT1 is *late* with respect to UTC, in which case the required UT1 correction must then be *subtracted*. The magnitude of the UT1 correction is transmitted as a BCD group at 40, 41, 42, and 43 seconds. Because UT1 corrections are expressed in tenths of seconds, the basic 8-4-2-1 weight of that particular binary group is multiplied by 0.1 to obtain its proper decimal equivalent.

Figure 3A shows a sample frame of the time code in rectified or dc form. The negative-going edge of each pulse coincides with the beginning of a second. Position identifiers are labeled P_1, P_2, P_3, P_4, P_5, and P_0. Brackets show the demarcation of the minutes, hours, days, and UT1 sets. The applicable weight factor is printed beneath the coded pulses in each BCD group. Except for the position identifiers and the frame reference marker, all uncoded pulses are binary zeros.

In figure 3A, the most significant digit of the minutes set is $(1 \times 40) + (0 \times 20) + (0 \times 10) = 40$; the least significant digit of that set is $(0 \times 8) + (0 \times 4) + (1 \times 2) + (0 \times 1) = 2$. Thus, at the beginning of the frame, UTC was precisely 42 minutes past the hour. The sets for hours and days reveal further that it is the 18th hour of the 258th day of the year. The UT1 correction is -0.7 second, so at the beginning of the frame the correct time on the UT1 scale was 258 days, 18 hours, 41 minutes, 59.3 seconds.



BINARY CODED DECIMAL TIME-OF-YEAR CODE WORD (23 DIGITS)
CONTROL FUNCTIONS (15 DIGITS) USED FOR UT_1 CORRECTIONS
6 PPM POSITION IDENTIFIER MARKERS AND PULSES (P_0 THRU P_5)
(REDUCED CARRIER 0.8 SECOND DURATION PLUS 0.2 SECOND DURATION PULSE)
W - WEIGHTED CODE DIGIT (CARRIER RESTORED IN 0.5 SECOND - BINARY ONE)
U - UNWEIGHTED CODE DIGIT (CARRIER RESTORED IN 0.2 SECOND - BINARY ZERO)

UTC AT POINT A
258 DAYS
18 HOURS
42 MINUTES

UT1 AT POINT A
258 DAYS
18 HOURS
41 MINUTES
59.3 SECONDS

NOTE: <u>BEGINNING</u> OF PULSE IS REPRESENTED BY NEGATIVE - GOING EDGE.

9/75

Figure 3A. WWVB time code format.

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Telephone Time of Day Service

WWV and WWVH broadcasts may be heard via telephone. Since the RF carriers cannot be detected over telephone circuits, only the audio portion of the broadcasts may be heard. Accuracy of the time signals as received anywhere in the contiguous 48 states is 30 milliseconds or better.

By calling (303) 499-7111 in Boulder, Colorado, the user will hear the live broadcasts as transmitted from WWV. This service is automatically limited to three minutes per call. Similar time-of-day broadcasts from WWVH can be heard by dialing (808) 335-4363 on the island of Kauai, Hawaii. NOTE: These are long distance toll calls for those users outside the local dialing area.

About the Announcers

The station identification and time-of-day announcements are pre-recorded—not "live." The regular announcer for WWV is Mr. Don Elliott of Atlanta, Georgia. Mrs. Jane Barbe, also of Atlanta, is the announcer for WWVH.

Tours

Guided tours are available at all of the NBS radio stations. Visiting hours at WWV, WWVB, and WWVL are every Wednesday, except holidays, from 2:00 to 4:00 p.m. Special tours may be scheduled at other times only by prior arrangement with the engineer-in-charge. WWVH does not have regularly scheduled visiting hours—arrangements for visiting the site should be made in advance.

Tours of the NBS Boulder Laboratories, including visits to the atomic clock and the other dissemination services, are available. Information can be obtained from the *Program Information Office, NBS, Boulder, CO 80302.*

Inquiries About the Stations

Correspondence pertaining directly to station operations may be addressed to:

Engineer-in-Charge
NBS Radio Stations WWV/WWVB/WWVL
2000 East County Road 58
Fort Collins, CO 80521
Telephone: (303) 484-2372

Engineer-in-Charge
NBS Radio Radio Station WWVH
P. O. Box 417
Kekaha, Kauai, HI 96752
Telephone: (808) 335-4361

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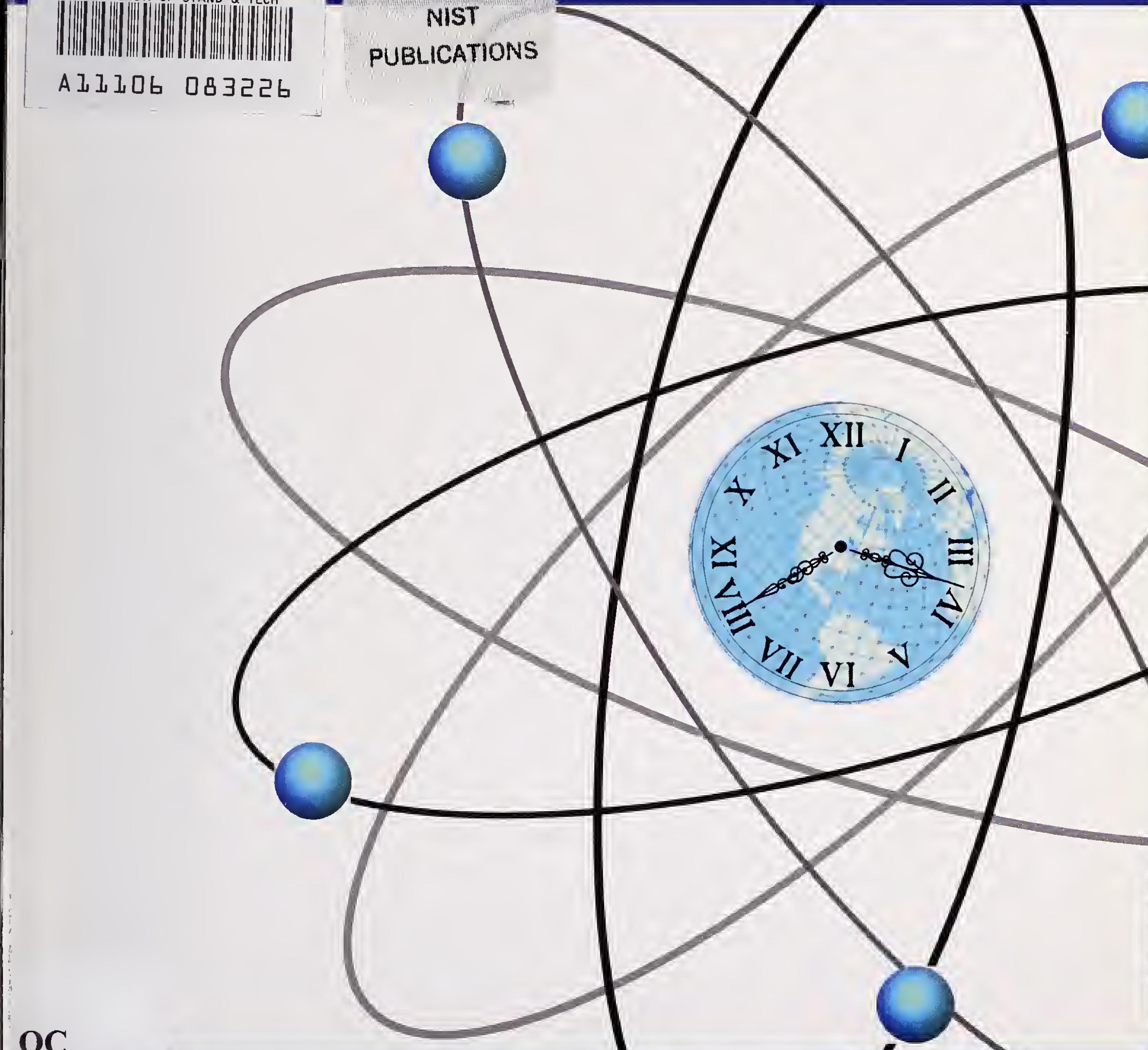
NIST Time and Frequency Services

Michael A. Lombardi



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NIST Time and Frequency Services

Michael A. Lombardi
Time and Frequency Division
Physics Laboratory

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January 2002

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Chapter 1

How NIST Provides Time and Frequency Standards for the United States

The National Institute of Standards and Technology (NIST) maintains the standards for time and frequency for most users in the United States. NIST provides a variety of services designed to deliver time and frequency signals to the people who need them. The signals are broadcast via several mediums, including high and low frequency radio, the Internet, and telephone lines. These signals are used to synchronize millions of clocks everyday, throughout the United States and around the world. This booklet is a guide to NIST Time and Frequency Services. It describes the signals and services offered by NIST, how they work, and how you can use them.

Beginning with Chapter 2, we'll take a detailed look at each of the time and frequency services that NIST provides. However, let's begin by discussing why time and frequency services are needed in the first place, and how NIST provides and controls them.

Who Needs Time and Frequency Standards?

Everybody needs time and frequency standards. If we stop and think about it, time and frequency standards are involved in one way or another in just about everything we do.

Time and frequency standards supply us with three basic types of information. The first type, *date and time-of-day*, tell us when something happened. Date and time-of-day can be used to record events, or to make sure that multiple events are *synchronized*, or happen at the same time. It's easy to think of ways we use date and time-of-day in our everyday lives. For example, we use date information to remind us when birthdays, anniversaries, and other holidays are scheduled to occur. We use time-of-day information to set our alarm clocks so we get out of bed on time. Our wristwatches and wall clocks help us get to school and work on time. And if we plan to meet a friend for dinner at 6 p.m., that's a simple example of synchronization. If our watches agree, we should both arrive at about the same time.

Date and time-of-day information have other, more sophisticated uses as well. Fighter planes flying in a high-speed formation require synchronized clocks. If one banks or turns at the wrong time, it could result in a collision and loss of life. If you are watching a network television program, the local station has to be ready to receive the network feed (usually from a satellite), at the exact instant it arrives. This requires synchronization of the station and network clocks. The instruments used to detect and measure earthquakes, called seismographs, require synchronized clocks so that data collected at various locations can be compared and combined. Stock market transactions need to be synchronized so that the buyer and seller can agree upon the same price at the same time. A time error of just a few seconds could result in a large difference in the price of a stock. The electric power companies also need time synchronization. They use synchronized clocks throughout their power grids, so they can instantly transfer power to the parts of the grid where it is needed most. They also use synchronized clocks to determine the location of short circuit faults along a transmission line.

The second type of information, *time interval*, tells us "how long" it takes for something to happen. We use time interval to state our age, or the amount of time we have been alive. Most workers are paid for the amount of time that they worked, usually measured in hours, weeks, or months. We pay for time as well—30 minutes on a parking meter, a 20 minute cab ride, a 5 minute long distance phone call, or a 30 second radio advertising spot.

The standard unit of time interval is the second (s), which is defined according to a property of the cesium atom, as we shall see shortly. However, many applications in science and technology require the measurement of intervals much shorter than one second; such as *milliseconds* (10^{-3} s), *microseconds* (10^{-6} s), *nanoseconds* (10^{-9} s), and even *picoseconds* (10^{-12} s).

The third type of information, *frequency*, is the rate at which something happens. The unit we use to measure frequency is the hertz (Hz), or the number of events per second. Many of the frequencies we depend upon are generated by fast moving electrical signals that are reproduced many thousands (kHz) or millions (MHz) of times per second, or even faster. For example, the quartz watch on your wrist keeps time by counting the frequency of a quartz crystal designed to run at a frequency of 32,768 Hz. When the crystal has oscillated 32,768 times, the watch records that one second has elapsed. Channel 7 on your television receives video at a frequency of 175.25 MHz. The station has to transmit on this frequency as accurately as possible, so that its signal does not interfere with the signals from other stations. Your television has to be able to pick out the channel 7 frequency from all the other available radio signals, so that you see the correct picture on your screen. A high speed Internet connection might use something called a T1 line, which sends data at a frequency of 1,544,000 bits per second (1.544 MHz). And the computer that you use to connect to the Internet might run at a frequency faster than 1 GHz (one billion cycles per second). All of these applications require an *oscillator* that produces a specific frequency. This oscillator should be *stable*, which means that the frequency it produces stays the same (with only minor variations) over long time intervals.

Accurate frequency is critical to today's communication networks. It shouldn't surprise you that the highest capacity networks run at the highest frequencies. In order to send data faster and faster, we need stable oscillators situated throughout a network that all produce nearly the same frequency. The process of making multiple oscillators run at the same frequency is called *syntonization*.

Of course, all three types of time and frequency information are very closely related. As we mentioned, the standard unit of time interval is the second. If we count seconds in an agreed upon fashion, we can calculate the date and the time-of-day. And if we count the number of events that occur during a second, we can measure the frequency.

It's easy to see that the world depends heavily on time and frequency information, and that we rely on many millions of clocks and oscillators to keep time and produce frequency. To keep the world running smoothly, these devices need to be periodically compared to an internationally recognized standard. This comparison might be as simple as setting our watch or alarm clock to the correct minute, or adjusting the frequency of an atomic oscillator so it keeps time within a few nanoseconds per day. The time and frequency standards maintained by NIST provide the reference for these comparisons.

NIST and the Primary Standards of Measurement

The task of maintaining the national standards for time and frequency is an important part of the work done at NIST, and it fits in perfectly with the agency's mission. NIST serves as the national measurement laboratory, or the ultimate reference point for measurements made in the United States. NIST is responsible for maintaining the seven base physical quantities at the highest possible accuracies. Time is one of the seven base quantities; the others are used in the measurement of length, light, electricity, chemical concentration, temperature, and mass. NIST distributes the standard units of measurement throughout the country in the form of measurement services and standard reference materials. By doing so, it provides measurement references to anyone

Figure 1.1. The NIST Boulder Laboratories

who needs them. If a measurement is made using a NIST reference, and if the uncertainty of the measurement is known and documented, the measurement is said to be *traceable*. Establishing *traceability* is important to many organizations, because it helps them prove that their measurements are being made correctly. In some cases, traceability is even a legal or contractual requirement.

NIST strives to develop in-house measurement capabilities that exceed the highest requirements of users in the United States. Since these requirements become more demanding every year, NIST scientists and researchers are continually developing new standards and measurement techniques to keep up with this demand. While these new standards are being developed, other NIST personnel are busy distributing the existing standards and measurement techniques, so that everyone can make traceable measurements that are nearly as good as those made inside the national laboratory.

Although most of NIST is located in Gaithersburg, Maryland, the Time and Frequency division is located in Boulder, Colorado (Figure 1.1). The time and frequency services controlled from Boulder are excellent examples of how NIST is able to distribute its standards and measurement capability to a wide variety of users throughout the United States.

Atomic Time and the Definition of the Second

We mentioned earlier that the standard unit for time interval is the second (s). Since 1967, the second has been defined as the duration of 9,192,631,770 cycles of the radiation associated with a specified transition of the *cesium atom*. Frequency (expressed in hertz) is obtained by counting events over a 1 s interval.

The second is one of the seven base units of measurement in the International System of Units (SI). These units are used to express the values of the seven physical quantities that we mentioned earlier. The seven base units were defined by international agreement and all other units of measurement can be derived from them. The International Bureau of Weights and Measures (BIPM) located near Paris, France, is responsible for ensuring that the major countries of the world use the SI units. This means that the second and the other base units are defined the same way all over the world. As a result, the timekeeping standards maintained by the major countries tend to closely agree with each other—typically to within one microsecond, and often to within a few nanoseconds.

Since the second is defined based on a property of the cesium atom, it should come as no surprise that the electronic device that produces the standard second is called a *cesium oscillator*. Cesium oscillators (and other types of atomic oscillators) are called *intrinsic standards*, because they produce frequency based on a natural phenomena, in this case a property of an atom. NIST maintains an *ensemble* of atomic oscillators in Boulder, Colorado. The outputs of these oscillators are averaged together to produce the national standard for time and frequency. Most of the oscillators in the ensemble are commercially available, but the primary standard, called NIST-F1, is a custom device that was designed and built at NIST (Figure 1.2). The *primary standard* is used to help calibrate the ensemble.

NIST-F1 became operational in late 1999, and is the latest in a long line of NIST primary time and frequency standards. NIST-F1 is a *cesium fountain* frequency standard, and has many performance advantages over the earlier *cesium beam* standards. At this writing (2001), NIST-F1 is one of the most accurate clocks in the world, and can keep time to within about 0.1 nanoseconds per day. Along with the other atomic clocks in the ensemble, NIST-F1 provides the reference for the NIST time and frequency services.

Coordinated Universal Time (UTC)

The ensemble and primary standard described above form what is known as the NIST *time scale*. This time scale produces a very stable and accurate frequency by using a weighted average of all its oscillators, with the best oscillators receiving the most weight. Small adjustments, never more than about 2 nanoseconds per day, are made to the NIST time scale to keep it in agreement with international standards. The output of the time scale is called UTC(NIST), which is short for Coordinated Universal Time kept at NIST.

You can think of UTC(NIST) as both a frequency and a time standard. It produces an extremely stable frequency that serves as the standard for the United States. It also produces the standard for time interval, by generating pulses that occur once per second. By counting these second pulses, NIST can keep time. The second pulses are added together to keep track of longer units of time interval—such as years, months, days, hours, and minutes.

Figure 1.2. NIST-F1 Primary Standard

The UTC system of timekeeping is similar to your local time, with two major differences. Since UTC is used internationally, it ignores local conventions such as Daylight Saving Time and time zones. In other words, UTC is the same no matter where you are located on Earth. Unlike local time, which is usually based on a 12-hour clock, UTC is a 24-hour clock system. The hours are numbered from 0 to 23. The time at midnight is 0 hours, 0 minutes, and 0 seconds. The time just before the next midnight is 23 hours, 59 minutes, and 59 seconds.

To convert UTC to local time, you need to add or subtract a specific number of hours. The number of hours to add or subtract depends on the number of time zones between your location and the zero meridian that passes through Greenwich, England. When local time changes from Daylight Saving to

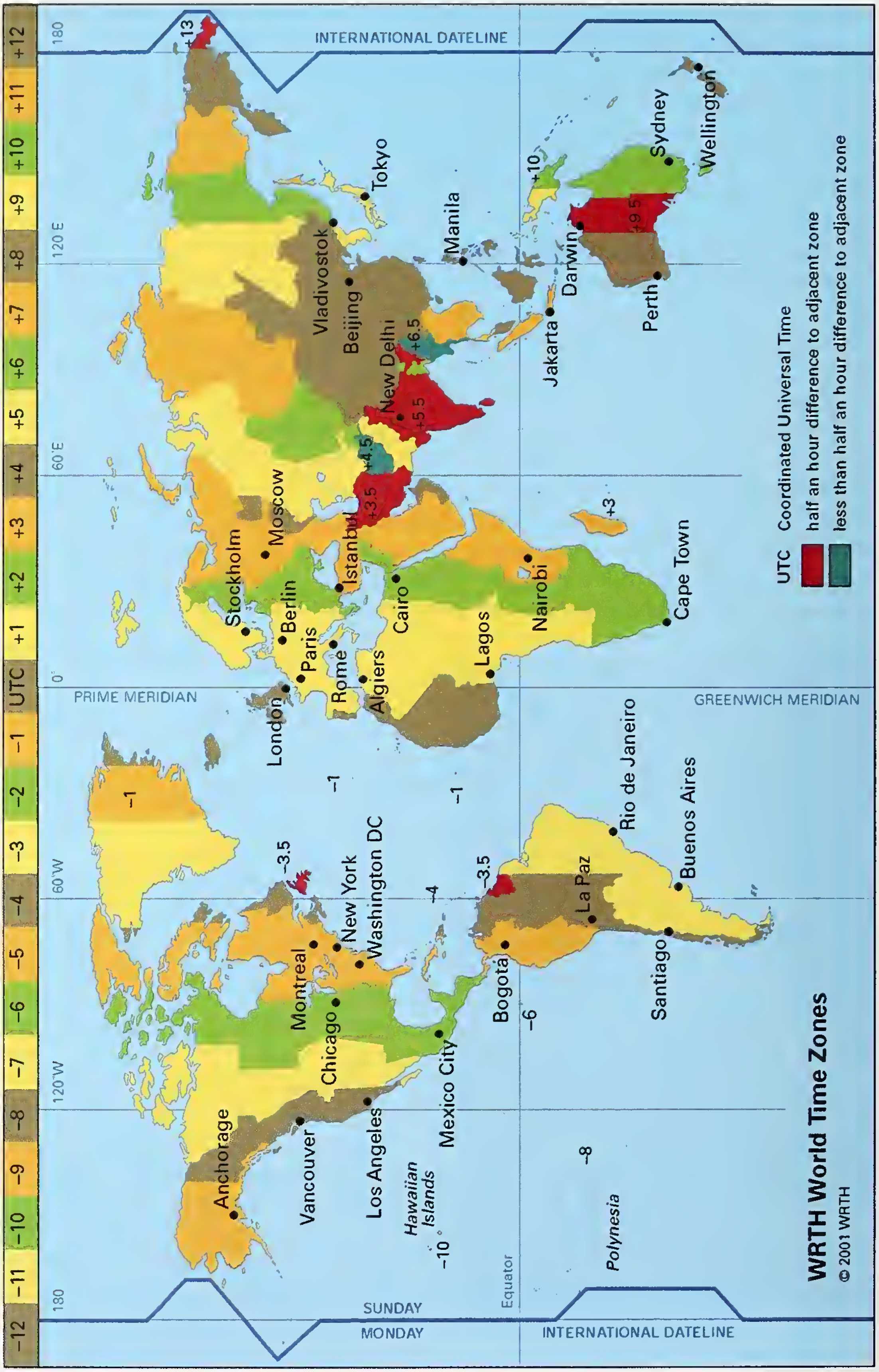

Figure 1.3. World Time Zone Map

Standard Time, or vice versa, UTC does not change. However, the difference between UTC and local time changes by 1 hour. For example, in New York City, the difference between UTC and local time is 5 hours when Standard Time is in effect, and 4 hours when Daylight Saving Time is in effect.

Most of the hardware and software products that access NIST services allow you to select your time zone and are capable of automatically converting UTC to your local time. These products also automatically correct for Daylight Saving Time. The conversion is fairly simple. The chart of world time zones in Figure 1.3 shows the number of hours to add or subtract from UTC to obtain your local standard time. If Daylight Saving Time is in effect at your location, add 1 hour to what is shown on the chart.

Leap Seconds

As we mentioned earlier, the second is defined according to the intrinsic properties of the cesium atom. This means that UTC is an *atomic time scale*, which runs at an almost perfectly constant rate. Prior to atomic time, time was kept using *astronomical time scales* that used the rotation of the Earth as their reference. When the switch to atomic time keeping occurred, it became obvious that while much was gained, some things were lost. A few people still needed time referenced to the Earth's rotation for applications such as celestial navigation, satellite observations of the Earth, and some types of surveying. These applications relied on an astronomical time scale named UT1.

For these reasons, it was agreed that UTC should never differ from UT1 by more than 0.9 s. Therefore, those who needed UT1 could just use UTC, since they could be sure that the difference between the two time scales would be less than 1 s. Keeping the two time scales in agreement requires making occasional 1 s adjustments to UTC. These adjustments are called *leap seconds*. A leap second can be positive or negative, but so far, only positive leap seconds have been needed. Leap seconds are announced by the International Earth Rotation Service and are usually inserted into the UTC time scale on June 30 or December 31, making those months 1 s longer than usual. Currently, about 4 leap seconds are required every 5 years.

All NIST services automatically add leap seconds when necessary. For the very few people who need to know UT1 with an uncertainty of less than 1 s, most NIST services also broadcast a UT1 *correction*. This correction reports the current time difference between UTC and UT1 to the nearest 0.1 s.

Traceability

Earlier, we introduced the concept of measurement traceability. Each of the NIST time and frequency services provides a way to establish traceability to NIST and to international standards. You can think of traceability as a chain that extends all the way from the definition of the SI unit to your measurement or application. Keeping the chain intact requires making a series of comparisons. Each link in the chain is continually compared to the previous link. Figure 1.4 illustrates the part of the traceability chain that extends from the SI definition of the second down to the NIST services.

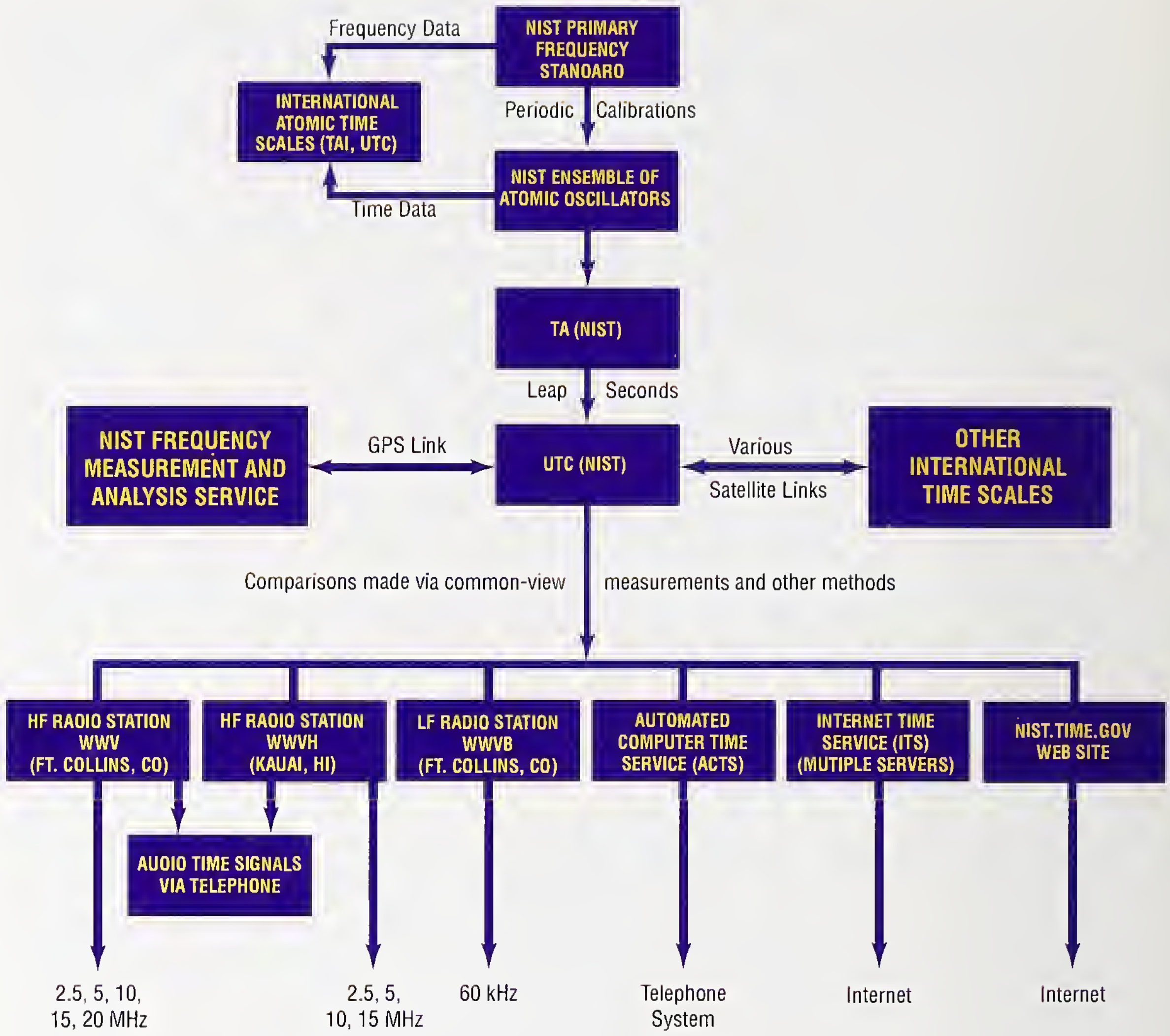

Figure 1.4. The Traceability Chain for NIST Time and Frequency Services

The traceability chain starts with a time and frequency source that is as nearly perfect as possible. For example, at the NIST laboratories it is possible to synchronize a clock to within nanoseconds or even picoseconds of UTC. However, as we transfer UTC down through the links in the chain, we add *uncertainty* to our measurement. By the time a NIST service is used to synchronize a computer clock, the time might only be within a few milliseconds of UTC, and these few milliseconds become our *measurement uncertainty* relative to UTC. This is an important concept. Whenever we talk about traceability, we also need to talk about measurement uncertainty. The typical uncertainty of each time and frequency service is discussed in the following chapters.

Let's examine Figure 1.4 to see how the traceability chain works. We mentioned that NIST compares its time and frequency standards to the time scales maintained in other countries. The comparison data are handled and processed by the BIPM, the same organization responsible for the SI units. Most international comparisons are done using a technique called *common-view*. Normally, if you wanted to compare one oscillator or clock to another, you would connect them both to the same measurement system and make a comparison. However, what if the two clocks aren't located in the same place? They might be in different buildings, different cities, or even different countries. For example, what if you want to compare a clock in the United States to one in Italy? Obviously, you can't directly compare them using the same measurement system, but you can indirectly compare them using the common-view technique.

To use the common-view technique, both oscillators are simultaneously compared to a common-view reference and measurement data are collected. The reference is usually a Global Positioning System (GPS) satellite, although other satellite and land based signals are sometimes used. The collected measurement data are then exchanged and processed to see how one oscillator compares to the other. For the purposes of illustration, let's say that the clock in the United States is measured to be 10 ns fast with respect to the satellite, and the clock in Italy is measured to be 10 ns slow with respect to the satellite. Even though we were unable to directly compare the two clocks, we now know that the United States clock was 20 ns ahead of the Italian clock at the time the common-view measurement was made.

NIST is one of about 50 laboratories that send their common-view data to the BIPM. Like NIST, most of these laboratories serve as the ultimate reference point for measurements made in their countries. The BIPM averages data from all of the contributing laboratories, and produces a time scale called International Atomic Time (TAI). When corrected for leap seconds, TAI becomes Coordinated Universal Time (UTC), or the true international time scale.

Unlike UTC(NIST) and similar time scales maintained by other laboratories, UTC is a paper time scale. About 250 oscillators contribute to UTC, but the BIPM has access only to the data, not the oscillators. Even so, the BIPM's role is very important. They publish the time offset or difference of each laboratory's version of UTC relative to the international average. For example, the BIPM publishes the time offset between UTC and UTC(NIST), which is typically less than 10 ns. The work of the BIPM makes it possible for NIST and the other laboratories to adjust their standards so that they agree as closely as possible with the rest of the world. Since every national measurement laboratory is always comparing itself to the other laboratories, you can rest assured that the units of time and frequency are defined in the same way all over the world.

The process of comparing the NIST time scale to the other standards of the world completes the first link of the traceability chain. The second link is used to control the broadcast services described in Chapters 2 through 4. These services are continuously compared to the NIST time scale, and much care is taken to keep the measurement uncertainty as small as possible. Some of the services used to synchronize computer equipment (Chapter 4) are directly connected to the NIST time scale, but most are referenced to atomic standards located outside of NIST's Boulder, Colorado, laboratory. For example, the NIST radio station sites described in Chapters 2 and 3 are located in Fort Collins, Colorado, and Kauai, Hawaii. Three cesium standards are kept at Fort Collins and

Kauai to provide the reference for each station's time code generators and transmitters. These standards are continuously compared and adjusted to agree with the Boulder time scale, using the same common-view technique used for the international comparisons. As a result, time can easily be kept within 100 ns of UTC(NIST) at each radio station.

The next link in the traceability chain connects NIST to the user. The signals broadcast by NIST must travel across a path en route to the user, and the uncertainties introduced by this link are much larger than those introduced by the previous two links. As we shall see in the following chapters, signals that travel over a low frequency (LF) radio or satellite path usually have smaller uncertainties than signals that travel over a high frequency (HF) radio path, or a telephone or Internet path.

The final link in the traceability chain occurs when you actually use the signal. Some uncertainty is always added after the signal arrives at your location. The amount of uncertainty added depends upon your application. In some cases, the amount of uncertainty added by this final link will be much larger than the combined uncertainty of all the previous links. For example, if you use a NIST signal to synchronize a computer clock (Chapter 4), the resolution of the clock is one limiting factor. If the clock displays only seconds, you won't be able to synchronize it to less than one second. Another source of uncertainty is the delay introduced by your client software or operating system, which might be larger than the total broadcast delay. If you calibrate a stop watch using an audio time signal (Chapter 3), the largest cause of uncertainty is human reaction time, which is not nearly as stable or consistent as the audio signal. In other cases, the uncertainty of the final link is very small. The best receivers and measurement systems use sophisticated electronics and software to preserve as much of the signal accuracy as possible.

As you read through the rest of this booklet, keep the traceability chain in mind. NIST maintains time and frequency standards that are as nearly perfect as possible. By providing time and frequency services, NIST makes it possible for all of us to use these standards as the reference for our own measurements.

Time and Frequency Services Offered by NIST

Table 1.1 lists the time and frequency services currently offered by NIST. It also lists the medium each service uses to deliver its time and frequency information, what you need to have in order to use the service, and some of its typical applications. The remaining chapters provide a detailed look at each service listed in the table.

For the current status of each of these services, including contact information, broadcast outage reports, and new developments, please visit the NIST Time and Frequency Division web site located at:

http://www.boulder.nist.gov/timefreq

TABLE 1.1 – TIME AND FREQUENCY SERVICES OFFERED BY NIST

NAME OF SERVICE	REQUIREMENTS	CHAPTER	TIME UNCERTAINTY	FREQUENCY UNCERTAINTY
nist.time.gov web site	Computer, Internet connection, web browser	4	< 2 s	Not applicable
Telephone time-of-day service	Telephone	3	< 30 ms	Not applicable
Automated Computer Time Service (ACTS)	Computer, analog modem, telephone line, client software	4	< 15 ms	Not applicable
Internet Time Service (ITS)	Computer, Internet connection, client software	4	< 100 ms	Not applicable
Radio Stations WWV and WWVH	HF receiver	3	1 to 20 ms	10^{-6} to 10^{-9}
Radio Station WWVB	LF receiver	2	0.1 to 15 ms	10^{-10} to 10^{-12}
Frequency Measurement Service (FMS)	Paid subscription, NIST provides equipment	5	< 20 ns	2×10^{-13}

Chapter 2

Synchronizing the Nation's Clocks: NIST Radio Station WWVB

There are literally millions of wall clocks, desk clocks, clock radios, wristwatches, and other devices that set themselves to NIST time. These *radio controlled clocks* contain tiny radio receivers tuned to NIST radio station WWVB, located near Fort Collins, Colorado. WWVB continuously broadcasts time and frequency signals at 60 kHz, in the part of the radio spectrum known as low frequency (LF). The WWVB signal includes a time code containing all of the information needed to synchronize radio controlled clocks in the United States and the surrounding areas. In addition, calibration and testing laboratories use the 60 kHz carrier frequency from WWVB as a reference for the calibration of electronic equipment and frequency standards.

History of WWVB

LF and VLF (very low frequency) broadcasts have long been used to distribute time and frequency standards. As early as 1904, the United States Naval Observatory (USNO) was broadcasting time signals from the city of Boston as an aid to navigation. This experiment and others like it made it evident that LF and VLF signals could cover a large area using a relatively small amount of power. By 1923, NIST radio station WWV (Chapter 3) had begun broadcasting standard carrier signals to the public on frequencies ranging from 75 to 2000 kHz. These signals were used to calibrate radio equipment, which became increasingly important as more and more stations became operational. Over the years, many radio navigation systems were designed using stable time and frequency signals broadcast on the LF and VLF bands. The most well known of these navigation systems is LORAN-C, which allows ships and planes to navigate by transmitting stable 100 kHz signals from multiple transmitters.

The station known today as WWVB began life as radio station KK2XEI in July 1956. The transmitter was located at Boulder, Colorado, and the radiated power was just 1.4 W. Even so, the signal was monitored at Harvard University in Massachusetts. The purpose of this experimental transmission was to show that the radio path was stable and the frequency error was small at low frequencies.

In 1962, NIST (then called the National Bureau of Standards or NBS) began building a new facility at a site north of Fort Collins, Colorado. This site became the home of WWVB and WWVL, a 20 kHz transmitter that was moved from the mountains west of Boulder.

The site was attractive for several reasons, one being its exceptionally high ground conductivity, which was due to the high alkalinity of the soil. It was also reasonably close to Boulder (about 80 km, 49.3 mi), which made it easy to staff and manage; but much farther away from the mountains. The increased distance from the mountains made it a better choice for broadcasting an omnidirectional signal.

WWVB went on the air on July 5, 1963, broadcasting a 7 kW signal on 60 kHz. WWVL began transmitting a 500 W signal on 20 kHz the following month. Although WWVL went off the air in July 1972, the WWVB signal became a permanent part of the nation's infrastructure.

A time code was added to WWVB on July 1, 1965. This made it possible for radio clocks to be designed that could decode the signal and automatically synchronize themselves. The time code format has changed only slightly since 1965; it uses a scheme known as binary coded decimal (BCD) which uses four binary digits (bits) to send one decimal number.

The radiated power of WWVB was increased to its current level of 50 kW in 1999. The power increase made the coverage area much larger, and made it easy for tiny receivers with simple antennas to receive the signal. This resulted in the introduction of many new low cost radio controlled clocks that "set themselves" to agree with NIST time.

Figure 2.1. Aerial View of WWVB/WWV Station Site

Figure 2.2. WWVB Antenna Towers

WWVB Station Description

WWVB is located on a 390 acre (158 hectare) site located near Fort Collins, Colorado. Radio station WWV (Chapter 3) shares the same location. An aerial view of the station site is shown in Figure 2.1.

WWVB uses two nearly identical antennas that were originally constructed in 1962, and refurbished in 1999. The north antenna was originally built for the now discontinued WWVL 20 kHz broadcast, and the south antenna was built for the WWVB 60 kHz broadcast. The antennas are spaced 867 m apart. Figure 2.2 shows two of the south antenna towers.

Each antenna is a top-loaded dipole consisting of four 122 m (400 ft) towers arranged in a diamond shape (Figure 2.3). A system of cables, often called a capacitance hat or top hat, is suspended between the four towers. This top hat is electrically isolated from the towers, and is electrically connected to a downlead suspended from the center of the top hat. The combination of the downlead and the top hat serves as the radiating element.

Ideally, an efficient antenna system requires a radiating element that is at least one-quarter wavelength long. However, at a low frequency such as 60 kHz, it is difficult to construct an antenna that large. The wavelength of 60 kHz is about 5000 m, so a one-quarter

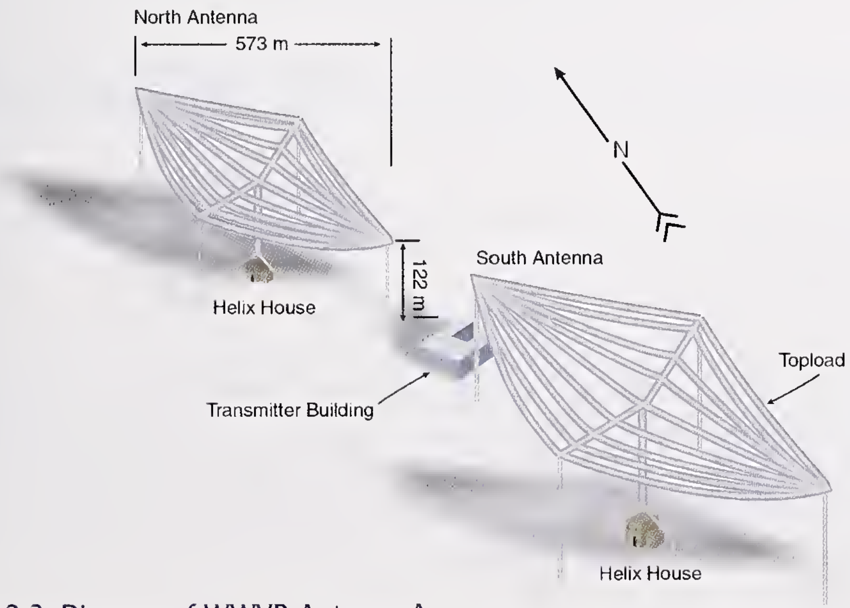

Figure 2.3. Diagram of WWVB Antenna Array

Figure 2.4. A WWVB Transmitter

wavelength antenna would be 1250 m tall, or about 10 times the height of the WWVB antenna towers. As a compromise, some of the missing length was added horizontally to the top hats of this vertical dipole, and the downlead of each antenna is terminated at its own helix house under the top hats. Each helix house contains a large inductor to cancel the capacitance of the short antenna and a variometer (variable inductor) to tune the antenna system. Energy is fed from the transmitters to the helix houses using underground cables housed in two concrete trenches. Each trench is about 435 m long.

A computer is used to automatically tune the antennas during icy and/or windy conditions. This automatic tuning provides a dynamic match between the transmitter and the antenna system. The computer looks for a phase difference between voltage and current at the transmitter. If one is detected, an error signal is sent to a three-phase motor in the helix house that rotates the rotor inside the variometer. This retunes the antenna and restores the match between the antenna and transmitter.

There are three transmitters at the WWVB site. Two are in constant operation and one serves as a standby. A photograph of one of the transmitters is shown in Figure 2.4. Each transmitter consists of two identical power amplifiers that are combined to produce the greatly amplified signal sent to the antenna. One transmitter delivers an amplified time code signal into the north antenna system, and one transmitter feeds the south antenna system. The time code is fed to a console where it passes through a control system and then is delivered to the transmitters.

Using two transmitters and two antennas allows the station to be more efficient than using a single transmitter and antenna. As we described, the length of the WWVB antennas is much less than one-quarter wavelength. And when the length of a vertical radiator is less than the wavelength, the efficiency of the antenna goes down, and some of the transmitter power is lost. In other words, if the efficiency of an antenna is less than 100%, the transmitter power is greater than the effective radiated power. The north antenna system at WWVB has an efficiency of about 57%, and the south antenna has an efficiency of about 59%. However, the combined efficiency of the north and south antennas is about 71%. As a result, each transmitter must produce only about 36 kW of power for WWVB to produce its effective radiated power of 50 kW.

On rare occasions, one of the WWVB antenna systems might require maintenance or repairs. When this happens, the power of one transmitter is temporarily increased to about 50 kW and a single transmitter and antenna are used to deliver the signal. Using this technique, the station is still able to deliver an effective radiated power of about 28 kW.

TABLE 2.1 – CHARACTERISTICS AND SERVICES OF WWVB

CHARACTERISTICS & SERVICES	NIST RADIO STATION WWVB
Date Service Began	July 1956
South Antenna Coordinates	40° 40' 28.3" N 105° 02' 39.5" W
North Antenna Coordinates	40° 40' 51.3" N 105° 03' 00.0" W
Standard Carrier Frequency	60 kHz
Power	50 kW
Standard Time Intervals	Seconds, 10 seconds, minutes
Time of Day Information	Time code frame sent every minute, BCD format

WWVB Signal Description

WWVB identifies itself by advancing its carrier phase 45° at 10 minutes after the hour and returning to normal phase at 15 minutes after the hour. If you plot WWVB phase, this results in an hourly phase shift of approximately 2.1 μs as shown in Figure 2.5.

WWVB is also identified by its unique time code. The time code is synchronized with the 60 kHz carrier and is broadcast continuously at a rate of 1 bit per second using a simple modulation scheme called *pulse width modulation*. The time code is sent in binary coded decimal (BCD) format, where four binary digits (bits) are used to represent one decimal number. The carrier power is reduced and restored to produce the time code bits. The carrier power is reduced 10 dB at the start of each second. If full power is

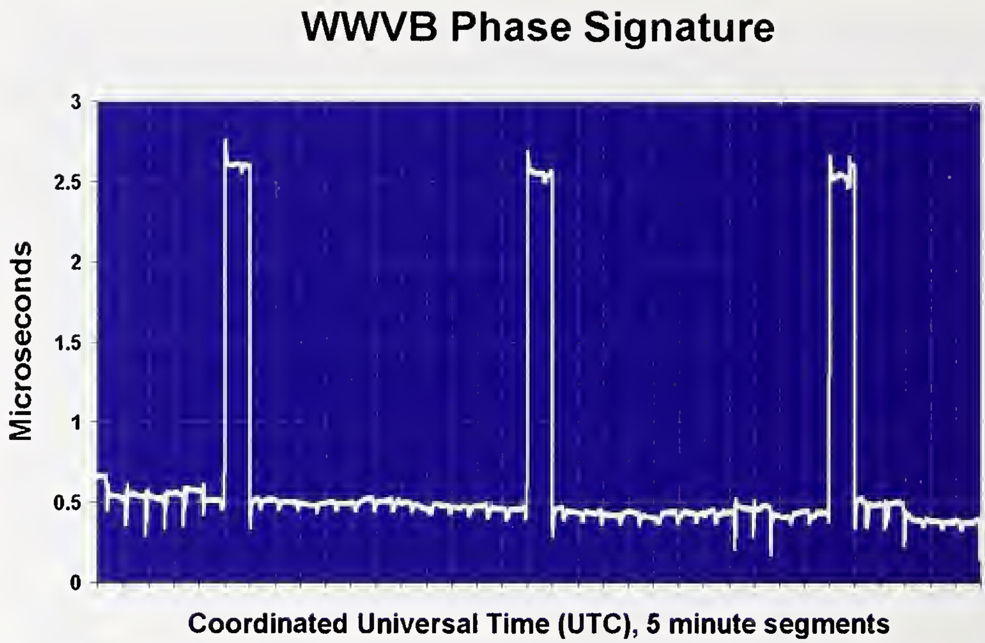

Figure 2.5. WWVB Phase Signature

restored 200 ms later, it represents a 0 bit. If full power is restored 500 ms later, it represents a 1 bit. If full power is restored 800 ms later, it represents a reference marker or a position identifier.

The binary-to-decimal weighting scheme is 8-4-2-1. The *most significant bit* is sent first. This is the reverse of the WWV/ WWVH time code described in Chapter 3. The BCD groups and the equivalent decimal numbers are shown in Table 2.2.

TABLE 2.2 - BCD WEIGHTING SCHEME USED BY WWVB TIME CODE

DECIMAL NUMBER	BIT 1 2^3	BIT 2 2^2	BIT 3 2^1	BIT 4 2^0
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

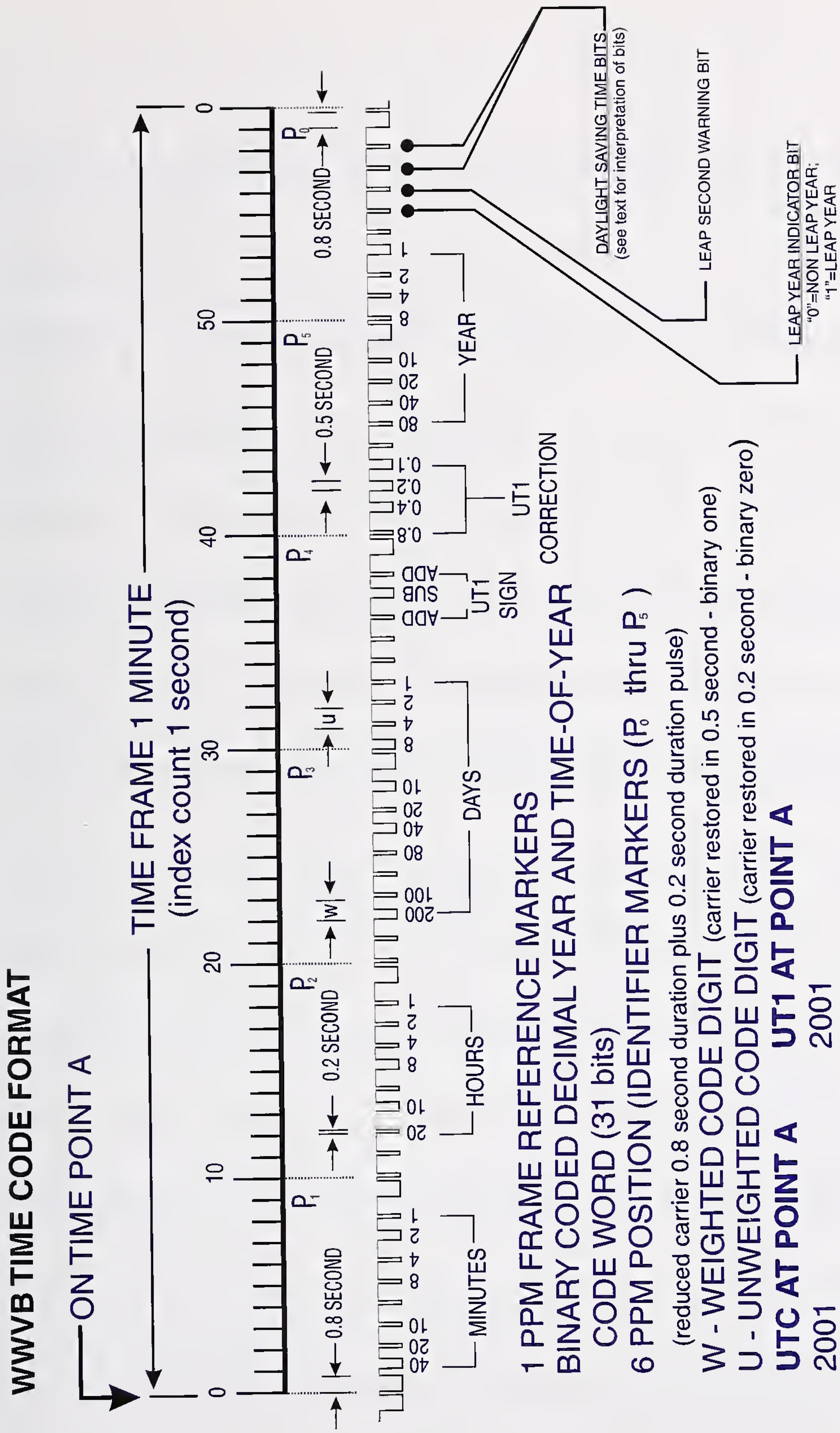

Figure 2.6. The WWVB Time Code Format

TABLE 2.3 - WWVB TIME CODE BITS

BIT NUMBER	BIT DESCRIPTION	BIT NUMBER	BIT DESCRIPTION
0	Frame Reference Bit, P_r	30	Day of Year, 8
1	Minutes, 40	31	Day of Year, 4
2	Minutes, 20	32	Day of Year, 2
3	Minutes, 10	33	Day of Year, 1
4	Reserved	34	Reserved
5	Minutes, 8	35	Reserved
6	Minutes, 4	36	UTI Sign, +
7	Minutes, 2	37	UTI Sign, -
8	Minutes, 1	38	UTI Sign, +
9	Position Marker 1, P_1	39	Position Marker 4, P_4
10	Reserved	40	UT1 Correction, 0.8 s
11	Reserved	41	UT1 Correction, 0.4 s
12	Hours, 20	42	UT1 Correction, 0.2 s
13	Hours, 10	43	UT1 Correction, 0.1 s
14	Reserved	44	Reserved
15	Hours, 8	45	Year, 80
16	Hours, 4	46	Year, 40
17	Hours, 2	47	Year, 20
18	Hours, 1	48	Year, 10
19	Position Marker 2, P_2	49	Position Marker 5, P_5
20	Reserved	50	Year, 8
21	Reserved	51	Year, 4
22	Day of Year, 200	52	Year, 2
23	Day of Year, 100	53	Year, 1
24	Reserved	54	Reserved
25	Day of Year, 80	55	Leap Year Indicator
26	Day of Year, 40	56	Leap Second Warning
27	Day of Year, 20	57	Daylight Saving Time
28	Day of Year, 10	58	Daylight Saving Time
29	Position Marker 3, P_3	59	Frame Reference Bit, P_0

WWVB requires one minute to send its time code (Figure 2.6). The time code frame contains the current minute, hour, day of year, the last two digits of the current year, the UT1 correction, leap year and leap second indicators, and information about daylight and standard time. Two BCD groups are used to express the hour (00 to 23), minute (00 to 59), and year (00 to 99); and three groups are used to express the day of year (001 to 366). The time code frame begins with a frame reference marker consisting of reference bits P_0 and P_r. The on-time reference point of the time code frame is the leading edge of the reference bit P_r. Seconds are determined by counting pulses within the frame. Position markers (P_1 through P_5) lasting for 0.8 s are transmitted every 10 s within the time code frame. The individual bits are annotated in Table 2.3.

UT1 corrections are broadcast at seconds 36 through 43. The bits transmitted at seconds 36, 37, and 38 show if UT1 is positive or negative with respect to UTC. If 1 bits are sent at seconds 36 and 38, the UT1 correction is positive. If a 1 bit is sent at second 37, the UT1 correction is negative. Bits 40, 41, 42, and 43 form a four-bit BCD group that show the magnitude of the correction in units of 0.1 s.

A *leap year* indicator is transmitted at second 55. If it is set to 1, the current year is a leap year. The bit is set to 1 during each leap year after January 1 but before February 29. It is set back to 0 on January 1 of the year following the leap year.

A *leap second* indicator is transmitted at second 56. If this bit is high, it indicates that a leap second will be added to UTC at the end of the current month. The bit is set to 1 near the start of the month in which a leap second is added. It is set to 0 immediately after the leap second insertion.

Daylight saving time (DST) and standard time (ST) information is transmitted at seconds 57 and 58. When ST is in effect, bits 57 and 58 are set to 0. When DST is in effect, bits 57 and 58 are set to 1. On the day of a change from ST to DST bit 57 changes from 0 to 1 at 0000 UTC, and bit 58 changes from 0 to 1 exactly 24 hours later. On the day of a change from DST back to ST bit 57 changes from 1 to 0 at 0000 UTC, and bit 58 changes from 1 to 0 exactly 24 hours later.

Figure 2.6 shows one frame of the time code. The six position identifiers are labeled as P0, P1, P2, P3, P4, and P5. The minutes, hours, days, year, and UT1 sets are marked by brackets; with the weighting factors printed below the bits. Wide pulses represent 1 bits and narrow pulses represent 0 bits. Unused bits are set to 0. The decoded UTC at the start of the frame is 2001, 258 days, 18 hours, and 42 minutes. Since the UT1 correction is −0.7 s, the decoded UT1 is 2001, 258 days, 18 hours, 41 minutes, 59.3 s.

WWVB Coverage Area

The propagation characteristics of LF radio waves make them well suited for time and frequency transfer. At these longer wavelengths, losses in the Earth's surface are low. Thus, the ground wave can travel well for thousands of kilometers and moderate amounts of transmitted power can cover large portions of a hemisphere.

Figures 2.7 and 2.8 show the estimated coverage area of WWVB during the daytime and nighttime hours in the Fall season (October). The dark color indicate areas where signal levels are estimated to be 100 microvolts per meter (μV/m) or greater. Table 2.4 provides a rough estimate of the expected seasonal signal strength at six different locations.

TABLE 2.4 - ESTIMATED SEASONAL SIGNAL STRENGTH OF WWVB, μV/M

Season	UTC	Cutler, Maine	Honolulu	Mexico City	Miami	San Diego	Seattle
Winter	0000	220	3.2	180	180	180	250
Winter	0400	220	125	560	560	1000	560
Winter	0800	220	320	560	560	1000	560
Winter	1200	320	320	560	560	1000	560
Winter	1600	32	3.2	180	100	180	250
Winter	2000	32	3.2	180	100	180	250
Spring	0000	25	3.2	180	100	180	250
Spring	0400	250	32	560	180	1000	560
Spring	0800	250	400	560	180	1000	560
Spring	1200	40	400	320	100	1000	560
Spring	1600	32	3.2	180	100	180	250
Spring	2000	32	3.2	180	100	180	250
Summer	0000	32	3.2	180	100	180	250
Summer	0400	250	8	560	560	1000	560
Summer	0800	250	400	560	560	1000	560
Summer	1200	32	100	180	100	560	320
Summer	1600	32	3.2	180	100	180	250
Summer	2000	32	3.2	180	100	180	250
Fall	0000	125	3.2	180	56	180	250
Fall	0400	250	180	560	500	1000	560
Fall	0800	250	100	560	500	1000	560
Fall	1200	12	100	560	18	1000	560
Fall	1600	32	3.2	180	100	180	250
Fall	2000	32	3.2	180	100	180	250

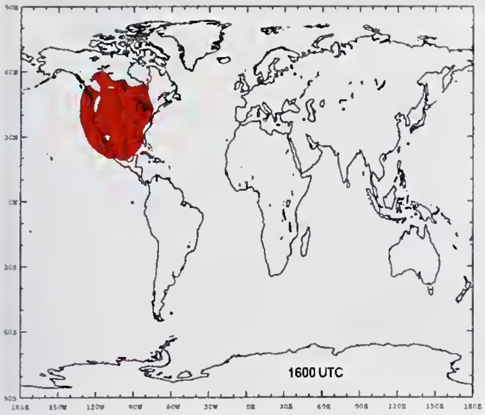

Figure 2.7. Daylight Coverage Area

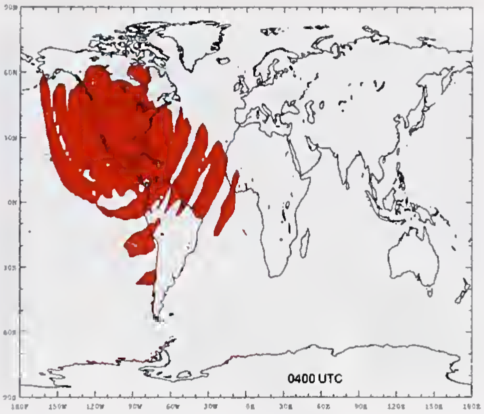

Figure 2.8. Nighttime Coverage Area

WWVB Receiving Equipment and Applications

WWVB receivers are used to control digital and analog wall clocks, desk clocks, travel alarms, clock radios, and wristwatches. New applications for WWVB receivers are found almost daily, and millions of units have been sold.

The simple WWVB receivers share several common characteristics. The receiver usually consists of a single integrated circuit that amplifies and demodulates the WWVB signal. A microprocessor (sometimes integrated into the receiver circuit) is often used to digitally process the time code and drive either an analog or digital display. On some models the microprocessor also outputs the time code to a serial interface so it can be read by a computer system.

Figure 2.9. WWVB Receiver Circuit

One major advantage of WWVB is that the signal can be received using an indoor antenna. LF signals have long wavelengths and when they collide with an object, the angle of incidence is very small. This allows much of the signal to penetrate the object it strikes instead of being reflected. The 60 kHz WWVB signal has a wavelength of approximately 5000 m and can penetrate buildings and walls and easily reach indoor antennas. The antennas used are surprisingly simple. One type of antenna often used in WWVB designs is a ferrite loop, similar to those found inside an AM radio. This antenna consists of a ferrite (a grayish-black metal) bar wrapped with a coil of fine wire. The length of wire and the way it is positioned and wrapped on the bar determine how well the antenna works. The goal is to make the antenna electrically resonant at either a quarter or half-wavelength of the 60 kHz carrier frequency. For the purpose of illustration, a WWVB receiver that was designed to be embedded inside another device is shown in Figure 2.9. The bar at the top of the photograph is a 4 in (10.16 cm) wide ferrite loop antenna, so you can see that the circuit board is just a few centimeters wide and contains just a few components. Obviously, the receivers and antennas used by some products, such as WWVB wristwatches, are much smaller than the one pictured here.

WWVB clocks like those you might find in a home or office are shown in Figure 2.10. These clocks not only keep accurate time, but they automatically adjust for Daylight Saving Time, leap seconds, and leap years. They work by synchronizing an inexpensive quartz oscillator to the WWVB time code. The period of synchronization varies from model to model, but many units synchronize only once every 24 hours; usually during the evening when the signal is strongest. In between synchronizations, time is kept using the quartz oscillator. Typically, the quartz oscillator can maintain frequency to within a few parts per million, so it will take at least two or three days to gain or lose a full second even if WWVB has not been received. Therefore, synchronizing once per day is usually enough to keep a clock's display on the right second. If you live within the coverage area and your WWVB clock is unable to synchronize, it usually means a source of radio interference is near the receiver. Some common culprits are computer monitors (some have a scan rate at or very close to 60 kHz), noisy AC wiring, fluorescent lamps, or nearby power lines, transformers, or radio transmitters.

Figure 2.10. WWVB Radio Controlled Clocks

More expensive WWVB receivers are used for applications that require better performance and reliability. These receivers continually track the signal, and require an outdoor antenna for best results. Figure 2.11 shows a receiver designed to distribute time to other systems, such as communications systems, computers, wall clocks, voice recorders, radio consoles, phone systems, and so on. This type of receiver includes a large digital clock

Figure 2.11. WWVB Time Distribution Receiver

display, and typically outputs a time code in several different formats. Time codes in text and binary format are output in computer readable format using standard serial interfaces such as RS-232 and RS-485. Standard time code formats like those defined by the Inter-Range Instrumentation Group (IRIG) or the National Emergency Number Association (NENA) might also be available. In addition, this type of receiver might include an on time 1 pulse per second signal that can be used as a measurement reference.

Another type of WWVB receiver is designed to work as a frequency standard that can distribute standard frequencies or be used as a reference to calibrate other oscillators. This type of device is known as a *carrier phase tracking receiver*. It disciplines a stable quartz oscillator so that it agrees with the WWVB signal and outputs standard frequencies such as 100 kHz, 1 MHz, 5 MHz, and 10 MHz. The receiver continuously compares its local oscillator to the WWVB signal and makes corrections as necessary. Some receivers designed as frequency standards ignore the time code entirely and do not output time-of-day or an on-time pulse.

WWVB Performance

NIST maintains the time and frequency standards at the WWVB site as closely as possible. The transmitted frequency of WWVB is maintained within a few parts in 10^{13} and time at the station site is kept within 100 ns of UTC(NIST).

The received performance of WWVB depends upon the quality of the received signal, the type of receiver and antenna used, and the distance between your receiving site and the transmitter. Let's look at a few examples of the type of performance you can obtain.

The majority of WWVB users use the station to get time-of-day, using low cost consumer clocks and watches such as those shown in Figure 2.10. The received time is delayed as it travels along the signal path from the transmitter to your receiver. The longer the path, the greater the delay. Like all radio signals, the WWVB signal travels at the speed of light and the longest possible delay in the continental United States is <15 ms. For most people and most applications, this small amount of delay really doesn't make any difference. For example, if the time displayed by a wall clock or wristwatch is 15 ms late, your eyes won't be able to tell.

If you need more accurate time, you might want to calibrate the path. For example, some WWVB receivers produce a 1 pulse per second (pps) signal. This signal is intended to be on time, or to coincide with the arrival of the UTC second. Receivers that produce 1 pps may have a switch or software setting that allows you to advance the on-time pulse to compensate for the path delay. You can estimate the path delay with software that computes the distance between your receiving site and WWVB (the station's coordinates are listed in Table 2.1), and then calculates the time required for a radio signal to travel that distance. Using this technique, it's possible to keep time within 0.1 ms of UTC.

If you use WWVB for frequency measurements or calibrations, there is no need to estimate or compensate for the path delay. For frequency, the important issue is *path stability*, or the changes in the path delay that occur over time. Part of the signal that leaves the WWVB transmitter travels along the ground (*groundwave*) and another part is reflected from the ionosphere (*skywave*). Groundwave reception provides better results than skywave reception. The reason is simple—the groundwave signal follows a direct route to your receiver, and therefore the path length doesn't change very much.

Since the groundwave doesn't travel as far as the skywave, it might not be possible to receive. The further you are from the transmitter, the more important it is to have a sensitive receiver and a good antenna in order to track the groundwave. If your receiving site is relatively close to the transmitter (<1000 km), the signal should be predominantly groundwave. For longer paths, a mixture of groundwave and skywave is received. And over a very long path, the groundwave might become so weak that it is only possible to receive the skywave. In this instance, the path becomes much less stable.

The characteristics of a LF path also vary at different times of day. For example, during the daylight and nighttime hours the path delay might vary by only a few hundred nanoseconds. However, if the skywave is being received, phase shifts will occur at sunrise and sunset. For instance, as the path changes from all darkness to all daylight, the ionosphere lowers and the path gets shorter. The path length then stabilizes until either the transmitter or receiver enters darkness. At this point, the ionosphere rises and the path gets longer. If the signal becomes weak and the receiver loses its tracking point on the carrier, it often has to find a new cycle of the carrier to track. Therefore, the received phase of WWVB often shifts by a multiple of 16.67 μs, or the period of the 60 kHz carrier, if the signal is weak or noisy.

WWVB receivers designed as frequency standards attempt to stay locked to the 60 kHz carrier as tightly as possible. Receivers that stay locked to the same groundwave

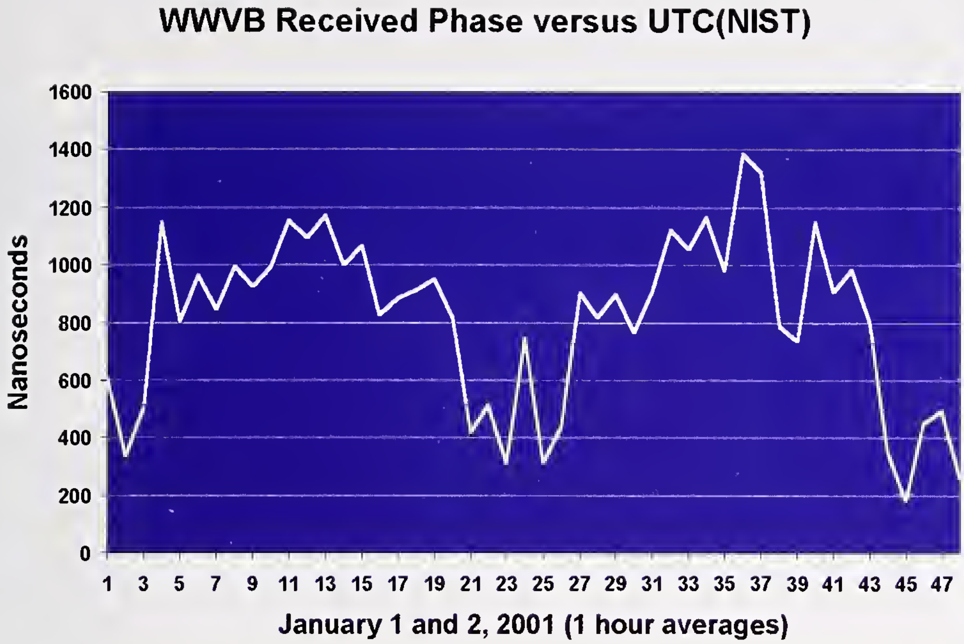

Figure 2.12. WWVB Phase as Received in Boulder, Colorado

cycle at all times can produce frequency traceable to UTC(NIST) with an uncertainty of $< 1 \times 10^{-12}$ when averaged over one or more days. The peak-to-peak variation in the phase is typically about 1 microsecond over 24 hours (Figure 2.12). If the receiver is changing cycles and/or losing lock due to a weak or noisy signal, large phase steps could be introduced and the frequency uncertainty might be 10 to 100 times larger.

The data points shown in Figure 2.12 are one-hour averages so the phase signature (Figure 2.4) has been averaged out. The phase plot shows a diurnal variation due to changes in the path length at sunrise and sunset. Each individual day looks like one "cycle" of the phase plot. This same pattern will repeat itself day after day if the receiver stays locked to the signal.

Chapter 3

Time Signals You Can Hear: NIST Radio Stations WWV and WWVH

The world's most famous time announcements undoubtedly are those broadcast by NIST radio stations WWV and WWVH. Millions of listeners are familiar with these broadcasts, where the announcer states the time in hours, minutes, and seconds "at the tone." These stations operate in the part of the radio spectrum that is properly known as HF (high frequency), but is commonly called shortwave. WWV is located just north of Fort Collins, Colorado, and WWVH is located on the island of Kauai, Hawaii. Both stations broadcast continuous time and frequency signals on 2.5, 5, 10, and 15 MHz, and WWV also broadcasts on 20 MHz. Both stations can also be heard by telephone. And as we shall see in this chapter, both stations provide much more information than just the time.

The coverage area of the two stations is essentially worldwide on 5, 10, and 15 MHz, although reception might be difficult in some areas, since standard time and frequency stations in other parts of the world use these same frequencies. Both stations send QSL cards confirming reports of long distance reception. WWV has received reports from as far away as the South Pole, and reports from Europe, Asia, and Australia are common. WWVH has received reports from as far away as South Africa, a distance of 19,300 km (12,000 miles) from Hawaii.

WWV and WWVH broadcast the same program on all frequencies, 24 hours a day. At least one of the frequencies should be usable at any given time of day. The most commonly used frequency is 10 MHz, since it is normally usable both during the day and at night. As a general rule, frequencies above 10 MHz work best in the daytime, and the lower frequencies work best at night. The 2.5 MHz broadcasts work best in the area near the stations. For example, the 2.5 MHz WWV broadcast should work well for residents of Colorado and its neighboring states, since propagation is similar to the commercial AM broadcast band.

History and Site Description of WWV

WWV has a long and storied history that dates back to the very beginning of radio broadcasting. The call letters WWV were assigned to NIST (then called the National Bureau of Standards) in October 1919. Although the call letters WWV are now synonymous with the broadcasting of time signals, it is unknown why those particular call letters were chosen or assigned. Testing of the station began from Washington, D.C. in May 1920, with the broadcast of Friday evening music concerts that lasted from 8:30 to 11 p.m. The 50 W transmissions used a wavelength of 500 m (about 600 kHz, or near the low end of today's commercial AM broadcast band), and could be heard out to about 40 km away from the station. A news release dated May 28, 1920 hinted at the significance of this event:

> *This means that music can be performed at any place, radiated into the air by means of an ordinary radio set, and received at any other place even though hundreds of miles away. The music received can be made as loud as desired by suitable operation of the receiving apparatus. Such concerts are sometimes sent out by the radio laboratory of the Bureau of Standards in connection with trials of experimental apparatus. This music can be heard by anyone in the states near the District of Columbia having a simple amateur receiving outfit. The pleasant evenings which have been experienced by persons at a number of such receiving stations suggest interesting possibilities of the future.*

Interesting possibilities, indeed! Keep in mind that KDKA of Pittsburgh, Pennsylvania, generally acknowledged as the first commercial broadcast station, did not go on the air until November 2, 1920.

On December 15, 1920 the station began assisting the Department of Agriculture in the distribution of market news to farm bureaus and agricultural organizations. A 2 kW spark transmitter and telegraphic code were used to broadcast 500 word reports, called the *Daily Market Marketgram*, on 750 kHz. The operating radius was about 300 km out of Washington. These broadcasts continued until April 15, 1921.

By December 1922, it was decided that the station's purpose would be the transmission of standard frequency signals. The first tests were conducted on January 29th and 30th of 1923, and included the broadcast of wavelengths from 200 to 545 kHz. By May of 1923, WWV was broadcasting frequencies from 75 to 2000 kHz on a weekly schedule. The accuracy of the transmitted frequency was quoted as being "better than three-tenths of one per cent." The output power of the station was 1 kW.

There were numerous changes in both the broadcast schedule, format, and frequency of WWV throughout the 1920's. In January 1931, the station was moved from Washington to the nearby city of College Park, Maryland. A 150 W transmitter operating at 5 MHz was initially used, but the power was increased back to 1 kW the following year. A new device, the *quartz oscillator*, made it possible to dramatically improve the stability of the output frequency of WWV. Quartz oscillators were first used at WWV in 1927, and by 1932 allowed the transmitted frequency to be controlled to less than 2 parts in 10^7.

The station moved again in December 1932, this time to a Department of Agriculture site near Beltsville, Maryland. By April of 1933, the station was broadcasting 30 kW on 5 MHz, and 10 and 15 MHz broadcasts (20 kW output power) were added in 1935. The 5 MHz frequency was chosen for several reasons, including "its wide coverage, its relative freedom from previously assigned stations, and its convenient integral relation with most frequency standards." The 10 and 15 MHz frequencies were chosen as *harmonics*, or multiples of 5 MHz. WWV continues to use all of these frequencies today, as well as another harmonic (20 MHz), and a sub-harmonic (2.5 MHz).

The Beltsville area was the home of WWV until December 1966 (although the location name for the broadcast was changed to Greenbelt, Maryland in 1961). During the years in Beltsville, many interesting developments took place. A fire destroyed the station in November 1940, but the standard frequency equipment was salvaged and the station returned to the air just five days later using an adjacent building. An act of Congress in July 1941 provided $230,000 for the construction of a new station, which was built 5 km south of the former site and went on the air in January 1943. The 2.5 MHz broadcasts began in February 1944 and have continued to the present day. Transmission on 20, 25, 30, and 35 MHz began in December 1946. The 30 and 35 MHz broadcasts were discontinued in January 1953 and the 25 MHz broadcast was stopped in 1977. With the exception of an almost two-year interruption in 1977 and 1978, the 20 MHz broadcasts have continued to the present day.

Much of the current broadcast format also took shape during the Beltsville years. The 440 Hz tone (A above middle C) was added to the broadcast in August 1936, at the request of several music organizations. Since 1939, 440 Hz (known to musicians as A4 or A440) has been the international standard for musical pitch. The second pulses were added in June 1937, and the geophysical alert messages began in July 1957. And as quartz oscillator technology improved, so did the frequency control of the broadcast. The transmitted frequency was routinely kept within 2 parts in 10^{10} of the national standard by 1958.

WWV's most well known feature, the announcement of time, also began during the Beltsville years. A standard time announcement in telegraphic code was added in October 1945, and voice announcements of time began on January 1, 1950. The original voice announcements were at five-minute intervals. It is interesting to note that WWV continued to broadcast local time at the transmitter site until 1967.

From 1955 to 1958, WWV played a key role in the definition of the atomic second. During this period the United States Naval Observatory (USNO) in Washington, D.C., and the National Physical Laboratory (NPL) in Teddington, United Kingdom made simultaneous common-view measurements of the signals broadcast from WWV. The USNO compared the signal to an astronomical time scale (UT2) and NPL compared the signal to the new cesium standard they had just developed. The data they collected helped the USNO and NPL equate the length of the astronomical second to the atomic second, and led to the atomic second being defined as the duration of 9,192,631,770 cycles of the cesium atom.

In 1966, WWV was moved to its current location, near Fort Collins, Colorado. The LF station WWVB had gone on the air in July 1963 near Fort Collins, and it was decided that WWV would share the same 390 acre (158 hectare) site. The new site was about 80 km from the Boulder laboratories where the national standards of time and frequency were kept. The proximity to Boulder and the use of atomic oscillators at the transmitter site would make it possible to control the transmitted frequency to within 2 parts in 10^{11}, a factor of 10 improvement. Today, the station's frequency is controlled within a few parts in 10^{13}.

At 0000 UTC on December 1, 1966 the Greenbelt, Maryland, broadcast was turned off and the new transmitter at Fort Collins was turned on. In April 1967, the station began broadcasting Greenwich Mean Time (GMT) instead of local time, and began its current format of using Coordinated Universal Time (UTC) in December 1968. The time announcements were made every minute, instead of every 5 minutes, beginning in July 1971.

On August 13, 1991 both WWV and WWVH began broadcasting voice recordings that were digitized and stored in solid state memory devices. Previous voice recordings were played back from mechanical drum recorders, which were more prone to failure. The male voice on WWV was designed to sound like Don Elliot, the station's original announcer. WWVH still uses the voice of its original announcer, Jane Barbe, although the digital storage device has made her voice sound slightly different.

Other new features and programming changes have been added to the WWV broadcast over the past decade, and the current station schedule is described in the remainder of this chapter. A photo of the station is shown in Figure 3.1.

Figure 3.1. Radio Station WWV

History and Site Description of WWVH

WWVH began operation on November 22, 1948 at Kihei on the island of Maui, in the then territory of Hawaii (Hawaii was not granted statehood until 1959). The original station broadcast a low power signal on 5, 10, and 15 MHz. As it does today, the program schedule of WWVH closely follows the format of WWV. However, voice announcements of time were not added to the WWVH broadcast until July 1964.

Figure 3.2. Radio Station WWVH

The original WWVH station site was constantly threatened by an eroding shoreline, and much of the station's equipment and property had been damaged. It was estimated that 75 feet of shoreline were lost in the period from 1949 to 1967. By 1965, the ocean was within a few meters of both the main building and the 15 MHz antenna, and it was obviously necessary to move WWVH to a new location.


Figure 3.3. Aerial View of WWVH Station Site

In July 1971, the station moved to its current location, a 30 acre (12 hectare) site near Kekaha on the Island of Kauai, Hawaii. Photographs of the entrance to WWVH and an aerial view are shown in Figures 3.2 and 3.3.

Station Specifications

WWV and WWVH radiate 10 kW on 5, 10, and 15 MHz. The radiated power is lower on the other frequencies: WWV radiates 2.5 kW on 2.5 and 20 MHz while WWVH radiates 5 kW on 2.5 MHz and does not broadcast on 20 MHz. This information is summarized in Table 3.1.

TABLE 3.1 – SPECIFICATIONS FOR WWV AND WWVH

Characteristics	WWV	WWVH
Date Service Began	March 1923	November 1948
Standard Carrier Frequencies	2.5, 5, 10, 15, & 20 MHz	2.5, 5, 10, & 15 MHz
Power	2.5 kW on 2.5 and 20 MHz, 10 kW on 5, 10, and 15 MHz	5 kW on 2.5 MHz, 10 kW on 5, 10, and 15 MHz

Antennas

The WWV antennas are half-wave vertical antennas that radiate omnidirectional patterns. Since there are five broadcast frequencies, five antennas are in use at all times. Each antenna is connected to a single transmitter using a rigid coaxial line, and the site is designed so that no two coaxial lines cross. Each antenna is mounted on a tower that is approximately one half-wavelength tall. The tallest tower, for 2.5 MHz, is about 60 m tall. The shortest tower, for 20 MHz, is about 7.5 m tall. The 10 m tall tower for the 15 MHz broadcast (with the 122 m tall WWVB towers in the background) is pictured in Figure 3.4.

Figure 3.4. 15 MHz WWV Antenna (WWVB Towers in Background)

The top half of each antenna is a quarter-wavelength radiating element. The bottom half of each antenna consists of nine quarter-wavelength wires that connect to the center of the tower and slope downwards to the ground at a 45° angle. This sloping skirt functions as the lower half of the radiating system and also guys the antenna (Figure 3.5). The WWV antenna coordinates are listed in Table 3.2.

TABLE 3.2 – WWV ANTENNA COORDINATES

Frequency (MHz)	Latitude	Longitude
2.5	40° 40' 55.2" N	105° 02' 31.3" W
5	40° 40' 42.1" N	105° 02' 24.9" W
10	40° 40' 47.8" N	105° 02' 25.1" W
15	40° 40' 45.0" N	105° 02' 24.5" W
20	40° 40' 53.1" N	105° 02' 28.5" W

WWV also has standby antennas that are used only if a primary transmitter or antenna fails. On 2.5, 15, and 20 MHz, these antennas are connected to the standby transmitters. The standby antenna for 15 MHz is an omnidirectional half-wave dipole. Broadband antennas serve as the standby units for 2.5 and 20 MHz. On 5 and 10 MHz, the primary and standby transmitters share the same antenna, and an automated RF switch is used to switch between transmitters if necessary.

The 2.5 MHz antenna at WWVH is nearly identical to its WWV counterpart. However, the 5, 10, and 15 MHz antennas are phased array vertical dipoles. They consist of two half-wave vertical dipoles that are separated by a quarter-wavelength and driven 90° out of phase. These antennas radiate a cardioid pattern with the maximum gain pointed toward the west. Each frequency also has a vertical monopole standby antenna connected to the standby transmitters, in the event that the primary system fails. The WWVH Antenna Coordinates are listed in Table 3.3.

TABLE 3.3 – WWVH ANTENNA COORDINATES

Frequency (MHz)	Latitude	Longitude
2.5	21° 59' 20.9" N	159° 45' 52.4" W
5	21° 59' 10.8" N	159° 45' 44.8" W
10	21° 59' 18.2" N	159° 45' 51.3" W
15	21° 59' 15.3" N	159° 45' 50.0" W

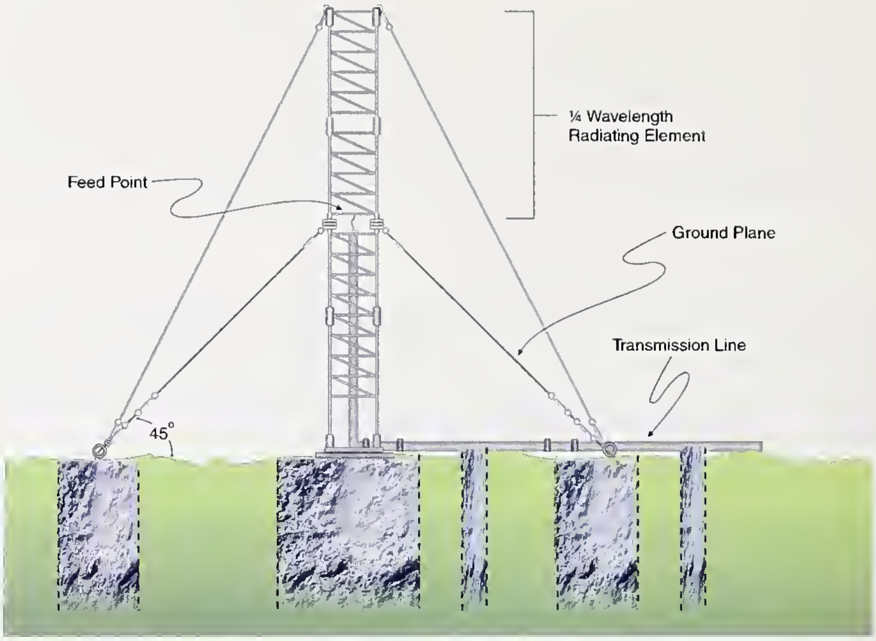

Figure 3.5. Diagram of WWV Antenna

Transmitters

The WWV transmitters consist of two types: plate modulated class C transmitters operating at 10 kW each on 5, 10 and 15 MHz, and class A transmitters operating at 2.5 kW each on 2.5 and 20 MHz. All frequencies have a standby transmitter/antenna system that will automatically begin operating within three minutes of a primary system failure.

WWVH uses class-C plate modulated transmitters on 5, 10, and 15 MHz that operate at 10 kW with 50% efficiency. The 2.5 MHz transmitter is of the class-A type and operates at 5 kW with 20% efficiency. All four frequencies have a backup transmitter/antenna system that will automatically begin transmission within three minutes after the primary system fails. All four of the backup transmitters are 5 kW class-A transmitters, identical to the primary transmitter on 2.5 MHz.

Figure 3.6. WWV Control Room

The signals broadcast by both stations use double sideband amplitude modulation. The modulation level is 50% for the steady tones, 50% for the BCD time code, 100% for the second pulses and the minute and hour markers, and 75% for the voice announcements.

The carrier frequencies and the information modulated on to the carrier are derived from cesium oscillators that are steered to agree with UTC(NIST). Figure 3.6 shows a portion of the equipment in the WWV control room, including the time code generators and cesium oscillators.

Information Transmitted

WWV and WWVH are best known for their audio time announcements, but the stations provide other information as summarized in Table 3.4.

TABLE 3.4 – INFORMATION PROVIDED BY WWV AND WWVH

SERVICE TYPE	INFORMATION PROVIDED
Standard Audio Frequencies	440, 500, & 600 Hz
Time Intervals	Seconds, 10 seconds, minutes, hours.
Time Signals: Voice	Voice announcement is made once per minute
Time Signals: Code	BCD code on 100 Hz subcarrier, 1 pulse/s
Official Announcements	Geoalerts, Marine Storm Warnings, Global Positioning System Status Reports

Figures 3.7 and 3.8 show the hourly program schedules of WWV and WWVH along with station location, radiated power, and details of the modulation.

Time Announcements

Voice announcements are made from WWV and WWVH once every minute. Since both stations can be heard in some areas, a man's voice is used on WWV, and a woman's voice is used on WWVH to avoid confusion. The WWVH announcement occurs first, at about 15 s before the minute. The WWV announcement follows at about 7.5 s before the minute. Though the announcements occur at different times, the tone markers are transmitted at the exact same time from both stations. However, they may not be received at exactly the same instant due to differences in the propagation delays from the two station sites.

Standard Time Intervals

The most frequent sounds heard on WWV and WWVH are the seconds pulses. These pulses are heard every second except on the 29^{th} and 59^{th} seconds of each minute. The first pulse of each hour is an 800 ms pulse of 1500 Hz. The first pulse of each minute is an 800 ms pulse of 1000 Hz at WWV and 1200 Hz at WWVH. The remaining second pulses are short audio bursts (5 ms pulses of 1000 Hz at WWV and 1200 Hz at WWVH) that sound like the ticking of a clock.

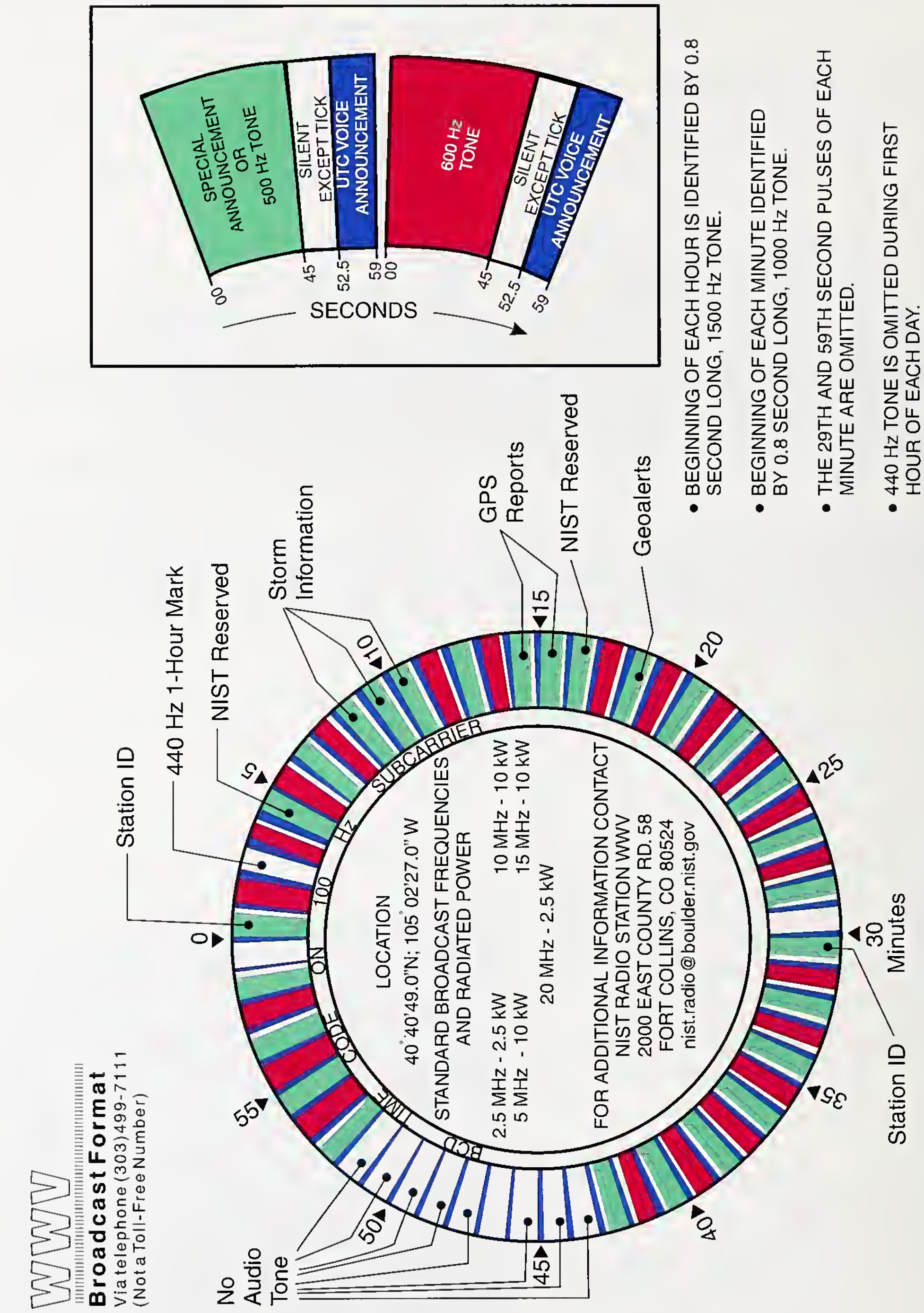

Figure 3.7. WWV Broadcast Format

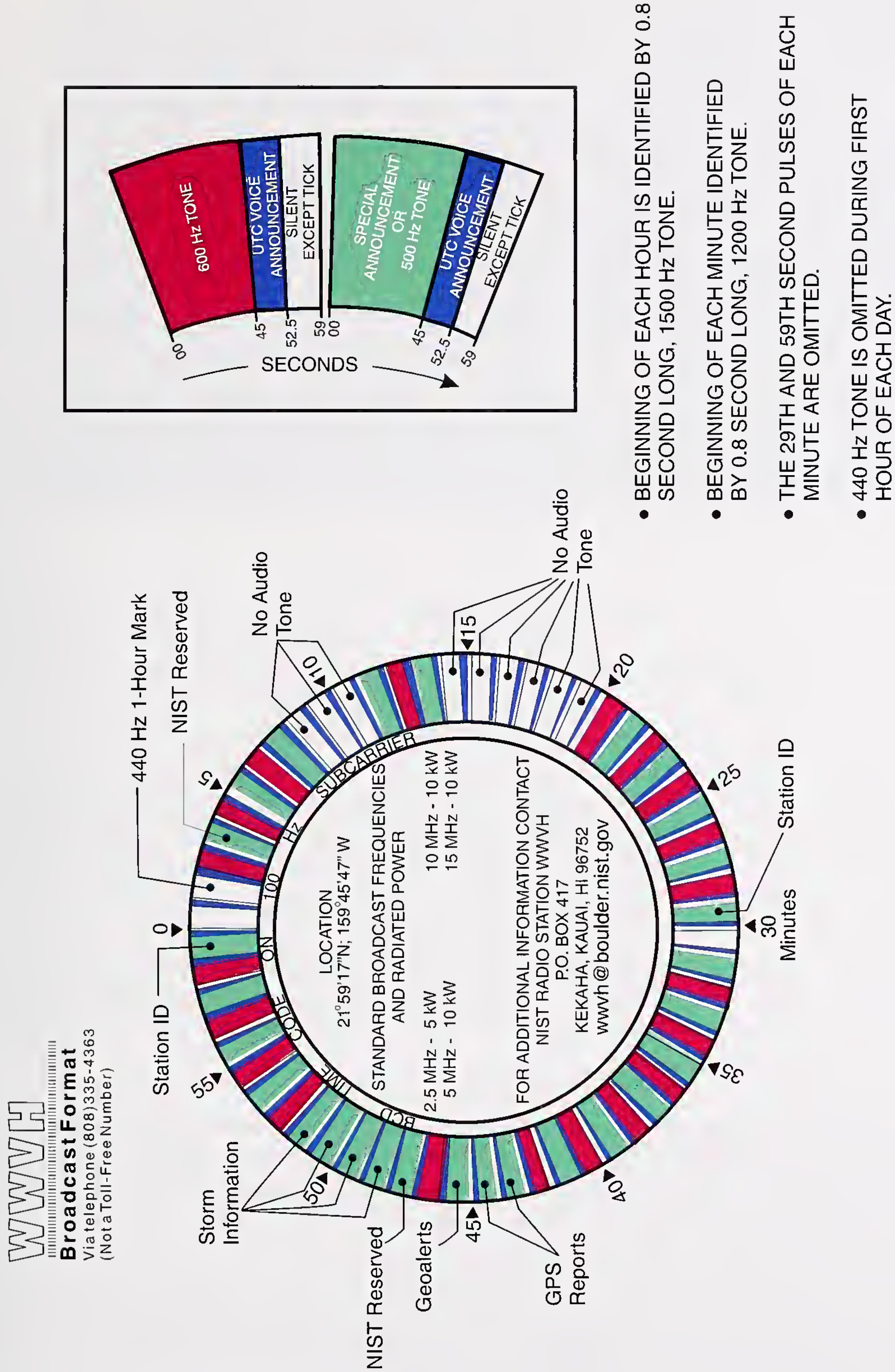

Figure 3.8. WWVH Broadcast Format

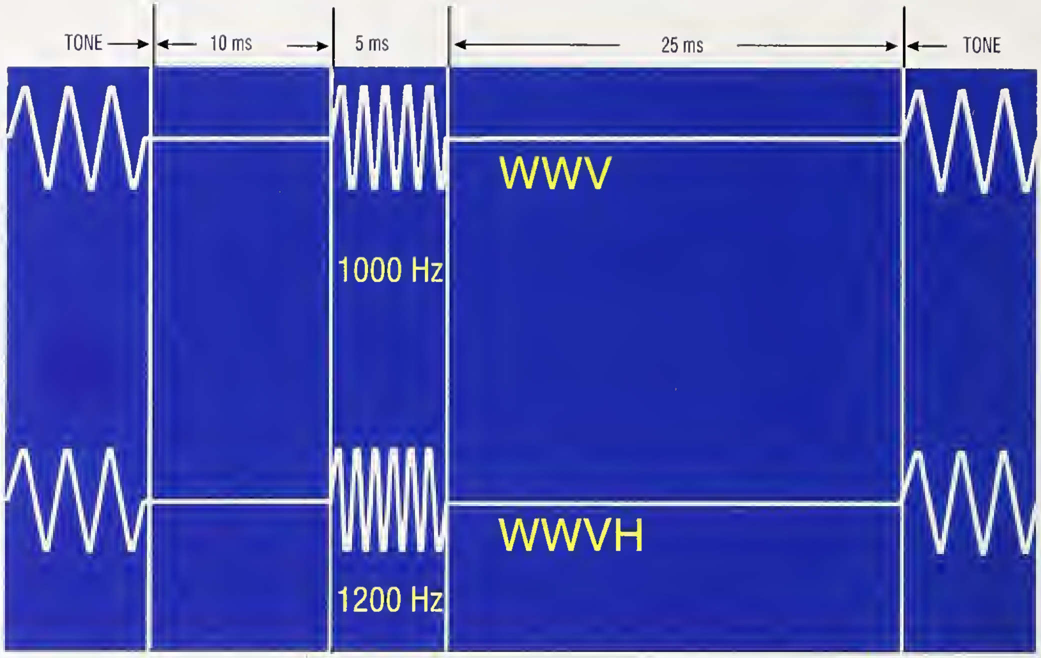

Figure 3.9. WWV and WWVH Second Pulses

Each seconds pulse is preceded by 10 ms of silence and followed by 25 ms of silence. The silence makes it easier to pick out the pulse. The total 40 ms protected zone around each seconds pulse is shown in Figure 3.9.

Standard Audio Frequencies and Silent Periods

In alternate minutes during most of each hour, 500 Hz or 600 Hz audio tones are broadcast. A 440 Hz tone (the musical note A above middle C) is broadcast once each hour. In addition to being a musical standard, the 440 Hz tone provides an hourly marker for chart recorders and other automated devices. The 440 Hz tone is omitted, however, during the first hour of each UTC day. See Figures 3.7 and 3.8 for further details.

The silent periods are without tone modulation. However, the carrier frequency, seconds pulses, time announcements, and the 100 Hz BCD time code continue during the silent periods. In general, one station will not broadcast an audio tone while the other station is broadcasting a voice message.

On WWV, the silent period extends from 43 to 52 minutes after the hour. WWVH has two silent periods; from 8 to 11 minutes after the hour and from 14 to 20 minutes after the hour. Minutes 29 and 59 on WWV and minutes 00 and 30 on WWVH are also silent.

UT1 Correction

UT1 corrections are encoded into the broadcasts by using doubled ticks during the first 16 s of each minute. You can determine the amount of the correction (in units of 0.1 s) by counting the number of doubled ticks. The sign of the correction depends on whether the doubled ticks occur in the first 8 s of the minute or in the second 8 s. If the doubled ticks are in the first 8 s (1 to 8) the sign is positive. If the doubled ticks are in the second

8 s (9 to 16) the sign is negative. For example, if ticks 1, 2, and 3 are doubled, the correction is +0.3 s. This means that UT1 equals UTC plus 0.3 s. If UTC is 8:45:17, then UT1 is 8:45:17.3. If ticks 9, 10, 11, and 12 are doubled, the correction is –0.4 s. If UTC is 8:45:17, then UT1 is 8:45:16.6. If none of the ticks are doubled, then the current correction is 0.

Official Announcements

Announcement segments are available by subscription to other United States government agencies. These segments are used for public service messages up to 45 s long. The accuracy and content of these messages is the responsibility of the originating agency. For information about the availability of these segments, contact the NIST Time and Frequency Division. The announcements that are currently part of the program schedule are described below.

Geophysical Alerts

The National Oceanic and Atmospheric Administration (NOAA) uses WWV and WWVH to broadcast geophysical alert messages that provide information about solar terrestrial conditions. Geophysical alerts are broadcast from WWV at 18 minutes after the hour and from WWVH at 45 minutes after the hour. The messages are less than 45 s in length and are updated every three hours (typically at 0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100 UTC). More frequent updates are made when necessary.

The geophysical alerts provide information about the current conditions for long distance HF radio propagation. The alerts use a standardized format and terminology that requires some explanation. After defining the terminology, we'll look at a sample message.

Solar flux is a measurement of the intensity of solar radio emissions with a wavelength of 10.7 cm (a frequency of about 2800 MHz). The daily solar flux measurement is recorded at 2000 UTC by the Dominion Radio Astrophysical Observatory of the Canadian National Research Council located at Penticton, British Columbia, Canada. The value broadcast is in solar flux units that range from a theoretical minimum of about 50 to numbers larger than 300. During the early part of the 11-year *sunspot cycle*, the flux numbers are low; but they rise and fall as the cycle proceeds. The numbers will remain high for extended periods around sunspot maximum.

Basically, solar flux is measured by counting sunspots, or storms on the surface of the sun. The greater the number of sunspots, the stronger is the ionosphere, the electrified region in the Earth's upper atmosphere. A strong ionosphere means that HF radio signals can be reflected over great distances. Therefore, high solar flux numbers usually, but not always, mean that HF propagation conditions are good. A solar flux figure might be 65 or lower in years of minimum solar activity. In most years, the average solar flux figure falls between 100 and 200.

The A and K indices are a measurement of the behavior of the *magnetic field* in and around the Earth. The *K index* uses a scale from 0 to 9 to measure the change in the horizontal component of the geomagnetic field. A new K index is determined and added to the broadcast every three hours based on magnetometer measurements made at the Table

Mountain Observatory, north of Boulder, Colorado, or an alternate middle latitude observatory. The *A index* is a daily value on a scale from 0 to 400 to express the range of disturbance of the geomagnetic field. It is obtained by converting and averaging the eight, 3 hour K index values. An estimated A index is first announced at 2100 UTC, based on seven measurements and one estimated value. At 0000 UTC, the announced A index consists entirely of known measurements, and the word "estimated" is dropped from the announcement. Table 3.5 shows the relationship between the A and K indices.

TABLE 3.5 – THE RELATIONSHIP BETWEEN THE A INDEX AND K INDEX

A Index	0	3	7	15	27	48	80	140	240	400
K Index	0	1	2	3	4	5	6	7	8	9

The A and K indices are probably the most widely discussed values in radio monitoring circles. If the A index is less than 10 or the K index is around 3, it indicates nearly ideal conditions for HF radio propagation. The lower the figure, the less the signals are absorbed by the Earth's geomagnetic field. Less absorption means that HF signals will travel farther and better.

Solar flux values and the A and K indices can also be used to compute the maximum usable frequency (MUF) and the lowest usable frequency (LUF) for a given time and location. This information is helpful to radio listeners who want to know the best time to tune in hard-to-hear signals.

Space Weather describes the conditions in space that affect earth and its technological systems. Space weather is a consequence of the behavior of the Sun, the nature of Earth's magnetic field and atmosphere, and our location in the solar system.

Space weather storms observed or expected to occur are characterized using the NOAA Space Weather scales. The tables below describe the terminology used in the announcements. The descriptor refers to the maximum level reached or predicted. These space weather scales are described in more detail on the NOAA Space Environment Center's web site (http://www.sec.noaa.gov).

TABLE 3.6 – NOAA SPACE WEATHER SCALES

GEOMAGNETIC STORMS	SOLAR RADIATION STORMS	RADIO BLACKOUTS	DESCRIPTOR
G5	S5	R5	Extreme
G4	S4	R4	Severe
G3	S3	R3	Strong
G2	S2	R2	Moderate
G1	S1	R1	Minor

Geomagnetic storm levels are determined by the estimated three hourly Planetary K-indices derived in real time from a network of western hemisphere ground-based magnetometers.

TABLE 3.7 – GEOMAGNETIC STORM LEVELS

PLANETARY K INDICES	GEOMAGNETIC STORM LEVEL
K = 5	G1
K = 6	G2
K = 7	G3
K = 8	G4
K = 9	G5

Solar Radiation storms levels are determined by the proton flux measurements made by NOAA's primary Geostationary Operational Environmental Satellite (GOES).

TABLE 3.8 – SOLAR RADIATION STORM LEVELS

FLUX LEVEL OF >10 MeV PARTICLES	SOLAR RADIATION STORM LEVEL
10	S1
10^2	S2
10^3	S3
10^4	S4
10^5	S5

Radio Blackout levels are determined by the x-ray level measured by the primary GOES satellite.

TABLE 3.9 – RADIO BLACKOUTS

PEAK X-RAY LEVEL AND FLUX	RADIO BLACKOUT LEVEL
M1 and (10^{-5})	R1
M5 and (5×10^{-5})	R2
X1 and (10^{-4})	R3
X10 and (10^{-3})	R4
X20 and (2×10^{-3})	R5

Every geophysical alert consists of three parts as shown in Tables 3.10 and 3.11. Table 3.10 describes the information contained in the geophysical alert. Table 3.11 provides example text from an actual message.

TABLE 3.10 – INFORMATION IN GEOPHYSICAL ALERT VOICE MESSAGE

SECTION	INFORMATION IN VOICE MESSAGE
1	The solar-terrestrial indices for the day: specifically the solar flux, the A index, and the K index.
2	Space weather storms observed during the previous 24 hours. Includes all observed geomagnetic storms, solar radiation storms (proton events) and Radio blackouts (class M1 and greater flares).
3	Space weather expected during the following 24 hours.

TABLE 3.11 – EXAMPLE TEXT FROM ACTUAL GEOPHYSICAL ALERT MESSAGE

SECTION	EXAMPLE OF ACTUAL GEOPHYSICAL ALERT MESSAGE
1	Solar-terrestrial indices for 08 November follow. Solar flux 173 and mid-latitude A-index 14 The Mid-latitude K-index at 1500 UTC on 08 November was 3.
2	Space weather for the past 24 hours has been severe. Solar radiation storm(s) reaching the S4 level is in progress. Radio blackouts(s) reaching the R2 level occurred.
Alternate section 2	No space weather storms have been observed during the past 24 hours.
3	Space weather for the next 24 hours is expected to be severe. Solar radiation storms reaching the S4 level are expected to continue. Radio blackouts reaching the R2 level are expected.
Alternate section 3	No space weather storms are expected during the next 24 hours.

The announcements describe the largest space weather event observed (section 2) or expected (section 3) in the first line of each section. The remaining lines give the type of events and the level observed for each one. In the example above, no geomagnetic storm information is included because none was observed or expected during the period. In the case where none of the three types of events are observed or expected, the announcement would contain section 1, plus alternate section 2 and alternate section 3.

To hear the current geophysical alert message by telephone, dial (303) 497-3235. For more information about these messages, contact: Space Weather Operations, NOAA R/SEC, 325 Broadway, Boulder, CO 80305-3328. Email: swo@sec.noaa.gov Voice: (303) 497-3171.

Marine Storm Warnings

Both WWV and WWVH broadcast marine storm warnings for the ocean areas where the United States has warning responsibility under international agreement. These brief voice messages warn mariners of storm threats present in their areas, and contain information provided by the National Weather Service. Atlantic high seas warnings are broadcast by WWV at 8 and 9 minutes after the hour and an eastern North Pacific high seas warning is broadcast at 10 minutes after the hour. WWVH broadcasts eastern and central North Pacific high seas warnings at 48, 49, 50 and 51 minutes after the hour. Additional segments (at 11 minutes after the hour on WWV and at 52 minutes after the hour on WWVH) are used when conditions are particularly bad.

The storm warnings are based on the most recent forecasts. The forecasts are updated at 0500, 1100, 1700, and 2300 UTC for WWV; and at 0000, 0600, 1200, and 1800 UTC for WWVH. All marine forecasts rely heavily on the Voluntary Observing Ship (VOS) program for obtaining meteorological observations.

A typical storm warning announcement might read like this:

> *North Atlantic weather West of 35 West at 1700 UTC; Hurricane Donna, intensifying, 24 North, 60 West, moving northwest, 20 knots, winds 75 knots; storm, 65 North, 35 West, moving east, 10 knots; winds 50 knots, seas 15 feet.*

For more information about marine storm warnings, write to: National Weather Service, NOAA, 1325 East West Highway, Silver Spring, MD 20910. Or, visit the National Weather Service web page at http://www.nws.noaa.gov.

Global Positioning System (GPS) Status Announcements

The United States Coast Guard sponsors two voice announcements per hour on WWV and WWVH, giving current status information about the GPS satellites and related operations. The 45 s long announcements begin at 14 and 15 minutes after each hour on WWV and at 43 and 44 minutes after each hour on WWVH. For further information, contact the U.S. Coast Guard Navigation Center, 7323 Telegraph Road, Alexandria, VA 22310, or call (703) 313-5900.

WWV/WWVH Time Code

WWV and WWVH each broadcast a binary coded decimal (BCD) time code on a 100 Hz subcarrier. The time code provides UTC information in serial fashion at a speed of 1 bit per second. The information carried by the time code includes the current minute, hour, and day of year. The time code also contains the 100 Hz frequency from the subcarrier. The 100 Hz frequency may be used as a standard with the same accuracy as the audio frequencies.

The time code is sent in binary coded decimal (BCD) format, where four binary digits (bits) are used to represent one decimal number. The binary-to-decimal weighting scheme is 1-2-4-8. The *least significant bit* is sent first. This is the reverse of the WWVB time code described in Chapter 2. The BCD groups and the equivalent decimal numbers are shown in Table 3.12.

TABLE 3.12 - BCD WEIGHTING SCHEME USED BY WWV AND WWVH TIME CODE

DECIMAL NUMBER	BIT 1 2^0	BIT 2 2^1	BIT 3 2^2	BIT 4 2^3
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	1	1	0	0
4	0	0	1	0
5	0	1	0	1
6	0	1	1	0
7	1	1	1	0
8	0	0	0	1
9	1	0	0	1

Bits are transmitted on the 100 Hz subcarrier using amplitude modulation. A 200 ms pulse (20 cycles of 100 Hz) is used to represent a 0 bit, and a 500 ms pulse (50 cycles of 100 Hz) is used to represent a 1 bit. However, tone suppression deletes the first 30 ms of each pulse. Therefore, 170 ms pulses are recognized as 0 bits, and 470 ms pulses are recognized as 1 bits. The leading edge of each pulse can serve as an on time marker, but due to the tone suppression it actually occurs 30 ms after the start of the second.

WWV and WWVH require 1 minute to send their time code (Figure 3.9). The time code frame contains the minute, hour, day of year, the last two digits of the current year, the UT1 correction, a leap second indicator, and information about daylight and standard time. Two BCD groups are used to express the hour (00 to 23), minute (00 to 59), and year (00 to 99); and three groups are used to express the day of year (001 to 366). The information in the time code refers to the time at the start of the one-minute frame. Seconds are determined by counting pulses within the frame. The individual time code bits are annotated in Table 3.13.

TABLE 3.13 – WWV AND WWVH TIME CODE BITS

BIT NUMBER	BIT DESCRIPTION	BIT NUMBER	BIT DESCRIPTION
0	Frame Reference Bit, Pr (hole)	30	Day of Year, 1
1	Reserved	31	Day of Year, 2
2	DST Indicator	32	Day of Year, 4
3	Leap Second Warning	33	Day of Year, 8
4	Year, 1	34	Reserved
5	Year, 2	35	Day of Year, 10
6	Year, 4	36	Day of Year, 20
7	Year, 8	37	Day of Year, 40
8	Reserved	38	Day of Year, 80
9	Position Marker 1, P1	39	Position Marker 4, P4
10	Minute, 1	40	Day of Year, 100
11	Minute, 2	41	Day of Year, 200
12	Minute, 4	42	Reserved
13	Minute, 8	43	Reserved
14	Reserved	44	Reserved
15	Minute, 10	45	Reserved
16	Minute, 20	46	Reserved
17	Minute, 40	47	Reserved
18	Reserved	48	Reserved
19	Position Marker 2, P2	49	Position Marker 5, P5
20	Hour, 1	50	UT1 Sign
21	Hour, 2	51	Year, 10
22	Hour, 4	52	Year, 20
23	Hour, 8	53	Year, 40
24	Reserved	54	Year, 80
25	Hour, 10	55	DST Indicator
26	Hour, 20	56	UT1 Correction, 0.1 s
27	Reserved	57	UT1 Correction, 0.2 s
28	Reserved	58	UT1 Correction, 0.4 s
29	Position Marker 3, P3	59	Frame Reference Bit, P0

Each time code frame begins with a unique spacing of pulses that mark the start of a new minute. During the first second of the minute, no pulse is transmitted. Since the pulses are already delayed 30 ms by the tone suppression, the UTC minute actually begins 1030 ms (1.03 s) earlier than the first pulse in the frame. For synchronization purposes, position markers lasting for 770 ms are transmitted every 10 s.

A *leap second* indicator is transmitted at second 3. If this bit is high, it indicates that a leap second will be added to UTC at the end of the current month. The bit is set to 1 near the start of the month in which a leap second is added. It is set to 0 immediately after the leap second insertion.

UT1 corrections are broadcast during the final 10 s of each frame. The bit transmitted at second 50 shows if UT1 is positive or negative with respect to UTC. If a 1 is sent, the UT1 correction is positive. If a 0 is sent, the UT1 correction is negative. Bits 56, 57, and 58 form a three-bit BCD group that shows the magnitude of the correction. Since the unit for the UT1 correction is 0.1 s, multiply the BCD group by 0.1 to obtain the correct value. Since only three bits are used, the WWV and WWVH time codes can only transmit UT1 corrections ranging from −0.7 to +0.7 s.

Daylight saving time (DST) and standard time (ST) information is transmitted at seconds 2 and 55. When ST is in effect, bits 2 and 55 are set to 0. When DST is in effect, bits 2 and 55 are set to 1. On the day of a change from ST to DST bit 55 changes from 0 to 1 at 0000 UTC, and bit 2 changes from 0 to 1 exactly 24 hours later. On the day of a change from DST back to ST bit 55 changes from 1 to 0 at 0000 UTC, and bit 2 changes from 1 to 0 exactly 24 hours later.

The year information is transmitted in two different parts of the time code. The last digit of the year is sent using bits 4 through 7. The next to last digit of the year, or the decade indicator, is sent using bits 51 through 54. For example, for the year 2001, bits 4 through 7 will return a decimal value of 1, and bits 51 through 54 will return a decimal value of 0.

Figure 3.10 shows one frame of the time code. The six position identifiers are labeled P0, P1, P2, P3, P4, and P5. The minutes, hours, days, year, and UT1 sets are marked by brackets, with the weighting factors printed below the bits. Wide pulses represent "1" bits and narrow pulses represent "0" bits. Unused bits are set to 0. The decoded UTC at the start of the frame is 2001, 173 days, 21 hours, and 10 minutes. Since the UT1 correction is +0.3 s, the decoded UT1 is 2001, 173 days, 21 hours, 10 minutes, and 0.3 s.

Receiving Equipment

WWV and WWVH can be heard with any *shortwave* receiver. A typical general coverage shortwave receiver provides continuous coverage of the spectrum from about 150 kHz, which is below the commercial AM broadcast band, to 30 MHz. These receivers allow reception of WWV and WWVH on all available frequencies. The best shortwave receivers are often referred to as communications receivers. These receivers are usually designed

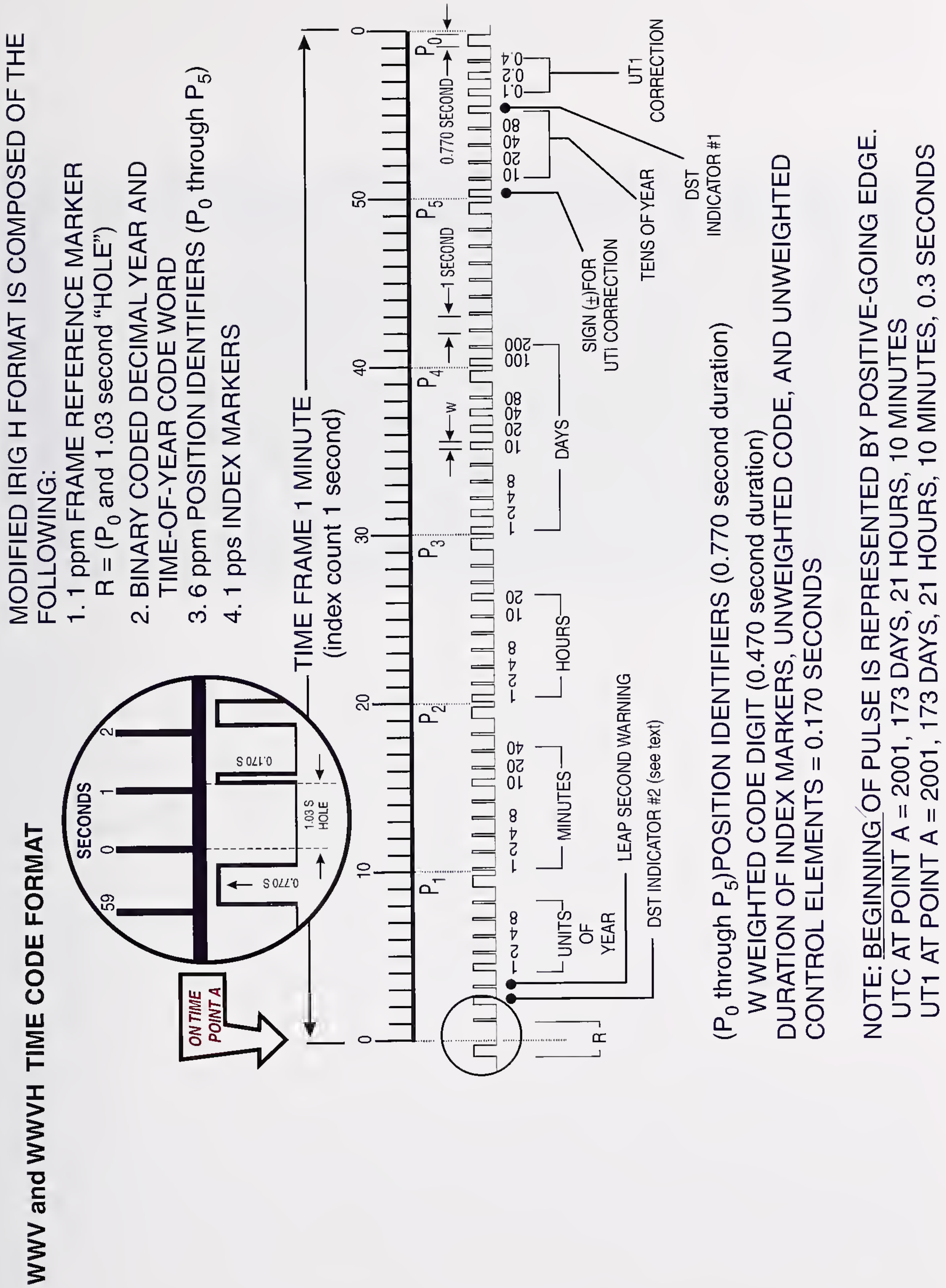

Figure 3.10. WWV and WWVH Time Code Format

as tabletop or rackmount units and are often used by amateur radio operators who operate both a transmitter and receiver. They are designed to work with large outdoor antennas, with quarter-wave or half-wave length dipole antennas often providing the best results. Prices range from less than $500 to more than $5000. A typical communications receiver is shown in Figure 3.11.

Figure 3.11. A HF Communications Receiver

Less expensive shortwave radios are usually portable, and can run off batteries. They typically use a built-in telescopic whip antenna that is less than 1 m long, but most have a connector for an external antenna. Some of the lower cost models only provide coverage of the frequencies commonly used for international broadcasts; typically from about 4 to 12 MHz. These receivers will still provide reception of both WWV and WWVH on 5 and 10 MHz, which are usually the easiest frequencies to receive.

A few low-cost commercially available receivers are dedicated to the task of receiving WWV and WWVH. These receivers might receive only a single frequency, often 10 MHz, and their sole purpose is producing the WWV or WWVH audio.

Receivers that decode and display the time code are also available, but are not nearly as common as their WWVB counterparts. Some units output a time code to a serial interface and/or output a standard time code format defined by the Inter-Range Instrumentation Group (IRIG). In addition, these receivers might include an on time one pulse per second signal for use as a measurement reference. Since it is difficult for a time code receiver to stay locked to a single frequency at all times, these units generally monitor several frequencies and use the one that currently offers the best reception.

Listening to the Signals by Telephone

If you don't have a shortwave receiver, you can still listen to WWV and WWVH by simply making a telephone call. The broadcasts are simulcast by telephone via NIST's

Telephone Time-of-Day Service. The uncertainty of the time announcement depends upon the type of phone call. The time signals are usually delayed by <30 ms if you call from an ordinary telephone (land line) from within the continental United States, and the stability (delay variations) are generally <1 ms during the call. If you are calling from a mobile phone, the delay is often more than 100 ms due to the multiple access methods used to share cell channels. And if you are making an overseas call, your call could be routed through a communications satellite, which might add 250 to 500 ms to the delay.

To hear these broadcasts, dial (303) 499-7111 for WWV and (808) 335-4363 for WWVH. You can listen for about two minutes before your call is disconnected. Please keep in mind that these are not toll-free numbers. Callers outside the local calling area are charged long distance rates.

NIST has provided time signals by telephone for several decades. The WWV number has been available since July 1971, and the Hawaii number has been available since April 1973.

HF Propagation

WWV and WWVH are referred to the primary NIST Frequency Standard and related NIST atomic time scales in Boulder, Colorado. The frequencies *as transmitted* are maintained within a few parts in 10^{13} for frequency and <100 ns for timing with respect to UTC(NIST). In fact, at the transmitter site WWV's frequency is controlled just as tightly as WWVB (Chapter 2). However, the received performance of WWV and WWVH is generally worse than the received performance of WWVB. This is because a HF radio path is much less stable than a LF radio path.

Why is a HF path less stable? Although HF radio propagation is a complex subject, we can provide a simplified explanation here. We mentioned in Chapter 2 that the groundwave signals from WWVB follow a direct route to your receiver, and therefore the path length doesn't change very much. Other types of radio signals, such as those that originate from satellites, follow even a more direct route. In fact, some signals require *line-of-sight* propagation, which means that nothing can block the path between the receiving antenna and the transmitter. An example would be a GPS satellite antenna, which requires a clear view of the sky.

HF signals are different. They don't have to follow a direct route. In fact, they rely on skywave propagation, which means that they follow an indirect route. HF signals travel past their horizon line, bounce off the ionosphere, and head back down toward Earth and your receiver, which might be on the opposite side of the Earth from the transmitter. This bouncing off the ionosphere is called *refraction*, or *skip*. Sometimes the signals bounce just once off the ionosphere, sometimes they bounce more than once. Each of these bounces or *hops* adds more delay to a timing signal. As you can see, the good news about refraction is that it allows stations to be heard over great distances. The bad news is that refraction makes the signal path (and therefore the amount of the path delay) variable and hard to predict.

The ionosphere generally ranges between 50 and 1200 km above the Earth's surface. The gases in these regions become ionized by the ultraviolet radiation from the Sun. The more radiation, the more ionization occurs. Too much ionization makes the ionosphere too dense to refract signals, and it absorbs signals instead of sending them back to Earth. Not enough ionization means that the ionosphere won't be dense enough to refract or absorb signals. Instead, signals will simply pass through the ionosphere and head off into space.

The ionosphere has several layers that effect HF propagation, specifically the D, E, and F layers. The D layer is usually between 50 and 100 km above the Earth's surface, the E layer is between 100 and 160 km, and the F layer is between 160 and 320 km above the Earth. Each layer reacts differently to different frequencies at different times of day, and even during different seasons of the year. For example, consider that the D layer is very dense during the daytime, and tends to absorb signals below 7 MHz. At night, however, it becomes less dense and is able to refract signals. This means that a 5 MHz signal from WWV probably won't travel very far during the daytime. Those who can receive it during the day are probably close enough to the station to receive the groundwave. At night, however, the 5 MHz signal will refract off the ionosphere and the coverage area will become much larger.

Since the HF radio path delay depends upon so many factors—the frequency used, the time of day, the season, and the ionospheric conditions, to name just a few; it's easy to see that it limits the performance of WWV and WWVH for time and frequency applications. Even so, the signals still meet the requirements for many applications and measurements, as described in the next section.

Applications and Measurement Results

What kind of results can you get using WWV and WWVH? Let's look at the results obtained for several different applications and measurements (summarized in Table 3.13).

Manual Synchronization of a Watch or Clock — Many thousands of people set their clocks or watches to the tones from WWV and WWVH. If you are listening from within the United States either by radio or by telephone, the time should be delayed by <20 ms (less for most listeners) with respect to UTC(NIST). This delay is insignificant when compared to human reaction time, which is no better than 100 ms for most people, and is sometimes several hundred milliseconds or more.

Stop Watch and Timer Calibrations — Calibration and testing laboratories use the audio tones from WWV and WWVH as the reference for stop watch and timer calibrations. These calibrations are actually a time interval measurement, tones from the broadcast are used as signals to start and stop the timer. In between the start and stop tones the timer runs continuously, usually for an interval of at least an hour. When the timer is stopped, the measured time interval on its display is compared to the actual time interval broadcast by the station. The difference between these two values is the time offset, or error of the timer. WWV and WWVH contribute practically zero uncertainty to these measurements. Even though both the start and stop tones are delayed as they travel to the listener, the difference between the start and stop delays should always be much less than a millisecond. Once again, the largest source of uncertainty is human reaction time.

Tuning a piano — The 440 Hz tones broadcast by WWV and WWVH near the beginning of each hour serve as the ultimate reference for the calibration of pianos and other musical instruments. Since 1939, A440 (the musical note A above middle C at 440 Hz) has been the internationally recognized standard for musical pitch. The piano tuner listens to a standard musical pitch and compares it to the same note on the piano keyboard. The piano is then adjusted (by tightening or loosening strings), until it agrees with the audio standard.

What is the smallest frequency error that a piano tuner can hear? It depends on lots of factors, including the sound volume, the duration of the tone, the suddenness of the frequency change, and the musical training of the listener. However, the *just noticeable difference* is often defined as 5 cents, where 1 cent is 1/100 of the ratio between two adjacent tones on the piano's keyboard. Since there are 12 tones in a piano's octave, the ratio for a frequency change of 1 cent is the 1200^{th} root of 2. Therefore, to raise a musical pitch by 1 cent, you would multiply by the 1200th root of 2, or 1.000577790. If you do this 5 times starting with 440 Hz, you'll see that 5 cents high is about 441.3 Hz, or high in frequency by 1.3 Hz. Obviously, WWV or WWVH will contribute no discernible uncertainty to these measurements, since their 440 Hz tone should have an error of less than 0.001 Hz.

Keep in mind that the actual piano tuning is generally done with a transfer standard such as a tuning fork or an audio tone generator, since those devices are easy to bring to the piano site and their signals are always available. In other words, if you use a transfer standard, you don't have to wait until the top of the hour to hear the tone. However, the audio from WWV or WWVH is often used as a reference for calibrating the transfer standard.

Calibrating a receiver dial — Radio amateurs and shortwave listening enthusiasts often use WWV or WWVH to calibrate their receiver dial. Receivers are usually tested after they have been turned on for at least an hour, so that their internal oscillator has a chance to stabilize. The calibration method varies for different radios, but the object is always to mix the incoming signal from WWV and WWVH with the signal from the receiver's beat frequency oscillator (BFO). This produces a beat note that sounds like a low frequency whistle. The receiver is tuned to the station, and the dial is moved up or down until the whistle completely goes away, a condition known as *zero beat*. Usually, headphones are used to listen for zero beat, since the receiver's speaker might not be able to produce the low frequency beat note signals. Since a person with average hearing can hear tones down to 20 or 30 Hz, an audio zero beat can resolve frequency within 2 or 3 parts in 10^6 at 10 MHz. To get closer, you can also look at the receiver's signal strength, or S-meter. This meter will fluctuate at its slowest rate as the beat note approaches 0 Hz. It should be possible to obtain a beat note of 1 Hz or less, as indicated by a slow "bobbing" of the S-meter back and forth. Once zero beat is reached, the difference between the receiver's dial reading and the carrier frequency of the radio station shows you the frequency offset of the radio. For example, if you zero beat the 10 MHz carrier from WWV with a dial reading of 10000.2 kHz, the receiver dial has a frequency offset of 200 Hz, or 2×10^{-5}.

Keep in mind that the precision of these calibrations is often limited by the resolution of the tuner. On some lower cost receivers the tuning resolution is 100 Hz, or even 1 or 5 kHz, so the dial will still appear to be correct even if the BFO has a fairly large frequency offset. More expensive receivers sometimes tune in 1 Hz increments. The uncertainty of WWV and WWVH is small enough to set the BFO of even the best receivers to within 1 Hz at 10 MHz, a frequency offset of 1×10^{-7}.

Frequency Calibrations (zero beat) — There are many variations of the zero beat method used to calibrate oscillators other than the BFO in a communications receiver. One simple method involves placing one end of a piece of insulated wire near the oscillator and the other end near the antenna input of your HF receiver. If the radio is tuned to 10 MHz and the oscillator under test is a 10 MHz oscillator, you should hear a slow pulsing sound (beat note) in addition to the WWV or WWVH audio. By adjusting the oscillator, this pulse should get slower and slower until zero beat is reached and no pulsing is heard. The uncertainty of this method is generally equal to 1 cycle of the carrier frequency, or 1×10^{-7} at 10 MHz. This makes it useful for calibrating oscillators such as those found in low cost frequency counters, signal generators, and other types of test equipment.

Time Synchronization — Some WWV and WWVH receivers are designed or modified to produce a 1 pulse per second (pps) signal. This signal is intended to be on time, or to coincide with the arrival of the UTC second. You can estimate the path delay with software that computes the distance between your receiving site and the station (the station coordinates are listed in Tables 3.2 and 3.3), and then calculates the time required for a radio signal to travel that distance. As we saw earlier, HF radio propagation depends on many factors. Without taking all of these factors into account, it's difficult to estimate the path delay to much better than 1 ms. Therefore, most WWV and WWVH time measurements have an uncertainty of about 1 ms, even if you compensate for the path delay. If you don't compensate for path delay at all, the uncertainty is dependent on your distance from the transmitter. It should be < 15 ms for receivers located in the continental United States or near Hawaii.

Frequency Calibrations (phase comparison) — Better results from WWV and WWVH can be obtained by comparing the received phase of the signal to the oscillator under test, and averaging for one day or longer. To use this method, you need a receiver that brings out an electrical pulse, for example a 1 pps signal referenced to the time code. A 1 pps signal is obtained from the oscillator under test using a frequency divider. The two signals are then compared using a time interval counter. While the receiver is locked to the signal, it should be stable to a few hundred microseconds or less. This translates to an uncertainty of parts in 10^9 when averaged for 24 hours, which is sufficient for measuring the frequency offset of most quartz oscillators. Lower uncertainties (parts in 10^{10}) can be realized by making a single measurement (or a short series of measurements) at the same time each day and then averaging the results over multiple days.

TABLE 3.13 – UNCERTAINTIES OF WWV/WWVH MEASUREMENTS

MEASUREMENT OF APPLICATION	REQUIREMENTS	BEST CASE UNCERTAINTY	LARGEST SOURCE OF UNCERTAINTY	UNCERTAINTY CONTRIBUTED BY WWV OR WWVH
Manual synchronization of a watch or clock	Audio time signal obtained with HF receiver or by telephone	100 ms	Human reaction time	Insignificant
Stop watch and timer calibrations	Audio time signal obtained with HF receiver or by telephone	1×10^{-4} in 10,000 s	Human reaction time	Insignificant
Tuning a Piano	Audio time signal obtained with HF receiver or by telephone	5 cents (~ 0.3%)	Human ear's ability to detect difference between two frequencies	Insignificant
Calibrating a Receiver Dial	HF receiver with beat frequency oscillator and S-meter, headphones	1×10^{-7} (1 Hz at 10 MHz)	Dial resolution of receiver	Insignificant for nearly all receiver calibrations
Frequency Calibrations (zero beat)	HF Receiver, oscillator whose output frequency is a multiple or sub multiple of HF carrier	1×10^{-7} (1 Hz at 10 MHz)	Radio path noise	1×10^{-7} (1 Hz at 10 MHz)
Time Synchronization	HF receiver with output pulse	1 ms	Inability to make good path delay estimate	1 ms
Frequency Calibrations (phase comparison)	HF receiver with output pulse, frequency divider for oscillator under test, time interval counter	Parts in 10^9 in 24 hours	Radio path noise	Parts in 10^9

Chapter 4

Keeping Computers on Time: NIST Computer Time Sychronization Services

Since we rely so heavily on computer systems in our daily lives, it shouldn't surprise you that one of the most common time and frequency applications is the synchronization of computer clocks. At this writing (2001) NIST is handling well over 300 million computer timing requests per day through its Internet Time Service, and this number is expected to become much larger in the coming months and years. This chapter describes the NIST services you can use to synchronize your computer clock. It also describes the nist.time.gov web site, which enables you to view NIST time with your web browser.

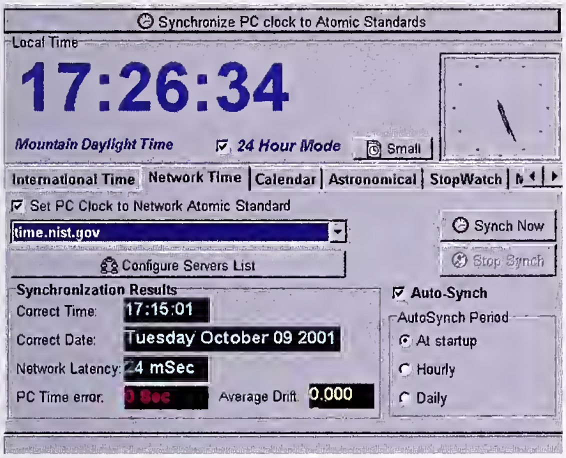

Figure 4.1. ITS Client Software

Internet Time Service (ITS)

The NIST Internet Time Service allows users to synchronize computer clocks via the Internet. The time information provided by the service is directly traceable to UTC(NIST). The service responds to time requests from any Internet client in several formats including the Daytime, Time, and Network Time protocol (NTP). Using the ITS is easy. It requires only an Internet connection and client software compatible with your computer's operating system. A sample ITS software client is shown in Figure 4.1, and software can easily be obtained from a number of publishers.

ITS Servers

The NIST Internet Time Service uses multiple time servers as listed in Table 4.1. NIST maintains a number of time servers. Some are located in Boulder, Colorado, and others reside at other facilities around the country. New servers are added whenever necessary to increase the capacity of the service. Each server is identified by its unique Internet protocol (IP) address. All servers provide the same information, and the same uncertainty relative to UTC(NIST), but some handle more traffic than others and might take longer to handle your request. You can configure your client software so that it points to the server of your choice.

TABLE 4.1 – NIST INTERNET TIME SERVERS

NAME	IP ADDRESS	LOCATION
time-a.nist.gov	129.6.15.28	NIST, Gaithersburg, Maryland
time-b.nist.gov	129.6.15.29	NIST, Gaithersburg, Maryland
time-a.timefreq.bldrdoc.gov	132.163.4.101	NIST, Boulder, Colorado
time-b.timefreq.bldrdoc.gov	132.163.4.102	NIST, Boulder, Colorado
time-c.timefreq.bldrdoc.gov	132.163.4.103	NIST, Boulder, Colorado
utcnist.colorado.edu	128.138.140.44	University of Colorado, Boulder
time.nist.gov	192.43.244.18	NCAR, Boulder, Colorado
time-nw.nist.gov	131.107.1.10	Microsoft, Redmond, Washington
nist1.datum.com	63.149.208.50	Datum, San Jose, California
nist1.dc.glassey.com	216.200.93.8	Abovenet, Virginia
nist1.ny.glassey.com	208.184.49.9	Abovenet, New York City
nist1.sj.glassey.com	207.126.103.204	Abovenet, San Jose, California
nist1.aol-ca.truetime.com	207.200.81.113	True Time, Sunnyvale, California
nist1.aol-va.truetime.com	205.188.185.33	True Time, Virginia

ITS Time Code Formats

Every ITS server is constantly "listening" for one of three different types of timing requests. When it receives one of these requests, it transmits a time code in the requested format. The combination of the timing request and the time code is called a protocol, and each of the three standard timing protocols has been defined by an Internet document called a Request for Comments (RFC). Each protocol is briefly described below. You can refer to the RFC document (available from several Internet sites) if you need more information.

Daytime Protocol (RFC-867)

This protocol is widely used by small computers running MS-DOS, Windows, and similar operating systems. The server listens on port 13, and responds to requests in either tcp/ip or udp/ip formats. The standard does not specify an exact format for the Daytime Protocol, but requires that the time be sent using standard ASCII characters. NIST chose a time code format nearly identical to the one used by its older dial-up Automated Computer Time Service (ACTS) shown in Table 4.3, except that a health digit (H) replaces the UT1 correction, and the time is sent 50 ms (as opposed to 45 ms) early. The health digit indicates the health of the server. If H = 0, the server is healthy. If H = 1, then the server is operating properly but its time may be in error by up to 5 s. This state should change to fully healthy within 10 min. If H = 2, then the server is operating properly but its time is known to be wrong by more than 5 s. If H = 4, then a hardware or software failure has occurred and the amount of the time error is unknown.

Unlike the Time protocol and NTP (described below), the Daytime protocol is not a universal standard. Client software designed to work with NIST's version of the Daytime protocol won't necessarily work with other versions, and vice versa. In contrast, NTP client software should be compatible with all NTP servers.

Time Protocol (RFC-868)

No longer widely used, this simple protocol returns a 32-bit unformatted binary number that represents the time in UTC seconds since January 1, 1900. The server listens for Time Protocol requests on port 37, and responds in either tcp/ip or udp/ip formats. Conversion to local time (if necessary) is the responsibility of the client program. The 32-bit binary format can represent times over a span of about 136 years with a resolution of 1 s. There is no provision for increasing the resolution or increasing the range of years.

The strength of the time protocol is its simplicity. Since many computers keep time internally as the number of seconds since January 1, 1970 (or another date), converting the received time to the necessary format is often a simple matter of binary arithmetic. However, the format does not allow any additional information to be transmitted, such as advance notification of leap seconds or Daylight Saving Time, or information about the health of the server.

Network Time Protocol (RFC-1305)

The Network Time Protocol (NTP) is the most complex and sophisticated of the time protocols, and the one that provides the best performance. Large computers and workstations often include NTP software with their operating systems. The client software runs continuously as a background task that periodically gets updates from one or more servers. The client software ignores responses from servers that appear to be sending the wrong time, and averages the results from those that appear to be correct.

Many of the available NTP software clients for personal computers don't do any averaging at all. Instead, they make a single timing request to a signal server (just like a Daytime or Time client) and then use this information to set their computer's clock. The proper name for this type of client is SNTP (Simple Network Time Protocol).

The NIST servers listen for a NTP request on port 123, and respond by sending a udp/ip data packet in the NTP format. The data packet includes a 64-bit timestamp containing the time in UTC seconds since January 1, 1900 with a resolution of 200 ps.

ITS Performance

The uncertainty of Daytime, Time, and SNTP time clients is usually <100 ms, but the results can vary due to the Internet path, and the type of computer, operating system, and client software. In extreme cases, the uncertainty might be 1 s or more. The uncertainty of a continuously running NTP client is often <10 ms.

Automated Computer Time Service (ACTS)

Although the great majority of computer clocks are now synchronized via the Internet, some applications still require an accurate timing signal that can be obtained over an ordinary telephone line using an analog modem. The Automated Computer Time Service (ACTS) is provided by NIST to satisfy those requirements. Using ACTS requires a computer, an analog modem, and some simple software. When a computer connects to ACTS by telephone, it receives an ASCII time code. The information in the time code is then used to set the computer's clock.

You can connect to ACTS using either a Colorado or Hawaii phone number as shown in Table 4.2.

TABLE 4.2 – ACTS INFORMATION

PHONE NUMBER	LOCATION	PHONE LINES	CAPACITY (CALLS PER DAY)
(303) 494-4774	NIST, Colorado	24	60,000
(808) 335-4721	WWVH, Hawaii	4	10,000

ACTS Time Code

ACTS works at speeds up to 9600 baud with 8 data bits, 1 stop bit, and no parity. To receive the full time code, you must connect at a speed of at least 1200 baud. The full time code is transmitted every second and contains more information than the 300 baud time code, which is transmitted every 2 seconds and omits the MJD and DUT1 information. The full time code is described in Table 4.3 and looks like this:

JJJJJ YY-MM-DD HH:MM:SS TT L DUT1 msADV UTC(NIST) OTM

TABLE 4.3 - THE ACTS TIME CODE

TIME CODE	DESCRIPTION
JJJJJ	The Modified Julian Date (MJD). The MJD is the last five digits of the Julian Date, which is the number of days since January 1, 4713 B.C. To get the Julian Date, add 2.4 million to the MJD.
YY-MM-DD	The last two digits of the year, the month, and the current day of month.
HH:MM:SS	The time in hours, minutes, and seconds. The time is always sent as Coordinated Universal Time (UTC). An offset needs to be applied to UTC to obtain local time. For example, Mountain Time in the United States is 7 hours behind UTC during Standard Time, and 6 hours behind UTC during Daylight Saving Time.
TT	A two digit code (00 to 99) that indicates whether the United States is on Standard Time (ST) or Daylight Saving Time (DST). It also indicates when ST or DST is approaching. This code is set to 00 when ST is in effect, or to 50 when DST is in effect. On the day of the transition from DST to ST, the code is set to 01. On the day of the transition from ST to DST, the code is set to 51. The client software is responsible for implementing the change at 2 a.m. on the day of the transition. During the month of the transition, the code is decremented every day until the change occurs. For example, October is the month of the transition (in the United States) from DST to ST. On October 1, the number changes from 50 to the actual number of days until the time change. It will decrement by 1 every day, and reach 01 on the day of the transition. It will be set to 00 the day after the transition, and will remain there until the following April.
L	A one-digit code that indicates whether a leap second will be added or subtracted at midnight on the last day of the current month. If the code is 0, no leap second will occur this month. If the code is 1, a positive leap second will be added at the end of the month. This means that the last minute of the month will contain 61 seconds instead of 60. If the code is 2, a second will be deleted on the last day of the month.
DUT1	A correction factor for converting UTC to UT1. It is always a number ranging from –0.8 to +0.8 seconds. This number is added to UTC to obtain UT1.
msADV	The number of milliseconds that NIST advances the time code. It is originally set to 45.0 ms. If you return the on-time marker (OTM) to the ACTS server, it will change to reflect the actual one way path delay.
UTC(NIST)	A label that indicates that you are receiving Coordinated Universal Time (UTC) from the National Institute of Standards and Technology (NIST).
OTM	OTM (on-time marker) is an asterisk (*). The time values sent by the time code refer to the arrival time of the OTM. In other words, if the time code says it is 12:45:45, this means it is 12:45:45 when the OTM arrives.

Since the OTM is delayed as it travels from NIST to your computer, ACTS sends it out 45 ms early. This always removes some of the delay. Better results are possible if the user's software returns the OTM to ACTS after it is received. When the OTM returns, ACTS measures the amount of time it took for the OTM to go from ACTS to the user and back to ACTS (round trip path delay). By dividing the round trip path delay by 2, ACTS obtains the one-way path delay. ACTS then advances the OTM by the one-way path delay and the OTM changes from an asterisk to a pound sign (#). When the # sign appears, the time code is synchronized to UTC(NIST) with an uncertainty of <15 ms.

Figure 4.2. nist.time.gov Web Site

nist.time.gov Web Site

If you point your web browser to http://nist.time.gov, you'll see a digital clock display that displays UTC(NIST), or the local time for the United States time zone that you select (Figure 4.2). Although the site can't set your computer's clock, it's useful for manually setting a clock or watch to NIST time. The estimated uncertainty of the display is shown on screen. The uncertainty is typically less than 1 s, and usually within 0.5 s of UTC(NIST).

One of the most popular United States government web sites, nist.time.gov currently (2001) receives millions of timing requests per month. It uses the Internet Time Service as its timing reference, so the time display is generally very accurate. However, keep in mind that it should be used as a time-of-day service only. It should not be used to measure frequency or time interval, nor should it be used to establish traceability to NIST.

Chapter 5

Remote Calibration Services

The services described in the previous chapters consist of signals broadcast by NIST for use as time and frequency references. These signals are provided free of charge as a service of the United States government and meet the needs of most users. However, some of the nation's calibration and testing laboratories require smaller measurement uncertainties. For these organizations, NIST offers a remote calibration service on a paid subscription basis that automates the process of establishing traceability to UTC(NIST).

NIST Frequency Measurement and Analysis Service

The NIST Frequency Measurement and Analysis Service (FMAS) was designed to make it easy for a customer to measure and calibrate any quartz, rubidium, cesium, or hydrogen maser frequency standard in their own laboratory, without sending the device to NIST for calibration. The service can measure any frequency from 1 Hz to 120 MHz in 1 Hz increments. This means it can measure standard output frequencies such as 5 and 10 MHz, telecommunication frequencies such as 1.544, 2.048, and 51.84 MHz, and even 1 Hz timing pulses. As many as five devices can be measured and calibrated at once, even if all five have different output frequencies. The FMAS uses Global Positioning System (GPS) signals as its reference frequency and will work anywhere on Earth. All measurements are made automatically, and are traceable to NIST at an uncertainty of 2×10^{-13} per day.

Subscribers to the NIST service receive a complete frequency measurement system that includes everything needed to make traceable frequency measurements. Once the system is installed, customers simply plug in the frequency standards they want to measure, and connect the system to either a dedicated phone line or Internet connection. This allows NIST personnel to remotely access the system, verify and analyze the data, and quickly troubleshoot any problems that may occur. The GPS signals provide traceability to NIST, since the same GPS signals received by subscribers are received at NIST and compared to the national frequency standard. The GPS receiver is software controlled and requires no operator attention. The customer is required to mount a small antenna in a location with a clear view of the sky. Figure 5.1 shows a two-week measurement of a hydrogen maser made at a customer's location using the FMAS.

NIST completely supports each FMAS customer. When enhancements to the software are developed, NIST installs them for the customer remotely. If any hardware component

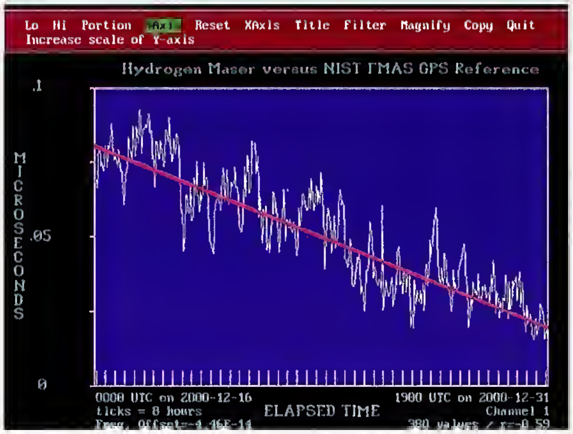

Figure 5.1. Sample FMAS Screen Display

fails, NIST replaces it immediately using an overnight delivery service. Each subscriber receives a monthly calibration report prepared by NIST personnel. The calibration report documents that the customer's primary standard is traceable to UTC(NIST). It includes a graph of the performance of the customer's standard and a statement of measurement uncertainty. The FMAS specifications are listed in Table 5.1.

The FMAS complies with the requirements of NVLAP (National Voluntary Laboratory Accreditation Program). Subscribers to the service who seek accreditation in the frequency calibration field can reduce or eliminate the proficiency testing and on-site assessment fees charged by NVLAP.

NIST offers the FMAS as part of its calibration program. The service identification number is 76100S. For more information, including pricing and delivery, visit the Time and Frequency Division web site at http://www.boulder.nist.gov/timefreq.

TABLE 5.1 – SPECIFICATIONS FOR NIST FMAS

FMAS	SPECIFICATION
Measurement Channels	Up to five frequency standards can be calibrated at one time. The FMAS accepts any input frequency from 1 Hz to 120 MHz in 1 Hz increments.
Measurement Resolution	<30 ps
Frequency Uncertainty using GPS	2×10^{-13} (24 h averaging time)
Relative Frequency Uncertainty without GPS (oscillator to oscillator comparisons)	2×10^{-15} (24 h averaging time)

Acknowledgments

The NIST time and frequency services described in this booklet would not be possible without the continuous efforts of a dedicated technical staff that is responsible for their development, operation, and maintenance. Thanks are due to Matt Deutch, the engineer-in-charge at WWV and WWVB; Dean Okayama, the engineer-in-charge at WWVH; and Judah Levine, who single handedly created the ITS and the current version of ACTS. Thanks are also due to Don Sullivan, the Chief of the Time and Frequency Division; John Lowe, the Services Group Leader; Andrew Novick, radio station staff members Douglas Sutton, Glenn Nelson, Bill Yates, Judy Foley, Don Patterson, Ernie Farrow, and Adele Ochinang. Since time and frequency services at NIST have such a long history, many retired NIST employees obviously made great contributions during their careers. Those I have had the pleasure to know and learn from include Wayne Hanson, Dick Davis, Roger Beehler, Chuck Snider, Joe Cateora, Jim Jespersen, and Al Clements. And finally, I would like to offer a special thank you to retired NIST engineer George Kamas for the many hours that we spent together early in my career, as he patiently and generously shared his knowledge of time and frequency metrology.

Michael A. Lombardi, NIST

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Bibliography

The following publications (listed alphabetically by author) provide more information about the topics presented in this booklet:

Allison, Ted, "How to Ensure Timebase Accuracy: Prepping the Techs in the Trenches," *Cal Lab: The International Journal of Metrology*, September-October 2000, pp. 23-25.

Anderson, Ross J., and Georgia L. Harris, "Specifications and Tolerances for Field Standard Stopwatches," *National Institute of Standards and Technology Handbook 105-5*, 1997.

Arey, T. J., *Radio Monitoring, the How-To Guide*, Index Publishing Group, Inc., San Diego, 1997.

Beehler, Roger E., and Michael A. Lombardi, "NIST Time and Frequency Services," *National Institute of Standards and Technology Special Publication 432*, 1990.

Beers, Yardley, "WWV Moves to Colorado - Part I and II," *QST*, January and February 1967, pp. 11-14 and 30-35.

Bergquist, James C., Steven R. Jefferts, and David J. Wineland, "Time Measurement at the Millenium," *Physics Today*, March 2001, pp. 37-42.

Bobbett, David, ed., *World Radio and TV Handbook*, WRTH Publications Limited, United Kingdom, vol. 55, 2001.

Braudaway, David W., "Low Signal Strength a Problem Receiving WWV? Try an All-Wave Antenna from 1936!," *Proceedings of the 1999 National Conference of Standards Laboratories Workshop and Symposium*, July 1999.

Carr, Joseph J., *Elements of Electronic Instrumentation and Measurement*, Prentice Hall, New Jersey, 3rd edition, 1996.

Cowan, John A., "Frequency Calibration using 60 kHz WWVB," *Ham Radio*, March 1988, pp. 45-52.

DeMaw, Doug, "WWV and CHU in Your Workshop," *QST*, October 1986, pp. 42-44.

Deutch, Matthew, Wayne Hanson, Glen Nelson, Charles Snider, Douglas Sutton, William Yates, Peder Hanson, and Bill Hopkins, "WWVB Improvements: New Power from an Old Timer," *Proceedings of the 31st Annual Precise Time and Time Interval Meeting*, December 1999.

Fey, Lowell, "New Signals from an Old Timer...WWV," *Broadcast Engineering*, July 1971, pp. 44-46.

Healy, Rus, "Propagation Broadcasts and Forecasts Demystified", *QST*, November 1991, pp. 20-24.

Hironaka, Nobu, and Chuck Trembath, "The Use of National Bureau of Standards High Frequency Broadcasts for Time and Frequency Calibrations," *National Bureau of Standards Technical Note 668*, 1975.

Howse, Derek, *Greenwich Time and the Longitude*, Philip Wilson Publishers Limited, London, 1997.

International Telecommunication Union, "Selection and Use of Precise Frequency and Time Systems," *ITU-R Recommendations*, TF Series, 1997.

International Telecommunication Union, "Time Signals and Frequency Standards Emissions," *ITU-R Recommendations*, TF Series, 1998.

Isenring, Harold, "WWVB Signal Processor," *Ham Radio*, March 1976, pp. 28-34.

Itano, Wayne M., and Norman F. Ramsey, "Accurate Measurement of Time," *Scientific American*, July 1993, pp. 56-65.

Kamas, George and Michael A. Lombardi, "Time and Frequency Users Manual," *National Institute of Standards and Technology Special Publication 559*, September 1990, 160 pages.

Jesperson, James, and Jane Fitz-Randolph, *From Sundials to Atomic Clocks: Understanding Time and Frequency*, Dover Publications, Inc., New York, 1999.

Jones, Tony, *Splitting the Second: The Story of Atomic Time*, Institute of Physics Publishing, London, 2000.

Lancaster, Don, "Experiment with WWVB," *Radio Electronics*, August 1973, pp. 48-51.

Levine, Judah, Marc Weiss, Dick D. Davis, David W. Allan, and Donald B. Sullivan, "The NIST Automated Computer Time Service," *NIST Journal of Research*, Vol. 94, No. 5, September-October 1989, pp. 311-321.

Levine, Judah, "Precise Synchronization of Computer Network Clocks", in the *Encyclopedia of Computer Science and Technology*, vol. 37, supplement 22, Marcel Dekker, Inc., New York, 1997, pp. 281-306.

Levine, Judah, "Time Synchronization Using the Internet," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 45, no. 2, March 1998, pp. 450-460.

Levine, Judah, "The NIST Internet Time Services," *Proc. 25th Annual Precise Time and Time Interval Meeting*, 1993, pp. 505-511.

Lombardi, Michael A., "Traceability in Time and Frequency Metrology," *Cal Lab: The International Journal of Metrology*, September-October 1999, pp. 33-40.

McCoy, Lew, "CQ Visits WWVH," *CQ*, July 1989, pp. 40-42.

Mills, David L., "Precise Synchronization of Computer Network Clocks," *ACM Computer Communications Review*, vol. 24, no. 2, April 1994.

Milton, John B., "Standard Time and Frequency: Its Generation, Control, and Dissemination by the National Bureau of Standards," NBS Technical Note 656, *U.S. Government Printing Office*, June 1974, 21 pages.

Morrison, Philip, "The Timekeeping ELF," *Scientific American*, April 1998, pp. 105-107.

Passaglia, Elio, "A Unique Institution: The National Bureau of Standards, 1950-1969", *National Institute of Standards and Technology Special Publication 925*, July 1999, 822 pages.

Quinn, Terry J., "The BIPM and the Accurate Measurement of Time," Proc. *IEEE*, Vol. 79, No. 7, July 1991, pp. 894-905.

Rosenthal, David A. and Joseph W. Hirman, "A Radio Frequency User's Guide to the Space Environment Services Center Geophysical Alert Broadcasts," *NOAA Technical Memorandum ERL SEL-80*, June 1990.

Rossing, Thomas D., *The Science of Sound*, Addison-Wesley, 1990.

Snyder, Wilbert F. and Charles L. Bragaw, *Achievement in Radio: Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards*, National Institute of Standards and Technology Special Publication 555, October 1986, 863 pages.

Walls, Hoy J., "The Standard-Frequency Set at WWV," *QST*, October 1924, pp. 9-12.

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